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MULTI-AGENCY RADIATION SURVEY AND SITE INVESTIGATION MANUAL (MARSSIM) DRAFT FOR PUBLIC COMMENT



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ABSTRACT

The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) provides information on planning, conducting, evaluating, and documenting building surface and surface soil radiological surveys for demonstrating compliance with requirements, often as part of a dose- or risk-based regulation or standard.¹ MARSSIM is a multi-agency consensus document that was developed collaboratively by four Federal agencies having authority and control over radioactive materials: Department of Defense (DOD), Department of Energy (DOE), Environmental Protection Agency (EPA), and Nuclear Regulatory Commission (NRC). MARSSIM's objective is to describe a consistent approach for planning, performing, and assessing building surface and surface soil radiological surveys to meet established dose or risk-based release criteria, while concurrently encouraging an effective use of resources.

¹ MARSSIM uses the word "should" as a recommendation, not as a requirement. Each recommendation in this manual is not intended to be taken literally and applied at every site. MARSSIM's survey planning documentation will address how to apply the process on a site-specific basis.

DISCLAIMER

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References within this manual to any specific commercial product, process, or service by trade name, trademark, or manufacturer does not constitute an endorsement or recommendation by the United States Government.

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DEDICATION

The MARSSIM Workgroup notes, with much sadness, the sudden loss of Dr. George Edward Powers of the U.S. Nuclear Regulatory Commission staff. Dr. Powers passed away in late 2011, as the effort to revise the MARSSIM manual was getting underway. As a member of the MARSSIM Workgroup, he made significant contributions on MARSSIM, both on the original document, on its revision in 2001, and on this latest revision. Dr. Powers also contributed in an important way to the development of the MARSAME and MARLAP manuals; his participation in the development of all three documents (MARSSIM, MARSAME, and MARLAP) is well recognized. The MARSSIM Workgroup members also are aware of the many contributions he made as an NRC employee, including his involvement in several USNRC NUREG publications over the years. Dr. Powers was truly a visionary in encouraging development of multi-agency documents in this collaborative and collegial manner for use by many people. Dr. Powers' sense of humor enhanced his ability to work so well in a positive manner with many of his colleagues in multi-agency settings. He was a technically accomplished, kind, and courteous man who contributed much to the Workgroup's efforts.

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ABBREVIATIONS

1st Lt.	First Lieutenant
AARST	American Association of Radon Scientists and Technologists
AEA	Atomic Energy Act
AEC	Atomic Energy Commission
AFI	Air Force Instructions
AGL	above ground level
AL	action level
ALARA	as low as reasonably achievable
AMC	Army Materiel Command
AMS	accelerator mass spectrometry
ANSI	American National Standards Institute
AR	Army Regulations
ARA	Army Radiation Authorization
ASQ	American Society for Quality
ASTM	American Society of Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
CAA	Clean Air Act
Capt.	Captain (Air Force)
CAPT	Captain (Navy)
CDR	Commander
CED	committed effective dose
CEDE	committed effective dose equivalent
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CFR	Code of Federal Regulations
CHP	Certified Health Physicist
COC	chain of custody
Col.	Colonel
CV	coefficient of variation
DCF	dose conversion factor
DCGL	derived concentration guideline level
DCGL _{EMC}	DCGL for small areas of elevated activity, used with the EMC
DCGL _W	DCGL for average concentrations over a wide area, used with statistical tests
DEFT	Decision Error Feasibility Trials
DGPS	differential global positioning system
DHS	Department of Homeland Security
DL	discrimination limit
DLC	Data Life Cycle
DOD	U.S. Department of Defense

DOE	U.S. Department of Energy
DOT	Department of Transportation
DQA	Data Quality Assessment
DQIs	Data Quality Indicators
DQO	Data Quality Objectives
ED	electronic dosimeter
EERF	Eastern Environmental Radiation Facility
Ehf	human factors efficiency
EIC	electret ion chamber
EMC	elevated measurement comparison
EML	Environmental Measurements Laboratory
EMMI	Environmental Monitoring Methods Index
EPA	U.S. Environmental Protection Agency
EPIC	Environmental Photographic Interpretation Center
ERAMS	Environmental Radiation Ambient Monitoring System
FA-MS	flowing afterglow mass spectrometer
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Maps
FRDS	Federal Reporting Data System
FSP	Field Sampling Plan
FSS	Final Status Survey
FUSRAP	Formerly Utilized Sites Remedial Action Program
FWPCA	Federal Water Pollution Control Act
GCS	geographic coordinate system
GEMS	Geographical Exposure Modeling System
GIS	geographic information system
GM	Geiger-Mueller
GPR	ground-penetrating radar
GPS	global positioning system
GRIDS	Geographic Resources Information Data System
GWSI	Ground Water Site Inventory
HASP	Health and Safety Plan
HPS	Health Physics Society
HSA	Historical Site Assessment
HSWA	Hazardous and Solid Waste Amendments
HRS	Hazard Ranking System
HTD	hard-to-detect
HWP	hazard work permit
IAEA	International Atomic Energy Agency
ICP	inductively coupled plasma
ICP-AES/MS	inductively coupled plasma-atomic emission spectrometry/mass spectrometry
ICP-MS	inductively coupled plasma mass spectrometer
IEEE	Institute of Electrical and Electronics Engineers

IR-MS	isotope ratio mass spectrometer
ISGS	<i>in situ</i> gamma spectroscopy
ISI	Information System Inventory
ISO	International Organization for Standardization
IV	independent verification
JSA	job safety analysis
KPA	kinetic phosphorescence analysis
LA-ICP-AES	laser ablation-inductively coupled plasma-atomic emission spectrometry
LA-ICP-MS	laser ablation-inductively coupled plasma-mass spectrometry
LANL	Los Alamos National Laboratory
LBGR	lower bound of the gray region
LCD	liquid crystal display
LCDR	Lieutenant Commander
LLD	lower limit of detection
LLNL	Lawrence Livermore National Laboratory
LLRWPA	Low-Level Radioactive Waste Policy Act, as Amended
LSC	liquid scintillation counter
Lt.	Lieutenant (Air Force)
LT	Lieutenant (Navy)
Lt. Col.	Lieutenant Colonel
MARLAP	Multi-Agency Radiation Laboratory Analytical Protocols (Manual)
MARSAME	Multi-Agency Radiation Survey and Assessment of Materials and Equipment (Manual)
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MCA	multichannel analyzer
MDA	minimum detectable activity
MDC	minimum detectable concentration
MDCR	minimum detectable count rate
MDER	minimum detectable exposure rate
MDLEST	Mobile Demonstration Laboratory for Environmental Screening Technologies
MED	Manhattan Engineering District
MeV	megaelectron volt
MQC	minimal quantifiable concentration
MQO	Measurement Quality Objectives
MS	mass spectrometry
MS/MD	matrix spike/matrix duplicate
NAREL	National Air and Radiation Environmental Laboratory
NARM	naturally occurring and accelerator produced radioactive material
NCAPS	National Corrective Action Prioritization System
NCP	National Contingency Plan
NCRP	National Council on Radiation Protection and Measurements
NIST	National Institute of Standards and Technology

NORM	naturally occurring radioactive material
NPDC	National Planning Data Corporation
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
NWWA	National Water Well Association
ODES	Ocean Data Evaluation System
ORISE	Oak Ridge Institute for Science and Education
ORNL	Oak Ridge National Laboratory
OSHA	U.S. Occupational Safety and Health Administration
OSL	optically stimulated luminescence
OSLNs	optically stimulated luminescence devices sensitive to neutrons
PAEC	potential alpha energy concentration
PCi	picocurie
PE	performance evaluation
PERALS	photon electron rejecting alpha liquid scintillator
PIC	pressurized ionization chamber
PMT	photomultiplier tube
PPE	personal protective equipment
QA	quality assurance
QAM	Quality Assurance Manual
QAPP	Quality Assurance Project Plan
QC	quality control
QMP	Quality Management Plan
RAGS/HHEM	Risk Assessment Guidance for Superfund/Human Health Evaluation Manual
RAS	Remedial Action Support
RASP	Radiological Affairs Support Program
RCRA	Resource Conservation and Recovery Act
RCRIS	Resource Conservation and Recovery Information System
RFI/CMS	RCRA Facility Investigation/Corrective Measures Study
RFP	Request for Proposal
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
RODS	Records of Decision System
RSS	Ranked Set Sampling
RSSI	Radiation Survey and Site Investigation
RWP	radiation work permit
SADA	Visual Sample Plan and Spatial Analysis and Decision Assistance
SAP	Sampling and Analysis Plan
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SFMP	Surplus Facilities Management Program

SOPs	Standard Operating Procedures
SOR	sum of the ratios
SOW	statement of work
SPP	systematic planning process
SRS	simple random sampling
STORET	Storage and Retrieval for Water Quality Data
TED	total effective dose
TEDE	total effective dose equivalent
TENORM	technologically enhanced naturally occurring radioactive material
TIMS	thermal ionizing mass spectrometry
TLD	thermoluminescent dosimeter
TOF-MS	time-of-flight mass spectrometry
TRU	transuranic
TSCA	Toxic Substances Control Act
TVA	Tennessee Valley Authority
UBGR	upper boundary of the gray region
UCL	upper confidence limit
UFP	Uniform Federal Policy
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plans
UFP-QS	Uniform Federal Policy for Implementing Environmental Quality Systems
UMTRCA	Uranium Mill Tailings Radiation Control Act
USGS	United States Geological Survey
USPHS	United States Public Health Service
USRADS	Ultrasonic Ranging and Data System
UXO	unexploded ordnance
VOCs	volatile organic compounds
WATSTORE	National Water Data Storage and Retrieval System
WL	working level
WQX	Water Quality Exchange
WRS	Wilcoxon Rank Sum
WSR	Wilcoxon signed rank
WT	Wilcoxon test

Symbols, Nomenclature, and Notations

<	less than
>	greater than
≤	less than or equal to
≥	greater than or equal to
°	degrees (angle or temperature)
%	percent
1-β	statistical power of a hypothesis test
α	Type I decision-error rate
α_Q	alpha used for the quantile test
α_S	alpha scintillation survey meter
a	half-width of a rectangular or triangular probability distribution
A	area
A	overall sensitivity of a measurement
Ac	actinium (isotope listed: ²²⁸ Ac)
A_{EA}	area of elevated activity
AL_i	action level value an individual radionuclide ($i = 1, 2, \dots, n$)
$AL_{meas,mod}$	modified action level for the radionuclide being measured when it is used as a surrogate for other radionuclide(s)
AL_{meas}	action level for the radionuclide being measured
AL_{infer}	action level for the inferred radionuclide (in surrogate measurements)
A_m	area factor
Am	americium (isotope listed: ²⁴¹ Am)
A_S	surface activity
β	Type II decision-error rate
b	background count rate
b_i	the average number of counts in the background interval (scanning)
B	mean background counts
Be	beryllium (isotope listed: ⁷ Be)
Bi	bismuth (isotopes listed: ²¹⁰ Bi, ²¹² Bi, ²¹⁴ Bi)
Bq	becquerel
γ_S	gamma scintillation (gross)
C	carbon (isotope listed: ¹⁴ C)
C	radionuclide concentration or activity
C	constant
C_b	number of background counts
C_{S+b}	number of gross counts
Ci	curie
C_i	concentration value an individual radionuclide ($i = 1, 2, \dots, n$)

c_i	sensitivity coefficient
$c_i\mu(x_i)$	component of the uncertainty in y due to x_i
$C_{\text{infer}}/C_{\text{meas}}$	ratio of amount of the inferred radionuclide to that of the measured surrogate radionuclide
C_S	concentration for the surrogate radionuclide
$^{\circ}\text{C}$	degrees Celsius
cm	centimeter
cm^2	square centimeter
cm^3	cubic centimeter
Cd	cadmium (isotope listed: ^{109}Cd)
Co	cobalt (isotopes listed: ^{57}Co , ^{60}Co)
cpm	counts per minute
Cr	chromium (isotope listed: ^{51}Cr)
Cs	cesium (isotope listed: ^{137}Cs)
CsI(Tl)	cesium iodide (thallium activated)
CZT	cadmium-zinc telluride
δ	estimate of the mean concentration of residual radioactive material in the survey unit
Δ	shift (width of the gray region, UBGR–LBGR)
Δ/σ	relative shift
Δt_i	the observation interval
d	parameter in the Stapleton Equation for the critical net signal
d	width of the detector in the direction of the scan
d'	detectability index (scanning)
$\text{DCGL}_{\text{gross}}$	derived concentration guideline level for a gross measurement
DCGL_i	derived concentration guideline level of the i th component leading to dose or risk
DCGL_{min}	lowest of the derived concentration guideline levels
$\text{DCGL}_{\text{S-mod}}$	modified derived concentration guideline level of the surrogate radionuclide
$\text{DCGL}_{\text{S-unmod}}$	derived concentration guideline level of the surrogate radionuclide before modification
dpm	disintegrations per minute
ε_i	instrument efficiency
ε_s	surface (or source) efficiency
ε_t	total efficiency of the instrument
eV	electron-volt
E_γ	energy of a gamma photon of concern in kiloelectron-volts (keV)
E_i	energy of a photon of interest
$^{\circ}\text{F}$	degrees Fahrenheit
f_i	relative fraction of activity contributed by radionuclide i to the total
ft	foot (feet)

ft ³	cubic foot (feet)
Fe	iron (isotopes listed: ⁵⁵ Fe, ⁵⁹ Fe)
g	gram
<i>G</i>	activity
GBq	gigabecquerel (1×10 ⁹ becquerels)
GG _{AL}	gross gamma action level
GM	Geiger-Mueller survey meter
GP _α	gas-flow proportional counter (α mode)
GP _β	gas-flow proportional counter (β mode)
h	hour
H	hydrogen (isotope listed: ³ H [tritium])
H ₀	null hypothesis
H ₁	alternative hypothesis
Hz	hertz
<i>i</i>	<i>i</i> th sample or measurement in a set
<i>i</i>	observation time interval length (scanning)
I	iodine (isotopes listed: ¹²³ I, ¹²⁵ I, ¹³¹ I)
in.	inch
Ir	iridium (isotope listed: ¹⁹² Ir)
IS _γ	in situ gamma spectrometry
k	k-statistic for the quantile test
<i>k</i>	coverage factor for the expanded uncertainty, <i>U</i>
<i>k</i>	Poisson probability sum for α and β (assuming α and β are equal)
k	critical value of the sign test
K	potassium (isotope listed: ⁴⁰ K)
<i>K_d</i>	distribution coefficient
kBq	kilobecquerel (1×10 ³ becquerels)
keV	kiloelectron-volt (1×10 ³ electron-volts)
kg	kilogram
km	kilometer
<i>k_Q</i>	multiple of the standard deviation defining <i>y_Q</i> , usually chosen to be 10
L	length
L	liter
<i>L</i>	grid size spacing
<i>L_C</i>	critical level
<i>L_D</i>	detection limit
<i>L_{EA}</i>	revised spacing of the systematic pattern
LaBr	lanthanum bromide
lb	pound
μ	micro (10 ⁻⁶)
μ	true mean

μ	theoretical mean of a population distribution
$(\mu_{en}/\rho)_{\text{air}}$	mass energy absorption coefficient in air centimeters squared per gram (cm ² /g)
μBq	microbecquerel
μCi	microcuries
μR	microroentgen (1×10^{-6} roentgen)
μSv	microsievert
m	number of reference measurements (WRS test or Quantile test)
m	number of ranking categories
m	adjusted reference sample measurements
m	meter
m^2	square meter
M_i	total amount of [dose counts, activity, etc.]
$m\text{Bq}$	millibecquerels
$\text{MDCR}_{\text{surveyor}}$	required number of net source counts
MeV	megaelectron-volt (1×10^6 electron-volt)
mg	milligram(s)
mGy	milligray
mm	millimeter(s)
Mn	manganese (isotope listed: ⁵⁴ Mn)
M/R	mass-to-charge ratio
mR	milliroentgen
mrad	millirad
mrem	millirem (1×10^{-3} rem)
mSv	milliseivert (1×10^{-3} Sv)
n	number of survey unit measurements (WRS test or Quantile test)
n	nth sample or measurement in a set
n	number of laboratory samples (for the Ranked Set Sampling test)
N	sample size (i.e., number of data points [or samples]) for the Sign test
N	number of field screening measurements (for the Ranked Set Sampling test)
n_{EA}	survey unit area divided by the maximum area corresponding to the area factor, which yields the number of measurements needed so the scan MDC is adequate
Na	sodium (isotope listed: ²² Na)
NaI	sodium iodide
NaI(Tl)	sodium iodide (thallium activated)
nBq	nanobecquerels
n_{EA}	required number of data points for assessing small areas of elevated activity
ng	nanogram
Ni	nickel (isotope listed: ⁵⁷ Ni, ⁶³ Ni)
Np	neptunium (isotope listed: ²³⁷ Np)
ξ_B	non-Poisson variance component of the background count rate correction

p	coverage probability for expanded uncertainty
p	efficiency of a less than ideal surveyor (scanning)
P	probability
Pa	protactinium (isotopes listed: ^{234}Pa , $^{234\text{m}}\text{Pa}$)
PA	probe area
Pb	lead (isotopes listed: ^{212}Pb , ^{214}Pb)
PC	personal computer
pCi	picocurie (1×10^{-12} curies)
PIC	pressurized ionization chamber
Pm	promethium (isotope listed: ^{147}Pm)
Po	polonium (isotopes listed: ^{210}Po , ^{212}Po , ^{214}Po , ^{216}Po)
ppt	parts per trillion
Pu	plutonium (isotopes listed: ^{238}P , ^{239}Pu , ^{240}Pu , ^{241}Pu)
q	critical value for statistical tests
ρ	density
$\rho(X_i, X_j)$	correlation coefficient for two input quantities, X_i and X_j
r	number of cycles
r	random number from a data set
r	r-statistic for the quantile test
R	ratio
R	roentgen (exposure rate)
Ra	radium (isotopes listed: ^{224}Ra , ^{226}Ra , ^{228}Ra)
R_B	mean background count rate
R_i	established ratio of the concentration of the i th radionuclide to the concentration of the surrogate radionuclide for $l = 2, \dots, n$
R_l	mean interference count rate
Rh	rhodium
Rn	radon (isotopes listed: ^{220}Rn , ^{222}Rn)
R_{net}	net counting rate
Ru	ruthenium (isotope listed: ^{106}Ru)
$r(x_i, x_j)$	correlation coefficient for two input estimates, x_i and x_j
σ	theoretical total standard deviation of the population distribution being sampled
σ^2	theoretical total variance of the population distribution being sampled
σ_M	theoretical measurement standard deviation of the population distribution being sampled, estimated by the combined standard uncertainty of the measurement
σ_M^2	theoretical measurement variance of the population distribution being sampled
σ_{MR}	required measurement method standard deviation (upper limit)
σ_n	standard deviation of the net count rate result
σ_r	estimate of the measurement variability in the reference area

σ_s	estimate of the measurement variability in the survey unit
σ_s^2	theoretical sampling variance of the population distribution being sampled
$\sigma(X_i, X_j)$	covariance for two input quantities, X_i and X_j
σ_y	total uncertainty
s	standard deviation of the survey unit
$S+$	Sign test statistic
$s(X)$	sample standard deviation of the input estimate, x_i
s_b^2	mean square between reference areas
S_C	critical value of the net instrument signal
S_D	mean value of the net signal that gives a specified probability, $1-\beta$, of yielding an observed signal greater than its critical value S_C
s_i	minimum detectable number of net source counts in the observation interval (scanning)
$S_{i,surveyor}$	minimum detectable number of net source counts in the observation interval by a less than ideal surveyor (scanning)
Sr	strontium (isotope listed: ^{90}Sr)
Sv	seivert
s_w^2	mean square within reference areas
t	t-test statistic
t	number of "less than" values
T	weighted sum
$t_{1/2}$	half-life
Tc	technicium (isotopes listed: ^{99}Tc , ^{99m}Tc)
Th	thorium (isotopes listed: ^{228}Th ; ^{230}Th , ^{232}Th , ^{234}Th)
Th nat	natural thorium
Tl	thallium (isotopes listed: ^{201}Tl , ^{204}Tl , ^{208}Tl)
t_b	count time for the background
t_i	time interval
t_s	count time for the source
t_{s+b}	gross count time
U	expanded uncertainty
U	uranium (isotopes listed: ^{234}U , ^{235}U , ^{238}U)
U nat	natural uranium
$u(x_i)$	standard uncertainty of the input estimate, x_i
$u(x_i)/ x_i $	relative standard uncertainty of x_i
$u(x_i, x_j)$	covariance of two input estimates, x_i and x_j
$u_c(y)$	combined standard uncertainty of y
$u_c(y)/y$	relative combined standard uncertainty of the output quantity for a particular measurement
$u_c^2(y)$	combined variance of y
$u_i(y)$	component of the combined standard uncertainty, $u_c(y)$, generated by the standard uncertainty of the input estimate x_i , $u(x_i)$, multiplied by the sensitivity coefficient, c_i

u_M	measurement method uncertainty
u_{MR}	required measurement method uncertainty
φ_{MR}	required relative measurement method uncertainty
$\varphi(x_i)$	relative standard uncertainty of a nonzero input estimate, x_i , for a particular measurement. $\varphi(x_i) = u(x_i)/x_i$
$\Phi(z)$	cumulative normal distribution function
V	volt(s)
v	scan speed
$\hat{\omega}^2$	variance
W	physical probe area
W_r	sum of the ranks of the (adjusted) reference measurements (WRS test)
W_s	sum of the ranks of the (adjusted) sample measurements (WRS test)
WS	weighted instrument sensitivity
x	estimate of the input quantity, X
x	reference area measurement
\bar{x}	sample mean
X	maximum length
$X_{[k]}$	survey unit measurements
x_i	results of the individual samples
X_i	an input quantity
x_c	the critical value of the response variable, x
x_Q	minimum quantifiable value of the response variable, x
y	year
y	estimate of the output quantity for a particular measurement, Y
Y	maximum width
Y	yttrium
Y	output quantity, measurand
y_c	critical value of the concentration
y_D	minimum detectable concentration (MDC)
y_Q	minimum quantifiable concentration (MQC)
yd	yard
yd^3	cubic yard
z	adjusted reference area measurements
Z	atomic number
$z_{1-\alpha}$	$(1 - \alpha)$ -quantile of the standard normal distribution
$z_{1-\beta}$	$(1 - \beta)$ -quantile of the standard normal distribution
$ZnS(Ag)$	zinc sulfide (silver activated)

CONVERSION FACTORS

To Convert From	To	Multiply By	To Convert From	To	Multiply By
acre	hectare	0.405	meter (m)	inch	39.4
	m ²	4,050		mile	0.000621
	ft ²	43,600	m ²	acre	0.000247
Bq	Ci	2.7x10 ⁻¹¹		hectare	0.0001
	dps	1		ft ²	10.8
	pCi	27	square mile	3.86x10 ⁻⁷	
Bq/kg	pCi/g	0.027	m ³	liter	1,000
Bq/m ²	dpm/100 cm ²	0.60	mrem	mSv	0.01
Bq/m ³	Bq/L	0.001	mrem/y	mSv/y	0.01
	pCi/L	0.027	mSv	mrem	100
centimeter (cm)	inch	0.394	mSv/y	mrem/y	100
Ci	Bq	3.70x10 ¹⁰	ounce (oz)	L	0.0296
	pCi	1x10 ¹²	pCi	Bq	0.037
dps	dpm	60		dpm	2.22
	pCi	27	pCi/g	Bq/kg	37
dpm	dps	0.0167	pCi/L	Bq/m ³	37
	pCi	0.451	rad	Gy	0.01
gray (Gy)	rad	100	rem	mrem	1,000
hectare	acre	2.47		mSv	10
liter (L)	cm ³	1000		Sv	0.01
	m ³	0.001	seivert (Sv)	mrem	100,000
	ounce oz (fluid)	33.8		mSv	1,000
				rem	100

Abbreviations: m = meter; ft = foot; Bq = becquerel; Ci = curie; dps = decays per second; pCi = picocurie; kg = kilogram; g = gram; L = liter; cm = centimeter; in. = inch; dpm = decays per minute; oz = ounce; mrem = millirem; mSv = millisievert; y = year; Gy = gray; Sv = sievert.

1

1 INTRODUCTION

2 1.1 Purpose and Scope of MARSSIM

3 Radioactive materials have been produced, processed, used, and stored at thousands of sites
4 throughout the United States. Many of them at one time had or now have residual radioactive
5 material in excess of natural background. The sites range in size from Federal weapons-
6 production facilities covering hundreds of square kilometers to the nuclear medicine
7 departments of small hospitals. Owners and managers would like to find and remove any
8 excess residual radioactive material and release these sites for restricted use or for unrestricted
9 public use.

10 The U.S. Environmental Protection Agency (EPA), the U.S. Nuclear Regulatory Commission
11 (NRC), and the U.S. Department of Energy (DOE), and the U.S. Department of Defense (DoD)
12 are responsible for the release of federally controlled sites after cleanup. Such sites include
13 DOE and DoD sites, sites licensed by the NRC and its Agreement States, and former
14 unlicensed industrial facilities that handled ores containing radioactive materials that are
15 addressed under Federal or State regulatory programs.

16 The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) provides a
17 nationally consistent consensus approach to conducting radiation surveys and investigations at
18 sites with the potential for residual radioactive material. This approach is both scientifically
19 rigorous and flexible enough to be applied to a diversity of site cleanup conditions.

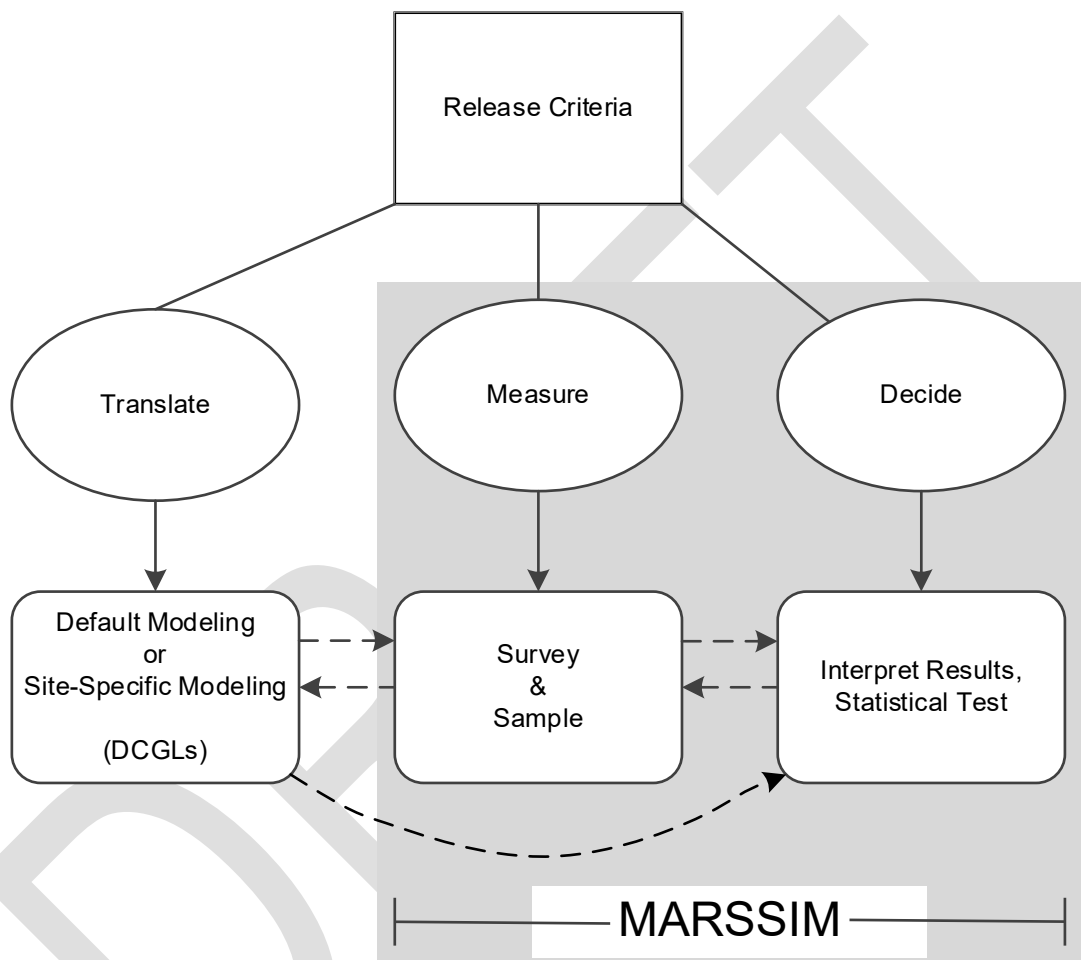
20 To release a site after remediation, it is normally necessary to demonstrate to the responsible
21 Federal or State agency that the cleanup effort was successful and that the release criteria
22 (specific regulatory limits) were met. In MARSSIM, the "Final Status Survey" (FSS) provides this
23 demonstration. This manual assists site personnel or others in performing or assessing such a
24 demonstration. (MARSSIM may also serve to guide or monitor other types of remediation
25 efforts.)

26 As illustrated in **Figure 1.1**, the demonstration of compliance with respect to conducting surveys
27 is comprised of three interrelated parts:

- 28 I. *Translate*: Translating the cleanup/release criteria (e.g., mSv/y, mrem/y, specific risk) into
29 corresponding derived concentration guideline levels (e.g., Bq/kg or pCi/g in soil) through
30 the use of environmental pathway modeling.
- 31 II. *Measure*: Acquiring scientifically sound and defensible site-specific data on the levels and
32 distribution of residual radioactive material, as well as levels and distribution of radionuclides

1 present in the background, by employing suitable field and/or laboratory measurement
2 techniques.¹

3 III. *Decide*: Determining that the data obtained from sampling support the conclusion that the
4 site meets the release criteria, within an acceptable degree of uncertainty, through
5 application of a statistically based decision rule.



6

7 **Figure 1.1: Compliance Demonstration**

8 MARSSIM provides standardized and consistent approaches for planning, conducting,
9 evaluating, and documenting environmental radiological surveys, with a specific focus on the
10 FSSs that are carried out to demonstrate compliance with cleanup regulations. The MARSSIM

¹ Measurements include field and laboratory analyses; however, MARSSIM leaves detailed discussions of laboratory sample analyses to another manual (i.e., a companion document, the Multi-Agency Radiation Laboratory Analytical Protocols [MARLAP] manual).

1 process gathers comprehensive technical information—specifically for II and III above—on
2 residual radioactive material in surface soils and on building surfaces. This information is used
3 in a performance-based approach for demonstrating compliance with a dose- or risk-based
4 regulation. This approach includes processes that identify data quality needs and may reveal
5 limitations on the data that can be collected from a survey. MARSSIM's approach supports
6 decision-making at sites with residual radioactive material in surface soil and on building
7 surfaces. In particular, MARSSIM describes generally acceptable approaches for the following:

- 8 • planning and designing scoping, characterization, remediation-support, and FSSs for sites
9 with residual radioactive material in surface soil and on building surfaces
- 10 • Historical Site Assessment (HSA)
- 11 • quality assurance/quality control (QA/QC) in data acquisition and analysis
- 12 • conducting surveys
- 13 • field and laboratory methods and instrumentation, and interfacing with radiation laboratories
- 14 • statistical hypothesis testing, and the interpretation of statistical data
- 15 • documentation

16 **Table 1.1** summarizes the scope of MARSSIM. Several issues related to releasing sites are
17 beyond the scope of MARSSIM. These include the translation of dose or risk standards into
18 radionuclide-specific concentrations or demonstrating compliance with ground water or surface
19 water regulations. MARSSIM can be applied to surveys performed at vicinity properties—those
20 not under Government or licensee control—but the decision to apply MARSSIM at vicinity
21 properties is a regulatory decision outside the scope of MARSSIM. Information on designing,
22 implementing, and assessing radiological surveys of materials and equipment is presented in
23 the Multi-Agency Radiation Survey and Assessment of Materials and Equipment (MARSAME)
24 supplement to MARSSIM. The potential presence of residual radioactive material in other media
25 (e.g., subsurface soil, ground water) is not addressed by MARSSIM. MARSSIM's main focus is
26 on FSSs, so the processes in this manual may follow remediation activities that remove below-
27 surface residual radioactive material. Therefore, some of the reasons for limiting the scope of
28 the document to surface soils and building surfaces include—

- 29 • Residual radioactive material is limited to these media for many sites following remediation.
- 30 • Because many sites have surface soil and building surface residual radioactive material as
31 the leading source of exposure to radiation, existing computer models used for calculating
32 the concentrations based on dose or risk generally consider only surface soils or building
33 surfaces as a source term.

1 **Table 1.1: Scope of MARSSIM**

Within Scope of MARSSIM		Beyond Scope of MARSSIM	
<i>Technical Information</i>	MARSSIM provides technical, performance-based guidance on conducting radiation surveys and site investigations, remediation and restoration activities, and demonstration of compliance with dose- or risk-based regulations. MARSSIM includes a framework for developing a phased approach to site investigations that include stakeholder involvement, and which emphasizes the development of the final status survey (FSS) for site release.	<i>Regulation</i>	MARSSIM does not set new regulations or requirements, or address non-technical issues (e.g., legal or policy) for site cleanup. Release criteria will be provided rather than calculated using MARSSIM.
<i>Tool Box</i>	MARSSIM can be thought of as an extensive tool box with many components—some within the text of MARSSIM, others by reference.	<i>Tool Box</i>	Many topics are beyond the scope of MARSSIM. For example— <ul style="list-style-type: none"> • a public participation program • staging, classification, packaging, and transportation of wastes for disposal • remediation and stabilization techniques • training
<i>Stakeholder Involvement</i>	MARSSIM encourages stakeholder involvement but does not provide specific guidance.	<i>Stakeholder Involvement</i>	Specific guidance is determined by the individual Federal and State agencies.
<i>Measurement</i>	The information given in MARSSIM is performance-based and directed toward acquiring site-specific data and goals.	<i>Procedure</i>	The approaches suggested in MARSSIM vary depending on the various site data needs—there are no set procedures for sample collection, measurement techniques, storage, or disposal established in MARSSIM.
<i>Modeling</i>	The interface between environmental pathway modeling and MARSSIM is an important survey design consideration addressed in MARSSIM.	<i>Modeling</i>	Environmental pathway modeling and ecological endpoints in modeling are beyond the scope of MARSSIM.

Within Scope of MARSSIM		Beyond Scope of MARSSIM	
<i>Soil and Buildings</i>	The two main media of interest in MARSSIM are surface soil and building surfaces affected by residual radioactive material.	<i>Other Media</i>	MARSSIM does not cover other media, including construction materials, equipment, subsurface soil, surface or subsurface water, biota, air, sewers, or sediments.
<i>Final Status Survey</i>	The focus of MARSSIM is on the FSS, as this is the deciding factor in judging whether the site meets the restricted or unrestricted release criteria.	<i>Instruments and Radiation Detection Equipment</i>	MARSSIM does not recommend the use of any specific radiation detection equipment—there is too much variability in the types of radiation sites.
<i>Radiation</i>	MARSSIM considers only radiation-derived hazards.	<i>Chemicals</i>	MARSSIM does not consider any hazards posed by chemicals.
<i>Remediation Method</i>	MARSSIM assists users in determining when sites are ready for an FSS and provides information on how to determine if remediation was successful.	<i>Remediation Method</i>	MARSSIM does not discuss selection and evaluation of remediation alternatives, public involvement, legal considerations, and policy decisions related to planning.
<i>Data Quality Objectives (DQO) Process</i>	MARSSIM presents a systemized approach for designing surveys to collect data needed for making decisions, such as whether to release a site.	<i>DQO Process</i>	MARSSIM does not provide prescriptive or default DQOs.
<i>Data Quality Assessment (DQA)</i>	MARSSIM provides a set of statistical tests for evaluating data and lists alternate tests that may be applicable at specific sites.	<i>DQA</i>	MARSSIM does not prescribe a statistical test for use at all sites.
<i>Radon Assessment</i>	MARSSIM does address measurements of radon (concentration or flux) at sites with the immediate radon parents present because of previous site operations.	<i>Radon Assessment</i>	MARSSIM does not include measurements of radon in ambient air, air emissions, effluents, water, or indoor air at sites with none of the immediate radon parents present because of previous site operations.

- 1 MARSSIM also recognizes that there may be other factors that have an impact on designing
- 2 surveys, such as cost or stakeholder concerns. Guidance on how to address these specific
- 3 concerns is outside the scope of MARSSIM. Unique site-specific cases may arise that require a
- 4 modified approach beyond what is presently described in MARSSIM. This includes examples
- 5 such as—

- 1 • sites affected by naturally occurring radioactive material (NORM) or technically enhanced
2 naturally occurring radioactive material (TENORM) in which the concentrations
3 corresponding to the release criteria are close to the variability of the background
- 4 • sites where a reference background cannot be established

5 However, the process of planning, implementing, assessing, and making decisions about a site
6 described in MARSSIM is applicable to all sites, even if the examples in this manual do not
7 meet a site's specific objectives.

8 Of MARSSIM's many topics, the Data Quality Objective (DQO) approach to data acquisition and
9 analysis and the Data Quality Assessment (DQA) for determining that data meet stated
10 objectives are a consistent theme throughout the manual. The DQO process and DQA
11 approach, described in **Chapter 2**, present a scientific, common-sense method for designing
12 and conducting surveys and making best use of the obtainable information. A formal framework
13 for systematizing the planning of data acquisition surveys can ensure that the information can
14 support important decisions, such as whether to release a particular site following remediation.

15 DQOs must be developed on a site-specific basis. The approaches presented in MARSSIM may
16 not meet the DQOs at every site, so other methods may be used to meet site-specific DQOs, as
17 long as an equivalent level of performance can be demonstrated.

18 **1.2 Structure of the Manual**

19 **Chapter 2** provides an overview of the Radiation Survey and Site Investigation (RSSI) process.
20 **Figures 2.4 through 2.8** are flowcharts that summarize the steps taken and decisions made in
21 the process. **Chapter 3** provides instructions for performing an HSA—a detailed investigation to
22 collect existing information on the site or facility and to develop a conceptual site model. The
23 results of the HSA are used to plan surveys, perform measurements, and collect additional
24 information at the site. **Chapter 4** covers issues that arise in all types of surveys. Detailed
25 information on performing specific types of surveys is included in **Chapter 5**. Information on
26 selecting the appropriate measurement method combining instruments and measurement
27 techniques is included in **Chapters 6 and 7**. **Chapter 6** discusses direct measurements and
28 scanning surveys, and **Chapter 7** discusses sampling and sample preparation for laboratory
29 measurements. The interpretation of survey results is described in **Chapter 8**.

30 MARSSIM also contains several appendices to provide additional information on specific topics.
31 **Appendix A** presents an example of how to apply the MARSSIM process to a specific site
32 through an FSS. **Appendix B** describes a simplified procedure for compliance demonstration
33 that may be applicable at certain types of sites. **Appendix C** summarizes the regulations and
34 requirements associated with radiation surveys and site investigations for each of the agencies
35 involved in the development of MARSSIM. Detailed information on the EPA Quality System is in
36 **Appendix D**. The ranked set sampling approach, a form of double sampling that can be useful
37 for hard-to-detect radionuclides, is in **Appendix E**. **Appendix F** describes the relationships
38 among MARSSIM; the Comprehensive Environmental Response, Compensation, and Liability
39 Act (CERCLA); and the Resource Conservation and Recovery Act (RCRA). Sources of
40 information used during site assessment are listed in **Appendix G**. **Appendix H** describes field

1 survey and laboratory analysis equipment that may be used for radiation surveys and site
2 investigations. **Appendix I** offers tables of statistical data and supporting information for
3 interpreting survey results described in Chapter 8. The derivation of the alpha scanning
4 detection limit calculations used in **Chapter 6** is described in **Appendix J**. Comparison tables
5 for QA documents are in **Appendix K**. **Appendix L** includes guidance for the use of stem and
6 leaf displays and quantile plots. Instructions for the calculation of power curves are included in
7 **Appendix M**. **Appendix N** includes three illustrative examples demonstrating the potential
8 consequences of using methods with different levels of precision for planning and designing an
9 FSS and for actually performing the FSS. **Appendix O** provides additional information about the
10 Wilcoxon Rank Sum test (WRS) and Sign test and illustrates examples of the derived
11 concentration guideline level (DCGL) determinations.

12 MARSSIM is presented in a modular format, with each module containing information on
13 conducting specific aspects of, or activities related to, the survey process. Followed in order,
14 each module leads to the generation and implementation of a complete survey plan. Although
15 this approach may involve some overlap and redundancy in information, it also allows many
16 users to concentrate only on those portions of the manual that apply to their own particular
17 needs or responsibilities. The procedures within each module are listed in order, and options
18 are provided to let the user skip portions of the manual that may not be applicable to a specific
19 site. Where appropriate, checklists condense and summarize major points in the process. The
20 checklists may be used to verify that every suggested step is followed or explain why a step was
21 not needed.

22 MARSSIM contains a simplified procedure (see **Appendix B**) that many users of radioactive
23 materials may be able to employ to demonstrate compliance with the release criteria—with the
24 approval of the responsible regulatory agency. Sites that may qualify for simplified release
25 procedures are those in which the radioactive materials used were—

- 26 • of relatively short half-life (e.g., $t_{1/2} \leq 120$ days) and have since decayed to insignificant
27 quantities
- 28 • kept only in small enough quantities so as to be exempted or not requiring a specific license
29 from a regulatory authority
- 30 • used or stored only in the form of non-leaking sealed sources
- 31 • combinations of the above

32 **1.3 Use of the Manual**

33 Potential users of this manual are Federal, State, and local government agencies with
34 regulatory authority and control of residual radioactive material in the environment; their
35 contractors; and other parties, such as organizations with licensed authority to possess and use
36 radioactive materials. The manual is intended for a technical audience having knowledge of
37 radiation health physics and statistics, as well as experience with the practical applications of
38 radiation protection. An understanding of instrumentation and methodologies and expertise in
39 planning, approving, and implementing surveys of environmental levels of radioactive material is

1 assumed. This manual has been written so that individuals responsible for planning, approving,
2 and implementing radiological surveys will be able to understand and apply the information
3 provided here. Certain situations and sites may require consultation with personnel with specific
4 types of expertise and experience.

5 MARSSIM uses the word “should” as a recommendation, not as a requirement. Each
6 recommendation in this manual is not intended to be taken literally and applied at every site.
7 MARSSIM’s survey planning documentation will address how to apply the process on a site-
8 specific basis.

9 As previously stated, MARSSIM supports compliance with dose- or risk-based regulations. The
10 translation of the regulatory dose limit to a corresponding concentration level is not addressed in
11 MARSSIM, so the information in this manual is applicable to a broad range of regulations,
12 including concentration-based regulations. The terms dose, risk, and dose-based and risk-
13 based regulation are used throughout the manual, but these terms are not intended to limit the
14 use of the manual.

Note that Federal or State agencies that can approve a demonstration of compliance may support requirements that differ from what is presented in this version of MARSSIM. It is essential, therefore, that the persons carrying out the surveys remain in close communication with the proper Federal or State regulatory authorities throughout the compliance demonstration process.

15 **1.4 Missions of the Federal Agencies Producing MARSSIM**

16 MARSSIM is the product of a multi-agency workgroup with representatives from EPA, NRC,
17 DOE, and DoD. This section briefly describes the missions of the participating agencies.
18 Regulations and requirements governing site investigations for each of the agencies associated
19 with radiation surveys and site investigations are presented in **Appendix C**.

20 **1.4.1 U.S. Environmental Protection Agency**

21 The mission of the EPA is to improve and preserve the quality of the environment, on both
22 national and global levels. The EPA’s scope of responsibility includes implementing and
23 enforcing environmental laws, setting guidelines, monitoring pollution, performing research, and
24 promoting pollution prevention. EPA Headquarters maintains overall planning, coordination, and
25 control of EPA programs, and EPA’s 10 regional offices are responsible for executing EPA’s
26 programs within the boundaries of each region. EPA also coordinates with State and local
27 governments’ pollution control activities and supports further research and development.

28 **1.4.2 U.S. Nuclear Regulatory Commission**

29 The mission of the NRC is to ensure adequate protection of public health and safety, the
30 common defense and security, and the environment in the use of certain radioactive materials in
31 the United States. The NRC’s scope of responsibility includes regulation of commercial nuclear
32 power reactors; nonpower research, test, and training reactors; fuel cycle facilities; medical,

1 academic, and industrial uses of nuclear materials; and the transport, storage, and disposal of
2 nuclear materials and waste. The Energy Reorganization Act of 1974 and the Atomic Energy
3 Act of 1954, as amended, provide the foundation for regulation of the Nation's commercial use
4 of radioactive materials.

5 **1.4.3 U.S. Department of Energy**

6 The mission of the DOE is to develop and implement a coordinated national energy policy to
7 ensure the availability of adequate energy supplies and to develop new energy sources for
8 domestic and commercial use. In addition, DOE is responsible for the development,
9 construction, and testing of nuclear weapons for the U.S. Military. DOE is also responsible for
10 managing the low- and high-level radioactive wastes generated by past nuclear weapons and
11 research programs and for constructing and maintaining a repository for civilian radioactive
12 wastes generated by commercial nuclear reactors. DOE has the lead in remediating facilities
13 and sites previously used in atomic energy programs.

14 **1.4.4 U.S. Department of Defense**

15 The global mission of the DoD is to provide for the defense of the United States. In doing this,
16 DoD is committed to protecting the environment. Each military service has specific regulations
17 addressing the use of radioactive sources and the development of occupational health
18 programs and radiation protection programs. The documents describing these regulations are
19 used as guidance in developing environmental radiological surveys within DoD and are
20 discussed in **Appendix C**.

21 In accordance with section 91b of the Atomic Energy Act of 1954, as amended, DoD (including
22 separate military services) has authority to acquire nuclear reactor systems and special nuclear
23 materials. Additionally, DoD (including separate military services) is the lead federal agency for
24 environmental remediation under several federal regulatory programs.

2 OVERVIEW OF THE RADIATION SURVEY AND SITE INVESTIGATION PROCESS

2.1 Introduction

The purpose of the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) is to provide a standardized approach to demonstrating compliance with release criteria.¹ This chapter provides a brief overview of the Radiation Survey and Site Investigation (RSSI) process, several important aspects of this process, and its underlying principles. The purpose of this chapter is to provide the overview information required to understand the rest of this manual. The concepts introduced here are discussed in detail throughout the manual.

- **Section 2.2** introduces and defines key terms used throughout the manual. Some of these terms may be familiar to the MARSSIM user, while others are new terms developed specifically for this manual.
- **Section 2.3** describes the flow of information used to decide whether a site or facility complies with release criteria. The section describes the framework that is used to demonstrate compliance with the release criteria and is the basis for all information presented in this manual. The decision-making process is broken down into four phases: (1) planning, (2) implementation, (3) assessment, and (4) decision-making.
- **Section 2.4** introduces the RSSI process, which can be used for compliance demonstration at many sites. The section describes a series of surveys that form the core of this process. Each survey has specified goals and objectives to support a final decision on whether a site or facility complies with the appropriate criteria. Flow diagrams are provided showing how the different surveys support the overall process, along with descriptions of the information obtained through each type of survey.
- **Section 2.5** presents major considerations that relate to the decision-making and survey-design processes. This section, in addition to the examples discussed in detail throughout the manual, focuses on residual radioactive material in surface soils and on building surfaces. Recommended survey designs for demonstrating compliance are presented, along with the rationale for selecting these designs.
- **Section 2.6** recognizes that the methods presented in MARSSIM may not represent the most appropriate survey design at all sites. Some alternate methods for applying the RSSI process are discussed. Different methods for demonstrating compliance that are technically defensible may be developed with the approval of the responsible regulatory agency.

MARSSIM provides an approach that is technically defensible and flexible enough to be applied to a variety of site-specific conditions. Applying this approach to dose- or risk-based criteria

¹ MARSSIM uses the word “should” as a recommendation, not as a requirement. Each recommendation in this manual is not intended to be taken literally and applied at every site. MARSSIM’s survey planning documentation will address how to apply the process on a site-specific basis.

1 provides a consistent approach to protecting human health and the environment. The manual's
2 performance-based approach to decision-making provides the flexibility needed to address
3 compliance demonstration at individual sites.

4 **2.2 Understanding Key MARSSIM Terminology and Survey Unit Classification**

5 **2.2.1 Key MARSSIM Terminology**

6 The first step in understanding the RSSI process is accomplished by understanding this
7 manual's scope, the terminology, and the concepts. Some terms were developed specifically for
8 MARSSIM, for the purposes of this manual, while other commonly used terms were adopted.
9 This section explains some of the terms roughly in the order of their presentation in the manual.
10 The italicized terms in this section are all defined in the Glossary of this document.

11 The process described in MARSSIM begins with the premise that release criteria have already
12 been provided in terms of a measurement quantity. The methods presented in MARSSIM are
13 generally applicable and are not dependent on the value of the release criteria.

14 *Release criteria* are regulatory limits expressed in terms of dose (millisieverts/year or
15 millirem/year) or risk (cancer morbidity or cancer mortality) or concentrations of radioactive
16 material specified in regulations or standards. The terms "release limit" and "cleanup standard"
17 are also used to describe this term. Release criteria that are typically based on dose (e.g., total
18 effective dose [TED], committed effective dose [CED], total effective dose equivalent [TEDE], or
19 committed effective dose equivalent [CEDE]) or risk (e.g., risk of cancer incidence [morbidity] or
20 risk of cancer death [mortality]) generally cannot be measured directly.

21 *Exposure pathway modeling* is an analysis of various *exposure pathways* and scenarios used to
22 convert dose or risk into concentration. Exposure pathway modeling is used to calculate a
23 radionuclide-specific predicted concentration of radioactive material or surface area
24 concentration of radioactive material of specific nuclides that could result in a dose or risk equal
25 to the release criteria within the required performance period. In this manual, such a
26 concentration is termed the *derived concentration guideline level (DCGL)*. In many cases,
27 DCGLs can be derived from applicable requirements or regulatory agency guidance based on
28 default modeling input parameters (e.g., screening-level analyses) if site conditions are
29 consistent with the underlying assumptions in the default modeling or screening analyses; in
30 other cases, it may be necessary to develop site-specific parameters. In general, the units for
31 the DCGL are the same as the units for measurements performed to demonstrate compliance
32 (e.g., becquerel/kilogram [Bq/kg] or picocurie/gram [pCi/g], becquerel/square meter [Bq/m²] or
33 decays per minute [dpm]/100 cm²). This allows direct comparisons between the survey results
34 and the DCGL. A discussion of the uncertainty associated with using DCGLs to demonstrate
35 compliance is included in **Appendix D, Section D.1.6**.

36 An *investigation level* is a derived media-specific, radionuclide-specific concentration that, if
37 exceeded, triggers some response, such as further investigation or remediation. An
38 investigation level may be used early in the process to identify areas requiring further
39 investigation; it may also be used as a screening tool during compliance demonstration to
40 identify potential problem areas. A DCGL is an example of a specific investigation level that is
41 based on the release criteria.

1 While the derivation of DCGLs is outside the scope of MARSSIM, it is important to understand
2 the assumptions that underlie this derivation of DCGLs to ensure consistency with the statistical
3 approach used to demonstrate compliance with regulatory criteria. For example, the estimated
4 dose, and consequently the cleanup level or DCGL, may be sensitive to assumptions regarding
5 the lateral extent (i.e., area) of residual radioactive material for relatively small exposure areas
6 (e.g., areas that do not approximate an infinite source for external radiation exposure, or areas
7 that would not support crop cultivation in quantities consistent with the assumed annual
8 consumption rates of contaminated produce for the resident farmer scenario). Other important
9 factors may include depth of residual radioactive material, chemical and physical form of the
10 source, hydrogeological considerations, and potential exposure scenarios. For more information
11 on environmental pathway modeling, check with your regulator's guidance on the topic.

12 MARSSIM defines two potential DCGLs based on the area of residual radioactive material:

- 13 • Evenly distributed activity—If the residual radioactive material is evenly distributed over a
14 large area, MARSSIM looks at the average or median concentration of radioactive material
15 over the entire area. The $DCGL_W^2$ (the DCGL used when applying the Wilcoxon Rank Sum
16 [WRS] or Sign tests; see **Section 2.5.1.2**) is derived based on assuming an average
17 concentration over a wide area in the exposure pathway modeling.
- 18 • Small areas of elevated concentrations of radioactive material—If the residual radioactive
19 material appears as small areas of elevated concentrations of radioactive material³ within a
20 larger area, MARSSIM also considers the results of individual measurements. The $DCGL_{EMC}$
21 (the DCGL used for the elevated measurement comparison [EMC], see **Section 2.5.1.1**) is
22 derived separately for these small areas and generally from different exposure assumptions
23 than those used for larger areas.

24 *Surface soil* is the top layer of soil on a site that is available for direct exposure, growing plants,
25 resuspension of particles for inhalation, and mixing from human disturbances. Surface soil may
26 also be defined as the thickness of soil that can be measured using direct measurement or
27 scanning techniques. Historically, this layer has often been represented as the top 15 cm
28 (6 inches) of soil (40 CFR 192), but it will vary depending on radionuclide, surface
29 characteristics, measurement method, and pathway modeling assumptions. For the purposes of
30 MARSSIM, surface soil may be considered to include gravel fill, waste piles, concrete, or
31 asphalt paving. Similarly, a *building surface* is defined as the thickness of building surface
32 material that can be measured using direct measurement or scanning techniques and will also

² The “W” in $DCGL_W$ historically stood for Wilcoxon Rank Sum test, which is the statistical test recommended in MARSSIM for demonstrating compliance when the radionuclide is present in background. However, as the Sign test is also a recommended test in MARSSIM for demonstrating compliance when the radionuclide is not present in background, the term now colloquially refers to “wide-area” or “average.”

³ A small area of elevated concentration of radioactive material, or maximum point estimate of residual radioactive material, might also be referred to as a “hot spot.” This term has been purposefully omitted from MARSSIM because the term often has different meanings based on operational or local program concerns. As a result, there may be problems associated with defining the term and reeducating MARSSIM users in the proper use of the term.

1 vary depending on radionuclide, surface characteristics, measurement technique, and pathway
2 modeling assumptions.

3 A *site* is any installation, facility, or discrete, physically separate parcel of land, or any building or
4 structure or portion thereof that is being considered for survey and investigation. *Area* is a very
5 general term that refers to any portion of a site, up to and including the entire site.

6 *Remediation* includes those actions that are consistent with a permanent remedy taken instead
7 of, or in addition to, removal action in the event of a release or threatened release of a
8 hazardous substance into the environment, to prevent or minimize the release of hazardous
9 substances so that they do not migrate to cause substantial danger to present or future public
10 health or welfare or the environment.

11 *Decommissioning* is a term for the process of safely removing a site from service, reducing the
12 concentration of residual radioactive material through remediation to a level that permits release
13 of the property, and termination of the license or other authorization for site operation.

14 A *survey unit* is a physical area consisting of structures or land areas of specified size and
15 shape at a site for which a separate decision will be made as to whether the unit meets the
16 release criteria. (This decision is made as a result of the *final status survey [FSS]*—the survey in
17 the RSSI process used to demonstrate compliance with release criteria.) Survey units are
18 established to facilitate the survey process and the statistical analysis of survey data. The size
19 and shape of the survey unit are based on such factors as the potential for residual radioactive
20 material, the expected distribution of residual radioactive material, and any physical boundaries
21 (e.g., buildings, fences, roads, soil type, and surface water body) at the site. Survey units are
22 generally formed by grouping contiguous site areas with a similar use history and the same
23 classification of potential for residual radioactive material.

24 *Measurement* in MARSSIM is used interchangeably to mean (1) the act of using a detector to
25 determine the level or quantity of radioactive material on a surface or in a sample of material
26 removed from a media being evaluated, or (2) the quantity obtained by the act of measuring.

27 *Direct measurements* are obtained by placing a detector near the surface or media being
28 surveyed for a prescribed amount of time. An indication of the resulting concentration of
29 radioactive material is read out directly.

30 *Scanning* is a measurement technique performed by moving a portable radiation detector at a
31 specified speed and distance next to a surface to detect radiation.

32 *Sampling* is the process of collecting a portion of an environmental medium as being
33 representative of the locally remaining medium. The collected portion, or aliquot, of the medium
34 is then analyzed to identify the radionuclide and determine the concentration. The word sample
35 may also refer to a set of individual measurements drawn from a population whose properties
36 are studied to gain information about the entire population. The latter is primarily used for
37 statistical discussions.

38 The *graded approach* is defined as the process where the level of application of managerial
39 controls for an item or work is determined according to the intended use of the results and the

1 degree of confidence needed in the quality of the results. To make the best use of resources for
2 decommissioning, MARSSIM places greater survey efforts on areas that have, or had, the
3 highest potential for residual radioactive material. The FSS uses statistical tests to support
4 decision-making. These statistical tests are performed using survey data from areas with
5 common characteristics, such as potential for residual radioactive material, which are
6 distinguishable from other areas with different characteristics.

7 *Categorization* is the act or result of separating an area or survey unit into one of two
8 categories: impacted or non-impacted. Areas that have no reasonable potential for residual
9 radioactive material are categorized as non-impacted areas. These areas have no radiological
10 impact from site operations and are typically identified early in the cleanup process. Areas with
11 some reasonable potential for residual radioactive material are categorized as impacted areas.

12 *Classification* is the process by which impacted areas or survey units are separated into
13 *Class 1, Class 2, or Class 3 areas* according to radiological characteristics. Survey unit
14 classification determines the FSS design and the procedures used to develop this design.
15 Preliminary area classifications, made earlier in the MARSSIM process, are useful for planning
16 subsequent surveys.

17 The *background reference area* is a geographical area from which representative reference
18 measurements are performed for comparison with measurements performed in specific survey
19 units. If the radionuclide of concern is present in the background, or if the measurement system
20 used to determine concentration in the survey unit is not radionuclide-specific, background
21 measurements are compared to the survey unit measurements to determine the concentration
22 of residual radioactive material. The site radiological reference area is defined as an area that
23 has similar physical, chemical, radiological, and biological characteristics as the survey unit(s)
24 being investigated but has not been affected by site activities (i.e., non-impacted).

25 The *Data Life Cycle* is the process of planning the survey, implementing the survey plan, and
26 assessing the survey results before making a decision. Survey planning uses the *Data Quality*
27 *Objectives (DQO) Process*, which is a series of logical steps to create a plan for the resource-
28 effective acquisition of environmental data, to ensure that the survey results are of sufficient
29 quality and quantity to support the final decision. *Measurement Quality Objectives (MQOs)* are
30 the specific analytical data requirements of the DQOs. *Quality assurance (QA)* is an integrated
31 system of management activities involving planning, implementation, assessment, reporting,
32 and quality improvement to ensure that a process, item, or service is of the type and quality
33 needed and expected by the customer. *Quality control (QC)* is the overall system of technical
34 activities that measure the attributes and performance of a process, item, or service against
35 defined standards to verify that they meet the stated requirements established by the customer,
36 operational techniques, and activities that are used to fulfill requirements for quality. QA/QC
37 procedures are performed during implementation of the survey plan to collect information
38 necessary to evaluate the survey results. *Data Quality Assessment (DQA)* is the scientific and
39 statistical evaluation of data to determine if the data are of the right type, quality, and quantity to
40 support their intended use.

41 A systematic process and structure for quality should be established to provide confidence in
42 the quality and quantity of data collected to support decision-making. The data used in decision-

1 making should be supported by a planning document that records how quality assurance and
2 quality control are applied to obtain the types and quality of results that are needed and
3 expected. There are several terms used to describe a variety of planning documents, some of
4 which document only a small part of the survey design process. MARSSIM uses the term
5 *Quality Assurance Project Plan (QAPP)* to describe a written document outlining the procedures
6 a monitoring project will use to ensure the data it collects and analyzes meets project
7 requirements. This term conforms to consensus guidance ANSI/ASQC E4-1994 (ASQC 1995)
8 and U.S. Environmental Protection Agency (EPA) guidance (EPA 2001b; EPA 2002a), and its
9 use is recommended to promote consistency. The use of the term QAPP in MARSSIM does not
10 exclude the use of other terms (e.g., Decommissioning Plan, Sampling and Analysis Plan, Field
11 Sampling Plan) to describe survey documentation, provided that the information included in the
12 documentation supports the objectives of the survey. The QAPP is a plan for obtaining data of
13 sufficient quality and quantity to satisfy data needs; it describes policy, organization, and
14 functional activities and includes DQOs and MQOs.

15 **2.2.2 Classification Assessment**

16 Impacted areas are divided into three classifications:

- 17 • **Class 1 Areas:** Areas that have, or had before remediation, a potential for residual
18 radioactive material (based on site operating history) or known residual radioactive material
19 (based on previous radiation surveys) above the DCGL_w. Examples of Class 1 areas
20 include—
 - 21 ○ site areas previously subjected to remedial actions⁴
 - 22 ○ locations where leaks or spills are known to have occurred
 - 23 ○ former burial or disposal sites
 - 24 ○ waste storage sites
 - 25 ○ areas with residual radioactive material in discrete solid pieces of material and high
26 specific activity
- 27 • **Class 2 Areas:** Areas that have, or had before remediation, a potential for residual
28 radioactive material or known residual radioactive material but are not expected to exceed
29 the DCGL_w. To justify changing an area's classification from Class 1 to Class 2, the existing
30 data (from the Historical Site Assessment [HSA], scoping surveys, or characterization
31 surveys) should provide a high degree of confidence that no individual measurement would
32 exceed the DCGL_w. Other justifications for this change in an area's classification may be

⁴ Remediated areas are identified as Class 1 areas because the remediation process often results in less than 100 percent removal of the radioactive material. The residual radioactive material that remains on the site after remediation is often associated with relatively small areas with elevated levels of radioactive material. This results in a non-uniform distribution of the radionuclide and a Class 1 classification. If an area is expected to have no potential to exceed the DCGL_w and was remediated to demonstrate the residual radioactive material is as low as reasonably achievable, the remediated area might be classified as Class 2 for the final status survey.

- 1 appropriate based on the outcome of the DQO process. Examples of areas that might be
2 classified as Class 2 for the FSS include—
- 3 ○ locations where radioactive materials were present in an unsealed form (e.g., process
4 facilities)
 - 5 ○ residual radioactive material potentially along transport routes
 - 6 ○ areas downwind from stack release points
 - 7 ○ upper walls, roof support frameworks, and ceilings of some buildings or rooms subjected
8 to airborne radioactive material
 - 9 ○ areas where low concentrations of radioactive materials were handled
 - 10 ○ areas on the perimeter of former buffer or radiological control areas
- 11 • *Class 3 Areas:* Any impacted areas that are not expected to contain any residual radioactive
12 material or are expected to contain levels of residual radioactive material at a small fraction
13 of the $DCGL_w$, based on site operating history and previous radiation surveys. To justify
14 changing an area's classification from Class 1 or Class 2 to Class 3, the existing data (from
15 the HSA, scoping surveys, or characterization surveys) should provide a high degree of
16 confidence that there is either no residual radioactive material, or that any levels of residual
17 radioactive material are a small fraction of the $DCGL_w$. Other justifications for this change in
18 an area's classification may be appropriate based on the outcome of the DQO process.
19 Examples of areas that might be classified as Class 3 include buffer zones around Class 1
20 or Class 2 areas, and areas with very low potential for residual radioactive material but
21 insufficient information to justify a non-impacted classification.
- 22 Class 1 areas have the greatest potential for residual radioactive material and, therefore,
23 receive the highest degree of survey effort for the FSS using a graded approach, followed by
24 Class 2, and then by Class 3.
- 25 Survey units should be classified as Class 1 unless there is sufficient justification for classifying
26 the survey as Class 2 or Class 3. Likewise, the classification of a survey unit should not be
27 reduced without sufficient justification.
- 28 Non-impacted areas do not receive any level of survey coverage, because they have no
29 reasonable potential for residual radioactive material. Non-impacted areas are determined on a
30 site-specific basis from information collected during site identification, the HSA, and scoping and
31 characterization surveys. Examples of areas that would be non-impacted rather than impacted
32 usually include administrative, residential, or other buildings that have not contained radioactive
33 materials except such devices as smoke detectors or exit signs with sealed radioactive sources.

34 **2.3 Making Decisions Based on Survey Results**

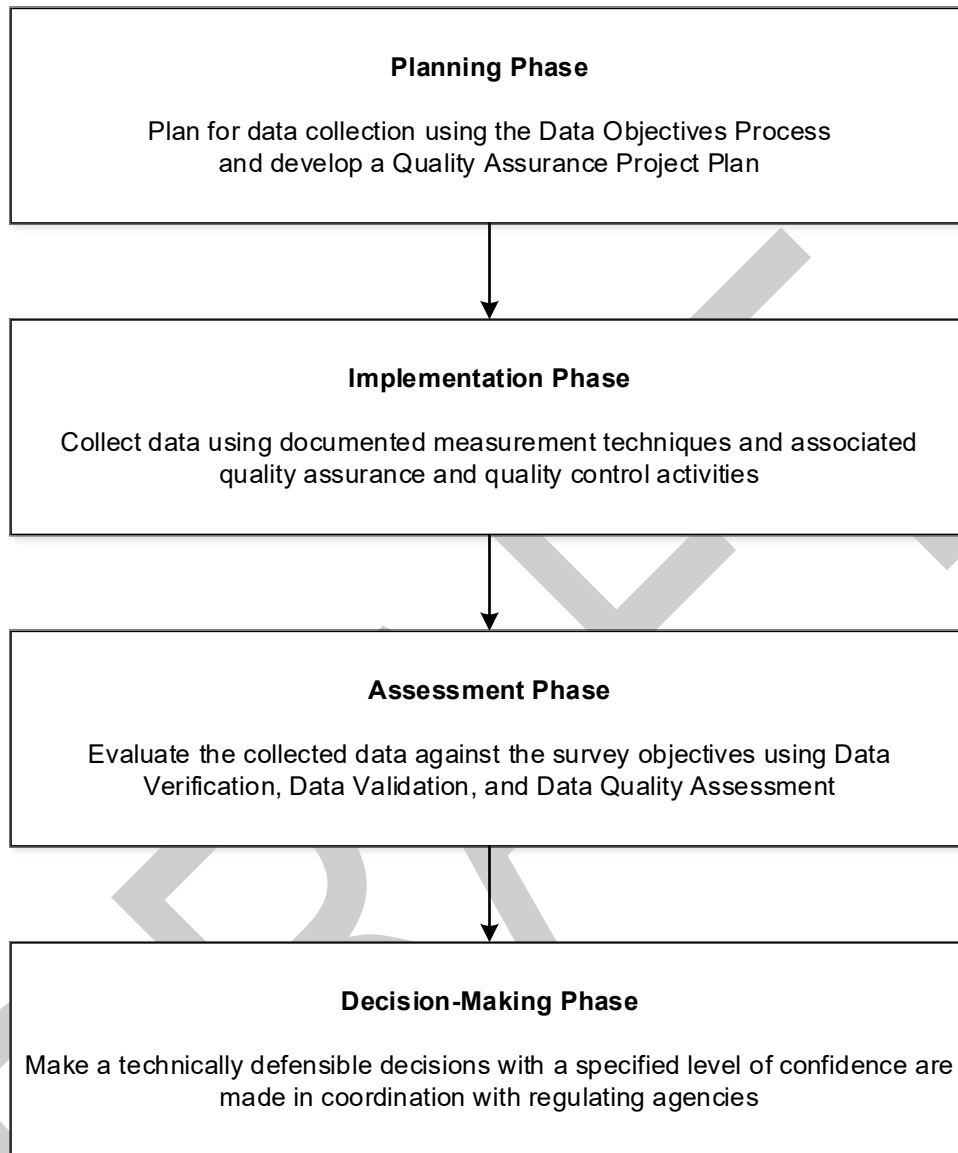
35 Compliance demonstration is simply a decision as to whether a survey unit meets the release
36 criteria. For most sites, this decision is based on the results of one or more surveys. When

1 survey results are used to support a decision, the decision maker⁵ needs to ensure that the data
2 will support that decision with satisfactory confidence. Uncertainty in the survey results is
3 unavoidable, so the possibility of errors in decisions supported by the survey results is
4 unavoidable. For this reason, actions must be taken to manage the uncertainty in the survey
5 results so that sound and defensible decisions can be made. These actions include proper
6 survey planning to control known causes of uncertainty, proper application of QC procedures
7 during implementation of the survey plan to detect and control significant sources of error, and
8 careful analysis of uncertainty before the data are used to support decision-making. These
9 actions describe the flow of data throughout each type of survey and are combined in the Data
10 Life Cycle, as shown in **Figure 2.1**.

11 There are four phases of the Data Life Cycle:

- 12 • *Planning Phase*: The survey design is developed and documented using the DQO process.
13 QA/QC procedures are developed and documented in the QAPP. The QAPP is the principal
14 product of the planning process, which incorporates the DQOs as it integrates all technical
15 and quality aspects for the life cycle of the project, including planning, implementation, and
16 assessment. The QAPP contains plans for survey operations and provides a specific format
17 for obtaining the type and quality of data needed for decision-making. The QAPP elements
18 are presented in the order of the Data Life Cycle and are grouped into two types of
19 elements: (1) project management and (2) collection and evaluation of environmental data
20 (ASQC 1995). The DQO process is described in **Appendix D** and applied in **Chapters 3, 4,**
21 **and 5** of this manual. Development of the QAPP is described in **Appendix D** and applied
22 throughout the RSSI process.
- 23 • *Implementation Phase*: The survey is carried out in accordance with the standard operating
24 procedures (SOPs) and QAPP, and it generates raw data. **Chapters 6–7** and **Appendix H**
25 provide information on the selection of data collection techniques. The QA and QC
26 measurements, discussed in **Chapters 6–7**, also generate data and other important
27 information that will be used during the Assessment Phase.
- 28 • *Assessment Phase*: The data generated during the Implementation Phase first are verified
29 to ensure that the SOPs specified in the QAPP were followed and that the measurement
30 systems performed in accordance with the criteria specified in the QAPP. Then the data are
31 validated to ensure that the results of data collection activities support the objectives of the
32 survey as documented in the QAPP or permit a determination that these objectives should
33 be modified. The DQA process is then applied using the validated data to determine if the
34 quantity and quality of the data satisfy their intended use. The DQA process is described in
35 **Appendix D** and is applied in **Chapter 8**.
- 36 • *Decision-making Phase*: A decision is made, in coordination with the regulatory agency,
37 based on the conclusions drawn from the assessment process. The ultimate objective is to
38 make technically defensible decisions with a specified level of confidence (**Chapter 8**).

⁵ The term decision maker is used throughout this section to describe the person, team, board, or committee responsible for the final decision regarding release of the survey unit.



1

2 **Figure 2.1: The Data Life Cycle**3 **2.3.1 Planning Effective Surveys—Planning Phase**

4 The first step in designing effective surveys is planning. The DQO process is a series of
 5 planning steps based on the scientific method for establishing criteria for data quality and
 6 developing survey designs (ASQC 1995, EPA 2006a, EPA 1987a, EPA 1987b). Planning
 7 radiation surveys using the DQO process improves the survey effectiveness and efficiency, and
 8 thereby the defensibility of decisions. Proper data collection planning minimizes expenditures by
 9 eliminating unnecessary, duplicative, or overly precise data. Using the DQO process ensures
 10 that the type, quantity, and quality of environmental data used in decision making will be

1 appropriate for the intended application. MARSSIM supports the use of the DQO process to
2 design surveys for input to both evaluation techniques (elevated measurement comparison and
3 the statistical test). The DQO process provides systematic procedures for defining the criteria
4 that the survey design should satisfy, including whether to perform scan-only surveys or scan
5 surveys in conjunction with direct measurements/sampling, what type of measurements to
6 perform, when and where to perform measurements, the level of decision errors for the survey,
7 and how many measurements to perform.

8 The level of effort associated with planning a survey is based on the complexity of the site.
9 Large and complicated sites generally receive a significant amount of effort during the planning
10 phase, while smaller sites may not require as much planning. In addition, the complexity of the
11 survey depends not only on the size of the site or survey unit, but also on the physical and
12 chemical characteristics of the site and the radioactive materials on the site. This graded
13 approach defines data quality requirements according to the type of survey being designed, the
14 risk of making a decision error based on the data collected, and the consequences of making
15 such an error. This approach provides a more effective survey design combined with a basis for
16 judging the usability of the data collected.

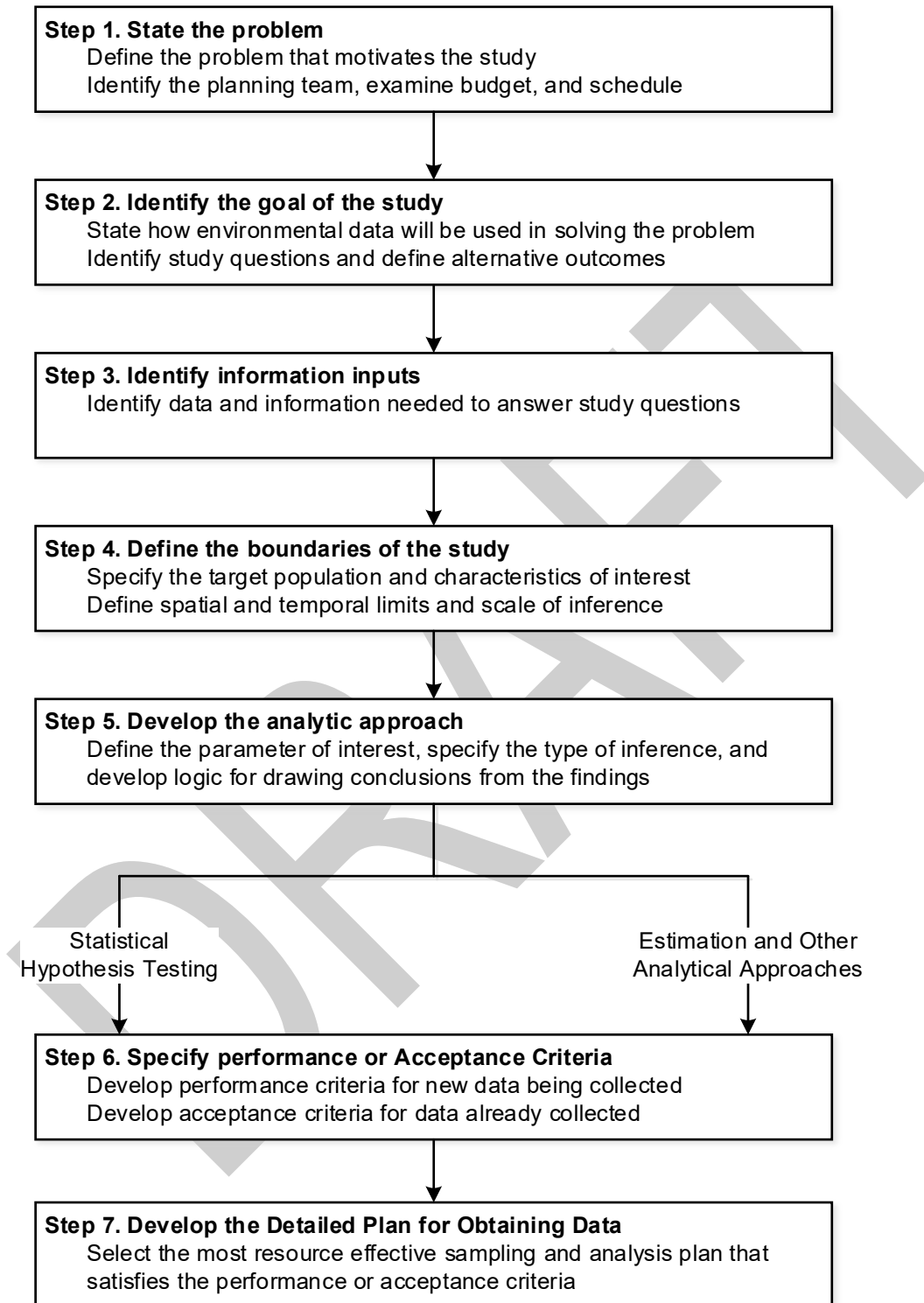
17 DQOs are qualitative and quantitative statements derived from the outputs of the DQO process
18 that—

- 19 • clarify the study objective
- 20 • define the most appropriate type of data to collect
- 21 • determine the most appropriate conditions (e.g., environmental, legal, safety) for collecting
22 the data
- 23 • specify limits on decision errors, which will be used as the basis for establishing the quantity
24 and quality of data needed to support the decision

25 The DQO process consists of seven steps, as shown in **Figure 2.2**. Each step is discussed in
26 detail in **Appendix D**. Although all of the outputs of the DQO process are important for
27 designing efficient surveys, there are some that are referred to throughout the manual. These
28 DQOs are mentioned briefly here and are discussed in detail throughout MARSSIM and in
29 **Appendix D**.

30 The minimum information (outputs) required from the DQO process to proceed with the
31 methods described in MARSSIM are—

- 32 • Classify and specify boundaries of survey units. This can be accomplished at any time but
33 must be finalized during FSS planning (**Section 4.6, Section 4.9**).



1 •
2 **Figure 2.2: The Data Quality Objectives Process**

- 1 • Determine if Scenario A or Scenario B will be used to evaluate the survey unit. Scenario A
2 uses a null hypothesis that assumes the concentration of radioactive material in the survey
3 unit exceeds the DCGL_w. Scenario A is sometimes referred to as “presumed not to comply”
4 or “presumed not clean.” Scenario B uses a null hypothesis that assumes the level of
5 concentration of radioactive material in the survey unit is less than or equal to the
6 discrimination level. Scenario B is sometimes referred to as “indistinguishable from
7 background” or “presumed clean” (**Section 5.3.1**).
- 8 • State the null hypothesis (H_0). For Scenario A, the concentration of residual radioactive
9 material in the survey unit exceeds the release criteria (**Section 2.5, Appendix D,**
10 **Section D.1.6**). For Scenario B, the residual radioactive material in the survey unit does not
11 exceed the release criteria (**Section 2.5, Appendix D, Section D.1.6**).
- 12 • Specify a gray region where the consequences of decision errors are considered relatively
13 minor. For Scenario A the upper bound of the gray region is defined as the DCGL_w, and the
14 lower bound of the gray region (LBGR) is a site-specific variable generally chosen to be a
15 conservative (slightly higher) estimate of the concentration of residual radioactive material
16 remaining in the survey unit and adjusted to provide an acceptable value for the relative
17 shift. For Scenario B the LBGR is the action level (AL), and the upper bound is defined by a
18 discrimination limit (DL) that can be reliably distinguished from the AL (**Section 5.3.3.1,**
19 **Section 5.3.4.1, Appendix D, Section D.1.7.3**).
- 20 • Define decision errors and assign their probability limits for the chosen Scenario (A or B).
21 The probability of making a Type I decision error (α) or a Type II decision error (β) is a site-
22 specific variable (**Section 5.3.2, Appendix D, Section D.1.6**).
- 23 • Estimate the standard deviation of the measurements in the survey unit. The standard
24 deviation (σ) is a site-specific variable, typically estimated from preliminary survey data.
- 25 • Specify the relative shift (Δ/σ). The relative shift is equal to the width of the gray region (Δ)—
26 which in Scenario A is equal to (DCGL_w - LBGR) and for Scenario B is equal to (DL - AL)—
27 divided by an estimate of the uncertainty (σ). The relative shift is generally designed to have
28 a value greater than one (**Section 5.3.3.2, Section 5.3.4.2**).
- 29 • Select a survey strategy based on the measurement requirements and site classifications to
30 include one of the following:
- 31 ○ a combination of scanning and direct measurements or sample collection and analysis
- 32 ○ scanning only, provided that the scanning measurement system meets the detection
33 capability and uncertainty requirements of a scan-only survey design (**Section 5.3.6.1,**
34 **Section 5.3.9**)
- 35 • For surveys utilizing the Sign or WRS test, calculate the estimated number of measurements
36 (N) and specify the measurement locations required to demonstrate compliance. The
37 number of measurements depends on the relative shift, Type I and Type II decision error
38 rates, and the potential for small areas of elevated activity (**Sections 5.3.3 and 5.3.4**).

- 1 • Determine the percentage of scanning coverage for survey units based on the assigned
2 classification of the survey unit and relative shift. Class 1 areas and survey units will have
3 scan coverage of 100 percent, while the scan coverage of Class 2 and Class 3 areas and
4 survey units will vary between 10 percent and 100 percent as a function of the relative shift
5 (**Section 5.3.6**).
- 6 • Specify the documentation requirements for the survey, including survey planning
7 documentation. Documentation supporting the decision on whether or not the site complies
8 with the release criteria is determined on a site-specific basis (**Appendix D, Section D.2**).
- 9 • Specify the required MQOs for all measurement techniques (scanning, direct measurement,
10 and sample analysis) specified in the QAPP. The MQOs are unique for each measurement
11 system (**Sections 6.2–6.4**).
- 12 MQOs are an important subset of inputs into the DQO process that define performance
13 requirements and objectives for the measurement system. MQOs that should be considered
14 include the following:
- 15 • *Method uncertainty*: Method uncertainty is the sum of the random and systematic
16 uncertainties in the measurement system. MARSSIM uses the term “measurement method
17 uncertainty” to refer to the predicted uncertainty of a measured value that would be
18 calculated if the method were applied to a hypothetical sample with a specified
19 concentration, typically the release limit. Reasonable values for measurement method
20 uncertainty can be predicted for a particular measurement technique based on typical
21 values for specific parameters (e.g., count time, efficiency) and previous surveys of the
22 areas being investigated. The MQO for the required measurement method uncertainty is
23 calculated based on the width of the gray region and is related to the minimum detectable
24 concentration (MDC).
- 25 • *Detection capability*: The MDC is recommended as the MQO for defining the detection
26 capability of the measurement system, which is the net response level that can be expected
27 to be seen using a detector with a fixed level of confidence. To account for cases where
28 decisions are being made based on multiple measurements, the MDC should be less than
29 50 percent of the DCGL in Scenario A and the DL in Scenario B.
- 30 • *Range*: The method range is the lowest and highest concentration of an analyte that a
31 method can accurately detect. The expected concentration range for a radionuclide of
32 concern may be an important MQO. Most radiation measurement techniques are capable of
33 measuring over a wide range of radionuclide concentrations. However, if the expected
34 concentration range is large, the range should be identified as an important measurement
35 method performance characteristic, and an MQO should be developed. The MQO for the
36 acceptable range should be a conservative estimate. This will help prevent the selection of
37 measurement techniques that cannot accommodate the actual concentration range.
- 38 • *Specificity*: Specificity is the ability of the measurement method to measure the radionuclide
39 of concern in the presence of interferences. To determine if specificity is an important MQO,
40 the planning team needs information on expected concentration ranges for the radionuclides

1 of concern and other chemical and radionuclide constituents, along with chemical and
2 physical attributes of the residual radioactive material being investigated.

- 3 • *Ruggedness*: For a project that involves field measurements that are performed in difficult or
4 variable environments, or laboratory measurements that are complex in terms of chemical
5 and physical characteristics, the measurement method's ruggedness may be an important
6 MQO. Ruggedness refers to the relative stability of the measurement technique's
7 performance when small variations in method parameter values are made. For field
8 measurements, the changes may include temperature, humidity, or atmospheric pressure.
9 For laboratory measurements, variability in sample conditions (e.g., pH) or laboratory
10 conditions may be important. To determine if ruggedness is an important measurement
11 method performance characteristic, the planning team needs detailed information on the
12 chemical and physical characteristics of the soil or surfaces being investigated and
13 operating parameters for the radiation instruments used by the measurement technique.

14 Precision, bias, representativeness and sensitivity, comparability, and completeness are the
15 Data Quality Indicators (DQIs) recommended for quantifying the amount of error for survey data
16 (EPA 2002a). These DQIs are discussed in detail in **Appendix D, Section D.1.6**.

17 **2.3.2 Evaluating Sources of Variability in Survey Results—Implementation Phase**

18 To encourage flexibility and the use of appropriate measurement techniques for a specific site,
19 MARSSIM does not provide detailed recommendations on specific techniques to be used.
20 Instead, MARSSIM encourages the decision maker to evaluate available techniques based on
21 the survey DQOs and MQOs. Information on evaluating whether these objectives have been
22 met, such as the required measurement method uncertainty and minimum detectable
23 concentration, is provided.

24 QC programs can both lower the chances of making an incorrect decision and help the data
25 user understand the level of uncertainty that surrounds the decision (EPA 2002a). As discussed
26 previously, QC data are collected and analyzed during implementation to provide an estimate of
27 the uncertainty associated with the survey results. QC measurements (scans, direct
28 measurements, and samples) are technical activities performed to measure the attributes and
29 performance of the survey. During any survey, a certain number of measurements should be
30 taken for QC purposes.

31 **2.3.3 Evaluating Survey Results—Assessment Phase**

32 Assessments of environmental data are used to evaluate whether the data meet the objectives
33 of the survey and are sufficient to determine compliance with the DCGL (EPA 1992a, EPA
34 1992b, EPA 2006a). The assessment phase of the Data Life Cycle consists of three phases:
35 data verification, data validation, and DQA.

- 36 • Data verification is used to ensure that the requirements stated in the planning documents
37 are implemented as prescribed (see **Appendix D.4.1**).

- 1 • Data validation is used to ensure that the results of the data collection activities support the
2 objectives of the survey as documented in the QAPP or to permit a determination that these
3 objectives should be modified (see **Appendix D.4.2**).
- 4 • DQA is the scientific and statistical evaluation of data to determine if the data are of the right
5 type, quality, and quantity to support their intended use (EPA 2006a). DQA helps complete
6 the Data Life Cycle by providing the assessment needed to determine that the planning
7 objectives are achieved (see **Section 8.2**). **Figure 2.3** illustrates where data verification,
8 data validation, and DQA fit into the Assessment Phase of the Data Life Cycle.

9 There are five steps in the DQA process:

- 10 • review the DQOs and survey design
- 11 • conduct a preliminary data review
- 12 • select the statistical test(s)
- 13 • verify the assumptions of the statistical test(s)
- 14 • draw conclusions from the data

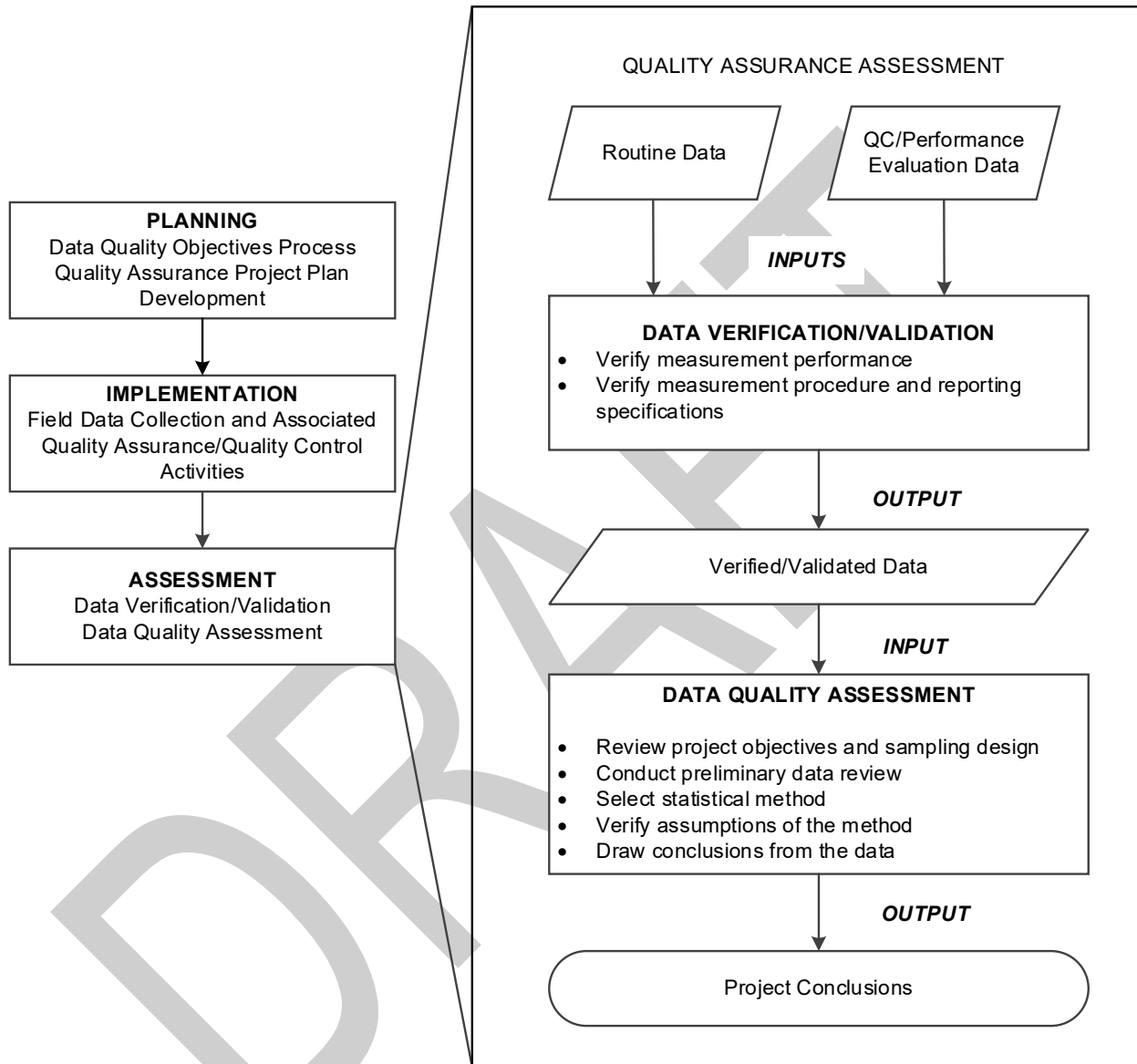
15 The strength of DQA is its design that progresses in a logical and efficient manner to promote
16 an understanding of how well the data meet the intended use. The Assessment Phase is
17 described in more detail in **Appendix D. Section 2.6** discusses the flexibility of the Data Life
18 Cycle and describes the use of survey designs other than those described later in MARSSIM.

19 **2.3.4 Uncertainty in Survey Results**

20 Uncertainty in survey results arises primarily from two sources—survey design errors and
21 measurement errors:

- 22 • Survey design errors occur when the survey design is unable to capture the complete extent
23 of variability that exists for the radionuclide distribution in a survey unit. Because it is
24 impossible in every situation to measure the concentration of residual radioactive material at
25 every point in space and time, the survey results will be incomplete to some degree. It is
26 also impossible to know with complete certainty the concentration of residual radioactive
27 material at locations that were not measured, so the incomplete survey results give rise to
28 uncertainty. The greater the natural or inherent variation in residual radioactive material, the
29 greater the uncertainty associated with a decision based on the survey results. The
30 unanswered question is, “How well do the survey results represent the true level of residual
31 radioactive material in the survey unit?”
- 32 • Measurement errors create uncertainty by masking the true level of residual radioactive
33 material and may be classified as random or systematic errors. Random errors affect the
34 precision of the measurement system and show up as variations among repeated
35 measurements. Systematic errors show up as measurements that are biased to give results

1 that are consistently higher or lower than the true value. Measurement uncertainty is
 2 discussed in **Section 6.4**.



3
 4 **Figure 2.3: The Assessment Phase of the Data Life Cycle (EPA 2006a)**

5 MARSSIM uses the Data Life Cycle to control and estimate the uncertainty in the survey results
 6 on which decisions are made. Adequate planning should minimize known sources of
 7 uncertainty. QC data collected during implementation of the survey plan provide an estimate of
 8 the uncertainty. Statistical hypothesis testing or comparison to an upper confidence limit during
 9 the assessment phase provides a level of confidence for the final decision. There are several
 10 levels of decisions included within each survey type. Some decisions are quantitative, based on

1 the numerical results of measurements performed during the survey. Other decisions are
2 qualitative based on the available evidence and best professional judgment. The Data Life
3 Cycle can and should be applied consistently to both types of decisions.

4 **2.3.5 Reporting Survey Results**

5 The process of reporting survey results is an important consideration in planning the survey.
6 Again, the level of effort for reporting should be based on the complexity of the survey. A simple
7 survey with relatively few results may require a single report, while a more complicated survey
8 may require several reports to meet the objectives of the survey. Reporting requirements for
9 individual surveys should be developed during planning and clearly documented in the QAPP.
10 These requirements should be developed with cooperation from the people performing the
11 analyses (e.g., the analytical laboratory should be consulted on reporting results for samples).
12 The Health Physics Society and Multi-Agency Radiological Laboratory Analytical Protocols
13 (MARLAP) have provided several suggestions for reporting survey results (EPA 1980a, NRC
14 2004):

- 15 • Report the actual result of the analysis. Do not report data as “less than the detection limit.”
16 Even negative results and results with large uncertainties can be used in the statistical tests
17 to demonstrate compliance. Results reported only as “< MDC” cannot be fully used and, for
18 example, complicate even such simple analyses as an average. Although the nonparametric
19 tests described in **Sections 8.3–8.4** and the upper confidence limit comparison described in
20 **Section 8.5** can accommodate situations where up to 40 percent of the results as non-
21 detects, it is better to report the actual results.
- 22 • Report results using the correct units and the correct number of significant digits. The choice
23 of reporting results using International System units (e.g., Bq/kg, Bq/m²) or conventional
24 units (e.g., pCi/g, dpm/100 cm²) is made on a site-specific basis. Generally, MARSSIM
25 recommends that all results be reported in the same units as the DCGLs. Sometimes the
26 results may be more convenient to work with as counts directly from the detector. In these
27 cases, the user should decide what the appropriate units are for a specific survey based on
28 the survey objectives. MARLAP suggests that the uncertainty and MDC should be reported
29 to two significant figures, while environmental radiation measurements seldom warrant more
30 than two or three significant figures.
- 31 • Report the measurement uncertainty for every analytical result or series of results, such as
32 for a measurement system. This uncertainty, while not directly used for demonstrating
33 compliance with the release criteria, is used for survey planning and data assessment
34 throughout the RSSI process. In addition, the uncertainty is used for evaluating the
35 performance of measurement systems using QC measurement results (as described in
36 **Section 6.2** for scans and direct measurements, and in **Section 7.2** for laboratory analysis
37 of samples). The uncertainty is also used for comparing individual measurements to the
38 action level, which is especially important in the early stages of the RSSI process (scoping,
39 characterization, and remedial action support surveys described in **Section 2.4**) when
40 decisions are made based on a limited number of measurements. **Section 6.4** discusses
41 methods for calculating the measurement uncertainty.

- 1 • Report the MDC for the measurement system as well as the method used to calculate the
2 MDC. The MDC is an a priori estimate of the capability for detecting an activity concentration
3 with a specific measurement system (EPA 1980a). As such, this estimate is valuable for
4 planning and designing radiation surveys. Optimistic estimates of the MDC (calculated using
5 ideal conditions that may not apply to actual measurements) overestimate the ability of a
6 technique to detect residual radioactive material, especially when scanning for alpha or low-
7 energy beta radiations. This can invalidate survey results, especially for scanning surveys.
8 Using a more realistic MDC during scoping and characterization surveys, as described in
9 **Section 6.3**, helps in the proper classification of survey units for FSSs and minimizes the
10 possibility of designing and performing subsequent surveys because of errors in
11 classification. Estimates of the MDC that minimize potential decision errors should be used
12 for planning surveys.

13 Reporting requirements for individual surveys should be developed during planning and clearly
14 documented in the QAPP.

15 **2.4 Radiation Survey and Site Investigation Process**

16 The Data Life Cycle discussed in **Section 2.3** is the basis for the performance-based approach
17 in MARSSIM. The RSSI process is a series of surveys designed to demonstrate compliance
18 with dose- or risk-based criteria for sites with residual radioactive material. The size, complexity,
19 and amount of existing information on the site will determine how many of the surveys in the
20 series will be necessary.

21 There are six principal steps in the RSSI process:

- 22 • site identification
- 23 • HSA
- 24 • scoping survey
- 25 • characterization survey
- 26 • remedial action support survey
- 27 • FSS

28 **Table 2.1** provides a simplified overview of the principal steps in the RSSI process and how the
29 Data Life Cycle can be used in an iterative fashion within the process. Each of these steps is
30 briefly described in the **Sections 2.4.1–2.4.6** and described in more detail in **Chapter 5**. In
31 addition, there is a brief description of regulatory agency confirmation and verification
32 (**Section 2.4.7**). Because MARSSIM focuses on demonstrating compliance with release criteria,
33 specifically by using an FSS, some of these surveys have additional objectives that are not fully
34 discussed in MARSSIM (e.g., health and safety of workers, supporting selection of values for
35 exposure pathway model parameters).

1 **Figure 2.4** illustrates the RSSI process in terms of area classification and lists the major
2 decision to be made for each type of survey. The flowchart demonstrates one method for
3 quickly estimating the survey unit classification early in the MARSSIM process based on limited
4 information. This figure is a useful tool for visualizing the classification process, but there are
5 site-specific characteristics that may cause variation from this scheme. This illustration is not
6 designed to comprehensively consider every possibility that may occur at individual survey
7 units.

8 The flowcharts in **Figures 2.5–2.8** present the principal steps and decisions in the site
9 investigation process and shows the relationship of the survey types to the overall assessment
10 process. As shown in these figures, there are several sequential steps in the site investigation
11 process and each step builds on information provided by its predecessor. Properly applying
12 each sequential step in the RSSI process should provide a high degree of assurance that the
13 release criteria have not been exceeded.

14 **2.4.1 Site Identification**

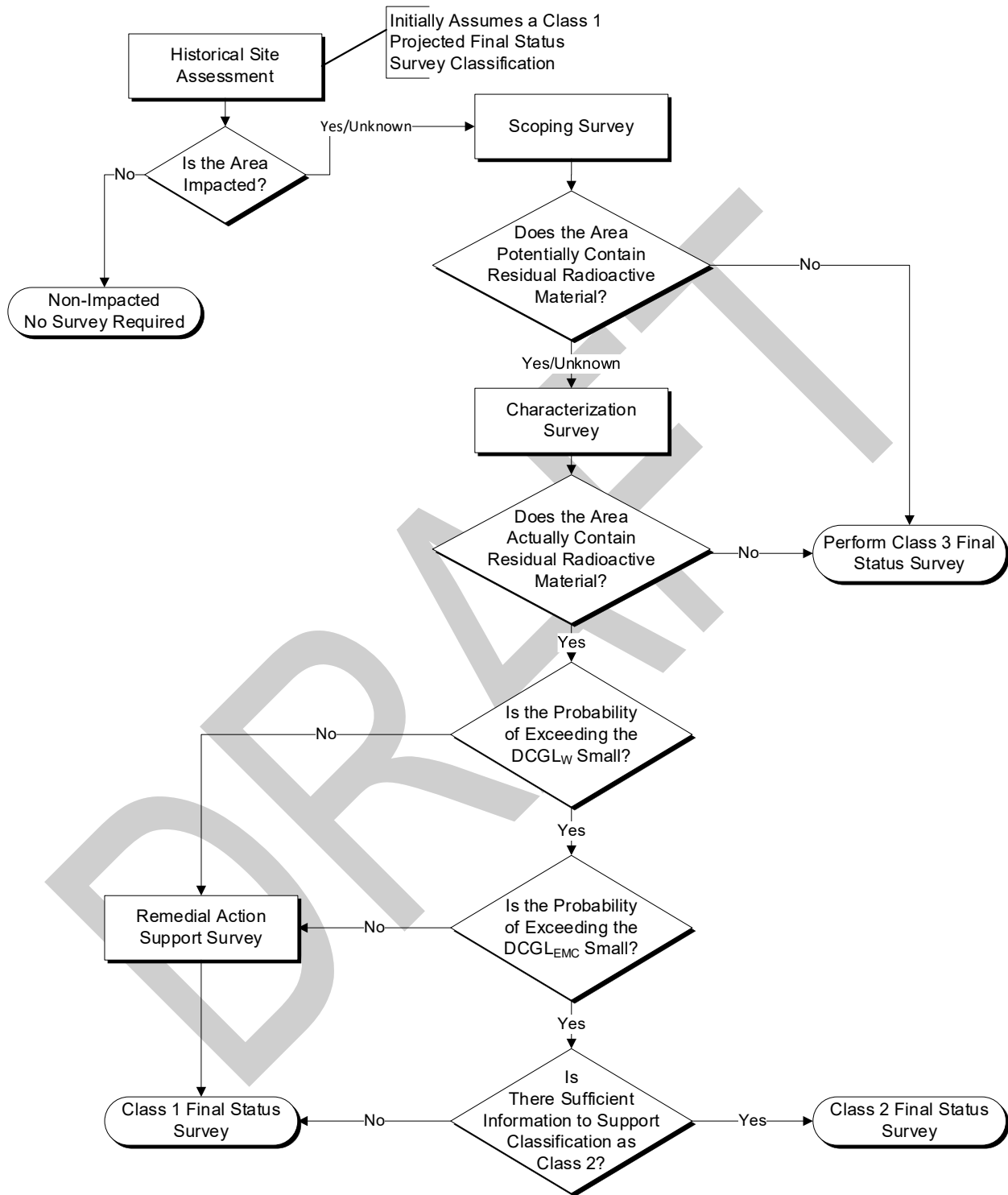
15 Often, sites where radioactive material is known or suspected to have been used or stored are
16 readily identified before decommissioning or cleanup. Any facility preparing to terminate an NRC
17 or agreement state license would be identified as a site. Formerly terminated NRC licenses may
18 also become sites for the EPA Superfund Program. Portions of military bases or
19 U.S. Department of Energy facilities may be identified as sites based on records of authorization
20 to possess or handle radioactive materials. Where records are incomplete, site identification can
21 be more difficult. In addition, information obtained during the performance of survey activities
22 may identify additional potential radiation sites related to the site being investigated. More
23 detailed information on site identification is provided in **Section 3.4**.

24 **2.4.2 Historical Site Assessment**

25 The primary purpose of the HSA is to collect existing information concerning the site and its
26 surroundings.

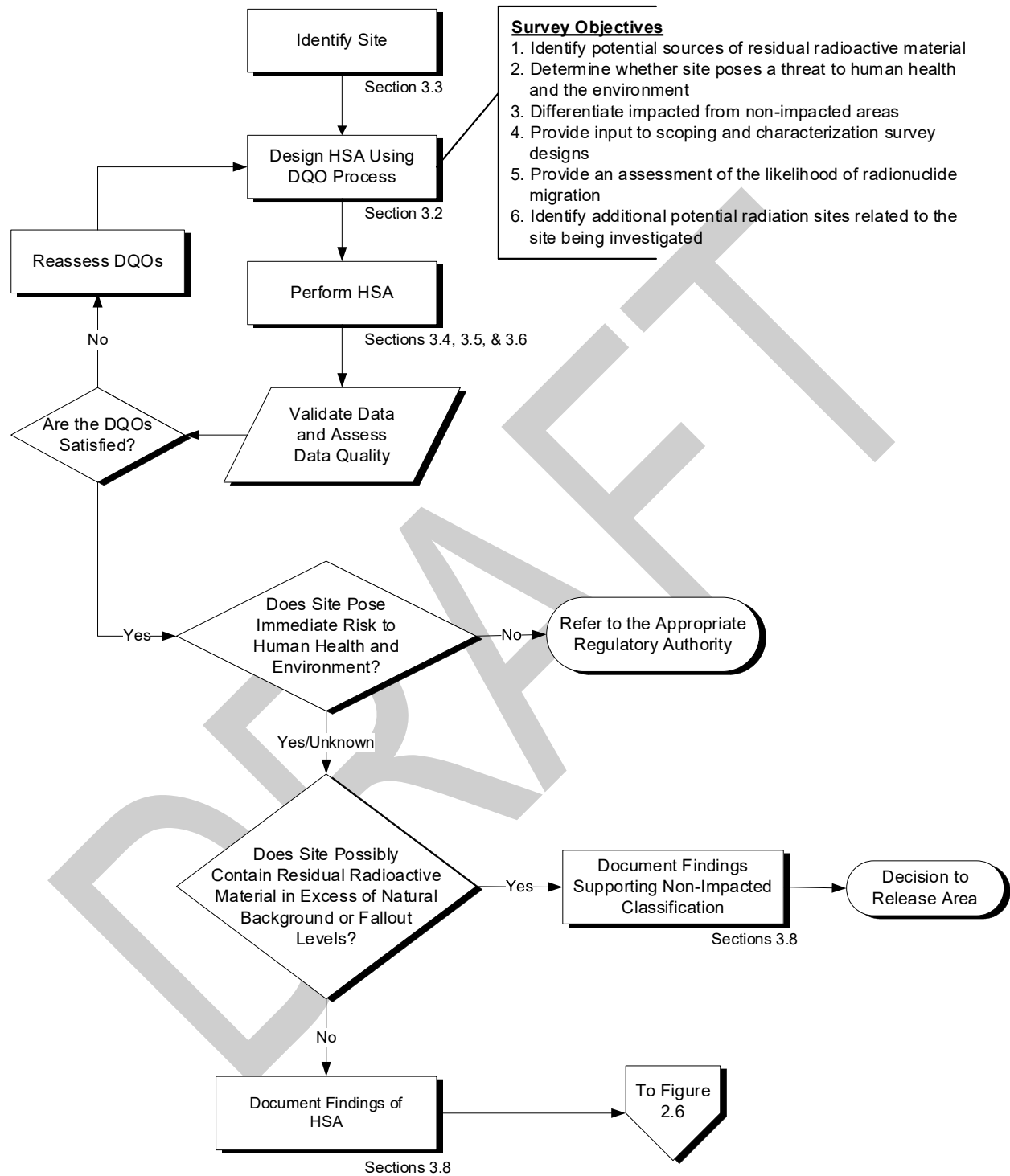
27 The primary objectives of the HSA are to—

- 28 • Identify potential sources of residual radioactive material.
- 29 • Determine whether sites pose an imminent threat to human health and the environment.
- 30 • Differentiate impacted from non-impacted areas.
- 31 • Provide input to scoping and characterization survey designs.
- 32 • Provide an assessment of the likelihood of migration of radioactive material.
- 33 • Identify additional potential sites containing radioactive material related to the site being
34 investigated.



1

2 **Figure 2.4: Radiation Survey and Site Investigation Process in Terms of Area Classification**

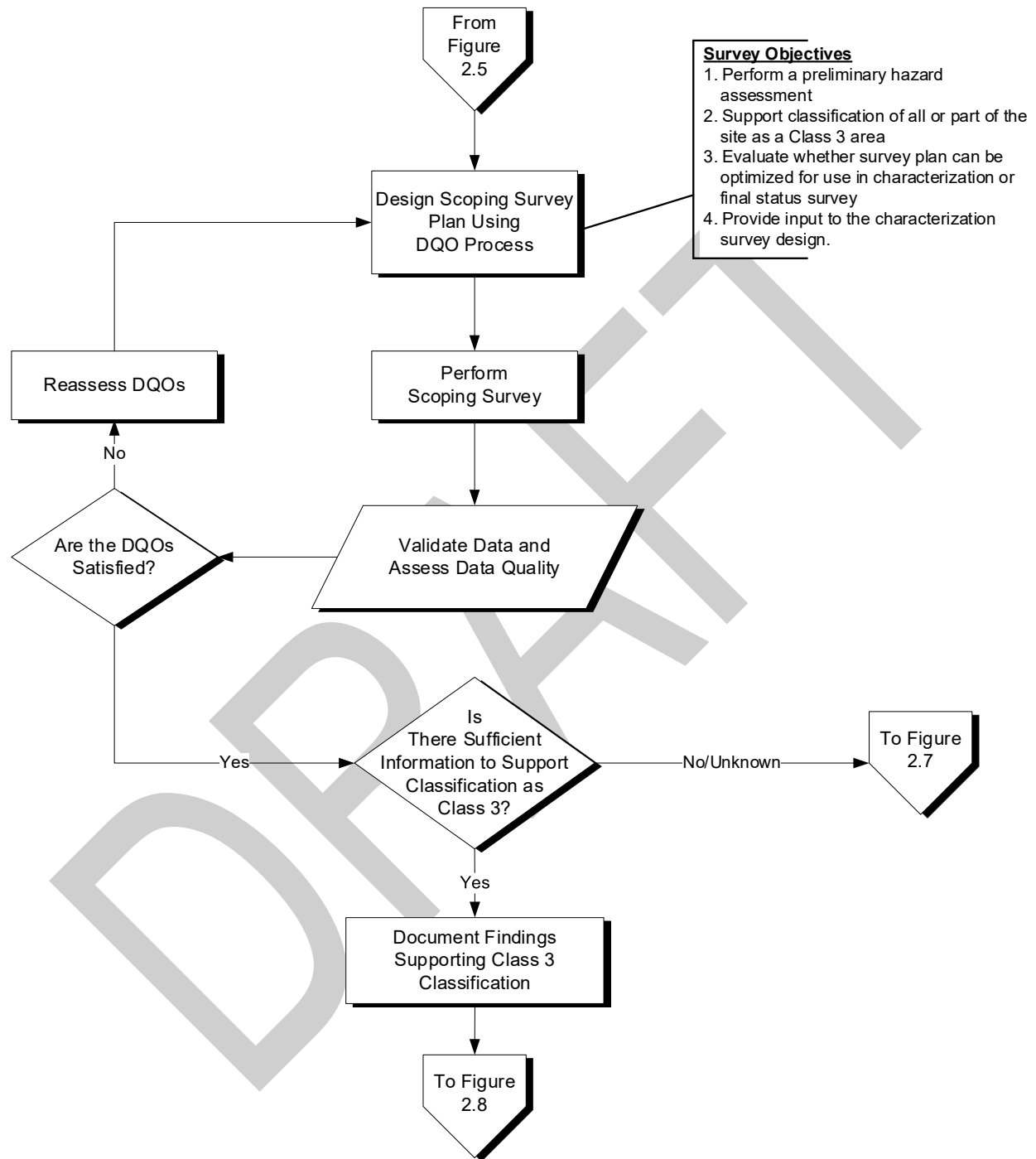


- Survey Objectives**
1. Identify potential sources of residual radioactive material
 2. Determine whether site poses a threat to human health and the environment
 3. Differentiate impacted from non-impacted areas
 4. Provide input to scoping and characterization survey designs
 5. Provide an assessment of the likelihood of radionuclide migration
 6. Identify additional potential radiation sites related to the site being investigated

1
2
3

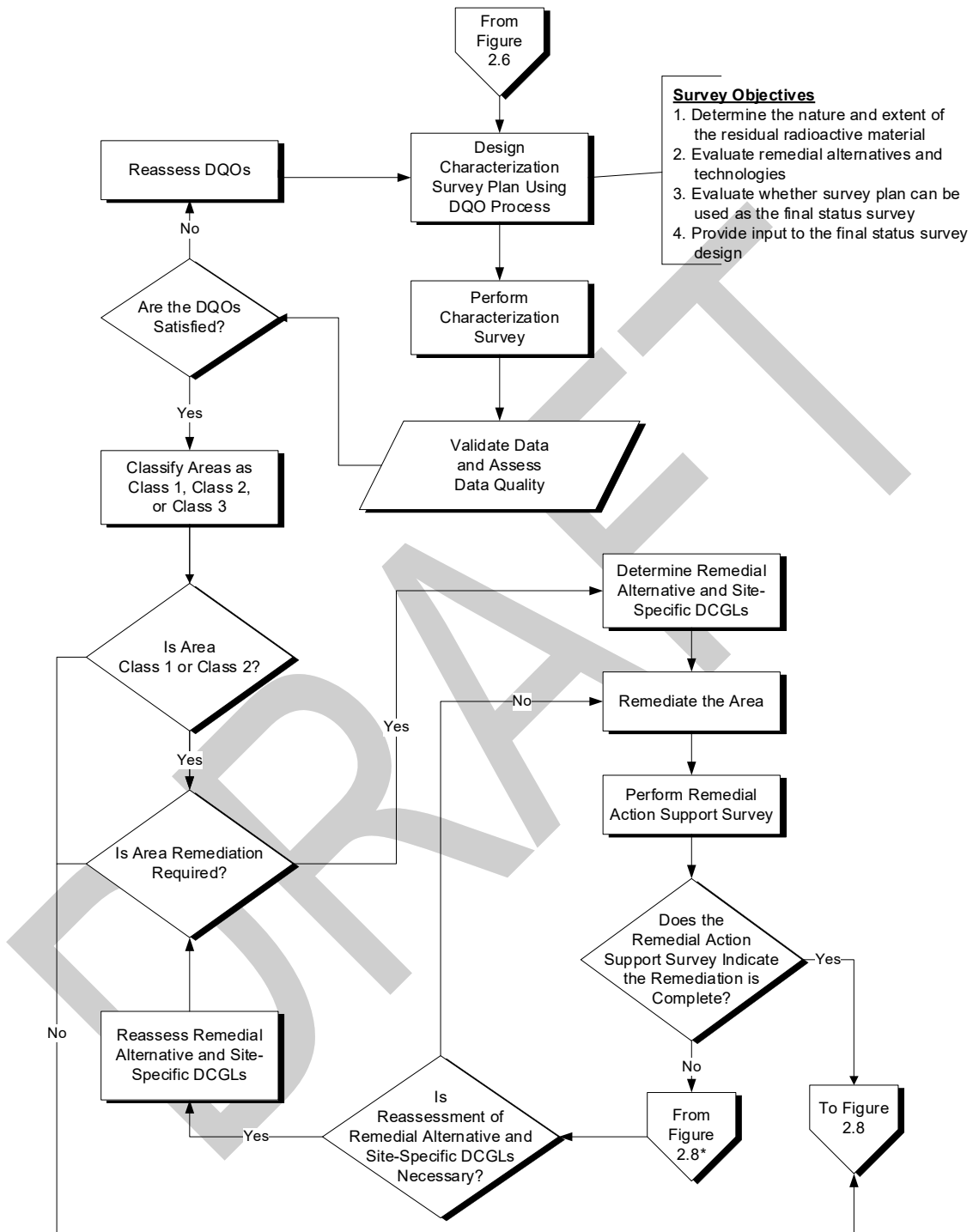
Figure 2.5: The Historical Site Assessment Portion of the Radiation Survey and Site Investigation Process

1



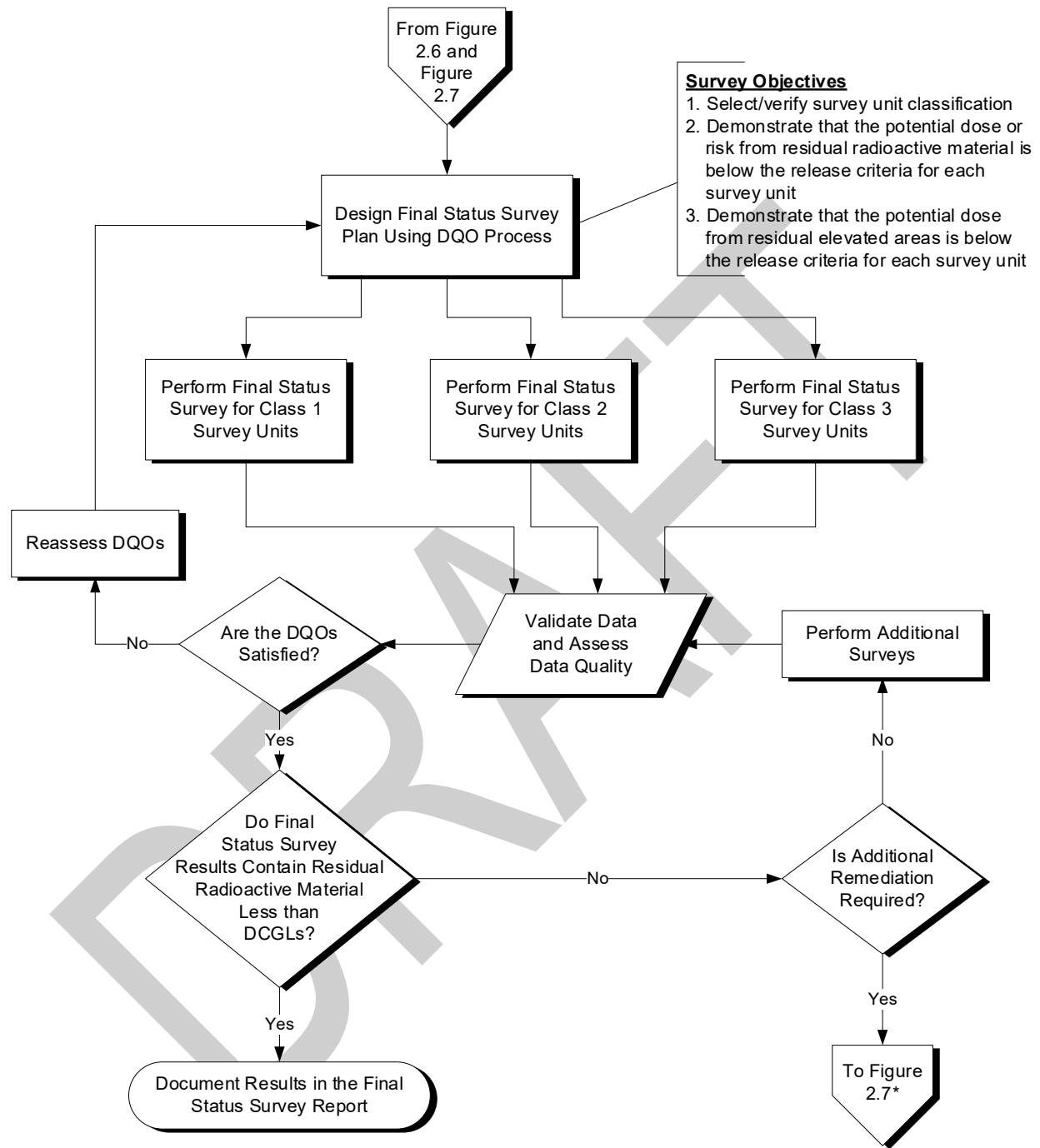
2

3 **Figure 2.6: The Scoping Survey Portion of the Radiation Survey and Site Investigation**
 4 **Process**



* The point where survey units that fail to demonstrate compliance in the final status survey in Figure 2.8 re-enter the process

1
 2 **Figure 2.7: The Characterization and Remedial Action Support Survey Portion of the**
 3 **Radiation Survey and Site Investigation Process**



1 * Connects with the Remedial Action Support Survey portion of the process in Figure 2.7

2 **Figure 2.8: The Final Status Survey Portion of the Radiation Survey and Site Investigation**
 3 **Process**

1 The HSA typically consists of three phases: identification of a candidate site, preliminary
 2 investigation of the facility or site, and site visits or inspections. Information collected during the
 3 HSA is then used to evaluate the site.

4 **2.4.3 Scoping Survey**

5 If the data collected during the HSA indicate that an area is impacted, a scoping survey may be
 6 performed. Scoping surveys provide site-specific information based on limited measurements.

7 The primary objectives of a scoping survey are to—

- 8 • Perform a preliminary hazard assessment.
- 9 • Support classification of all or part of the site as a Class 3 area, if appropriate.
- 10 • Evaluate whether the survey plan can be optimized for use in the characterization survey or
 11 FSS.
- 12 • Provide data to complete the site prioritization scoring process (Comprehensive
 13 Environmental Response, Compensation, and Liability Act [CERCLA] and Resource
 14 Conservation and Recovery Act [RCRA] sites only).
- 15 • Provide input to the characterization survey design, if necessary.

16 **Table 2.1** provides an overview of how the Data Life Cycle (Plan, Implement, Assess, and
 17 Decide) can be used to support each of the steps in the RSSI process up through the FSS.

18 **Table 2.1: The Data Life Cycle⁶ used to Support the Radiation Survey and Site**
 19 **Investigation Process**

RSSI Process	Data Life Cycle	MARSSIM Methodology
Site Identification	—	Provides information on identifying potential radiation sites (Section 3.3)
Historical Site Assessment	Historical Site Assessment Data Life Cycle	Provides information on collecting and assessing existing site data (Sections 3.4–3.9) and potential sources of information (Appendix F)
Scoping Survey	Scoping Data Life Cycle	Discusses the purpose and general approach for performing scoping surveys, especially as sources of information when planning final status surveys (Section 5.2.1)

⁶ The steps of the Data Life Cycle can be found in **Figure 2.1**. The DQO process for each of the steps can be found in **Figure 2.2**.

RSSI Process	Data Life Cycle	MARSSIM Methodology
Characterization Survey	Characterization Data Life Cycle	Discusses the purpose and general approach for performing characterization surveys, especially as sources of information when planning final status surveys (Section 5.2.2)
Remedial Action Support Survey	Remedial Action Data Life Cycle	Discusses the purpose and general approach for performing remedial action support surveys, especially as sources of information when planning final status surveys (Section 5.2.3)
Final Status Survey	Final Status Data Life Cycle	Provides detailed information for planning final status surveys (Chapter 4, Section 5.3), selecting measurement techniques (Chapter 6, Chapter 7, Appendix H), and assessing the data collected during final status surveys (Chapter 8, Appendix D)

1 Scoping surveys can be conducted after the HSA is completed and typically consist of judgment
2 measurements based on the HSA data. If the results of the HSA indicate that an area is Class 3
3 and no residual radioactive material is found during a scoping survey, the area may be
4 classified as Class 3, and a Class 3 FSS is performed. If the scoping survey locates residual
5 radioactive material, the area may be considered as Class 1 (or Class 2) for the FSS, and a
6 characterization survey is typically performed. Sufficient information should be collected to
7 identify situations that require immediate radiological attention. For sites where the CERCLA
8 requirements are applicable, the scoping survey should collect sufficient data to complete the
9 Hazard Ranking System (HRS) scoring process. For sites where the RCRA requirements are
10 applicable, the scoping survey should collect sufficient data to complete the National Corrective
11 Action Prioritization System (NCAPS) scoring process. Sites that meet the National Contingency
12 Plan (NCP) criteria for a removal should be referred to the Superfund removal program (EPA
13 1996c). A comparison of the MARSSIM approach to CERCLA and RCRA requirements is
14 provided in **Appendix F**.

15 **2.4.4 Characterization Survey**

16 If the results of the HSA and scoping survey indicate that an area could be classified as Class
17 1 or Class 2 for the FSS, a characterization survey may be warranted. The characterization
18 survey is planned based on the HSA and scoping survey results. This type of survey typically is
19 a detailed radiological environmental characterization of the area.

20 The primary objectives of a characterization survey are as follow:

- 21 • Determine the nature and extent of the residual radioactive material.
- 22 • Collect data to support evaluation of remedial alternatives and technologies.

- 1 • Support a hazard assessment of the potential dose and risk to workers or the public during
2 remediation.
- 3 • Evaluate whether the survey plan can be optimized for use in the FSS.
- 4 • Support remedial investigation/feasibility study requirements (CERCLA sites only) or facility
5 investigation/corrective measures study requirements (RCRA sites only).
- 6 • Provide input to the FSS design.

7 The characterization survey can be the most comprehensive of all the survey types and typically
8 generates the most data. This can include preparing a reference grid, taking systematic or
9 judgment measurements, and performing surveys of different media (e.g., surface soils, interior
10 and exterior surfaces of buildings). The decision as to which media will be surveyed is site-
11 specific and will be addressed throughout the RSSI process.

12 **2.4.5 Remedial Action Support Survey**

13 If an area is adequately characterized and has concentrations of residual radioactive material
14 above the DCGLs, a remediation plan should be prepared. A remedial action support survey is
15 performed while remediation is being conducted and guides the remediation in a real-time
16 mode.

17 Remedial action support surveys are conducted to—

- 18 • support remediation activities
- 19 • determine when a site or survey unit is ready for the FSS
- 20 • provide updated estimates of site-specific parameters used for planning the FSS

21 This manual does not provide information on the routine operational surveys used to support
22 remediation activities. The determination that a survey unit is ready for an FSS following
23 remediation is an important step in the RSSI process. In addition, remedial activities result in
24 changes to the distribution of residual radioactive material within the survey unit. For most
25 survey units, the site-specific parameters used during FSS planning (e.g., variability in the
26 radionuclide concentration, probability of small areas of elevated activity) will need to be re-
27 established following remediation. Obtaining updated values for these critical parameters should
28 be considered when planning a remedial action support survey.

29 **2.4.6 Final Status Survey**

30 The FSS is used to demonstrate compliance with release criteria. This type of survey is the
31 major focus of this manual.

32 The primary objectives of the FSS are as follow:

- 33 • Verify that survey unit classification is correct.

1 • Demonstrate that the total potential dose or risk from all residual radioactive material in each
2 survey unit is below the release criteria.

3 • Demonstrate that the potential dose or risk from any small areas of elevated concentration
4 of radioactive material is below the release criteria for each survey unit, if necessary.

5 The FSS provides data to demonstrate that all radiological parameters satisfy the established
6 guideline values and conditions. Data from other surveys conducted during the RSSI process—
7 such as scoping, characterization, and remedial action support surveys—can provide valuable
8 information for planning an FSS, provided they are of sufficient quality.

9 Professional judgment in sampling is often used for locating and characterizing the extent of
10 residual radioactive material at a site. However, the MARSSIM focus is on planning the FSS,
11 which utilizes a more systematic approach to sampling. Systematic sampling is based on rules
12 that endeavor to achieve the representativeness in sampling consistent with the application of
13 statistical tests.

14 **2.4.7 Regulatory Agency Confirmation and Verification Survey**

15 The regulatory agency responsible for the site often confirms whether the site may be released.
16 Terms for this process can include confirmatory surveys or independent verification. This
17 confirmation may be accomplished by the agency or an impartial party either as an ongoing
18 activity during site remediation or after remediation and the FSS has been completed. Although
19 some actual measurements may be performed, much of the work required for confirmation and
20 verification will involve evaluation and review of documentation and data from survey activities,
21 though the evaluation may include site visits to observe survey and measurement procedures or
22 split-sample analyses by the regulatory agency's laboratory. Therefore, accounting for
23 confirmation and verification activities during the planning stages is important to each type of
24 survey. In some cases, post-remedial sampling and analysis may be performed by an impartial
25 party. The review of survey results should include verifying that the DQOs and MQOs are met,
26 reviewing the analytical data used to demonstrate compliance, and verifying that the statistical
27 test results support the decision to release the site.

28 **2.5 Demonstrating Compliance with Dose- or Risk-Based Criteria**

29 MARSSIM presents a process for demonstrating compliance with dose- or risk-based criteria.
30 The RSSI process provides flexibility in planning and performing surveys based on site-specific
31 considerations. Dose- or risk-based criteria usually allow one to account for radionuclide and
32 site-specific differences.

33 The FSS is designed to demonstrate compliance with the release criteria. The earlier surveys in
34 the RSSI process are performed to support decisions and assumptions used in the design of the
35 FSS. These preliminary surveys (e.g., scoping, characterization) may have other objectives in
36 addition to compliance demonstration that need to be considered during survey planning that
37 are not fully discussed in this manual. For this reason, MARSSIM focuses on FSS design. To
38 allow maximum flexibility in the survey design, MARSSIM provides information on designing a
39 survey using the RSSI process. This allows users with few resources available for planning to
40 develop an acceptable survey design. The rationale for the development of the information in

1 MARSSIM is presented in the following sections. Users with available planning resources are
2 encouraged to investigate alternate survey designs for site-specific applications using the
3 information provided in **Section 2.6**.

4 **2.5.1 The Decision to Use Statistical Tests**

5 The objective of compliance demonstration is to provide an acceptable level of confidence that
6 the release criteria are not exceeded. As previously stated, 100 percent confidence in a decision
7 cannot be proven because the data always contain some uncertainty. The use of statistical
8 methods is necessary to provide a quantitative estimate of the probability that average
9 concentration of radioactive material at a particular site results in a dose or risk above the
10 release criteria. Statistical methods provide for specifying (controlling) the probability of making
11 decision errors and for extrapolating from a set of measurements to the entire site in a
12 scientifically valid fashion (EPA 1994a).

13 Clearly stating the null hypothesis is necessary before statistical hypothesis testing can be
14 performed. MARSSIM provides the option to establish the null hypothesis under either
15 Scenario A or Scenario B. The Scenario A null hypothesis in MARSSIM is the concentration of
16 residual radioactive material in the survey unit exceeds the release criteria. This statement
17 directly addresses the issue of compliance demonstration for the regulator and places the
18 burden of proof for demonstrating compliance on the site owner or responsible party. The
19 Scenario B null hypothesis in MARSSIM is the concentration of residual radioactive material in
20 the survey unit does not exceed the release criteria. This statement also addresses the issue of
21 compliance demonstration for the regulator; however, it places the burden of proof for
22 demonstrating a lack of compliance on the regulator.

23 In Scenario B, the burden of proof is no longer on the individuals designing the survey and thus
24 should be used with caution and only in those situations where Scenario A is not an effective
25 alternative and regulators have agreed on the use of Scenario B. Regardless of the scenario
26 selected, the probability of rejecting the null hypothesis (i.e., the statistical power) will depend on
27 the variability in the survey unit and the tolerable Type II error probability (i.e., β). Under
28 Scenario A, this type of decision error can result in deciding that a survey unit does not meet the
29 release criteria when it actually does. However, under Scenario B, this type of decision error can
30 result in deciding that a survey unit does meet the release criteria when it actually does not. For
31 this reason, the value of β under Scenario B should be chosen carefully and in consultation with
32 regulatory authorities.

33 Because inadequate statistical power under Scenario B can result in a decision error that a
34 survey meets release criteria when it does not, individuals designing a MARSSIM Survey using
35 Scenario B should make conservative assumptions for σ so that, even if the variability in the
36 survey unit is higher than expected, the power of the resulting survey ($1-\beta$) will still be sufficient
37 to ensure that survey units with residual radioactive material in excess of the DCGL will be
38 discovered at least $1-\beta$ percent of the time. To ensure adequate statistical power, a
39 retrospective power analysis that indicates that regulatory agency requirements on β were met
40 needs to be completed following the completion of Scenario B MARSSIM Surveys. See
41 **Chapter 8** and **Appendix I** for more information on performing retrospective power analyses.

1 The information needed to perform a statistical test is determined by the assumptions used to
2 develop the test. MARSSIM recommends the use of nonparametric statistical tests because
3 these tests use fewer assumptions and, consequently, require less information to verify these
4 assumptions. If a large number of measurements will be made (scan-only surveys), then
5 MARSSIM recommends comparison to an upper confidence limit. If the radionuclide is not part
6 of the natural background and radionuclide-specific measurements will be made, MARSSIM
7 recommends the Sign test. If the radionuclide is part of the natural background, or radionuclide-
8 specific measurements will not be made, MARSSIM recommends the WRS test. For
9 Scenario B, MARSSIM also recommends the quantile test and a retrospective power analysis.
10 These additional tests provide assurance that when the null hypothesis is not rejected, it is not
11 because there is insufficient power in the statistical tests. The retrospective power analysis can
12 also be useful for Scenario A in identifying the reasons why the null hypothesis was not
13 rejected. The tests described in MARSSIM (see **Chapter 8**) are relatively easy to understand
14 and implement. Ranked set sampling (see **Appendix E**) is another method for performing
15 statistical testing of samples and can be useful for hard-to-detect radionuclides. For the reasons
16 described above, Scenario A is preferred to Scenario B. Scenario B should be used instead of
17 Scenario A only when there is sufficient justification for its use.

18 Site conditions can potentially affect the validity of statistical tests. The distribution of residual
19 radioactive material is particularly of concern. Is the residual radioactive material distributed
20 uniformly, or is it located in small areas? Is the residual radioactive material present in the
21 surface soil or on building surfaces, or does it extend into the subsurface? MARSSIM addresses
22 only surface soil and building surfaces for the FSS to demonstrate compliance. This represents
23 a situation that is expected to commonly occur at sites with residual radioactive material, and it
24 allows the survey design to account for the ability to directly measure surface radioactivity using
25 scanning techniques. Radioactive material in other media may be identified during the HSA or
26 preliminary surveys (i.e., scoping, characterization, remedial action support). If radioactive
27 material in other media (e.g., subsurface soils or building materials) is identified, methodologies
28 for demonstrating compliance other than those described in this manual may need to be
29 developed or evaluated. Situations where scanning techniques may not be effective
30 (e.g., volumetric or subsurface radioactive material) are discussed in existing guidance (EPA
31 1989a, EPA 1994a, EPA 2001a).

32 *2.5.1.1 Small Areas of Elevated Activity*

33 While the development of DCGLs is outside the scope of MARSSIM, this manual assumes that
34 DCGLs will be developed using exposure pathway models that assume a relatively uniform
35 distribution of radioactive material. While this represents an ideal situation, small areas of
36 elevated activity are a concern at many sites.

37 MARSSIM addresses the concern for small areas of elevated activity by using a simple
38 comparison to an investigation level as an alternative to statistical methods. Using the EMC is a
39 conservative approach, because additional investigation is required unless every measurement
40 is below the investigation level. For Class 1 survey units, the investigation level for this
41 comparison is called the $DCGL_{EMC}$. The $DCGL_{EMC}$ can be higher than the $DCGL_W$ due to the
42 lower dose or risk resulting from a smaller area of radioactive material. In the case of multiple
43 areas of elevated activity in a survey unit, a posting plot (discussed in **Section 8.2.2.2**) or similar

1 representation of the distribution of activity in the survey unit can be used to determine any
2 pattern in the location of these areas.

3 If elevated levels of residual radioactive material are found in an isolated area in addition to
4 residual radioactive material distributed relatively uniformly across the survey unit, the unity rule
5 (**Section 4.4**) can be used to ensure that the total dose or risk meets the release criteria. If there
6 is more than one of these areas, a separate term should be included in the calculation for each
7 area of elevated activity. As an alternative to the unity rule, the dose or risk from the actual
8 distribution of residual radioactive material can be calculated if there is an appropriate exposure
9 pathway model available. Note that these considerations generally only apply to Class 1 survey
10 units, since areas of elevated activity should not be present in Class 2 or Class 3 survey units.

11 *2.5.1.2 Relatively Uniform Distribution of Residual Radioactive Material*

12 As discussed previously, the development of a DCGL starts with the assumption of a relatively
13 uniform distribution of residual radioactive material. Some variability in the measurements is
14 expected. This is primarily due to a random spatial distribution of residual radioactive material
15 and uncertainties in the measurement process.

16 With a scan-only survey, the upper confidence limit (UCL) for the mean derived from the
17 arithmetic mean, the variance, and the number of the measurements would represent the
18 parameter of interest for demonstrating compliance. Survey units where a large number of
19 measurements are taken (scan-only surveys) can utilize this technique. Instructions on
20 generating a UCL from scan-only survey data are provided in **Section 8.5**.

21 When statistical sampling is performed, whether the radionuclide of concern is present in
22 background helps determine the form of the statistical test. The WRS test is recommended for
23 comparisons of survey unit radionuclide concentrations with background. When the radionuclide
24 of concern is not present in background, the Sign test is recommended. Instructions on
25 performing these tests are provided in **Section 8.3** and **Section 8.4**.

26 The WRS and Sign tests are designed to determine whether the level of residual activity
27 uniformly distributed throughout the survey unit exceeds the $DCGL_W$. Because these methods
28 are based on ranks or number of measurements below the DCGL, the statistical tests are tests
29 of the median. When the underlying measurement distribution is symmetric, the mean is equal
30 to the median. When the underlying distribution is asymmetric, these tests are still true tests of
31 the median but only approximate tests of the mean. However, numerous studies show that this
32 is a fair approximation (Hardin and Gilbert, 1993). The assumption of symmetry is less
33 restrictive than that of normality, because the normal distribution is itself symmetric. If, however,
34 the measurement distribution is skewed to the right, the mean will generally be greater than the
35 median. In severe cases, the mean may exceed the $DCGL_W$ while the median does not. For this
36 reason, MARSSIM recommends comparing the arithmetic mean of the survey unit data to the
37 $DCGL_W$ as a first step in the interpretation of the data (see **Section 8.2.2.1**). A mean survey unit
38 concentration less than the $DCGL_W$ is a necessary, but not sufficient, condition for a survey unit
39 to meet the release criteria.

40 The WRS test compares the distribution of a set of measurements in a survey unit to that of a
41 set of measurements in a reference area. In scenario A, the test is performed by first adding the

1 value of the $DCGL_W$ to each measurement in the reference area. The combined set of survey
2 unit data and adjusted reference area data are listed, or ranked, in increasing numerical order. If
3 the ranks of the adjusted reference site measurements are significantly higher than the ranks of
4 the survey unit measurements, the survey unit demonstrates compliance with the release
5 criteria.

6 The quantile test is a statistical test to account for non-uniform distributions of radioactive
7 material. The quantile test was developed to detect differences between the survey unit and the
8 reference area that consist of a shift to higher values in only a fraction of the survey unit. The
9 quantile test is only performed when Scenario B is used, and only if the null hypothesis is not
10 rejected for the WRS test. Using the quantile test and the WRS test in tandem results in higher
11 statistical power to identify survey units that do not meet the release criteria than either test by
12 itself.

13 The Sign test compares the distribution of a set of measurements in a survey unit to a fixed
14 value, namely the $DCGL_W$. First, the value for each measurement in the survey unit is
15 subtracted from the $DCGL_W$. The resulting distribution is tested to determine if the center of the
16 distribution is greater than zero. If the adjusted distribution is significantly greater than zero, the
17 survey unit demonstrates compliance with the release criteria.

18 Information on performing the statistical tests and presenting graphical representations of the
19 data are provided in **Chapter 8** and **Appendix I**.

20 **2.5.2 Categorization and Classification**

21 Categorizing and classifying a survey unit determine the level of survey effort based on the
22 potential for residual radioactive material. Areas are initially categorized as impacted or non-
23 impacted based on the results of the HSA. Non-impacted areas have no reasonable potential
24 for residual radioactive material and require no further evidence to demonstrate compliance with
25 the release criteria, although documentation of the decision to categorize an area as non-
26 impacted would still be needed. When planning the FSS, impacted areas may be further
27 classified into survey units. If a survey unit is given a less restrictive classification than is
28 warranted, the potential for making decision errors increases. For this reason, all impacted
29 areas are initially assumed to be Class 1. Class 1 areas require the highest level of survey effort
30 because they are known to have concentrations of residual radioactive material above the
31 $DCGL_W$, or the residual radioactive material concentrations are unknown.

32 Information indicating the potential or known residual radioactive material concentration is less
33 than the $DCGL_W$ can be used to support re-classification of an area or survey unit as Class 2 or
34 Class 3.

35 There is a certain amount of information necessary to demonstrate compliance with the release
36 criteria. The amount of this information that is available and the level of confidence in this
37 information are reflected in the area classification. The initial assumption for affected areas is
38 that none of the necessary information is available. This results in a default Class 1
39 classification.

1 Not all of the information available for an area will have been collected for purposes of
2 compliance demonstration. For example, data are collected during characterization surveys to
3 determine the extent, and not necessarily the amount, of residual radioactive material. This
4 does not mean that the data do not meet the objectives of compliance demonstration, but it may
5 mean that statistical tests would be of little or no value because the data have not been
6 collected using appropriate protocols or design. Rather than discard potentially valuable
7 information, MARSSIM allows for a qualitative assessment of existing data (**Chapter 3**). Non-
8 impacted areas represent areas where all of the information necessary to demonstrate
9 compliance is available from existing sources. For these areas, no statistical tests are
10 considered necessary. A classification as Class 2 or Class 3 indicates that some information on
11 describing the potential for residual radioactive material is available for that survey unit. The
12 data collection recommendations are modified to account for the information already available,
13 and the statistical tests are performed on the data collected during the FSS. The HSA
14 (described in **Chapter 3**) is used to provide an initial categorization for the area of impacted or
15 non-impacted based on existing data and professional judgment.

16 **2.5.3 Design Considerations for Small Areas of Elevated Activity**

17 Scanning surveys are typically used to identify small areas of elevated activity. The size of the
18 area of elevated activity that the survey is designed to detect affects the $DCGL_{EMC}$, which in turn
19 determines the ability of a scanning technique to detect these areas. Larger areas have a lower
20 $DCGL_{EMC}$ and are more difficult to detect than smaller areas. Ranked set sampling (RSS), as
21 described in **Appendix E**, provides an alternative approach for identifying small areas of hard-
22 to-detect radionuclides through a combination of field measurements and samples to identify
23 small areas.

24 The percentage of the survey unit to be covered by scans is also an important consideration.
25 One-hundred percent coverage means that the entire surface area of the survey unit has been
26 covered by the field of view of the scanning instrument. One-hundred percent scanning
27 coverage provides a high level of confidence that all areas with elevated concentrations of
28 radioactive material have been identified. One-hundred percent coverage is recommended for
29 all Class 1 survey units. If the available information concerning the survey unit provides
30 information demonstrating that areas of elevated concentrations of radioactive material may not
31 be present, the survey unit may be classified as Class 2 or Class 3. Because there is already
32 some level of confidence that areas of elevated activity are not present, 100 percent coverage
33 may not be necessary to demonstrate compliance. **Section 5.3.6** provides information on
34 determining the scan area for Class 2 and 3 areas. For Class 2 areas, the scan area will be
35 based on the width of the gray region and the uncertainty, typically somewhere between 10–
36 100 percent of the area, with a combination of systematic scanning and scanning in areas
37 judged to have the highest potential for residual radioactive material. For Class 3 areas, the
38 scan area is the same as Class 2 survey units, except for surveys where samples and/or direct
39 measurements are collected, in which case the scan area can be less than 10 percent and is
40 typically only in areas judged to have the highest potential for residual radioactive material. A
41 general recommendation when deciding which areas to scan is to always err in the direction that
42 minimizes the decision error. In general, scanning the entire survey unit is less expensive than
43 finding areas of elevated concentrations of radioactive material later in the survey process.

1 Finding such areas will lead to performing additional surveys due to survey unit
2 misclassification.

3 Another consideration for scanning surveys is the selection of scanning locations. This is not an
4 issue when 100 percent of the survey unit is scanned. Whenever less than 100 percent of the
5 survey unit is scanned, a decision must be made on what areas should be scanned. The
6 general recommendation is that when large amounts of the survey unit are scanned (e.g., less
7 than 50%), the scans should be systematically performed along transects of the survey unit.
8 When smaller amounts of the survey unit are scanned, selecting areas based on professional
9 judgment may be more appropriate and efficient for locating areas of elevated activity
10 (e.g., drains, ducts, piping, ditches, floor joints, sumps). A combination of 100 percent scanning
11 in portions of the survey unit based on professional judgment and less coverage (e.g., 20–
12 50 percent) for all remaining areas may result in an efficient scanning survey design for some
13 survey units.

14 **2.5.4 Design Considerations for Relatively Uniform Distributions of Residual** 15 **Radioactive Material**

16 The survey design for areas with relatively uniform distributions of residual radioactive material
17 is primarily controlled by classification and the requirements of the statistical test. Again, the
18 recommendations provided for Class 1 survey units are designed to minimize the decision error.
19 Recommendations for Class 2 or Class 3 surveys may be based on existing information if the
20 level of confidence associated with this information is sufficient.

21 The first consideration is the identification of survey units. The identification of survey units may
22 be accomplished early (e.g., scoping) or late (e.g., final status) in the survey process but must
23 be accomplished before performing an FSS. Early identification of survey units can help in
24 planning and performing surveys throughout the RSSI process. Late identification of survey
25 units can prevent misconceptions and problems associated with reclassification of areas based
26 on results of subsequent surveys. The area of an individual survey unit is determined based on
27 the area classification and modeling assumptions used to develop the DCGL_w. Identification of
28 survey units is discussed in **Section 4.6**.

29 When performing surveys for which the Sign or WRS test is used, another consideration is the
30 estimated number of measurements to demonstrate compliance using the statistical tests.
31 **Sections 5.3.3–5.3.4** describe the calculations used to estimate the number of measurements.
32 These calculations use information that is usually available from planning or from preliminary
33 surveys (i.e., scoping, characterization, remedial action support).

34 The information needed to perform these calculations is—

- 35 • acceptable values for the probabilities of making Type I or Type II decision errors
- 36 • the estimates of the measurement variability in the survey unit (σ_s) and the reference area
37 (σ_r) if necessary
- 38 • Δ , or the shift

1 MARSSIM recommends that site-specific values be determined for each of these parameters.
2 When selecting site-specific values for decision error rates and Δ , MARSSIM recommends that
3 an initial value be selected and adjusted to develop a survey design that is appropriate for a
4 specific site. For Scenario A, the $DCGL_W$ is chosen as the upper bound of the gray region, and
5 the lower bound of the gray region is typically chosen to represent a conservative (slightly
6 higher) estimate of the concentration of residual radioactive material remaining in the survey
7 unit at the beginning of the FSS. For Scenario B, the AL is chosen as the lower bound of the
8 gray region and the upper bound is the DL, a value that represents how much effort will be
9 taken to determine there is no residual radioactive material. For decision error rates, a value
10 that minimizes the risk of making a decision error is recommended for the initial calculations.
11 The number of measurements can be recalculated using different values for the LBGR, DL, or
12 decision error rates until an appropriate survey design is obtained.⁷ A prospective power curve
13 (see **Appendix M**) that considers the effects of these parameters can be very helpful in
14 designing a survey and considering alternative values for these parameters and is highly
15 recommended.

16 To ensure that the desired power is achieved with the statistical test and to account for
17 underestimated values of the measurement variability, MARSSIM recommends that the
18 estimated number of measurements calculated using the formulas in **Sections 5.3.3–5.3.4** be
19 increased by 20 percent to account for a reasonable amount of uncertainty in the parameters
20 used to calculate and still allow flexibility to account for some lost or unusable data. Insufficient
21 numbers of measurements may result in failure to achieve the DQO for power and result in
22 increased Type II decision errors, where survey units below the release criteria fail to
23 demonstrate compliance in Scenario A. Of more concern to the regulator, Type II decision
24 errors for Scenario B lead to the incorrect release of survey units with average or median
25 concentrations above the release criteria.

26 Once survey units are identified and the number of measurements is determined, measurement
27 locations should be selected. The statistical tests assume that the measurements are taken
28 from random locations within the survey unit. A systematic grid with a random starting point is
29 used for Class 1 and Class 2 survey units. A systematic grid with a random starting point or a
30 random survey design is used for Class 3 survey units.

31 **2.5.5 Developing an Integrated Survey Design**

32 To account for assumptions used to develop the $DCGL_W$ and the realistic possibility of small
33 areas of elevated activity, if required, an integrated survey design should be developed to
34 include all the design considerations. An integrated survey design combines a scanning survey
35 for areas of elevated activity with random measurements for relatively uniform distributions of
36 radioactive material. **Table 2.2** presents the recommended conditions for demonstrating
37 compliance for an FSS based on classification.

⁷ Note that for some areas, an appropriate survey design may not be possible within initial survey design constraints, such as the requirements on α and survey power ($1-\beta$), available funds, and estimated values for the average and variability of the concentration of residual radioactive material remaining at the site. In these cases, the planning team will have to reconsider the survey design constraints or their decision to conduct a final status survey, in consultation with their regulator.

1 **Table 2.2: Recommended Conditions for Demonstrating Compliance Based on**
 2 **Survey Unit Classification for a Final Status Survey**

Survey Unit Classification		Statistical Test(s) ^a	Elevated Measurement Comparison	Sampling and Direct Measurements ^b	Scanning
Impacted	Class 1	Yes	Yes	Systematic	100% Coverage
	Class 2	Yes	Yes	Systematic	10–100% Systematic/Judgmental
	Class 3	Yes	Yes	Random or Systematic	10–100% ^c Systematic/Judgmental
Non-Impacted		No	No	No	None

3 ^a Statistical tests may consist of the Sign test, Wilcoxon Rank Sum test, quantile test, or comparison to an upper
 4 confidence limit, depending on the survey design chosen.

5 ^b For scan-only surveys, omit the sampling and direct measurements.

6 ^c For surveys utilizing sampling and/or direct measurements, this percentage can be lower than 10% judgmental.

7 Random-start systematic grids are used for Class 1 and Class 2 survey units because there is
 8 an increased probability of small areas of elevated activity. The use of a systematic grid allows
 9 the decision maker to draw conclusions about the size of any potential areas of elevated activity
 10 based on the area between measurement locations, while the random starting point of the grid
 11 provides an unbiased method for determining measurement locations for the statistical tests.
 12 The random start numbers should be furnished by an unbiased source to ensure that the survey
 13 results are similarly unbiased.

14 Random measurement patterns are used for Class 3 survey units to ensure that the
 15 measurements are independent and meet the requirements of the statistical tests.

16 Scan-only surveys can be used in place of direct measurements and/or sampling and analysis if
 17 the scanning measurement system has an MDC that is less than 50 percent of the DCGL_W and
 18 meets requirements for measurement method uncertainty. When scanning is used alongside
 19 sampling and/or direct measurements, it is used to identify locations within the survey unit that
 20 exceed the investigation level. These locations are marked and receive additional investigations
 21 to determine the concentration, area, and extent of the residual radioactive material. For Class 1
 22 areas, scanning surveys are designed to detect small areas of elevated activity that are not
 23 detected by the measurements using the systematic grids. For this reason, the measurement
 24 locations and the number of measurements may need to be adjusted based on the sensitivity of
 25 the scanning technique (see **Section 5.3.5**). This is also the reason for recommending
 26 100 percent coverage for the scanning survey.

27 Scanning surveys in Class 2 areas are also performed primarily to find areas of elevated activity
 28 not detected by the measurements using the systematic pattern. However, the measurement
 29 locations are not adjusted based on sensitivity of the scanning technique, and scanning is only

1 performed in portions of the survey unit. The level of scanning effort should be proportional to
2 the potential for finding areas of elevated activity. In Class 2 survey units that have
3 concentrations of residual radioactive material closer to the release criteria or a higher variability
4 across the survey unit, a larger portion of the survey unit would be scanned; for survey units that
5 are closer to background or have a lower variability, scanning a smaller portion of the survey
6 unit may be appropriate. Class 2 survey units have a lower probability for areas of elevated
7 activity than Class 1 survey units, but some portions of the survey unit may have a higher
8 potential than others. Judgmental scanning surveys would focus on the portions of the survey
9 unit with the highest probability for areas of elevated activity. If the entire survey unit has an
10 equal probability for areas of elevated activity, or the judgmental scans do not cover at least
11 10 percent of the area, systematic scans along transects of the survey unit or scanning surveys
12 of randomly selected grid blocks are performed.

13 Class 3 areas have the lowest potential for areas of elevated activity. For scan-only surveys, the
14 scan area and methodology are the same as for Class 2, but for surveys that contain both
15 statistical sampling and scanning, scanning surveys should be performed in areas of highest
16 potential (e.g., corners, ditches, and drains) based on professional judgment. This provides a
17 qualitative level of confidence that no areas of elevated activity were missed by the random
18 measurements or that there were no errors made in the classification of the area.

19 **2.6 Flexibility in Applying MARSSIM Approach**

20 **Section 2.5** describes an example that applies the performance-based approach presented in
21 **Sections 2.3–2.4** to design a survey for a site with residual radioactive material in surface soils
22 and/or building surfaces. Obviously, this design cannot be uniformly applied at every site with
23 residual radioactive material, so flexibility has been provided in the form of a performance-based
24 approach. This approach encourages the user to develop a site-specific survey design to
25 account for site-specific characteristics. It is expected that most users will adopt the portions of
26 the MARSSIM methodology that apply to their site. In addition, changes to the overall survey
27 design that account for site-specific differences would be presented as part of the survey plan.
28 The plan should also demonstrate that the extrapolation from measurements performed at
29 specific locations to the entire site or survey unit is performed in a technically defensible
30 manner.

31 Where **Section 2.5** describes the development of a generic survey design that will be applicable
32 at most radiation sites, this section describes the flexibility available within the MARSSIM for
33 designing a site-specific survey design. Alternate methods for accomplishing the demonstration
34 of compliance are briefly described, and references for obtaining additional information on these
35 alternate methods are provided.

36 **2.6.1 Alternate Statistical Methods**

37 MARSSIM encourages the use of statistics to provide a quantitative estimate of the probability
38 that the release criteria are not exceeded at a site. While it is unlikely that any site will be able to
39 demonstrate compliance with dose- or risk-based criteria without at least considering the use of
40 statistics, MARSSIM recognizes that the use of statistical tests may not always provide the most
41 effective method for demonstrating compliance. For example, MARSSIM recommends a simple

1 comparison to an investigation level to evaluate the presence of small areas of elevated activity
2 in place of complicated statistical tests.

3 MARSSIM recommends the use of nonparametric statistical tests for evaluating environmental
4 data. There are two reasons for this recommendation: (1) Environmental data are usually not
5 normally distributed, and (2) there are often a significant number of qualitative survey results
6 (e.g., less than MDC). Either one of these conditions means that parametric statistical tests may
7 not be appropriate. If one can demonstrate that the data are normally distributed and that there
8 are sufficient results to support a decision concerning the survey unit, parametric tests will
9 generally provide higher power (or require fewer measurements to support a decision
10 concerning the survey unit). The tests to demonstrate that the data are normally distributed
11 generally require more measurements than the nonparametric tests. EPA provides guidance on
12 selecting and performing statistical tests to demonstrate that data are normally distributed (EPA
13 2006a). Guidance is also available for performing parametric statistical tests (NRC 1992a, EPA
14 1989a, EPA 1994a, EPA 2006a).

15 There are a wide variety of statistical tests designed for use in specific situations. These tests
16 may be preferable to the generic statistical tests recommended in MARSSIM when the
17 underlying assumptions for these tests can be verified. **Table 2.3** lists several examples of
18 statistical tests that may be considered for use at individual sites or survey units. A brief
19 description of the tests and references for obtaining additional information on these tests are
20 also listed in the table. Applying these tests may require consultation with a statistician.

21 **2.6.2 Integrating MARSSIM with Other Survey Designs**

22 **2.6.2.1 Accelerated Cleanup Models**

23 There are a number of approaches designed to expedite site cleanups. These approaches can
24 save time and resources by reducing sampling, preventing duplication of effort, and reducing
25 inactive time periods between steps in a cleanup process. Although **Section 2.4** describes the
26 RSSI process recommended in MARSSIM as one with seven principal steps, MARSSIM is not
27 intended to be a serial process that would slow site cleanups. Rather, MARSSIM supports
28 existing programs and encourages approaches to expedite site cleanups. Planning in
29 MARSSIM promotes saving time and resources.

Table 2.3: Examples of Alternate Statistical Tests

Alternate Tests	Probability Model Assumed	Type of Test	Reference	Advantages	Disadvantages
Alternate 1-Sample Tests (No Reference Area Measurements)					
Student's t Test	Normal	Parametric test for H ₀ : Mean < t	<i>Guidance for Data Quality Assessment</i> , EPA QA/G-9, p. 3.2-2.	Appropriate if data appear to be normally distributed and symmetric.	Relies on a non-robust estimator for μ and σ . Sensitive to outliers and departures from normality.
t Test Applied to Logarithms	Lognormal	Parametric test for H ₀ : Median < t	<i>Guidance for Data Quality Assessment</i> , EPA QA/G-9, p. 3.2-2.	A well-known and easy-to-apply test. Useful for a quick summary of the situation if the data are skewed to right.	Relies on a non-robust estimator for σ . Sensitive to outliers and departures from lognormality.
Minimum Variance Unbiased Estimator for Lognormal Mean	Lognormal	Parametric estimates for mean and variance of lognormal distribution	Gilbert, <i>Statistical Methods for Environmental Pollution Monitoring</i> , p. 164, 1987.	A good parametric test to use if the data are lognormal.	Inappropriate if the data are not lognormal.
Chen Test	Skewed to right, including lognormal	Parametric test for H ₀ : Mean > 0	<i>Journal of the American Statistical Association (90)</i> , p. 767, 1995.	A good parametric test to use if the data are lognormal.	Applicable only for testing H ₀ : "survey unit is clean." Survey unit must be significantly greater than 0 to fail. Inappropriate if the data are not skewed to higher values.

Alternate Tests	Probability Model Assumed	Type of Test	Reference	Advantages	Disadvantages
Bayesian Approaches	Varies, but a family of probability distributions must be selected	Parametric test for H_0 : Mean < L	DeGroot, <i>Optimal Statistical Decisions</i> , 2005.	Permits use of subjective “expert judgment” in interpretation of data.	Decisions based on expert judgment may be difficult to explain and defend.
Bootstrap	No restriction	Nonparametric; uses resampling methods to estimate sampling variance	Hall, <i>Annals of Statistics</i> (22), p. 2011–2030, 1994.	Avoids assumptions concerning the type of distribution.	Computer-intensive analysis required. Accuracy of the results can be difficult to assess.
Lognormal Confidence Intervals Using Bootstrap	Lognormal	Uses resampling methods to estimate one-sided confidence interval for lognormal mean	Angus, <i>The Statistician</i> (43), p. 395, 1994.	Nonparametric method applied within a parametric lognormal model.	Computer-intensive analysis required. Accuracy of the results can be difficult to assess.
Alternate 2-Sample Tests (Reference Area Measurements Are Required)					
Student’s <i>t</i> Test	Symmetric, normal	Parametric test for difference in means $H_0: \mu_x < \mu_y$	<i>Guidance for Data Quality Assessment</i> , EPA QA/G-9, p. 3.3-2.	Easy to apply. Performance for non-normal data are acceptable.	Relies on a non-robust estimator for σ ; therefore, test results are sensitive to outliers.

Alternate Tests	Probability Model Assumed	Type of Test	Reference	Advantages	Disadvantages
Mann-Whitney Test	No restrictions	Nonparametric test difference in location $H_0: \mu_x < \mu_y$	Hollander, <i>Nonparametric Statistical Methods</i> , 2014.	Equivalent to the WRS test, but used less often. Similar to resampling, because test is based on set of all possible differences between the two data sets.	Assumes that the only difference between the test and reference areas is a shift in location.
Kolmogorov-Smirnov	No restrictions	Nonparametric test for any difference between the two distributions	Hollander, <i>Nonparametric Statistical Methods</i> , 2014.	A robust test for equality of two sample distributions against all alternatives.	May reject because variance is high, although mean is in compliance.
Bayesian Approaches	Varies, but a family of probability distributions must be selected	Parametric tests for difference in means or difference in variance	Box and Tiao, <i>Bayesian Inference in Statistical Analysis</i> , 2011.	Permits use of “expert judgment” in the interpretation of data.	Decisions based on expert judgment may be difficult to explain and defend.
2-Sample Quantile Test	No restrictions	Nonparametric test for difference in shape and location	EPA, <i>Methods for Evaluating the Attainment of Cleanup Standards</i> , Vol. 3, p. 7.1, 1994.	Will detect if survey unit distribution exceeds reference distribution in the upper quantiles.	Applicable only for testing H_0 : “survey unit is clean.” Survey unit must be significantly greater than 0 to fail.
Sign Test when Background is Present	No restrictions	Nonparametric test for difference in location assuming uniform background	Abelquist, <i>Decommissioning Health Physics: A Handbook for MARSSIM Users</i> , 2 nd Edition, 2014.	Less computationally intensive. Consistent with pre-MARSSIM survey designs.	Less powerful than the Wilcoxon Rank Sum Test because of assumptions concerning background distributions.

Alternate Tests	Probability Model Assumed	Type of Test	Reference	Advantages	Disadvantages
Bootstrap and Other Resampling Methods	No restrictions	Nonparametric; uses resampling methods to estimate sampling variance	Hall, <i>Annals of Statistics</i> (22), p. 2011, 1994.	Avoids assumptions concerning the type of distribution. Generates informative resampling distributions for graphing.	Computer-intensive analysis required.
Alternate to Statistical Tests					
Decision Theory	No restrictions	Incorporates loss function in the decision theory approach	DOE, <i>Statistical and Cost-Benefit Enhancements to the DQO Process for Characterization Decisions</i> , 1996.	Combines elements of cost-benefit analysis and risk assessment into the planning process.	Limited experience in applying the method to compliance demonstration and decommissioning. Computer-intensive analysis required.

Abbreviations: H_0 = null hypothesis; t : = t-test statistic, L = bayesian test statistic; μ = mean; σ = standard deviation.

1 Sandia National Laboratories in New Mexico used a combination of the observational approach,
2 process knowledge, judgmental soil sampling, and Global Positioning System (GPS)/gamma
3 survey techniques to identify and remediate potential residual radioactive material during
4 execution of the Environmental Restoration Project there. Depleted uranium was almost
5 exclusively the radionuclide of concern. There were 268 individual designated test locations on
6 the site ranging from tens of square meters to hundreds of acres, necessitating the application
7 of a flexible, graded approach, as appropriate. GPS/gamma in situ surveys were particularly
8 valuable in cost-effectively screening large areas and identifying sub-areas that warranted more
9 rigorous investigation than other, non-affected areas. As-completed survey maps and data files
10 consisted of ArcGIS figures generated from the GPS/gamma surveys (before and after)
11 supplemented by analytical laboratory results which were correlated to the GPS/gamma
12 surveys, when both were used. Use of in situ GPS/gamma surveys complemented by ArcGIS
13 analytical tools enabled convenient statistical treatment of thousands of data points, making
14 demonstration of successful remediation much easier to present, as well as easier to
15 understand by the stakeholders.

16 At the U.S. Department of Energy's Hanford Site, the parties to the Tri-Party Agreement
17 negotiated a method to implement the CERCLA process in order to (1) accelerate the
18 assessment phase, and (2) coordinate RCRA and CERCLA requirements whenever possible,
19 thereby resulting in cost savings. The Hanford Past Practice Strategy was developed in 1991 to
20 accelerate decision-making and initiation of remediation through activities that include
21 maximizing the use of existing data consistent with DQOs (DOE 1991).

22 The Adaptive Sampling and Analysis Programs at the Environmental Science Division of
23 Argonne National Laboratory quantitatively fuse soft data (e.g., historical records, aerial photos,
24 nonintrusive geophysical data) with hard sampling results to estimate residual radioactive
25 material extent, measure the uncertainty associated with these estimates, determine the
26 benefits from collecting additional samples, and assist in siting new sample locations to
27 maximize the information gained (DOE 2001).

28 *2.6.2.2 Superfund Soil Screening Guidance*

29 The Soil Screening Guidance for Radionuclides (EPA 1996a, EPA 1996b) is a tool developed
30 by EPA to help standardize and accelerate the evaluation and cleanup of radioactively
31 contaminated soils at sites on the National Priorities List (NPL) where future residential land use
32 is anticipated. The guidance provides a methodology for calculating risk-based, site-specific soil
33 screening levels for radionuclides in soil that may be used to identify areas needing further
34 investigation at NPL sites. The Soil Screening Guidance assumes that there is a low probability
35 of residual radioactive material and does not account for small areas of elevated activity. These
36 assumptions correlate to a Class 3 area in MARSSIM. Because the Soil Screening Guidance is
37 designed as a screening tool instead of a final demonstration of compliance, the specific values
38 for decision error levels, the bounds of the gray region, and the number and location of
39 measurements are developed to support these objectives. However, the MARSSIM approach
40 can be integrated with the survey design in the Soil Screening Guidance using this guidance as
41 an alternate MARSSIM survey design.

- 1 The Soil Screening Guidance survey design is based on collecting samples, so scan surveys
- 2 and direct measurements are not considered. To reduce analytical costs, the survey design
- 3 recommends compositing samples and provides a statistical test for demonstrating compliance.
- 4 If utilizing the Soil Screening Guidance in conjunction with MARSSIM, factor in the effects of the
- 5 compositing technique when calculating measurement method uncertainty and detection
- 6 capability and in the determination of areas of elevated radioactive material.

DRAFT

1

3 HISTORICAL SITE ASSESSMENT

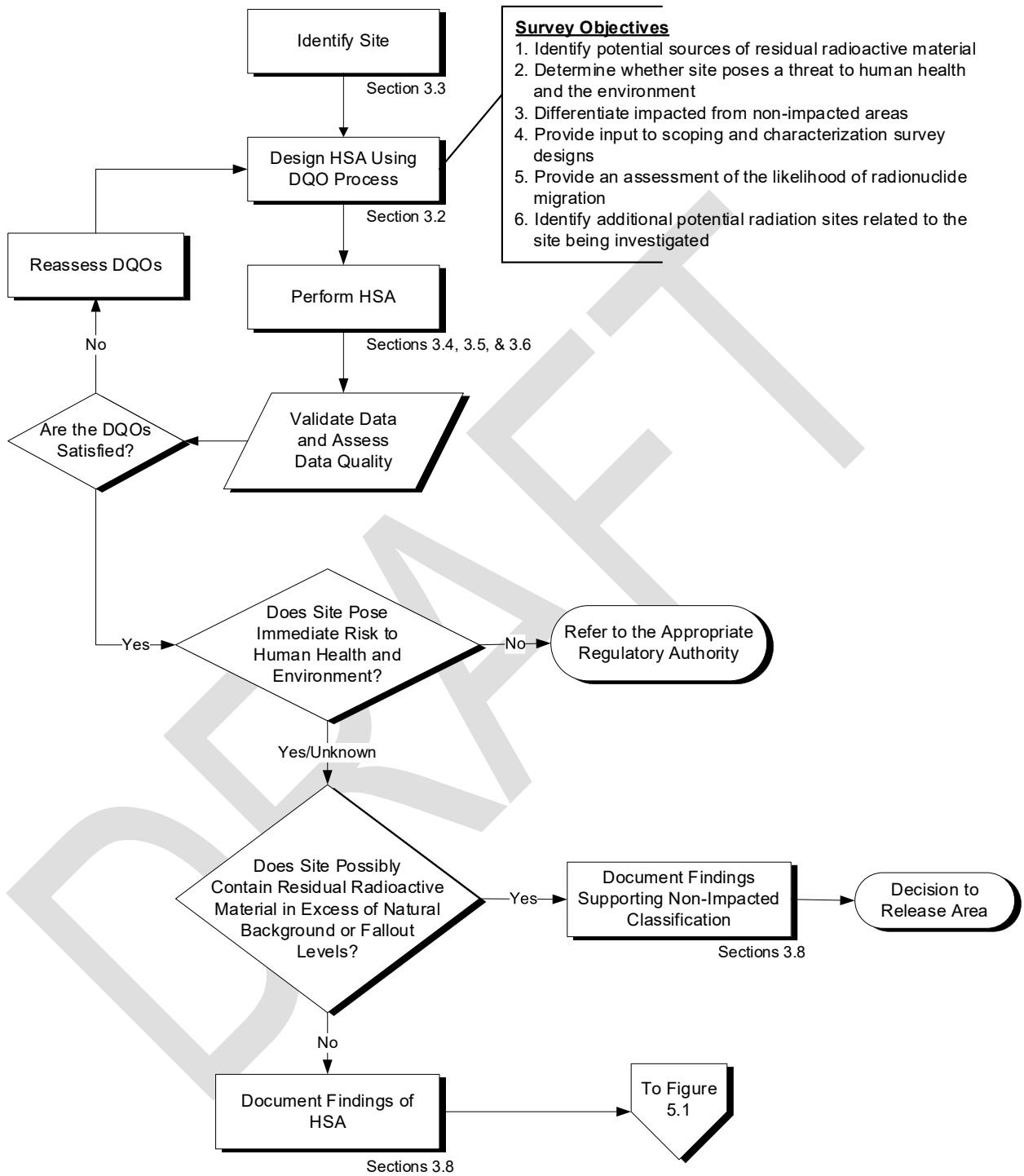
3.1 Introduction

3 The Radiation Survey and Site Investigation (RSSI) process uses a graded approach that starts
4 with the Historical Site Assessment (HSA) and is later followed by other surveys that lead to the
5 final status survey (FSS). The HSA is an investigation to collect existing information describing a
6 site's complete history from the start of site activities to the present time. During the HSA
7 process, additional information is collected to categorize the site or areas within the site as
8 impacted or non-impacted and to make preliminary site classification assessments. In this
9 chapter¹—

- 10 • **Section 3.1** provides an overview of the HSA.
- 11 • **Section 3.2** describes the Data Quality Objectives (DQO) process, utilized to establish
12 criteria for planning HSA data collection activities.
- 13 • **Section 3.3** describes how site identification is used to establish a site or an area within a
14 site as having the potential to have residual radioactive material based on prior activities at
15 the site.
- 16 • **Section 3.4** describes the preliminary investigation, utilized to obtain sufficient information to
17 determine an initial categorization of a site or survey unit.
- 18 • **Section 3.5** explains how site reconnaissance is utilized to gather sufficient information to
19 support decisions on further action.
- 20 • **Section 3.6** covers the evaluation of HSA data to differentiate sites that need further action
21 from those that pose little to no threat from the environment.
- 22 • **Section 3.7** describes how to utilize the data gathered from the HSA to determine the next
23 step in the RSSI process.
- 24 • **Section 3.8** covers the preparation of an HSA report to summarize what is known about a
25 site, assumptions and inferences made about the site, activities conducted during the HSA,
26 and all researched information.
- 27 • **Section 3.9** provides a review of the HSA process.
- 28 • **Figure 3.1** presents a flowchart of HSA activities and **Figure 3.2** provides initial
29 categorization of the site or survey unit² as impacted or non-impacted.

¹ MARSSIM uses the word “should” as a recommendation, not as a requirement. Each recommendation in this manual is not intended to be taken literally and applied at every site. MARSSIM’s survey planning documentation will address how to apply the process on a site-specific basis.

² Refer to **Section 4.6.2** for a discussion of survey units.



1 •

2 **Figure 3.1: Historical Site Assessment Process Flowchart**

1 The HSA may provide information needed to calculate derived concentration guideline levels
2 (DCGLs, initially described in **Section 2.2**), as well as information that reveals the magnitude of
3 a site's DCGLs. This information is used for comparing historical data to potential DCGLs and
4 determining the suitability of the existing data for assessment of the site. The HSA also supports
5 emergency response and removal activities within the context of the the U.S. Environmental
6 Protection Agency's (EPA) Superfund program, fulfills public information needs, and furnishes
7 appropriate information about the site early in the RSSI process. For a large number of sites,
8 such as currently licensed facilities, site identification and reconnaissance may not be needed.
9 For certain response activities, such as reports concerning the possible presence of radioactive
10 material, preliminary investigations may consist more of site reconnaissance and a scoping
11 survey in conjunction with collection of historical information.

12 This chapter describes three sections of an HSA: (1) identification of a candidate site
13 (**Section 3.3**), (2) preliminary investigation of the facility or site (**Section 3.4**), and (3) site
14 reconnaissance (**Section 3.5**). The site reconnaissance is not a scoping survey, however,
15 because the intent is to find physical conditions that may affect the investigative process and not
16 to collect measurements. The HSA is followed by an evaluation of the site based on information
17 collected during the HSA.

18 The amount of detailed information and effort needed to conduct an HSA depends on the type
19 of site, associated historical events, regulatory framework, and availability of documented
20 information. For example, information for an HSA is readily available at some facilities that
21 routinely maintain records throughout their operations, such as licensees of the U.S. Nuclear
22 Regulatory Commission (NRC) or Agreement States. At other facilities, such as Comprehensive
23 Environmental Response, Compensation, and Liability Act (CERCLA) sites, a comprehensive
24 search may be necessary to gather information for an HSA (see **Appendix F**). In the former
25 case, the HSA is essentially complete, and a review of the following sections will serve to
26 ensure that the information justifies the recommendation. In the latter case, the HSA process
27 has identified data gaps that will be addressed in subsequent scoping or characterization
28 surveys. In still other cases, where sealed sources or small amounts of radionuclides are
29 described by the HSA, the site may qualify for a simplified decommissioning procedure (see
30 **Appendix B**).

31 **3.2 Data Quality Objectives**

32 The Data Quality Objectives (DQO) process assists in directing the planning of data collection
33 activities performed during the HSA. Information gathered during the HSA can also support the
34 DQOs of subsequent surveys.

35 Three inputs to the HSA/DQO process are expected:

- 36 • identifying an individual or a list of planning team members, including the decision maker
37 (DQO Step 1, **Appendix D, Section D.1**)
- 38 • concisely describing the problem (DQO Step 1, **Appendix D, Section D.1**)
- 39 • initially classifying site and survey unit as impacted or non-impacted (DQO Step 4,
40 **Appendix D, Section D.2.2**)

1 Other inputs may accompany these three, and this added information may be useful in
2 supporting subsequent applications of the DQO process.

3 The planning team clarifies and defines the DQOs for a site-specific survey. This
4 multidisciplinary team of technical experts offers the greatest potential to solve the problems
5 encountered in designing a survey. Including a stakeholder group representative is an important
6 consideration when assembling this team. Once formed, the team can also consider the role of
7 public participation in this assessment and the possible surveys to follow. The number of team
8 members is directly related to the scope and complexity of the problem. For a small site or
9 simplified situations, planning may be performed by the site owner. For a large, complex facility,
10 the team may include project managers, site managers, scientists, engineers, community and
11 local government representatives, health physicists, statisticians, and regulatory agency
12 representatives. A reasonable effort should be made to include other individuals—that is,
13 specific decision makers or data users—who may use the study findings sometime in the future.

14 The role of the regulatory agency representatives is to facilitate survey planning—without direct
15 participation in survey plan development—by offering comments and information based on past
16 precedent, current guidance, and potential pitfalls. A regulatory agency representative may also
17 be included at specific sites when needed (e.g., CERCLA).

18 The planning team is generally led by a member who is referred to as the decision maker. This
19 individual is often the person with the most authority over the study and may be responsible for
20 assigning the roles and responsibilities to planning team members. Overall, the decisionmaking
21 process arrives at final decisions based on the planning team's recommendations. The problem
22 or situation description provides background information on the fundamental issue to be
23 addressed by the assessment (EPA 2006b). The following steps may be helpful during DQO
24 development:

- 25 • Describe the conditions or circumstances surrounding the problem or situation and the
26 reason for undertaking the survey.
- 27 • Describe the problem or situation as it is currently understood by briefly summarizing
28 existing information.
- 29 • Conduct literature searches and interviews.
- 30 • Examine past or ongoing studies to ensure that the problem is correctly defined. Consider
31 breaking complex problems into more manageable pieces.

32 **Section 3.5** provides information on gathering existing site data and determining the usability of
33 this data.

34 The initial classification of the site involves developing a conceptual model based on the existing
35 information collected during the preliminary investigation. Conceptual models describe a site or
36 facility and its environs and present hypotheses regarding the radionuclides for known and
37 potential residual radioactive material (EPA 1987a, 1987b). The classification of the site is
38 discussed in **Section 3.7**.

1 Several steps in the DQO process may be addressed initially during the HSA. This information
2 or decision may be based on limited or incomplete data. As the site assessment progresses and
3 as decisions become more difficult, the iterative nature of the DQO process allows for re-
4 evaluation of preliminary decisions. This is especially important for classification of sites and
5 survey units where the final classification is not made until the FSS is planned.

6 **3.3 Site Identification**

7 A site may already be known for its prior use and presence of radioactive materials. Elsewhere,
8 potential radioactive materials sites may be identified through such situations and information as
9 the following:

- 10 • records of authorization to possess or handle radioactive materials, including—
 - 11 ○ NRC or NRC Agreement State License
 - 12 ○ U.S. Department of Energy facility records
 - 13 ○ Naval Radioactive Materials Permit
 - 14 ○ U.S. Air Force Master Materials License
 - 15 ○ Army Radiation Authorization
 - 16 ○ State Authorization for Naturally Occurring and Accelerator Produced Radioactive
17 Material (NARM)
- 18 • notification to government agencies of possible releases of radioactive substances
- 19 • citizens filing a petition under section 105(d) of the Superfund Amendments and
20 Reauthorization Act of 1986 (EPA 1986)
- 21 • ground and aerial radiological surveys
- 22 • contacts with knowledge of the site

23 Once identified, the name, location, and current legal owner or custodian (where available) of
24 the site should be recorded.

25 **3.4 Preliminary Investigation**

26 The preliminary investigation serves to collect readily available information concerning the
27 facility or site and its surroundings. The investigation is designed to obtain sufficient information
28 to provide initial categorization of the site or survey unit as impacted or non-impacted.
29 Information on the potential distribution of residual radioactive material may be used for
30 classifying each site or survey unit as Class 1, Class 2, or Class 3 and is useful for planning
31 scoping and characterization surveys.

1 **Table 3.1** provides a set of questions that can be used to assist in the preliminary investigation.
 2 Apart from obvious cases (e.g., NRC licensees), this table focuses on characteristics that
 3 identify a previously unrecognized or known but undeclared source of potential residual
 4 radioactive material. Furthermore, these questions may identify confounding factors for
 5 selecting reference sites.

6 **Table 3.1: Questions Useful for the Preliminary Investigation**

Question	Purpose of Question
1. Was the site ever licensed for the manufacture, use, or distribution of radioactive materials under Agreement State Regulations, U.S. Nuclear Regulatory Commission licenses, or Armed Services permits, or for the use of 91B material?	Indicates a higher probability that the area is impacted.
2. Did the site ever have permits to dispose of or incinerate radioactive material onsite? Is there evidence of such activities?	Evidence of radioactive material disposal indicates a higher probability that the area is impacted.
3. Has the site ever had deep wells for injection or permits for such?	Indicates a higher probability that the area is impacted.
4. Did the site ever have permits to perform research with radiation-generating devices or radioactive materials except medical or dental X-ray machines?	Research that may have resulted in the release of radioactive material indicates a higher probability that the area is impacted.
5. As a part of the site's radioactive materials license, were there ever any soil moisture density gauges (americium-beryllium or plutonium-beryllium sources) or radioactive thickness monitoring gauges stored or disposed of onsite?	Leak-test records of sealed sources may indicate whether a storage area is impacted. Evidence of radioactive material disposal indicates a higher probability that the area is impacted.
6. Was the site used to create radioactive material by activation?	Indicates a higher probability that the area is impacted.
7. Were radioactive sources stored at the site?	Leak-test records of sealed sources may indicate whether or not a storage area is impacted.
8. Is there evidence that the site was involved in the Manhattan Project or any Manhattan Engineering District activities (1942–1946)?	Indicates a higher probability that the area is impacted.
9. Was the site ever involved in the support of nuclear weapons testing (1945–1962)?	Indicates a higher probability that the area is impacted.
10. Were any facilities on the site used as a weapons storage area? Was weapons maintenance ever performed at the site?	Indicates a higher probability that the area is impacted.

Question	Purpose of Question
11. Was there ever any decontamination, maintenance, or onsite storage of ships, vehicles, or planes with residual radioactive material?	Indicates a higher probability that the area is impacted.
12. Is there a record of any aircraft accident at or near the site (e.g., depleted uranium counterbalances, thorium alloys, radium dials)?	May include other considerations, such as evidence of radioactive material that was not recovered.
13. Are there records indicating use or storage of radium dials and other radioactive luminous devices as a source?	Indicates a higher probability that the area is impacted.
14. Was there ever any radiopharmaceutical manufacturing, storage, transfer, or disposal onsite?	Indicates a higher probability that the area is impacted.
15. Was animal research ever performed at the site?	Evidence that radioactive material was used for animal research indicates a higher probability that the area is impacted.
16. Were naturally occurring radioactive material (NORM) or technologically enhanced naturally occurring radioactive material (TENORM)—such as uranium, thorium, or radium compounds—used in manufacturing, research, or testing at the site, or were these compounds stored at the site?	Indicates a higher probability that the area is impacted or results in a potential increase in background variability.
17. Has the site ever been involved in the processing or production of NORM or TENORM (e.g., radium, fertilizers, phosphorus compounds, vanadium compounds, refractory materials, rare earth elements, or precious metals) or mining, milling, processing, or production of uranium or thorium?	Indicates a higher probability that the area is impacted or results in a potential increase in background variability.
18. Were coal or coal products used onsite? If yes, did combustion of these substances leave ash or ash residues onsite? If yes, are runoff or production ponds onsite?	May indicate other considerations, such as a potential increase in background variability.
19. Was there ever any onsite disposal of material known to be high in naturally occurring radioactive material (e.g., monazite sands used in sandblasting)?	May indicate other considerations, such as a potential increase in background variability.

Question	Purpose of Question
20. Did the site contain or use pipe from the oil and gas industries?	Indicates a higher probability that the area is impacted or results in a potential increase in background variability.
21. Is there any reason to expect that the site may contain radioactive material (other than previously listed)?	See Section 3.7.

1 Definition: 91B = “highly classified radioactive material covered under Section 91(b) of the Atomic Energy Act (AEA)
 2 of 1954 associated with current nuclear weapons material, legacy nuclear weapons maintenance wastes, residuals
 3 from nuclear weapons accident/incidents, some residuals from atmospheric testing of nuclear weapons, and
 4 residuals from nuclear reactor operations.” (George Air Force Base, n.d.)

5 **Appendix G** of this document provides a general listing and cross-reference of information
 6 sources—each with a brief description of the information contained in each source.

7 **3.4.1 Existing Radiation Data**

8 Sources of useful information for an HSA include site files; monitoring data; former site
 9 evaluation data; and Federal, State, and local investigations or emergency actions. Existing site
 10 data may provide specific details about the identity, concentration, and areal distribution of
 11 residual radioactive material. However, these data should be examined carefully because—

- 12 • Previous survey and sampling efforts may not be compatible with HSA objectives or may not
 13 be extensive enough to characterize the facility or site fully.
- 14 • Measurement protocols and standards may not be known or compatible with HSA objectives
 15 (e.g., quality assurance/quality control [QA/QC] procedures, limited analysis rather than full-
 16 spectrum analysis) or may not be extensive enough to characterize the facility or site fully.
- 17 • Conditions may have changed since the site was last sampled (i.e., substances may have
 18 been released, migration may have spread the residual radioactive material, additional
 19 waste disposal may have occurred, or decontamination may have been performed).

20 Existing data can be evaluated using the Data Quality Assessment (DQA) process described in
 21 **Appendix D.** (Also see DOE 1987 and EPA 1980a, 1992a, 1992b, 2006a for additional
 22 guidance on evaluating data.)

23 **3.4.1.1 Licenses, Site Permits, and Authorizations**

24 The facility or site radioactive materials license and supporting or associated documents are
 25 potential sources of information for licensed facilities. If a license does not exist, there may be a
 26 permit or other document that authorized site operations involving radioactive material. These
 27 documents may specify the quantities of radioactive material authorized for use at the site, the
 28 chemical and physical form of the materials, operations for which the materials are (or were)
 29 used, locations of these operations at the facility or site, and total quantities of material used at
 30 the site during its operating lifetime.

1 EPA and State agencies maintain files on a variety of environmental programs. These files may
2 contain permit applications and monitoring results with information on specific waste types and
3 quantities, sources, type of site operations, and operating status of the facility or site. Some of
4 these information sources are listed in Appendix G.

5 *3.4.1.2 Operating Records*

6 Records and other information sources useful for site evaluations include those describing
7 onsite activities, current and past radiation control procedures, and past operations involving—

- 8 • demolition
- 9 • effluent releases
- 10 • discharge to sewers or onsite septic systems
- 11 • production of residues
- 12 • land filling
- 13 • waste and material storage
- 14 • pipe and tank leaks
- 15 • spills and accidental releases
- 16 • release of facilities or equipment from radiological controls
- 17 • onsite or offsite radioactive and hazardous waste disposal

18 Some records may be or may have been classified for national security purposes, and means
19 should be established to review all pertinent records. Past operations should be summarized in
20 chronological order, along with information about permits and approvals. Estimates of the total
21 amount of radioactive material disposed of or released at the site and the physical and chemical
22 form of the radioactive material should also be included. Records on waste disposal,
23 environmental monitoring, site inspection reports, license applications, operational permits,
24 waste disposal material balance and inventory sheets, and purchase orders for radioactive
25 materials are useful for estimating total activity. Information on accidents—such as fires,
26 flooding, spills, unintentional releases, or leakage—should be collected, because they indicate
27 potential sources of residual radioactive material. Possible areas of localized radioactive
28 material should be identified.

29 Site plats or plots, blueprints, drawings, and sketches of structures are especially useful to
30 illustrate the location and layout of buildings on the site. Site photographs, aerial surveys, and
31 maps can help verify the accuracy of these drawings or indicate changes after the drawings
32 were prepared. Processing locations, waste streams to and from the site, and the presence of
33 stockpiles of raw materials and finished product should be noted on these photographs and
34 maps. Buildings or outdoor processing areas may have been modified or converted to other

1 uses or configurations. The locations of sewers, pipelines, electric lines, water lines, etc., should
2 also be identified. This information facilitates planning the site reconnaissance and subsequent
3 surveys, developing a site conceptual model, and increasing the efficiency of the survey
4 program.

5 Corporate contract files may also provide useful information during subsequent stages of the
6 RSSI process. Older facilities may not have complete operational records, especially for
7 obsolete or discontinued processes. Financial records may also provide information on
8 purchasing and shipping that, in turn, help to reconstruct a site's operational history.

9 While operating records can be useful tools during the HSA, the investigator should be careful
10 not to place too much emphasis on this type of data. These records are often incomplete and
11 lack information on substances previously not considered hazardous. Out-of-date blueprints and
12 drawings may not show modifications made during the lifetime of a facility, but they may be
13 useful to identify additional areas that should be investigated.

14 **3.4.2 *Contacts and Interviews***

15 Conduct interviews with current or previous employees to collect first-hand information about
16 the site or facility and to verify or clarify information gathered from records. Interviews cover
17 general topics, such as radioactive waste handling procedures. Results from interviews
18 conducted early in the process are useful in guiding subsequent data collection activities.

19 Interviews scheduled late in the data gathering process can also be very useful. Questions can
20 be directed to specific areas of the investigation that need additional information or clarification.

21 Photographs and sketches can be used to assist the interviewer and allow the interviewees to
22 recall information of interest. Conducting interviews onsite where the employees performed their
23 tasks often stimulates memories and facilitates information gathering. In addition to interviewing
24 managers, engineers, and facility workers, interviews may be conducted with laborers and truck
25 drivers to obtain information from their perspective.

26 The investigator should be cautious in the use of interview information. Whenever possible,
27 anecdotal evidence should be assessed for accuracy, and results of interviews should be
28 backed up with supporting data. To ensure that specific information is confirmed and properly
29 recorded, it may be advisable to hire trained investigators and take affidavits.

30 **3.5 *Site Reconnaissance***

31 The objective of the site reconnaissance or site visit is to gather sufficient information to support
32 a decision regarding further action. Reconnaissance activity is not a risk assessment, a scoping
33 survey, or a study of the full extent of residual radioactive material at a facility or site. The
34 reconnaissance offers an opportunity to record information concerning hazardous site
35 conditions as they apply to conducting future survey work. In this regard, information describing
36 physical hazards, structural integrity of buildings, or other conditions defines potential problems
37 that may impede future work. Site reconnaissance is most applicable to sites with less available
38 information and may not be necessary at other sites having greater amounts of records, such as
39 NRC licensed facilities.

1 To prepare for the site reconnaissance, begin by reviewing what is known about the facility or
2 site and identify data gaps. Given the site-specific conditions, consider whether a site
3 reconnaissance is necessary and practical. This type of effort may be deemed necessary if a
4 site is abandoned or not easily observed from areas of public access, or if file searches disclose
5 little information. These same circumstances may also make a site reconnaissance risky for
6 health and safety reasons—in view of the many unknowns—and may make entry difficult. This
7 investigative step may be less critical for active facilities whose operators grant access and
8 provide requested information. Remember to arrange for proper site access and prepare an
9 appropriate health and safety plan, if required, before initiating the site visit.

10 Investigators should acquire signed consent forms from the site or equipment owner to gain
11 access to the property to conduct the reconnaissance. Investigators are to determine if State
12 and Federal officials, and local individuals, should be notified of the reconnaissance schedule. If
13 needed, local officials should arrange for public notification. Guidance on obtaining access to
14 sites can be found in *Entry and Continued Access Under CERCLA* (EPA 1987c).

15 A study plan should be prepared before the site reconnaissance to anticipate every
16 reconnaissance activity and identify specific information to be gathered. This plan should
17 incorporate a survey of the site's surroundings and provide details for activities that verify or
18 identify the location of nearby residents, worker populations, drinking water or irrigation wells,
19 and foods, as well as other site environs information.

20 Materials and equipment for a site reconnaissance should be prepared in advance. This
21 includes a camera to document site conditions, as well as health and safety monitoring
22 instruments, including a radiation detection meter, a GPS receiver or extra copies of
23 topographic maps to mark target locations, water distribution areas, and other important site
24 features.

25 A logbook is critical to keeping a record of field activities and observations as they occur. The
26 Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) recommends that the
27 logbook be completed in waterproof ink, preferably by one individual. Furthermore, each page of
28 the logbook should be signed and dated, including the time of day, after the last entry on the
29 page. Corrections should be documented and approved. Alternatively, a computerized logbook
30 may also be used, with the adequate provision of controls to ensure appropriate quality
31 assurance and version control. For example, logbook entries should be signed daily and closed
32 out, so that future revisions would require date/time stamping and signature of the individual
33 making changes.

34 **3.6 Evaluation of Historical Site Assessment Information**

35 The main purpose of the HSA is to determine the current status of the site or facility, but the
36 data collected may also be used to differentiate sites that need further action from those that
37 pose little or no threat to human health and the environment. The information gathered during
38 this screening process can show the need for additional surveys or may be sufficient to
39 recommend a site release. Because much of the information collected during HSA activities is
40 qualitative, and analytical data may be of unknown quality, many decisions regarding a site are
41 the result of professional judgment.

1 Historical analytical data indicating the presence of residual radioactive material in
2 environmental media (surface soil, subsurface soil, surface water, ground water, air, or
3 buildings) can be used to support the hypothesis that radioactive material was released at the
4 facility or site. A decision that the site does not meet release criteria can be made regardless of
5 the quality of the data, its attribution to site operations, or its relationship to background levels.
6 In such cases, elevated results are sufficient to support the hypothesis—it is not necessary to
7 definitively demonstrate that a problem exists. Conversely, historical analytical data can also be
8 used to support the hypothesis that no release has occurred. However, these data should not
9 be the sole basis for this hypothesis. If historical analytical data constitute the principal evidence
10 for ruling out the presence of residual radioactive material, the data must be of sufficient quality
11 to clearly demonstrate that a problem does not exist.

12 In most cases, it is assumed there will be some level of process knowledge available in addition
13 to historical analytical data. If process knowledge suggests that no residual radioactive material
14 should be present, and the historical analytical data also suggests that no residual radioactive
15 material is present, the process knowledge provides an additional level of confidence and
16 supports categorizing the area as non-impacted. However, if process knowledge suggests no
17 residual radioactive material should be present, but the historical analytical data indicate the
18 presence of residual radioactive material, the area will probably be categorized as impacted.

19 The following sections describe the recommended information to accurately and completely
20 support a site release recommendation. If some of the information is not available, it should be
21 identified as a data need for future surveys. Data needs are collected during Step 3 of the DQO
22 process (Identify Inputs to the Decision) as described in **Appendix D, Section D.1.3**.
23 **Section 3.6.5** provides information on professional judgment and how it may be applied to the
24 decisionmaking process.

25 **3.6.1 Identify Potential Sources of Residual Radioactive Material**

26 An efficient HSA gathers information sufficient to identify the radionuclides used at the site,
27 including their chemical and physical form. The first step in evaluating HSA data is to estimate
28 the potential for residual radioactive material from these radionuclides.

29 Site operations are a strong indicator of the potential for residual radioactive material
30 (NRC 1992a). An operation that handled only encapsulated sources is expected to have a low
31 potential for residual radioactive material—assuming that the integrity of the sources was not
32 compromised. A review of leak-test records for such sources may be adequate to demonstrate
33 the low probability of residual radioactive material. A chemical manufacturing process facility
34 would likely have residual radioactive material in piping, ductwork, and process areas, with a
35 potential for residual radioactive material in soil where spills, discharges, or leaks occurred.
36 Sites using large quantities of radioactive ores—especially those with outside waste collection
37 and treatment systems—are likely to have residual radioactive material on the premises. If loose
38 dispersible materials were stored outside or process ventilation systems were poorly controlled,
39 then windblown surface deposition of residual radioactive material may be possible.

40 Consider how long the site was operational. If enough time elapsed since the site discontinued
41 operations, radionuclides with short half-lives may no longer be present in significant quantities.

1 In this case, calculations demonstrating that residual activity could not exceed the DCGL may
2 be sufficient to evaluate the potential residual radioactive material at the site. A similar
3 evaluation can be made based on knowledge of a radionuclide's chemical and physical form.
4 Such a determination relies on records of radionuclide inventories, chemical and physical forms,
5 total amounts of material and activity in waste shipments, and purchasing records to document
6 and support this decision. However, a number of radionuclides experience significant decay
7 product ingrowth, which should be considered when evaluating existing site information.

8 **3.6.2 Identify Potential Areas with Residual Radioactive Material**

9 Information gathered during the HSA should be used to provide an initial categorization of the
10 site areas as impacted or non-impacted.

11 Impacted areas are either known to contain residual radioactive material based on radiological
12 surveillance or are suspected of containing it based on historical information. This includes
13 areas where—

- 14 • Radioactive material was used and stored.
- 15 • Records indicate spills, discharges, or other unusual occurrences that could result in the
16 spread of radioactive material.
- 17 • Radioactive material was buried or disposed.

18 Areas immediately surrounding or adjacent to these locations are also considered impacted
19 because of the potential for inadvertent spread of radionuclides.

20 Non-impacted areas are those areas where there is no reasonable possibility for residual
21 radioactive material based on site history or previous survey information. The criteria used for
22 this distinction need not be as strict as those used to demonstrate final compliance. However,
23 the reasoning for categorizing an area as non-impacted should be maintained as a written
24 record.

25 All potential sources of radioactive material in impacted areas should be identified and their
26 dimensions recorded (in two or three dimensions, to the extent they can be measured or
27 estimated). Sources can be delineated and characterized through visual inspection during the
28 site reconnaissance; interviews with knowledgeable personnel; and historical information
29 concerning disposal records, waste manifests, and waste sampling data. The HSA should
30 address potential residual radioactive material from the site whether it is physically within or
31 outside of site boundaries. This approach describes the site in a larger context, but as noted in
32 **Chapter 1**, MARSSIM's scope concerns releasing a site and does not include areas outside a
33 site's boundaries.

34 **3.6.3 Identify Potential Media with Residual Radioactive Material**

35 The next step in evaluating the data gathered during the HSA is to identify media at the site with
36 a potential for containing residual radioactive material. Identification of those media that do not

1 contain residual radioactive material and those that may contain it is necessary for both
2 preliminary area classification (**Section 4.4**) and planning subsequent survey activities.

3 This section provides information on evaluating the likelihood for release of radioactive material
4 into the following environmental media: surface soil, subsurface soil, sediment, surface water,
5 ground water, air, and buildings. Although MARSSIM's scope is focused on surface soils and
6 building surfaces, other media will still need to be considered.

7 The evaluation will result in a finding either of suspected residual radioactive material or of no
8 suspected residual radioactive material. The finding may be based on analytical data,
9 professional judgment, or a combination of the two.

10 Subsequent sections describe the environmental media and pose questions pertinent to each
11 type. Each question is accompanied by a commentary. Carefully consider the questions within
12 the context of the site and the available data. Avoid spending excessive amounts of time on
13 particular questions, because answers to every question are unlikely to be available at each
14 site. Questions that cannot be answered based on existing data can be used to direct future
15 surveys of the site. Also, keep in mind the numerous differences in site-specific circumstances
16 and that the questions do not identify every characteristic that might apply to a specific site.
17 Additional questions or characteristics identified during a specific site assessment should be
18 included in the HSA report (**Section 3.9**; EPA 1991e).

19 **3.6.3.1 Surface Soil**

20 Surface soil is the top layer of soil on a site that is available for direct exposure, growing plants,
21 resuspension of particles for inhalation, and mixing from human disturbances. Surface soil may
22 also be defined as the thickness of soil that can be measured using direct measurement or
23 scanning techniques. Historically, this layer has often been represented as the top
24 15 centimeters (cm; 6 inches [in.]) of soil (40 CFR 192), but will vary depending on radionuclide,
25 surface characteristics, measurement technique, and pathway modeling assumptions. For the
26 purposes of MARSSIM, surface soil may be considered to include gravel fill, waste piles,
27 concrete, or asphalt paving. For many sites where radioactive material was used, one first
28 assumes that radioactive material on the site exists on surfaces, and the evaluation is used to
29 identify areas of high and low probability of residual radioactive material (Class 1, Class 2, or
30 Class 3 areas).

- 31 • **Were all radiation sources used at the site encapsulated sources?** A site where only
32 encapsulated sources were used would be expected to have a low potential for residual
33 radioactive material. A review of the leak-test records and documentation of encapsulated
34 source location may be adequate to make a finding of no suspected residual radioactive
35 material.
- 36 • **Were radiation sources used only in specific areas of the site?** Evidence that
37 radioactive material was confined to certain areas of the site may be helpful in determining
38 which areas are impacted and which are non-impacted.
- 39 • **Was surface soil regraded or moved elsewhere for fill or construction purposes?** This
40 helps identify additional potential sites of radioactive material.

1 3.6.3.2 Subsurface Soil and Other Subsurface Media

2 Subsurface soil and other subsurface media are defined as any solid materials beneath the
3 surface soil layer. The purpose of these subsurface investigations is to locate and define the
4 lateral and vertical extent of the potential residual radioactive material in the subsurface.
5 Subsurface measurements can be expensive, especially for beta- or alpha-emitting
6 radionuclides. To effectively use project resources, subsurface investigations should be biased
7 (e.g., limited to known or potential areas containing subsurface radioactive material). After
8 identifying areas of subsurface concern, further subsurface investigations would be necessary
9 to delineate the lateral and vertical extent of radioactive material during the remedial
10 investigation and design phase. The latter would aid in planning the necessary resources
11 (e.g., budgets, contractors, obtaining access) and to set the schedule for the remedial action
12 phase.

- 13 • **Is there evidence of changes in surface features?** Understanding the development
14 history of an area can aid the investigation in identifying subsurface areas of potential
15 concern. Historically, industrial wastes potentially containing radioactive material were used
16 as fill material (e.g., to fill in old streams, wetlands, low-lying areas) or as subgrade material
17 (e.g., beneath buildings, basement floors). Changes in surface features over time can affect
18 the distribution of radioactive material. Reviewing historical records can be of great benefit in
19 identifying subsurface areas of potential concern and in providing subsequent cost effective
20 and defensible graded approaches to better characterize the site. Examples of helpful
21 records include aerial photographs, topography maps, railroad/road maps, navigation maps,
22 Sanborn Fire Insurance Maps, construction photographs, postcards, and correspondence.
- 23 • **Are there areas of known or suspected residual radioactive material in surface soil?**
24 Residual radioactive material in surface soil can migrate deeper into the soil. Surface soil
25 sources should be evaluated based on radionuclide mobility, soil permeability, and
26 infiltration rate to determine the potential for residual radioactive material in the subsurface.
27 Computer modeling may be helpful for evaluating these types of situations.
- 28 • **Is there a ground water plume without an identifiable source?** Radioactive material in
29 ground water indicates that a source of residual radioactive material is present. If no source
30 is identified during the HSA, residual radioactive material in the subsurface is a probable
31 source.
- 32 • **Is there potential for enhanced mobility of radionuclides in soils?** Radionuclide mobility
33 can be enhanced by the presence of solvents or other chemicals that affect the sorption
34 capacity of soil.
- 35 • **Is there evidence that the surface has been disturbed?** Recent or previous excavation
36 activities are obvious sources of surface disturbance. Areas with developed plant life
37 (forested or old growth areas) may indicate that the area remained undisturbed during the
38 operating life of the facility. Areas where vegetation is removed during previous excavation
39 activity may be distinct from mature plant growth in adjacent areas. If a site is not purposely
40 replanted, vegetation may appear in a sequence starting with grasses that are later replaced

1 by shrubs and trees. Typically, grasslands recover within a few years, sagebrush or low
2 ground cover appears over decades, and mature forests may take centuries to develop.

3 • **Is there evidence of subsurface disturbance?** Non-intrusive, non-radiological
4 measurement techniques may provide evidence of subsurface disturbance. Magnetometer
5 surveys can identify buried metallic objects, and ground-penetrating radar can identify
6 subsurface anomalies such as trenches or dump sites. Techniques involving special
7 equipment are discussed in **Section 6.9**.

8 • **Are surface structures present?** Structures constructed during a site's operational history
9 may cover residual radioactive material below ground. Some consideration for residual
10 radioactive material that may exist beneath parking lots, buildings, or other onsite structures
11 may be warranted as part of the investigation. There may be underground piping, drains,
12 sewers, or tanks that caused the spread of residual radioactive material.

13 3.6.3.3 Surface Water

14 Surface waters include streams and rivers, lakes, coastal tidal waters, and oceans. Note that
15 certain ditches and intermittently flowing streams also qualify as surface water. The evaluation
16 determines whether radionuclides are likely to migrate to surface waters or their sediments.
17 Where a previous release is not suspected, the potential for future release depends on the
18 distance to surface water and the flood potential at the site. One can also consider the
19 interaction between soil and water in relation to seasonal factors, including soil cracking
20 because of freezing, thawing, and desiccation that influence the dispersal or infiltration of
21 radionuclides.

22 • **Is surface water nearby?** The proximity of residual radioactive material to local surface
23 water is essentially determined by runoff and radionuclide migration through the soil. The
24 definition for *nearby* depends on site-specific conditions and the time performance period. If
25 the terrain is flat, precipitation is low, and soils are sandy, *nearby* may be within several
26 meters. If annual precipitation is high or occasional precipitation events are high, within
27 1,200 meters (3/4 mile) might be considered nearby.

28 • **Is the waste quantity particularly large?** Depending on the physical and chemical form of
29 the waste and its location, *large* is a relative term. A *small* quantity of liquid waste may be of
30 more importance (i.e., a greater risk or hazard) than a *large* quantity of solid waste stored in
31 watertight containers.

32 • **Is the drainage area large?** The drainage area includes the area of the site itself plus the
33 upgradient area that produces runoff flowing over the site. Larger drainage areas generally
34 produce more runoff and increase the potential for residual radioactive material in surface
35 water.

36 • **Is precipitation heavy?** If the site and surrounding area are flat, a combination of heavy
37 precipitation and low infiltration rate may cause precipitation to pool on the site. Otherwise,
38 these characteristics may contribute to high runoff rates that carry radionuclides overland to
39 surface water. Total annual precipitation exceeding one meter (40 in.), or a once in 2-years

1 24-hour precipitation event exceeding 5 cm (2 in.) might be considered “heavy.”

2
3 The amount of precipitation varies for locations across the continental United States from
4 high (e.g., approximately 200 cm/year [y; 89 in./y], Mt. Washington, New Hampshire) to low
5 values (e.g., approximately 10.7 cm/y [4.2 in./y], Las Vegas, Nevada). Certified data on
6 precipitation rates for locations throughout the United States can be obtained from the
7 National Centers for Environmental Information (<https://www.ncdc.noaa.gov>).

- 8 • **Is the infiltration rate low?** Infiltration rates range from very high in gravelly and sandy
9 soils to very low in fine silt and clay soils. Paved sites prevent infiltration and generate
10 runoff.
- 11 • **Are sources of residual radioactive material poorly contained or prone to runoff?**
12 Proper containment that prevents radioactive material from migrating to surface water
13 generally uses engineered structures such as dikes, berms, run-on and runoff control
14 systems, and spill collection and removal systems. Sources prone to releases via runoff
15 include leaks, spills, exposed storage piles, or intentional disposal on the ground surface.
16 Sources not prone to runoff include underground tanks, aboveground tanks, and containers
17 stored in a building.
- 18 • **Is a runoff route well defined?** A well-defined runoff route—along a gully, trench, berm,
19 wall, etc.—will more likely contribute to migration to surface water than a poorly defined
20 route. However, a poorly defined route may contribute to dispersion of radioactive material
21 to a larger area of surface soil.
- 22 • **Has deposition of waste into surface water been observed?** Indications of this type of
23 activity will appear in records from past practice at a site or from information gathered during
24 personal interviews.
- 25 • **Is ground water discharge to surface water probable?** The hydrogeology and
26 geographical information of the area around and inside the site may be sufficiently
27 documented to indicate discharge locations.
- 28 • **Does analytical or circumstantial evidence suggest residual radioactive material in**
29 **surface water?** Any condition considered suspicious can be considered circumstantial
30 evidence.
- 31 • **Is the site prone to flooding?** The Federal Emergency Management Agency publishes
32 flood insurance rate maps that delineate 100-year and 500-year flood plains. Ten-year
33 floodplain maps may also be available. Generally, a site on a 500-year floodplain is not
34 considered prone to flooding.

35 *3.6.3.4 Ground Water*

36 Proper evaluation of ground water includes a general understanding of the local geology and
37 subsurface conditions. Of particular interest is descriptive information relating to subsurface
38 stratigraphy, aquifers, and ground water use.

- 1 • **Are sources poorly contained?** Proper containment—which prevents radioactive material
2 from migrating to ground water—generally uses engineered structures, such as liners, layers
3 of low permeability soil (e.g., clay), and leachate collection systems.
- 4 • **Is the source likely to affect ground water?** Underground tanks, landfills,³ surface
5 impoundments, and lagoons are examples of sources that are likely to release residual
6 radioactive material that migrates to ground water. Aboveground tanks, drummed solid
7 wastes, or sources inside buildings are less likely to contribute to residual radioactive
8 material in ground water.
- 9 • **Is waste quantity particularly large?** Depending on the physical and chemical form of the
10 waste and its location, *large* is a relative term. A *small* quantity of liquid waste may be of
11 more importance (i.e., greater risk or hazard) than a *large* quantity of solid waste stored in
12 watertight containers.
- 13 • **Is precipitation heavy?** If the site and surrounding area are flat, a combination of heavy
14 precipitation and low infiltration rate may cause precipitation to pool on the site. Otherwise,
15 these characteristics may contribute to high runoff rates that carry radionuclides overland to
16 surface water. Total annual precipitation exceeding one meter (40 in.), or a once in 2-years
17 24-hour precipitation event exceeding 5 cm (2 in.) might be considered “heavy.”
18
- 19 The amount of precipitation varies for locations across the continental United States from
20 high (e.g., approximately 200 cm/y [89 in/y] in Mt. Washington, New Hampshire) to low
21 values (e.g., approximately 10.7 cm/y [4.2 in/y] in Las Vegas, Nevada). Certified data on
22 precipitation rates for locations throughout the United States can be obtained from the
23 National Centers for Environmental Information (<https://www.ncdc.noaa.gov>).
- 24 • **Is the infiltration rate high?** Infiltration rates range from very high in gravelly and sandy
25 soils to very low in fine silt and clay soils. Unobstructed surface areas are potential
26 candidates for further examination to determine infiltration rates.
- 27 • **Is the site located in an area of karst terrain?** In karst terrain, ground water moves rapidly
28 through channels caused by dissolution of the rock material (usually limestone) that
29 facilitates migration of radioactive material and chemicals.
- 30 • **Is the subsurface highly permeable?** Highly permeable soils favor downward movement
31 of water that may transport radioactive materials. Well logs, local geologic literature, or
32 interviews with knowledgeable individuals may help answer this question.
- 33 • **What is the distance from the surface to an aquifer?** The shallower the source of ground
34 water, the higher the threat of residual radioactive material. It is difficult to determine
35 whether an aquifer may be a potential source of drinking water in the future (e.g., next

³ Landfills can affect the geology and hydrogeology of a site and produce heterogeneous conditions. It may be necessary to consult an expert on landfills and the conditions they generate.

1 1,000 years). Use the shallowest aquifer below the site when determining the distance to the
2 surface.

3 • **Are suspected radionuclides highly mobile in ground water?** Mobility in ground water
4 can be estimated based on the distribution coefficient (K_d) of the radionuclide. Elements with
5 a high K_d , like thorium (e.g., $K_d = 3,200 \text{ cm}^3/\text{gram [g]}$), are not mobile while elements with a
6 low K_d , like hydrogen (e.g., $K_d = 0 \text{ cm}^3/\text{g}$), are very mobile. EPA provides a compilation of K_d
7 values. These values can be influenced by site-specific considerations such that site-
8 specific K_d values need to be evaluated or determined. Also, the mobility of a radionuclide
9 can be enhanced by the presence of solvents or other chemicals.

10 • **Does analytical or circumstantial evidence suggest residual radioactive material in**
11 **ground water?** Evidence for residual radioactive material may appear in current site data;
12 historical, hydrogeological, and geographical information systems records; or as a result of
13 personal interviews.

14 3.6.3.5 Air

15 Evaluation of air is different than evaluation of other media with a potential for residual
16 radioactive material. Air is evaluated as a pathway for resuspending and dispersing radioactive
17 material.

18 • **Were there observations of releases of radioactive material into the air?** Direct
19 observation of a release to the air might occur where radioactive materials are suspected to
20 be present in particulate form (e.g., mine tailings, waste pile) or adsorbed to particulates
21 (e.g., radioactive material in soil), and where site conditions favor air transport (e.g., dry,
22 dusty, windy).

23 • **Does analytical or circumstantial evidence suggest a release to the air?** Other
24 evidence for releases to the air might include areas of residual radioactive material in
25 surface soil that do not appear to be caused by direct deposition or overland migration of
26 radioactive material.

27 • **For radon exposure only, are there elevated amounts of radium (^{226}Ra) in the soil or**
28 **water that could act as a source of radon in the air?** The source ^{226}Ra decays to ^{222}Rn ,
29 which is radon gas. Once radon is produced, the gas needs a pathway to escape from its
30 point of origin into the air. Radon is readily released from water sources that are open to air.
31 Soil, however, can retain radon gas until it has decayed (see **Section 6.8**). The rate that
32 radon is emitted by a solid (i.e., radon flux) can be measured directly to evaluate potential
33 sources of radon.

34 • **Is there a prevailing wind direction and a propensity for windblown transport of**
35 **radioactive material?** Information pertaining to geography, ground cover (e.g., amount and
36 types of local vegetation), meteorology (e.g., wind speed at 7 meters [23 feet] above ground
37 level) for and around the site, and site-specific parameters related to surface soil
38 characteristics enter into calculations used to describe particulate transport. Mean annual

1 wind speed can be obtained from the National Weather Service surface station nearest to
2 the site.

3 3.6.3.6 Structures

4 Structures used for storage, maintenance, or processing of radioactive materials are potential
5 sources of residual radioactive material. The questions presented in **Table 3.1** help determine
6 whether a building might be affected by residual radioactive material. The questions listed in this
7 section are for identifying structures, or portions of structures, that might not be identified using
8 **Table 3.1** but have a potential for residual radioactive material. **Section 4.8.3.1** also presents
9 useful information on identifying structures with residual radioactive material.

- 10 • **Were adjacent structures used for the storage, maintenance, or processing of**
11 **radioactive material?** *Adjacent* is a relative term for this question. A processing facility with
12 a potential for venting radioactive material to the air could deposit residual radioactive
13 material on buildings downwind. A facility with little potential for release outside of the
14 structures handling the material would be less likely to deposit radioactive material on
15 nearby structures.
- 16 • **Is a building, its addition, or a new structure located on a former radioactive waste**
17 **burial site or on land with residual radioactive material?** Comparing past and present
18 photographs or site maps and retrieving building permits or other structural drawings and
19 records in relation to historical operations information will reveal site locations where
20 structures may have been built over buried waste or land with residual radioactive material.
- 21 • **Was the building constructed using materials containing residual radioactive**
22 **material?** Building materials (e.g., concrete, brick, plaster, cement, wood, metal, cinder
23 block) may contain residual radioactive material.
- 24 • **Does the potentially non-impacted portion of the building share a drainage system or**
25 **ventilation system with areas with potential residual radioactive material?** Technical
26 and architectural drawings for site structures, along with visual inspections, are required to
27 determine if this is a concern in terms of current or past operations.
- 28 • **Is there evidence that previously identified areas of residual radioactive material were**
29 **remediated by painting or similar methods of immobilization?** Removable sources of
30 residual radioactive material were sometimes immobilized by painting, partition, or the
31 addition of floor layers (e.g., tiles, carpet). These sources may be more difficult to locate and
32 may need special consideration when planning subsequent surveys.

33 3.6.4 Develop a Conceptual Model of the Site

34 Starting with project planning activities, gather and analyze available information to develop a
35 conceptual site model. The model is essentially a site diagram showing locations of known
36 radioactive material, areas of suspected residual radioactive material, types and concentrations
37 of radionuclides in impacted areas, media with potential residual radioactive material, and
38 locations of potential reference (background) areas. The diagram should include the general
39 layout of the site, including buildings and property boundaries. When possible, one should

1 produce three-dimensional diagrams. The conceptual site model will be upgraded and modified
2 as information becomes available throughout the RSSI process. The process of developing this
3 model is also briefly described in Attachment A of EPA 1996a.

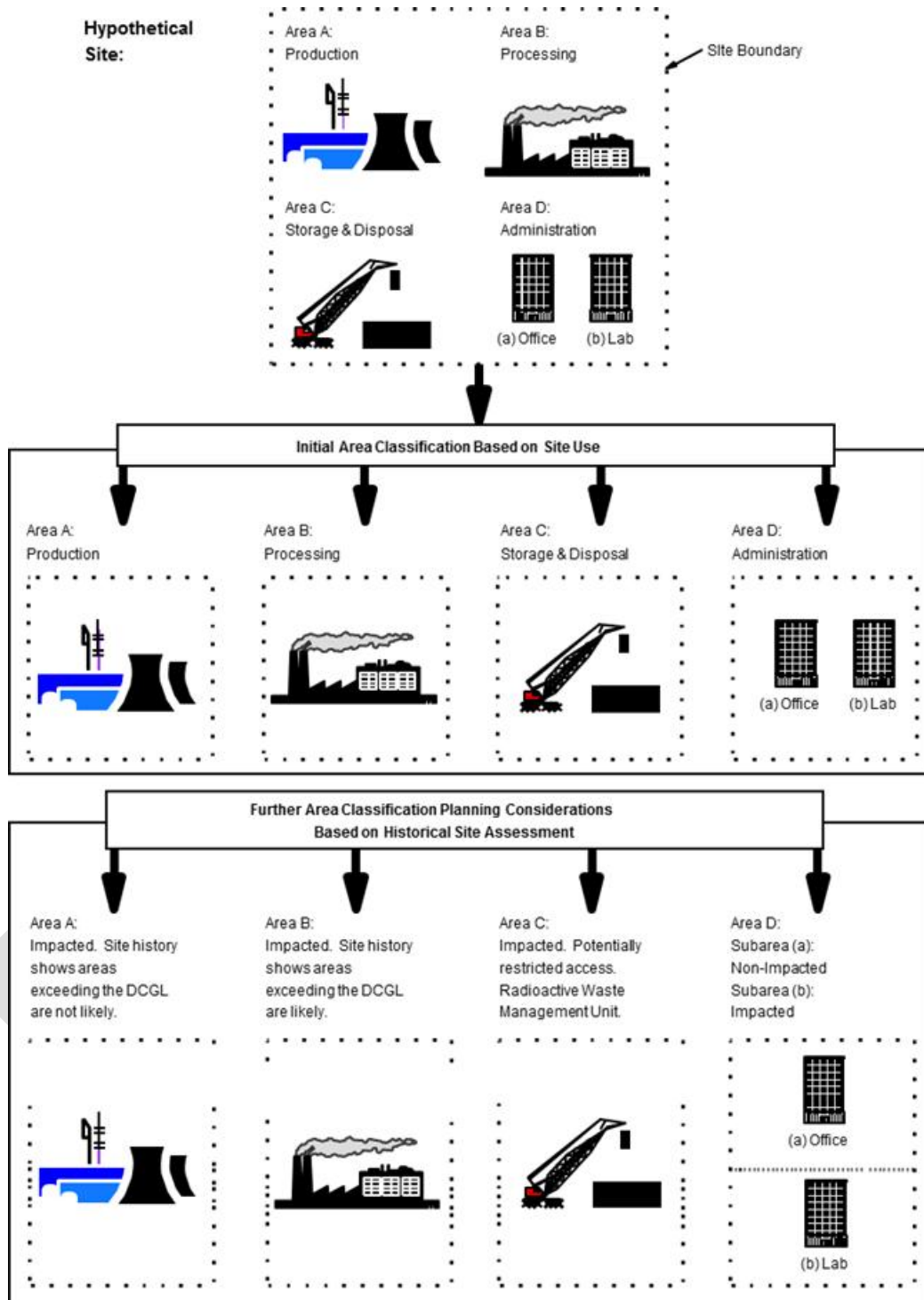
4 The model is used to assess the nature and the extent of residual radioactive material; to
5 identify potential sources of residual radioactive material, release mechanisms, exposure
6 pathways, and human and environmental receptors; and to develop exposure scenarios.
7 Further, this model helps identify data gaps and determine media to be sampled, and it assists
8 staff in developing strategies for data collection. Site history and preliminary survey data
9 generally are extremely useful sources of information for developing this model. The conceptual
10 site model should include known and suspected sources of residual radioactive material, the
11 types of radioactive material, and affected media. Such a model can also illustrate known or
12 potential routes of migration and known or potential human and environmental receptors.

13 The site should be classified or initially divided into similar areas. Classification may be based
14 on the operational history of the site or observations made during the site reconnaissance (see
15 **Section 3.5**). After the site is classified using current and past site characteristics, further divide
16 the site or facility based on anticipated future use. This classification can help (1) assign limited
17 resources to areas that are anticipated to be released without restrictions, and (2) identify areas
18 with little or no possibility of unrestricted release. **Figure 3.2** shows an example of how a site
19 might be classified in this manner. Further classification of a site may be possible based on site
20 disposition recommendations (unrestricted vs. release with passive controls).

21 **3.6.5 Professional Judgment**

22 In some cases, traditional sources of information, data, models, or scientific principles are
23 unavailable, unreliable, conflicting, or too costly or time consuming to obtain. In these instances,
24 professional expert judgment may be the only practical tool available to the investigator or
25 regulator. Expert judgment, or “expert elicitation,” means using the judgments obtained from
26 experts about their field of expertise that are explicitly stated and documented for review and
27 appraisal by others. It is a formal, highly structured, and well-documented process for obtaining
28 the judgment of multiple experts regarding a scientific inquiry or decisionmaking (NRC 1990).
29 For most instances, the issue is not whether to use judgment, but whether to use it in an explicit
30 and disciplined fashion or in an ad hoc manner. An important interrelated question is when and
31 whose judgment should be used. For this guidance, it is often useful to formalize the elicitation
32 and use of judgment for significant technical, environmental, and socioeconomic problems. For
33 general applications, this type of judgment is a routine part of scientific investigation where
34 knowledge is incomplete. For MARSSIM guidance, professional judgment can be used as an
35 independent review of historical data to support decision-making during the HSA or the use of
36 statistical tools or methodology. Professional or expert judgment should be used as necessary,
37 particularly in situations where data are not reasonably obtainable by collection,
38 experimentation, field measurements, or when the cost of data collection is prohibitive.

39 Typically, the process of recruiting professionals for expert judgment should be documented and
40 as unbiased as possible. The credentials of the selected individual or individuals should
41 enhance the credibility of the elicitation, and their ability to communicate their reasoning is a
42 primary determinant of the quality of the results. Qualified expert professionals can be identified



1
 2 **Figure 3.2: Example Showing How a Site Might be Categorized Before Cleanup Based on**
 3 **the Historical Site Assessment**

1 by different sources, including the planning team, professional organizations, government
2 agencies, universities, consulting firms, and public interest groups. The selection criteria for the
3 professionals should include potential conflict of interest (economic or personal), evidence of
4 expertise in a required topic, objectiveness, and availability.

5 **3.7 Determining the Next Step in the Site Investigation Process**

6 Upon completion, the HSA will support one of three possible recommendations:

- 7 1. An emergency action may be necessary to reduce the risk to human health and the
8 environment, such as a Superfund removal action, which is discussed in detail by EPA
9 (EPA 1988a).
- 10 2. The site or area is categorized as impacted, and further investigation is needed before a
11 decision regarding final release can be made. The area may be classified as Class 1,
12 Class 2, or Class 3, and a scoping survey or a characterization survey may be performed as
13 necessary. Information collected during the HSA can be very useful in planning these
14 subsequent survey activities.
- 15 3. The site or area is categorized as non-impacted, a term that is applied where there is no
16 reasonable potential to contain radionuclide concentration(s) or radioactive material above
17 background (10 CFR 50). The site or area can be released.

18 As stated in **Section 1.1**, the purpose of this manual is to describe a process-oriented approach
19 for demonstrating that the concentration of residual radioactive material does not exceed the
20 release criteria. The highest probability of demonstrating this can be obtained by sequentially
21 following each step in the RSSI process. In some cases, however, performing each step in the
22 process is not practical or necessary. This section provides information on how the results of the
23 HSA can be used to determine the next step in the process.

24 The best method for determining the next step is to review the purpose for each type of survey
25 described in **Chapter 5**. For example, a scoping survey is performed to provide sufficient
26 information for determining (1) whether the present residual radioactive material warrants further
27 evaluation, and (2) initial estimates of the level of effort for decontamination and for preparing a
28 plan for a more detailed survey. If the HSA demonstrates that this information is already
29 available, do not perform a scoping survey. On the other hand, if the information obtained during
30 the HSA is limited, a scoping survey may be necessary to narrow the scope of the
31 characterization survey.

32 The exception to conducting additional surveys before an FSS is the use of HSA results to
33 release a site. Generally, the analytical data collected during the HSA are not adequate to
34 statistically demonstrate compliance for impacted areas as described in **Chapter 8**. This means
35 that the decision to release the site will be based on professional judgment. This determination
36 will ultimately be decided by the responsible regulatory agency.

1 **3.8 Historical Site Assessment Report**

2 A narrative report is generally the best format to summarize what is known about the site, what
3 is assumed or inferred, activities conducted during the HSA, and all researched information.
4 Cite a supporting reference for each factual statement given in the report. Attach copies of
5 references (i.e., those not generally available to the public) to the report. The narrative portion of
6 the report should be written in plain English and avoid the use of technical terminology.

7 A sample HSA report format is provided in **Example 1**. Additional information not identified in
8 the outline may be requested by the regulatory agency at its discretion. The level of effort to
9 produce the report should reflect the amount of information gathered during the HSA.

10 **3.9 Review of the HSA**

11 The planning team should ensure that someone (a first reviewer) conducts a detailed review of
12 the HSA report for internal consistency and as a QC mechanism. A second reviewer with
13 considerable site assessment experience should then examine the entire information package
14 to ensure consistency and to provide an independent evaluation of the HSA conclusions. The
15 second reviewer also evaluates the package to determine if special circumstances exist where
16 radioactive material may be present but not identified in the HSA. Both the first reviewer and the
17 second independent reviewer should examine the HSA written products to ensure internal
18 consistency in the report's information, summarized data, and conclusions. The site review
19 ensures that the HSA's recommendations are appropriate.

20 An important QA objective is to find and correct errors. A significant inconsistency indicating
21 either an error or a flawed conclusion, if undetected, could contribute to an inappropriate
22 recommendation. Identifying such a discrepancy directs the HSA investigator and site reviewers
23 to re-examine and resolve the apparent conflict.

24 Under some circumstances, experienced investigators may have differing interpretations of site
25 conditions and draw differing conclusions or hypotheses regarding the likelihood of residual
26 radioactive material. Any such differences should be resolved during the review. If a reviewer's
27 interpretations contradict those of the HSA investigator, the two should discuss the situation and
28 reach a consensus. This aspect of the review identifies significant points about the site
29 evaluation that may need detailed explanation in the HSA narrative report to fully support the
30 conclusions. Throughout the review, the HSA investigator and site reviewers should keep in
31 mind the need for conservative judgments in the absence of definitive proof to avoid
32 underestimating the presence of residual radioactive material, which could lead to an
33 inappropriate HSA recommendation.

Example 1: HSA Report Format

1. Glossary of Terms, Acronyms, and Abbreviations
2. Executive Summary
3. Purpose of the Historical Site Assessment
4. Property Identification
 1. Physical Characteristics
 1. Name—CERCLIS ID# (if applicable) owner/operator name, address
 2. Location—street address city county state geographical coordinates
 3. Topography—USGS 7.5-minute quadrangle or equivalent
 4. Stratigraphy
 2. Environmental Setting
 1. Geology
 2. Hydrogeology
 3. Hydrology
 4. Meteorology
5. Historical Site Assessment Methodology
 1. Approach and Rationale
 2. Boundaries of Site
 3. Documents Reviewed
 4. Property Inspections
 5. Personal Interviews
6. History and Current Usage
 1. History—years of operation, type of facility, description of operations, regulatory involvement permits and licenses, waste handling procedures
 2. Current Usage—type of facility, description of operations, probable source types and sizes, description of spills or releases, waste manifests, radioactive inventories, emergency or removal actions
 3. Adjacent Land Usage—sensitive areas, such as wetlands or preschools
7. Findings
 1. Potential Sources of Residual Radioactive Material
 2. Potential Areas with Residual Radioactive Material
 1. Impacted Areas—Known and Potential
 2. Non-Impacted Areas
 3. Potential Media with Residual Radioactive material
 4. Related Environmental Concerns
8. Conclusions
9. References
10. Appendices
 - A. Conceptual Model and Site Diagram Showing Classifications
 - B. List of Documents
 - C. Photo Documentation Log
 - a. Original Photographs of the Site and Pertinent Site Features

4 CONSIDERATIONS FOR PLANNING SURVEYS

4.1 Introduction

4.1.1 Purpose

This chapter is intended to introduce the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) user to general considerations for planning MARSSIM-based surveys by presenting areas of consideration common to Radiation Surveys and Site Investigations (RSSIs) with an emphasis on final status surveys (FSSs).¹ Detailed technical information about planning surveys will follow in the subsequent chapters. For the purposes of this chapter, it is assumed that a Historical Site Assessment (HSA) has been performed, and the results are available to the survey design team.

4.1.2 Scope

The emphasis in MARSSIM is on FSSs of surface soil and surfaces of buildings and outdoor areas to demonstrate compliance with cleanup regulations. However, MARSSIM discusses four types of surveys:

- Scoping
- Characterization
- Remedial Action Support (RAS)
- Final status

These survey types are discussed in more detail in **Chapter 5**. The emphasis on FSSs should be kept in mind during the design phase of all surveys. The topics discussed in this chapter focus on planning the FSS.

4.1.3 Overview of Survey Planning

In the following sections of this chapter, you will be introduced to many potentially unfamiliar concepts, terms, definitions, etc., specifically related to planning surveys. Informal definitions will be given in this chapter; however, the reader should refer to the **Glossary** for complete definitions. The following topics related to survey planning are discussed in this chapter:

- *Data Quality Objectives (DQO) process*: The DQO process is used to develop performance and acceptance criteria that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions.
- *Survey types*: There are four MARSSIM survey types: scoping, characterization, RAS, and final status. The emphasis of this chapter will be on FSSs.

¹ MARSSIM uses the word “should” as a recommendation, not as a requirement. Each recommendation in this manual is not intended to be taken literally and applied at every site. MARSSIM’s survey planning documentation will address how to apply the process on a site-specific basis.

- 1 • *Unity rule:* The unity rule is used when more than one radionuclide is present at a
2 concentration that is distinguishable from background and where a single concentration
3 comparison does not apply. In this case, the mixture of radionuclides is compared against
4 default concentrations by applying the unity rule. This is accomplished by determining:
5 (1) the ratio between the concentration of each radionuclide in the mixture, and (2) the
6 concentration for that radionuclide in an appropriate listing of default values. The sum of the
7 ratios for all radionuclides in the mixture should not exceed 1.
- 8 • *Radionuclides and derived concentration guideline levels (DCGLs):* The design team needs
9 to determine the radionuclides of concern and final form of the DCGLs. The DCGLs are
10 typically based on dose (or risk) pathway modeling, which is used to determine release
11 criteria expressed in measurable radiological quantities. These can be a soil concentration,
12 surface (areal) concentration, or external dose (or exposure) rate.
- 13 • *Area and site considerations:* Properly classifying areas as impacted or non-impacted,
14 identifying survey units, and selecting background reference areas is critical for the
15 successful execution of a FSS.
- 16 • *Statistical considerations:* MARSSIM recommends the use of statistical hypothesis testing in
17 all but the simplest of surveys (See **Appendix B**). The MARSSIM user must be conversant
18 with the statistical concepts discussed in the manual and should consider incorporating a
19 statistician in the design team.
- 20 • *Measurements:* The detection capabilities of all the measurement (sampling included)
21 techniques must be evaluated to ensure that the data and measurement quality objectives
22 are met.
- 23 • *Site preparation:* Site preparation includes efforts to gain permission to access the site,
24 ensuring that the survey team and equipment can operate safely, and establishing the
25 logistical means to perform the survey should be started early.
- 26 • *Health and safety:* The health and safety of the workers is a high priority, so each site must
27 have a documented health and safety plan.
- 28 • *Survey design examples:* A few simplified examples are presented in **Section 4.12** to
29 illustrate the process for planning surveys.

30 4.2 Data Quality Objectives Process

31 DQOs were introduced in **Chapter 1**, expanded upon in **Chapter 2**, and discussed in detail in
32 **Appendix D**. The survey design team must be familiar with the DQO process to properly design
33 a survey. The DQO process can be summarized in seven steps:

- 34 1. State the problem.
- 35 2. Identify the decisions to be made.
- 36 3. Identify inputs to the decision.
- 37 4. Define the study boundaries.
- 38 5. Develop a decision rule.

- 1 6. Specify limits on decision errors.
- 2 7. Optimize the survey design.

3 **4.2.1 Planning Phase**

4 Using the DQO process allows the survey design team to use a graded approach to ensure that
5 the level of effort meets the design goals in a technically defensible and cost-effective manner.
6 The intent of any survey is to ensure that the decision makers have the appropriate type,
7 quantity, and quality of environmental data needed to make the correct decision. DQOs are
8 qualitative and quantitative statements derived from the DQO process that do the following:

- 9 • *Clarify the study objective:* The first step in any survey is to determine the objectives of the
10 survey (DQO Steps 1 and 2). Depending on the data available from the previous RSSI
11 activities (e.g., HSA review), the objectives of a survey can range from augmenting HSA
12 information to be used as input in designing a characterization survey to releasing a survey
13 unit. An important part of this clarification is the determination of the initial condition of each
14 survey unit: The survey unit is assumed to be “not clean” (Scenario A) or “clean”
15 (Scenario B). See **Section 2.5.1** and **Sections D.1.1 and D.1.2 of Appendix D** for more
16 details.
- 17 • *Define the most appropriate type of data to collect:* Once the objectives of the survey have
18 been agreed upon, the design team needs to determine what data need to be collected
19 (DQO Step 3). Implicit in this step is the determination of the radionuclides of concern,
20 choice of equipment, detection limits, analytical methods, statistical tests, etc., that will be
21 used to meet the objectives of the survey.
- 22 • *Determine the most appropriate conditions for collecting the data:* In general, the “study
23 boundaries” of a survey (DQO Step 4) are spatial; for example, the selection of the survey
24 units. However, if the objective of the survey is to collect data for classification, then the
25 spatial boundary of the survey might be the entire site under consideration. Throughout the
26 RSSI process, decisions need to be made; for example, based on a review of the HSA’s
27 conclusions and the results of scoping/characterization surveys, the decision maker will
28 determine survey unit boundaries and classifications.
- 29 • *Specify limits on decision errors that will be used as the basis for establishing the quantity
30 and quality of data needed to support the decision:* To make decisions, the outputs of the
31 survey must be in a form amenable to decision-making (DQO Step 5). MARSSIM
32 recommends the use of statistical hypothesis testing to make decisions to release a survey
33 unit. Because of the overall uncertainty in the surveying process, there is always a chance
34 of a decision error (e.g., incorrectly concluding that a survey unit meets the release criteria,
35 when in fact it does not). The chance of a decision error cannot be eliminated; however, it
36 can be controlled (DQO Step 6). The survey design team must be aware of the chance of
37 decision errors and take measures to control them (e.g., collecting more samples, using
38 more precise measurement techniques, and using better surveying and sampling designs).

39 When the previous steps are completed, the survey design team can optimize the survey plan
40 (DQO Step 7); the team might need to work through this step several times to arrive at the best
41 design. **Appendix D** discusses the planning phase of the data life cycle in detail. The MARSSIM
42 user should read and be conversant with **Appendix D**.

1 Regardless of the survey type under consideration, the DQOs remain the overarching guide for
2 planning; the design team needs to explain the “who, what, where, when, why, and how” for a
3 survey.

4 **4.2.2 Quality System**

5 MARSSIM requires that all environmental data collection and use take place in accordance with
6 a site-specific systematic planning process that incorporates industry-established quality
7 assurance and quality control (QA/QC). The goal of a QA/QC program is to identify and
8 implement sampling and analytical methodologies which limit the introduction of error into
9 analytical data. For MARSSIM data collection and evaluation, a quality system is needed to
10 ensure that radiation surveys produce results that are of the type and quality needed and
11 expected for their intended use. A quality system is a management system that describes the
12 elements necessary to plan, implement, and assess the effectiveness of QA/QC activities. This
13 system establishes many functions, including—

- 14 • quality management policies and guidelines for the development of organization- and
15 project-specific quality plans
- 16 • criteria and guidelines for assessing data quality
- 17 • assessments to ascertain the effectiveness of QA/QC implementation
- 18 • training programs related to QA/QC implementation.

19 A quality system ensures that MARSSIM decisions will be supported by sufficient data of
20 adequate quality and usability for their intended purpose, and it further ensures that such data
21 are authentic, appropriately documented, and technically defensible. MARSSIM uses the
22 project-level components of a quality system as a framework for planning, implementing, and
23 assessing environmental data collection activities.

24 In accordance with the environmental data quality system described in **Appendix D**, all
25 environmental data collection and use are to take place in accordance with a site-specific
26 systematic planning process (SPP) that consists of planning, implementation, and assessment
27 phases. The results of the SPP are usually documented in a Quality Assurance Project Plan
28 (QAPP). A QAPP integrates all technical and quality aspects and defines in detail how specific
29 QA/QC activities will be implemented during the survey project will be developed. The Uniform
30 Federal Policy (UFP) for QAPPs (EPA 2005a, 2005b, 2005c) was developed to provide
31 procedures and guidance for consistently implementing the national consensus standard
32 ANSI/ASQ E-4, Quality Systems for Environmental Data and Technology Programs, for the
33 collection and use of environmental data. The UFP for QAPPs is presented in three volumes:

- 34 • Part 1, UFP-QAPP Manual (EPA-505-B-04-900A, DTIC ADA 427785) (EPA 2005a.)
- 35 • Part 2A, UFP-QAPP Workbook (EPA-505-B-04-900C, DTIC ADA 427486) (EPA 2005c.)
- 36 • Part 2B, Quality Assurance/Quality Control Compendium: Minimum QA/QC Activities (EPA-
37 505-B-04-900B, DTIC ADA 426957) (EPA 2005b.)

38 Using this scientific, logical approach to planning for data collection and assessment at a site
39 helps ensure that the amounts and types of data collected are appropriate for decisionmaking
40 and that the physical, environmental, chemical, and radiological characteristics of the site are

1 adequately defined. The development of a QAPP is one of the first team-based QA/QC activities
2 performed in the project planning stage.

3 The objective of the UFP-QAPP is to provide a single national consensus document for
4 consistently and systematically implementing the project-specific requirements of ANSI/ASQ E4
5 (ASQC 1995) and help ensure the quality, objectivity, utility, and integrity of environmental data.
6 Information on selecting the number and type of QC measurements for a specific project are
7 provided in **Section 3.4**; Tables 4, 5, and 6 of the UFP-QAPP Part 1; and Worksheet 28 of the
8 UFP-QAPP Part 2A.

9 Minimum QA/QC activities are specified for all environmental data collection and use in the
10 UFP-QAPP Part 2B. However, this matrix of minimum requirements is not meant to be a
11 replacement for a site-specific QAPP. A wide range of site-specific guidelines for data collection
12 activities specified in the survey plan should be determined that relate to the ultimate use of the
13 data. These guidelines include, but are not limited to—

- 14 • types of decisions that will be supported by the data
- 15 • project quality objectives
- 16 • acceptance criteria for data quality indicators (also known as measurement performance
17 criteria)
- 18 • survey plan, including location of environmental and QC samples and measurements
- 19 • types of radionuclides and analyses that require laboratory analysis (on-site, field, or fixed
20 lab)

21 The QA/QC activities specified in the QA matrix represent a minimum list of activities. Other
22 QA/QC activities may be added, depending on the decisions to be made and on site-specific
23 conditions. The matrix of minimum QA/QC activities is organized by—

- 24 • survey type (i.e., scoping or characterization) for surveys prior to the FSS
- 25 • data uses (e.g., confirmatory measurements) for RAS surveys
- 26 • data type (i.e., screening versus definitive data)
- 27 • project stage (i.e., plan, implement, assess, decide)

28 **4.3 Survey Types**

29 **4.3.1 Scoping**

30 MARSSIM defines a scoping survey as “a type of survey that is conducted to identify
31 (1) radionuclides present, (2) relative radionuclide ratios, and (3) general concentrations and
32 extent of residual radioactive material.” In conjunction with an HSA, the results of a scoping
33 survey can help determine (1) preliminary radionuclides of concern, (2) interim site and survey
34 unit boundaries, (3) initial area classifications, (4) data gaps, and (5) initial estimates of the level
35 of effort for remediation, and (6) information for planning a more detailed survey, such as a
36 characterization survey. Methods for planning, conducting, and documenting scoping surveys
37 are described in **Section 5.2.1**.

1 **4.3.2 Characterization**

2 MARSSIM defines a characterization survey as “a type of survey that includes facility or site
3 sampling, monitoring, and analysis activities to determine the extent and nature of residual
4 radioactive material. Characterization surveys provide the basis for acquiring necessary
5 technical information to develop, analyze, and select appropriate cleanup techniques.”
6 Characterization surveys can be developed to meet a very broad range of objectives, many of
7 which are outside the scope of MARSSIM. The guidance in **Section 5.2.2** concentrates on
8 providing characterization survey planning information with an emphasis on the FSS design.

9 **4.3.3 Remedial Action Support**

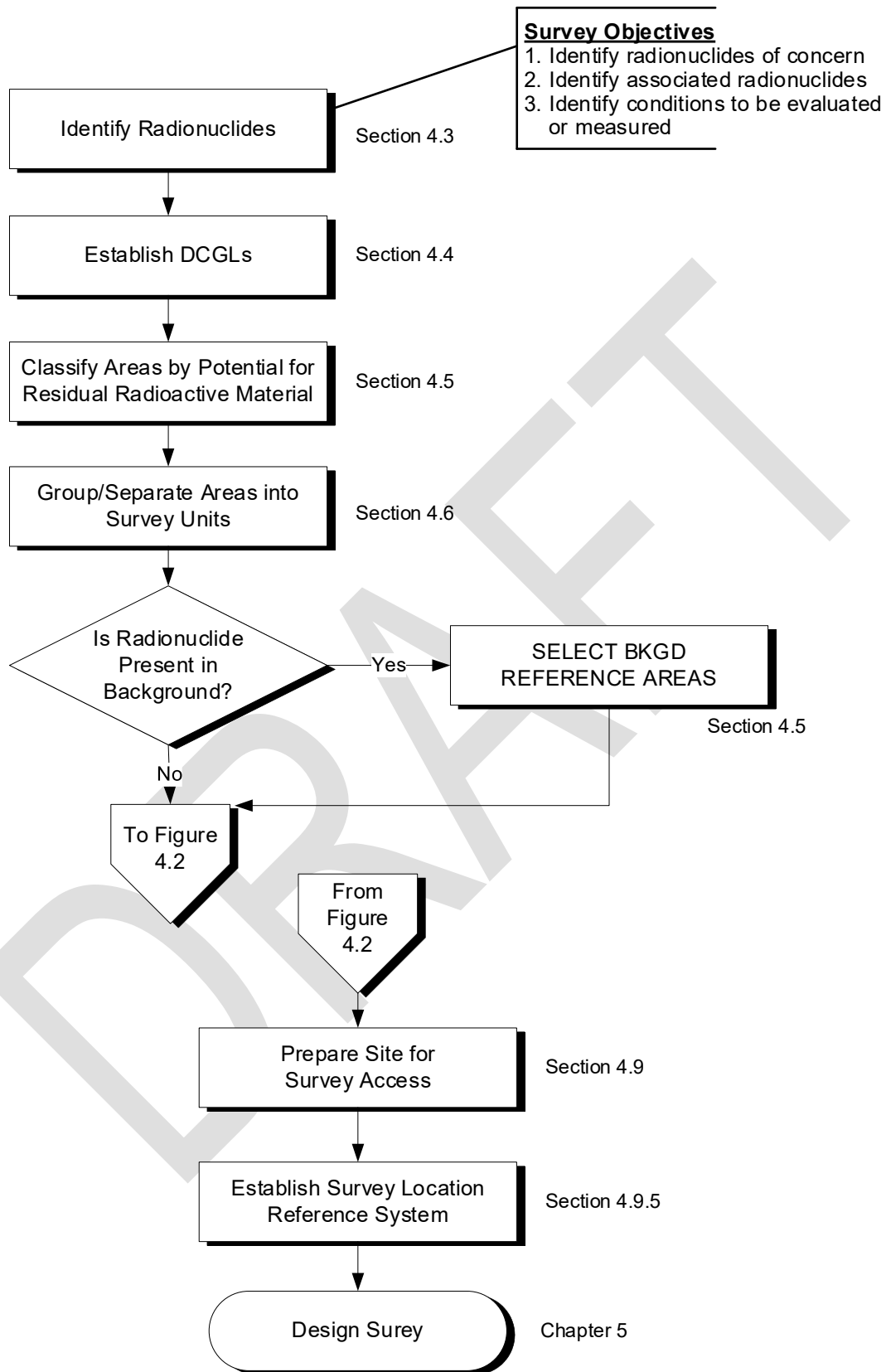
10 MARSSIM defines remedial action as “Those actions that are consistent with a permanent
11 remedy taken instead of, or in addition to, removal action in the event of a release or threatened
12 release of a hazardous substance into the environment, to prevent or minimize the release of
13 hazardous substances so that they do not migrate to cause substantial danger to present or
14 future public health or welfare or the environment.” A RAS survey supports remediation
15 activities and is used to monitor the effectiveness of remediation efforts intended to reduce
16 residual radioactive material to acceptable levels. The general objectives of an RAS are to
17 (1) support remediation activities, (2) determine when a site or survey unit is ready for the FSS,
18 and (3) provide updated estimates of site-specific parameters to use for planning the FSS.
19 Methods for planning, conducting, and documenting an RAS are described in **Section 5.2.3**.

20 **4.3.4 Final Status**

21 **4.3.4.1 Survey**

22 MARSSIM defines an FSS as “measurements and sampling to describe the radiological
23 conditions of a site, following completion of remediation activities (if any) in preparation for
24 release.” An FSS is performed to demonstrate that a survey unit meets the agreed-upon release
25 criteria. In other words, that FSS is designed to answer the question, “Does the concentration of
26 residual radioactive material in each survey unit satisfy the predetermined criteria for release for
27 unrestricted use or, where appropriate, for use with designated limitations (restricted release)?”
28 The primary objective of MARSSIM is the FSS. The design of FSSs is discussed in detail in
29 **Section 5.3**, with the remainder of MARSSIM expanding on the design, execution, and
30 assessment of FSSs.

31 **Figure 4.1** illustrates the sequence of activities described in this chapter and their relationship to
32 the survey design process.



1

2 **Figure 4.1: Sequence of Preliminary Activities Leading to an FSS Design**

1 4.3.4.2 *Verification Process*

2 Historically, regulators commissioned verification surveys after the completion of an FSS.
3 However, the application of the DQO process to the verification process has led to the
4 development of more effective processes, such as in-process decommissioning inspections
5 (Abelquist, 2014). For example, NRC (2008) and DOE (2011c) require verification inspections of
6 some sort; these documents can be used as guides for including verification processes in the
7 FSS design project. The personnel who plan and execute an FSS should be familiar with
8 independent verification (IV) process and be prepared to work with regulators and their
9 contractors to support the verification process during all phases of the FSS. Abelquist (2014)
10 provides an example of decommissioning inspection plan that might be useful when designing
11 an FSS.

12 Bailey (2008) summarized the experiences from IV activities of Oak Ridge Institute for Science
13 and Education (ORISE) in support of U.S. Department of Energy decommissioning projects. In
14 conclusion, Bailey (2008) states that—

15 Independent verification should be integrated into the planning stages rather than
16 after the cleanup contractor has completed the remediation work and
17 demobilized from the site. The IV of onsite remediation and FSS activities should
18 be coordinated and if possible implemented in parallel with the contractor to
19 minimize schedule impacts. A well-implemented and thorough IV program for a
20 site requires IV involvement throughout the D&D [Decontamination and
21 Decommissioning] process. Independent verification is not a substitute for routine
22 contractor quality assurance; however, IV activities often improve the contractor's
23 performance. IV recommendations often improve the contractor's FSS
24 procedures and results, while increasing the probability of complete remediation
25 and documentation.

26 4.3.5 *Simplified Procedures*

27 The design team should be aware that under certain conditions (e.g., sites where only small
28 quantities of radioactive materials exempted from or not requiring a specific license) a simplified
29 procedure might be able to be used to demonstrate regulatory compliance. The design team
30 should refer to **Appendix B** and seek regulatory approval before using this simplified procedure.

31 4.3.6 *A Note on Subsurface Assessments*

32 Many users might need to assess subsurface residual radioactive materials. Strictly speaking,
33 this is beyond the scope of MARSSIM; however, the general concepts contained in MARSSIM
34 (e.g., the DQO process, statistical survey and sampling design, etc.) may be appropriate to
35 address subsurface contamination. As always, any approach to site decommissioning needs to
36 be discussed with the appropriate regulatory authorities.

37 4.3.7 *Uranium Mill Tailings Radiation Control Act of 1978 Sites*

38 At Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA) sites, EPA's Health and
39 Environmental Protection Standards for Uranium and Thorium Mill Tailings (see 40 CFR 192)
40 are applicable. However, the technical requirements in these standards are not always
41 consistent with some of the recommendations in MARSSIM. Specifically, the soil cleanup
42 standards for ²²⁶Ra and ²²⁸Ra are specified as averages over an area of 100 square meters
43 (m²). Additional details for planning at UMTRCA site are provide in **Section 4.12.9**.

1 4.4 The Unity Rule

2 The unity rule is used to ensure that the total dose (risk) from all sources (or media) and all
 3 radionuclides associated with each source does not exceed the release criteria. It is to be used
 4 when more than one radionuclide is present and distinguishable from background and a single
 5 concentration does not apply. Essentially, this means that if measurements of different
 6 quantities are made at a location, then the unity rule must be used. For example, the unity rule
 7 would be used if two radionuclides are measured in each soil sample or if gross alpha and gross
 8 beta measurements are made at each location and the results are being compared to specific
 9 DCGLs.

10 The total amount of anything, whether dose, counts, or activity, is simply the sum of its parts
 11 (M_i):

$$\text{Total} = M_1 + M_2 + \dots + M_i + \dots + M_n = \sum_{i=1}^n M_i \quad (4-1)$$

12 Dividing both sides of **Equation (4-1)** by the total yields the following fundamental equation
 13 (**Equation (4-2)**):

$$1 = f_1 + f_2 + \dots + f_i + \dots + f_n = \sum_{i=1}^n f_i \quad (4-2)$$

14 The basic statement of this equation is that sum of all fractions must add to unity (1).

15 When using the sum of fractions to demonstrate compliance in MARSSIM, each fraction is
 16 determined by dividing each "part" (e.g., the concentration of residual radioactive material due to
 17 a specific radionuclide/source) by the respective release criterion (e.g., a derived concentration
 18 guideline level [DCGL]). In an FSS for a survey unit to be released, the dose or risk from all
 19 radionuclides and all sources in a survey unit must be less than or equal to the applicable
 20 release criterion, and the sum of fractions for multiple radionuclides/sources must be less than
 21 or equal to unity:

$$\text{Total Dose or Risk} = \sum_{i=1}^n (\text{Dose or Risk Component})_i \leq \text{Release Criterion} \quad (4-3)$$

22 Dividing the terms in **Equation (4-3)** by the applicable release criterion:

$$\frac{\text{Total Dose or Risk}}{\text{Release Criterion}} = \sum_{i=1}^n \left(\frac{\text{Dose or Risk Component}}{\text{Release Criterion}} \right)_i \leq 1 \quad (4-4)$$

- 1 If the dose/risk components and release criteria are expressed as concentrations (e.g., express
 2 the dose/risk as concentration and release criterion as DCGLs as discussed above),
 3 **Equation (4-4)** can be written in terms of concentrations (see **Equation (4-5)**):

$$\sum_{i=1}^n \left(\frac{\text{Dose or Risk Component}}{\text{Release Criterion}} \right)_i = \sum_{i=1}^n \frac{C_i}{\text{DCGL}_i} \leq 1 \quad (4-5)$$

4 where

- 5 • C_i is the concentration of the i th component (e.g., radionuclide or source) leading to dose
 6 or risk.
- 7 • DCGL_i is the derived concentration guideline level of the i th component (e.g., radionuclide
 8 or source) leading to dose or risk.

9 This is the traditional form of the unity rule as used and defined in MARSSIM.

10 Other applications of **Equation (4-1)** or derivatives, such as deriving a gross activity DCGL, will
 11 be covered in the corresponding section of this and other chapters as needed.

12 4.5 Radionuclides

13 4.5.1 Radionuclides of Concern

14 During the design of an FSS, the survey team should thoroughly review of all the remediation
 15 activities conducted before the FSS to determine the radionuclides of concern and their
 16 expected concentrations in each survey unit. The team should also determine if the
 17 concentrations of the radionuclides of concern in the background need to be accounted for in
 18 the FSS design; for example, if a radionuclide is not present in the background, the FSS can be
 19 designed based on the one-sample Sign test.

20 If neither remedial action nor HSA data exist, then the survey design team should make the
 21 identification of the radionuclides of concern a primary objective of the team's actions. Whether
 22 through an HSA, a scoping survey, a characterization survey, or some combination of them, the
 23 team must make an initial characterization of the types, concentrations, and distribution of the
 24 residual radioactive material at the site.

25 4.5.2 Release Criteria and Derived Concentration Guideline Levels

26 The decommissioning process ensures that residual radioactive material will not result in
 27 individuals being exposed to unacceptable levels of radiation dose or risk. Regulatory agencies
 28 establish radiation dose standards based on risk considerations and scientific data relating dose
 29 to risk. These radiation dose standards are the fundamental release criteria; however, they are
 30 not measurable. To translate these release criteria into measurable quantities, residual levels of

1 radioactive material corresponding to the release criteria are derived (calculated) by analysis of
2 various pathways (e.g., direct radiation, inhalation, and ingestion) and scenarios (e.g., resident
3 farmer, industrial, recreational) through which exposures could occur.

4 These DCGLs are usually presented in terms of surface or mass activity concentrations of
5 radioactive material (typically becquerels [Bq]/m², disintegrations per minute/centimeters
6 squared [dpm/100 cm²], Bq/kilogram [Bq/kg], or picocurie/gram [pCi/g], respectively). The
7 details of the derivation of DCGLs are beyond of the scope of MARSSIM. However, the survey
8 design team should understand how DCGLs were derived, because the models and
9 assumptions used to derive DCGLs can drive how measurements are made. For example, if
10 DCGLs for soil were derived based on an assumption that the residual radioactive material was
11 restricted to the top 15 cm of soil, a condition verified in a characterization survey, then for the
12 FSS it would not be appropriate to collect soil samples from the top 30 cm of soil. In many
13 cases, generally applicable DCGLs can be obtained from the relevant regulatory agency. In
14 other cases, DCGLs derived for site-specific conditions can be used with permission of the
15 relevant regulatory agency.

16 There are two types of DCGLs (DCGL_W and DCGL_{EMC})² applicable to satisfying
17 decommissioning objectives:

- 18 • The DCGL_W is the mean³ concentration of residual radioactive material within a survey unit
19 that corresponds to release criteria (e.g., regulatory limit in terms of dose or risk).
- 20 • The DCGL_{EMC} accounts for the smaller area of elevated residual radioactive material and is
21 typically derived based on dose (or risk) pathway modeling. The DCGL_{EMC} is always greater
22 than or equal to the DCGL_W.

23 The contributions to dose or risk from both the uniform area and areas of elevated residual
24 radioactive material, if applicable, must meet the condition expressed in **Equation 8-4** in
25 **Section 8.6.2**. The development of regulatory requirements leading to the establishment of a
26 DCGL_{EMC} is beyond the scope of MARSSIM and is determined strictly through the requirements
27 of regulatory agencies. Therefore, it is important to work with the applicable regulatory agency
28 to determine whether requirements for a DCGL_{EMC} should be consistent with the approach
29 presented in MARSSIM or those in regulatory documents. When properly justified to and
30 accepted by the regulatory agency, no DCGL_{EMC} requirement may be needed at all. DCGL_{EMC}s
31 and associated requirements for areas of elevated radioactive material should be clearly stated
32 and properly approved, and surveys should demonstrate compliance with those requirements.
33 More discussion about elevated areas of radioactive material and their consideration during
34 radiological survey activities can be found in **Section 5.3.5**.

35 To prove compliance with requirements for discrete radioactive particles, some surveys have
36 used the MARSSIM Elevated Measurement Comparison (EMC) process (see **Section 8.6.1**).
37 As discussed in **Section 4.12.8**, the MARSSIM EMC process might not apply to discrete
38 radioactive particles; the survey design team should use the DQO process to address such
39 particles in surface soils or building surfaces. More discussion about discrete radioactive

² The "W" in DCGL_W colloquially refers to "wide-area" or "average." The "EMC" in DCGL_{EMC} refers to the Elevated Measurement Comparison.

³ The mean is sum of the values divided by the number of measurements and is commonly called the average.

1 particles and their consideration during radiological survey activities can be found in
2 **Section 4.12.8.**

3 The MARSSIM user should remember five things about release criteria and DCGLs:

- 4 • The fundamental release criteria are dose or risk based and cannot be measured.
- 5 • The fundamental release criteria are translated into measurable DCGLs.
- 6 • The determination of acceptable DCGLs must be coordinated with the regulator.
- 7 • The derivation of radionuclide-specific DCGLs is beyond the scope of MARSSIM.
- 8 • The application of radionuclide-specific DCGLs to derive operational DCGLs for FSSs is the
9 responsibility of MARSSIM user.

10 **4.5.3 Applying DCGLs**

11 This section focuses on introducing the application and modifications of DCGLs to derive
12 operational DCGLs for various situations commonly encountered while planning FSSs. An
13 operational DCGL is any modification or combination of radionuclide-specific DCGLs to derive
14 measurable quantity (e.g., a gross beta activity DCGL). The simplest application of a DCGL is
15 when a single radionuclide is distributed uniformly throughout a survey unit. When multiple
16 radionuclides are present in a survey unit, (1) the ratios of the concentrations of radionuclides
17 are roughly constant (correlated), or (2) the concentrations are unrelated. There are statistical
18 tests that can be performed to calculate the degree of correlation among the concentrations.
19 Ultimately, sound judgment must be used when interpreting the results of the calculations. If
20 there is no physical reason for the concentrations to be correlated, then they are likely not.
21 However, if there is sound evidence of correlation, then that evidence should be used. The
22 survey design team should consult closely with the appropriate regulatory agency during the
23 design phase.

24 Fundamentally, the measurement of residual radioactive material involves one or more of the
25 following:

- 26 • radionuclide-specific analyses
- 27 • gross activity measurements
- 28 • external radiation measurements

29 The choice of the operational DCGL depends on the types of measurements being made. If
30 multiple radionuclides are considered using gross activity measurements, then it might be
31 acceptable to use the smallest DCGL of the radionuclides present. To use surrogate
32 measurements to demonstrate compliance, all significant radionuclides should be identified, the
33 contributions of the various radionuclides should be known, and DCGLs should be developed
34 for each of the radionuclides of concern. If there is a well-established correlation between
35 radionuclide concentrations, then a weighted gross activity DCGL or surrogate-based DCGL
36 might be acceptable. If no correlation exists or a combination of the above options is proposed,
37 then the unity rule must be used.

1 4.5.3.1 DCGLs for a Single Radionuclide

2 For a single radionuclide, compliance can be easily demonstrated if all the measurements in the
 3 survey unit are below the DCGL. Otherwise, an appropriate statistical test must be used. This is
 4 straightforward when there is one radionuclide (e.g., Sr/Y-90) where radioactive decay products
 5 are included in the DCGL. If the radioactive decay products are not included in the DCGL, and
 6 the radioactive decay products are present, the survey team must use one of the methods
 7 outlined below. Additionally, the methods described below can be used for radionuclides that
 8 are not part of the same decay chain (e.g., presence of a mix of fission products, such as Sr-90
 9 and Cs-137).

10 If a DCGL for the parent of a serial decay chain includes contributions from the progeny, then
 11 the direct application of that DCGL is possible. It is incumbent on the design team to determine
 12 if the radionuclides of concern are parents of a decay series and if progeny are accounted for in
 13 all DCGLs. For example, values for natural thorium (Th-nat) and natural uranium (U-nat)
 14 typically include progeny; however, the design team must confirm this for each case. For
 15 information on serial radioactive decay, see **Section 4.5.3.8**.

16 4.5.3.2 Most Conservative DCGL Approach for Multiple Radionuclides

17 If there are multiple radionuclides in a survey unit, then it might be possible to use the lowest
 18 (most restrictive) DCGL. Note that if $DCGL_{min}$ is the lowest of the DCGLs, then **Equation (4-6)**
 19 applies, and $DCGL_{min}$ may be applied to the total activity concentration rather than using the
 20 unity rule.

$$\frac{C_1}{DCGL_1} + \frac{C_2}{DCGL_2} + \dots + \frac{C_n}{DCGL_n} \leq \frac{(C_1 + C_2 + \dots + C_n)}{DCGL_{min}} \leq 1 \quad (4-6)$$

21 The goal is then to demonstrate that the ratio of the total concentration of all radionuclides to
 22 $DCGL_{min}$ is less than 1, or alternatively that the total concentration of all radionuclides is less
 23 than $DCGL_{min}$. Although this option may be considered, in many cases it will be too conservative
 24 to be useful. Furthermore, the ease of detection must be taken into account during the DQO
 25 process if use of the $DCGL_{min}$ is being considered.

26 4.5.3.3 DCGLs for Multiple Radionuclides in Known Ratios (Surrogate Measurements)

27 For sites with multiple radionuclides, it may be possible to measure just one of the radionuclides
 28 and still demonstrate compliance for all radionuclides present by using surrogate
 29 measurements. If there is an established ratio among the concentrations of the radionuclides in
 30 a survey unit, then the concentration of every radionuclide can be expressed in terms of any
 31 one of them. The measured radionuclide is often called a *surrogate* radionuclide for the others.
 32 In this case, the unity rule can be used to derive a new, modified DCGL for the surrogate
 33 radionuclide, which accounts for the dose or risk contributions of the other radionuclides that are
 34 not measured.

35 The fundamental aspect of the unity rule is that the sum of the ratios of the concentrations to the
 36 DCGLs for each radionuclide should be less than or equal to one, as shown in **Equation (4-7)**:

$$\sum_{i=1}^n \frac{C_i}{DCGL_i} \leq 1 \tag{4-7}$$

1 where

- 2 • C_i is the concentration of the i th radionuclide.
- 3 • $DCGL_i$ is the DCGL of the i th radionuclide.

4 The terms in the denominator are the original, unmodified DCGLs for all the radionuclides in the
 5 survey unit. However, when using a surrogate radionuclide, the design team needs to ensure
 6 that the DCGL for the surrogate radionuclide is modified ($DCGL_{S-mod}$) to account for the
 7 presence of all the radionuclides. This is done by applying the unity rule as shown in
 8 **Equation (4-8):**

$$\frac{C_s}{DCGL_{S-mod}} \leq 1 \tag{4-8}$$

9 where

- 10 • C_s is the concentration of the surrogate radionuclide.
- 11 • $DCGL_{S-mod}$ is the modified DCGL for the surrogate radionuclide.

12 Here, $DCGL_{S-mod}$ is the DCGL for the surrogate radionuclide modified so that it represents all
 13 radionuclides that are present in the survey unit. The $DCGL_{S-mod}$ is a variation of the unity rule
 14 that uses established ratios as shown below in **Equation (4-9):**

$$DCGL_{S-mod} = \frac{1}{\left(\frac{1}{DCGL_{S-unmod}} + \frac{R_2}{DCGL_2} + \dots + \frac{R_i}{DCGL_i} + \dots + \frac{R_n}{DCGL_n} \right)} \tag{4-9}$$

15 where

- 16 • $DCGL_{S-unmod}$ is the DCGL of the surrogate radionuclide before modification.
- 17 • $DCGL_i$ is the DCGL of the i th radionuclide for $i = 2, \dots, n$.
- 18 • R_i is the established ratio of the concentration of the i th radionuclide to the concentration of
 19 the surrogate radionuclide for $i = 2, \dots, n$.

20 $DCGL_{S-mod}$ is then used for survey design purposes described in **Chapter 5**. An example
 21 calculation of a surrogate DCGL and additional discussion are shown in **Section 4.12.2.1**.

22 This scheme is applicable only when radionuclide-specific measurements of the surrogate
 23 radionuclide are made. It is unlikely to apply in situations where the surrogate radionuclide

1 appears in background, as background variations would increase the uncertainty in the
2 calculation of the surrogate measurements to unacceptable levels.

3 When using surrogates, it is often difficult to establish a consistent ratio between two or more
4 radionuclides. Rather than follow prescriptive guidance on acceptable levels of variability for the
5 surrogate ratio, a more reasonable approach may be to review the data collected to establish
6 the ratio and to use the DQO process to select an appropriate ratio from that data. The DQO
7 process should be used to assess the feasibility of use of surrogates. The benefit of using the
8 surrogate approach is avoiding the need to perform costly wet chemistry analyses on each
9 sample. This benefit should be considered relative to the difficulty in establishing the surrogate
10 ratio, as well as the potential consequence of unnecessary investigations that result from
11 decision errors, which may arise from using a “conservative” surrogate ratio (i.e., determining
12 that the site is dirty when the site is clean). Selecting a conservative surrogate ratio ensures that
13 potential exposures from individual radionuclides are not underestimated. The surrogate method
14 can only be used with confidence when dealing with the same media in the same
15 surroundings—for example, soil samples with similar physical and geological characteristics.
16 The planning team will need to consult with the regulatory agency for concurrence on the
17 approach used to determine the surrogate ratio.

18 The potential for shifts or variations in the radionuclide ratios means that the surrogate method
19 should be used with caution. Physical or chemical differences between the radionuclides may
20 produce different migration rates, causing the radionuclides to separate and changing the
21 radionuclide ratios. Remediation activities have a reasonable potential to alter the surrogate
22 ratio established prior to remediation. MARSSIM recommends that when the ratio is established
23 prior to remediation, additional post-remediation samples should be collected to ensure that the
24 data used to establish the ratio are still appropriate and representative of the existing site
25 condition. If these additional post-remediation samples are not consistent with the pre-
26 remediation data, surrogate ratios should be re-established.

27 4.5.3.4 Gross Activity DCGLs for Multiple Radionuclides in Known Ratios

28 For situations where multiple radionuclides with their own DCGLs are present, a gross activity
29 DCGL can be developed. This approach enables field measurement of gross activity
30 (e.g., Bq/m²), rather than determination of individual radionuclide activity, for comparison to the
31 DCGL. The gross activity DCGL for surfaces with multiple radionuclides is calculated as follows:

- 32 1. Determine the relative fraction, f_i of the total activity contributed by each of the n
33 radionuclides present for $i = 1, \dots n$.
- 34 2. Obtain the $DCGL_i$ for each i th radionuclide present for $i = 1, \dots n$.
- 35 3. Substitute the values f_i and $DCGL_i$ in the following equation (**Equation (4-10)**) for $i = 1, \dots n$.

$$DCGL_{\text{gross}} = \frac{1}{\left(\frac{f_1}{DCGL_1} + \frac{f_2}{DCGL_2} + \dots + \frac{f_i}{DCGL_i} + \dots + \frac{f_n}{DCGL_n} \right)} \quad (4-10)$$

36 This process can be used to calculate a gross activity DCGL to be used as a $DCGL_W$ or a
37 $DCGL_{EMC}$. See **Appendix O.4** for the derivation. The example in **Section 4.12.2.3** illustrates the
38 calculation of a gross activity DCGL.

1 Just as in the case of surrogate radionuclides, note that **Equation (4-10)** might not work for
 2 sites having unknown or highly variable relative fractions of radionuclides throughout the site. In
 3 these situations, the best approach may be to select the most conservative surface DCGL from
 4 the mixture of radionuclides present (**Section 4.5.3.2**) or the unity rule (**Section 4.5.3.5**). If the
 5 radionuclide with the most restrictive DCGL cannot be measured or is hard to detect with field
 6 instruments, the DQOs must be revisited to determine the best approach. If the mixture contains
 7 radionuclides that cannot be measured using field survey equipment, laboratory analyses of
 8 surface materials may be necessary. Check with the regulator whether the use of a gross
 9 activity DCGL is appropriate for the site.

10 **4.5.3.5 DCGLs for Multiple Radionuclides with Unrelated Concentrations**

11 If the concentrations of the different radionuclides appear to be unrelated in the survey unit, the
 12 surrogate approach cannot be used. There is little choice but to measure the concentration of
 13 each radionuclide and use the unity rule. The alternative would involve performing gross
 14 measurements (e.g. alpha or beta) and applying the most restrictive DCGL_w to all radionuclides.

15 Recall from **Section 4.4** that the fundamental release criterion is that the sum of all the radiation
 16 dose from all the residual radionuclides in a survey unit must be less than or equal to the dose
 17 or risk criteria. In terms of DCGLs, the unity rule states that for a survey unit to meet the release
 18 criteria, the sum of the ratios of the concentrations of each radionuclide to their respective
 19 DCGLs must be less than or equal to one, as shown in **Equation (4-11)**:

$$\frac{C_1}{DCGL_1} + \frac{C_2}{DCGL_2} + \dots + \frac{C_i}{DCGL_i} + \dots + \frac{C_n}{DCGL_n} \leq 1 \quad (4-11)$$

20 where

- 21 • C_i is the concentration of the *i*th radionuclide for *i* = 1, ... *n*.
- 22 • DCGL_{*i*} is the DCGL of the *i*th radionuclide for *i* = 1, ... *n*.

23 By using the unity rule in this manner, the design team creates an effective DCGL of 1. Note
 24 that the DCGL is no longer expressed as a concentration; it is a unitless sum of fractions. To
 25 apply the unity rule, the design team must calculate the *sum of the ratios* (SOR) or *weighted*
 26 *sum (T)* of the ratios in the survey unit for each quantity measured at a given location, as
 27 illustrated in **Equation (4-12)** and **Example 4.12.4**.

$$T = \frac{C_1}{DCGL_1} + \frac{C_2}{DCGL_2} + \dots + \frac{C_i}{DCGL_i} + \dots + \frac{C_n}{DCGL_n} \quad (4-12)$$

28 where

- 29 • C_{*i*} is the concentration in the sample of the *i*th radionuclide for *i* = 1, ... *n*.
- 30 • DCGL_{*i*} is the DCGL of the *i*th radionuclide for *i* = 1, ... *n*.

1 In a given sample, the concentration of each radionuclide is divided by its DCGL
 2 (normalization). This weighted sum, T , and its standard deviation, $\sigma(T)$, will be used in the
 3 statistical tests to determine whether a survey unit can be released. The standard deviation in
 4 the weighted sum is calculated as shown in **Equation (4-13)**:

$$\sigma(T) = \sqrt{\left[\frac{\sigma(C_1)}{DCGL_1}\right]^2 + \left[\frac{\sigma(C_2)}{DCGL_2}\right]^2 + \dots + \left[\frac{\sigma(C_i)}{DCGL_i}\right]^2 + \dots + \left[\frac{\sigma(C_n)}{DCGL_n}\right]^2} \quad (4-13)$$

5 where

- 6 • $\sigma(C_i)$ is the estimate of uncertainty in the concentration in the sample of the i th radionuclide
 7 for $i = 1, \dots, n$.
- 8 • $DCGL_i$ is the DCGL of the i th radionuclide for $i = 1, \dots, n$.

9 Note that if there is a fixed ratio between the concentrations of some radionuclides but not
 10 others, a combination of the methods in **Sections 4.5.3.4 and 4.5.3.5** may be used. The
 11 appropriate value of the DCGL with the concentration of the measured surrogate radionuclide
 12 should replace the corresponding terms in **Equations (4-12) and (4-13)**. **Example 4.12.4**
 13 illustrates the calculation of the weighted sum and its associated uncertainty for two
 14 radionuclides.

15 During the planning stage, data from characterization, scoping, or other surveys can be used to
 16 estimate the values of T and $\sigma(T)$ in the survey unit to determine the number of samples
 17 needed for the statistical tests.

18 Although this chapter does not discuss interpreting the data from an FSS (**Chapter 8**), a note on
 19 how T is used can be helpful at this point. If the sum of the normalized concentrations is below
 20 1.0 for every sample in a survey unit, compliance has been demonstrated. If a survey unit has
 21 several individual locations where T_i exceeds 1, this does not mean that the survey unit fails to
 22 meet the release criteria. If any individual T_i exceeds 1, then, as for the case for a single
 23 radionuclide, an appropriate statistical test and the elevated measurement comparison test must
 24 be performed.

25 *4.5.3.6 The Use of External Radiation Measurements as a Surrogate*

26 In lieu of using measurements of radionuclide concentrations to determine compliance with
 27 release criteria, the DQO process can be used to determine if in situ measurements of external
 28 radiation levels (e.g., exposure rates) can be used, particularly for radionuclides that deliver the
 29 majority of their dose through the direct radiation pathway. This approach can be desirable
 30 because external radiation measurements are generally easier to make and less expensive than
 31 measuring radionuclide concentrations.

32 This method requires that a consistent ratio for the surrogate and unmeasured radionuclides be
 33 established. The appropriate exposure rate DCGL could also account for radionuclides that do
 34 not deliver the majority of their dose through the direct radiation pathway. This is accomplished
 35 by determining the fraction of the total activity represented by radionuclides that do deliver the
 36 majority of their dose through the direct radiation pathway and weighting the exposure rate limit

1 by this fraction (see surrogate discussion above). Note that the previously mentioned
 2 considerations for establishing consistent ratios also apply to this surrogate approach. The
 3 regulatory agency should be consulted before using this surrogate approach.

4 **4.5.3.7 Small Areas of Elevated Activity**

5 The concept of the elevated measurement comparison and $DCGL_{EMC}$ for small areas of elevated
 6 activity was introduced in **Section 4.5.2**. The $DCGL_{EMC}$ accounts for the smaller area of
 7 elevated residual radioactive material and is equal to or greater than the $DCGL_W$. Recall that the
 8 development of regulatory requirements leading to the establishment of a $DCGL_{EMC}$ is beyond
 9 the scope of MARSSIM and is determined strictly through the requirements of regulatory
 10 agencies. Therefore, it is important to work with the applicable regulatory agency to determine
 11 whether requirements for establishing a $DCGL_{EMC}$ should be consistent with the approach
 12 presented in MARSSIM or those in regulatory documents.

13 All the methods used to modify individual DCGLs to account for multiple radionuclides can be
 14 used to modify the $DCGL_{EMC}$. When the ratios between the radionuclides is unknown, the unity
 15 rule inequality for the EMC is as shown below in **Equation (4-14)**:

$$\frac{C_1}{DCGL_{EMC,1}} + \frac{C_2}{DCGL_{EMC,2}} + \dots + \frac{C_i}{DCGL_{EMC,i}} + \dots + \frac{C_n}{DCGL_{EMC,n}} \leq 1 \quad (4-14)$$

16 In **Equation (4-14)**, C_i is concentration of the i th radionuclide for $i = 1, \dots, n$, and $DCGL_{EMC,i}$ is
 17 the $DCGL_{EMC}$ for i th radionuclide for $i = 1, \dots, n$.

18 The use of **Equation (4-14)** may not be appropriate for scanning. For scanning, minimum
 19 detectable concentration (MDC) considerations are a little more nuanced than for discrete
 20 sampling. For example, when scanning for areas with potentially elevated concentrations of
 21 residual radioactive material, the scan MDC should be below the DCGL—preferably at a fraction
 22 (approximately 50 percent) of the DCGL. In a Class 1 survey unit, the scan MDC should be less
 23 than the $DCGL_{EMC}$. Additional information is provided in **Sections 5.3.5.1 and 5.3.5.2**. The
 24 radionuclide yielding the lowest detector response may or may not have the most restrictive
 25 DCGL.

26 As illustrated in **Equation (4-15)**, to use the surrogate (known ratios) method for the elevated
 27 measurement comparison, the $DCGL_{EMC}$ for the surrogate radionuclide is replaced by—

$$DCGL_{EMC,S-mod} = \frac{1}{\frac{1}{DCGL_{EMC,S-unmod}} + \frac{R_2}{DCGL_{EMC,2}} + \dots + \frac{R_i}{DCGL_{EMC,i}} + \dots + \frac{R_n}{DCGL_{EMC,n}}} \quad (4-15)$$

28 where

- 29 • $DCGL_{EMC,S-unmod}$ is the unmodified $DCGL_{EMC}$ for the first radionuclide.
- 30 • R_i is the concentration ratio of the i th radionuclide to the first radionuclide for $i = 2, \dots, n$.
- 31 • $DCGL_{EMC,i}$ is the $DCGL_{EMC}$ for the i th radionuclide for $i = 2, \dots, n$.

32 When dealing with discrete radioactive particles (hot particles), the MARSSIM EMC process is
 33 not valid when the instrumentation dose-to-rate conversion factor modeling assumes a “point

1 source” as opposed to an “area source” or “plane source.” This violates the assumption inherent
2 in the dose or risk model of an activity concentration averaged over some definable area. The
3 FSS planning team should use the DQO process to address discrete radioactive particles, if
4 there is a reasonable potential for them to be present. See **Section 4.12.8** for more information
5 on release criteria for discrete radioactive particles.

6 *4.5.3.8 A Note on Serial Radioactive Decay*

7 For decay series (e.g., thorium and uranium) whose radionuclides emit alpha, beta, and gamma
8 radiation, compliance with building surface activity DCGLs may be demonstrated by assessing
9 alpha, beta, or gamma radiations. However, relying on the use of alpha surface measurements
10 often proves problematic because of the highly variable level of alpha attenuation by rough,
11 porous, and dusty surfaces. Beta measurements typically provide a more accurate assessment
12 of thorium and uranium on most building surfaces because surface conditions cause
13 significantly less attenuation of beta particles than alpha particles. Beta measurements,
14 therefore, may provide a more accurate determination of surface activity than alpha
15 measurements. The presence of gamma-emitting radionuclides can introduce uncertainty into
16 the beta measurements, and field measurement techniques need to be used to account for the
17 gamma interference at each beta measurement location.

18 The relationship of beta and alpha emissions from decay chains or various enrichments of
19 uranium should be considered when determining the surface activity for comparison with the
20 DCGL values. When the initial member of a decay chain has a long half-life, the concentration
21 of radioactive material associated with the subsequent members of the series will increase at a
22 rate determined by the individual half-lives until all members of the decay chain are present at
23 activity levels equal to the activity of the parent. This condition is known as secular equilibrium.
24 **Section 4.12.2.1** provides an example of the calculation of beta activity $DCGL_W$ for thorium-232
25 in equilibrium with its decay products.

26 *4.5.4 Investigation Levels*

27 The survey design should include the development of investigation levels during the DQO
28 process for the FSS. A measurement result is compared to an investigation level to indicate
29 when additional action might be necessary (e.g., a measurement that exceeds the $DCGL_W$ in a
30 Class 2 area). Investigation levels can be radionuclide-specific levels of radioactive material or
31 an instrument response (e.g., counts per minute). Additional discussions of investigation levels
32 are in **Section 5.3.8**.

33 *4.5.5 Conclusions*

34 The foregoing discussion of DCGLs highlights the following:

- 35 • Measurements can be made for specific radionuclides, typically through gamma
36 spectrometry or radiochemical analyses.
- 37 • The FSS design team should be familiar with the operational DCGLs and their applications.
- 38 • Gross activity measurements—typically gross alpha or beta concentrations—can be made,
39 especially on surfaces.
- 40 • Measurement of surrogate quantities can be used based on known relationships among the
41 various radionuclides.

- 1 • The use of surrogates or ratios determined from data collected before the FSS must be
2 approved by the appropriate regulatory authorities, and if remediation or other activities
3 occur which could affect the ratios, additional support for the assumed ratios or revisions to
4 the ratios is needed.
- 5 • The unity rule can be used to determine the DCGLs for use in the design of the FSS when
6 multiple radionuclides/sources are present.
- 7 • If DCGLs are modified for use of surrogates, that modification will affect instrument
8 selection.

9 The choice of how the DCGLs are applied and measured affects the statistical methods,
10 background reference unit selection, and other design features of a survey. For example,
11 MARSSIM recommends using the Wilcoxon Rank Sum (WRS) test if the radionuclides are
12 present in the background or if gross activity measurements are made (see **Section 8.2.3**).

13 **4.6 Area and Site Considerations**

14 **4.6.1 Area Classification**

15 All areas of a site will not have the same potential for residual radioactive material and,
16 accordingly, will not need the same level of survey coverage to demonstrate compliance with
17 the established release criteria. The process will be more efficient if the survey is designed so
18 that areas with higher potential for residual radioactive material (based in part on results of the
19 HSA in **Chapter 3**) will receive a higher degree of survey effort. The following is a discussion of
20 site area classifications.

21 *Non-impacted areas:* Areas that have no reasonable potential for residual radioactive material
22 and do not need any level of survey coverage. Those areas have no radiological impact from
23 site operations and are typically identified during the HSA (**Chapter 3**). Background reference
24 areas are normally selected from non-impacted areas (**Section 4.6.3**).

25 *Impacted areas:* Areas that have some potential for containing residual radioactive material.
26 They can be classified into three classes:

- 27 • *Class 1 areas:* Areas that have, or had prior to remediation, a potential for residual
28 radioactive material above the $DCGL_W$ (based on site operating history) or known residual
29 radioactive material (based on previous radiological surveys). Examples of Class 1 areas
30 include—
 - 31 ○ site areas previously subjected to remedial actions
 - 32 ○ locations where leaks or spills are known to have occurred
 - 33 ○ former burial or disposal sites
 - 34 ○ waste storage sites
 - 35 ○ areas with residual radioactive material in discrete solid pieces of material having high
36 specific activity

37 Note that areas containing residual radioactive material in excess of the $DCGL_W$ prior to
38 remediation should be classified as Class 1 areas. Justification is not required for a Class 1

1 designation, unlike a Class 2 or Class 3 designation. The less restrictive the classification,
2 the greater the justification required.

- 3 • *Class 2 areas:* Areas that have, or had prior to remediation, a potential for residual
4 radioactive material or known residual radioactive material but are not expected to exceed
5 the DCGL_W. To justify a Class 2 designation, the existing data (from the HSA, scoping
6 surveys, or characterization surveys) should provide a high degree of confidence that no
7 individual measurement would exceed the DCGL_W. Other justifications may be appropriate
8 based on the outcome of the DQO process. Examples of areas that might be classified as
9 Class 2 for the FSS include—
 - 10 ○ locations where radioactive materials were present in an unsealed form
 - 11 ○ residual radioactive material potentially along transport routes
 - 12 ○ areas downwind from stack release points
 - 13 ○ upper walls, roof support frameworks, and ceilings of some buildings or rooms subjected
14 to airborne radioactive material
 - 15 ○ areas where low concentrations of radioactive materials were handled
 - 16 ○ areas on the perimeter of former buffer or radiological control areas
- 17 • *Class 3 areas:* Any impacted areas that are not expected to contain any residual radioactive
18 material or are expected to contain levels of residual radioactive material at a small fraction
19 of the DCGL_W, based on site operating history and previous radiological surveys. To justify a
20 Class 3 designation, the existing data (from the HSA, scoping surveys, or characterization
21 surveys) should provide a high degree of confidence either that there is no residual
22 radioactive material or that any levels of residual radioactive material are a small fraction of
23 the DCGL_W. Other justifications for an area's classification may be appropriate based on the
24 outcome of the DQO process. Examples of areas that might be classified as Class 3
25 include—
 - 26 ○ buffer zones around Class 1 or Class 2 areas
 - 27 ○ areas with very low potential for residual radioactive material but insufficient information
28 to justify a non-impacted classification

29 Classification is a critical step in the survey design process, as well as for the FSS (see
30 **Table 2.2**). Class 1 areas have the greatest potential for residual radioactive material and,
31 therefore, receive the highest degree of survey effort, followed by Class 2 and then Class 3
32 areas. All areas should be considered Class 1 areas unless some basis for classification as
33 Class 2 or Class 3 is provided.

34 The criteria used for designating areas as Class 1, 2, or 3 should be described in the FSS plan.
35 Compliance with the classification criteria should be demonstrated in the FSS report. A thorough
36 analysis of HSA findings (**Chapter 3**) and the results of scoping and characterization surveys
37 provide the basis for an area's classification. As a survey progresses, reevaluation of this
38 classification may be necessary based on newly acquired survey data. For example, if residual
39 radioactive material at concentrations that are a substantial fraction of the DCGL_W is identified in
40 a Class 3 area, an investigation and reevaluation of that area should be performed to determine
41 if the Class 3 area classification is appropriate. Typically, the investigation will result in part or all

1 of the area being reclassified as Class 1 or Class 2. If survey results identify residual radioactive
 2 material in a Class 2 area exceeding the DCGL or suggest that there may be a reasonable
 3 potential that residual radioactive material is present in excess of the DCGL, an investigation
 4 should be initiated to determine whether all or part of the area should be reclassified as Class 1.
 5 More information on investigations and reclassifications is provided in **Section 5.3.8**.

6 **4.6.2 Identification of Survey Units**

7 A survey unit is a physical area consisting of structures or land areas of specified size and
 8 shape for which a separate decision will be made whether that survey unit exceeds the release
 9 criteria. This decision is made as a result of the FSS. Therefore, the survey unit is the primary
 10 entity for demonstrating compliance with the release criteria.

11 To facilitate survey design and ensure that the number of survey data points for a specific site
 12 are relatively uniformly distributed among areas of similar potential for residual radioactive
 13 material, the site is divided into survey units that share a common history or other
 14 characteristics or are naturally distinguishable from other portions of the site. A site may be
 15 divided into survey units at any time before the FSS. Areas that have been classified can be one
 16 survey unit or multiple survey units. For example, HSA or scoping survey results may provide
 17 sufficient justification for partitioning the site into Class 1, 2, or 3 areas. Note, however, that
 18 dividing the site into survey units is critical only for the FSS; scoping, characterization, and RAS
 19 surveys may be performed without dividing the site into survey units.

20 A survey unit cannot include areas that have different classifications. A survey unit's
 21 characteristics should be consistent with exposure pathway modeling that is used to convert
 22 dose or risk into radionuclide concentrations. For indoor areas classified as Class 1, each room
 23 may be designated as a survey unit. Indoor areas may also be subdivided into several survey
 24 units of different classification, such as separating floors and lower walls from upper walls and
 25 ceilings (and other upper horizontal surfaces) or subdividing a large warehouse based on floor
 26 area.

27 Survey units should be limited in size based on classification, exposure pathway modeling
 28 assumptions, and site-specific conditions. The suggested areas for survey units are provided in
 29 **Table 4.1**.

30 **Table 4.1: Suggested Area for Survey Units**

Classification	Suggested Area for Survey Units	
	Structures (Floors, Walls, and Ceilings)	Land Areas
Class 1	Up to 100 m ²	Up to 2,000 m ²
Class 2	Up to 1,000 m ²	Up to 10,000 m ²
Class 3	No Limit	No Limit

31 Abbreviation: m² = square meters

32 The limitation on survey unit size ensures that the density of the measurements/samples is
 33 commensurate with the potential of residual radioactive materials in excess of the DCGL_w. The

1 rationale for selecting a larger survey unit area should be developed using the DQO process
2 (**Section 2.3**) and fully documented.

3 Special considerations may be necessary for survey units with structure surface areas up to
4 10 m² or land areas up to 100 m². In this case, the number of data points obtained from the
5 statistical tests is unnecessarily large and not appropriate for smaller survey unit areas. Instead,
6 some specified level of survey effort should be determined based on the DQO process and with
7 the concurrence of the regulatory agency. For such small survey units, scan-only surveys or in
8 situ measurement may be more appropriate. The data generated from these smaller survey
9 units should be obtained based on judgment, rather than on systematic or random design, and
10 compared individually to the DCGLs.

11 One example special case for FSSs occurs at UMTRCA sites at which the radioactive materials
12 are from the processing of uranium or thorium ores for their source material content. See
13 **Section 4.12.9** and **Appendix O.6** for more details for UMTRCA sites.

14 **4.6.3 Selection of Background Reference Areas**

15 Certain radionuclides may also occur at significant levels as part of background in the media of
16 interest (e.g., soil, building material). Examples include members of the naturally occurring
17 uranium, thorium, and actinium series; potassium-40 (⁴⁰K); carbon-14 (¹⁴C); and tritium (³H).
18 ¹³⁷Cs and other radionuclides are also present in background as a result of fallout (Wallo et al.,
19 1994). Establishing a distribution of background concentrations is necessary to identify and
20 evaluate contributions attributable to site operations. Determining background levels for
21 comparison with the conditions determined in specific survey units entails conducting surveys in
22 one or more reference areas to define the background radiological conditions of the site.
23 NUREG-1505 (NRC 1998a) provides additional information on background reference areas.

24 The recommended site background reference area should have similar physical, chemical,
25 geological, radiological, and biological characteristics as the survey unit being evaluated.
26 Background reference areas should be selected from non-impacted areas, but they are not
27 limited to natural areas undisturbed by human activities. In some situations, a reference area
28 may be contiguous to the survey unit being evaluated, as long as the reference area does not
29 have any residual radioactive material resulting from site activities. For example, background
30 measurements may be taken from core samples of a building or structure surface or pavement.
31 This option should be discussed with the regulatory agency during survey planning. Reference
32 areas should not be part of the survey unit being evaluated.

33 Reference areas provide a location for background measurements that are used for
34 comparisons with survey unit data. The radioactive material present in a reference area would
35 ideally be the same as in the survey unit, had the survey unit never been affected by site
36 operations. If a site includes physical, chemical, geological, radiological, or biological variability
37 that is not represented by a single reference background area, selecting more than one
38 reference area may be necessary. Additionally, the concentration of some radionuclides may
39 vary over short (hours to days), medium (months or years), or long (centuries) time frames.
40 NUREG-1501 (NRC 1994a) provides more detailed information about sources of temporal
41 variability and methods to account for this variability.

42 It may be difficult to find a reference area within a residential or industrial complex for
43 comparison to a survey unit if the radionuclides of potential concern are naturally occurring.
44 Background may vary greatly due to different construction activities that have occurred at the
45 site. Examples of construction activities that change background include—

- 1 • leveling
- 2 • excavating
- 3 • adding fill dirt
- 4 • importing rocks or gravel to stabilize soil or underlay asphalt
- 5 • manufacturing asphalt with different matrix rock
- 6 • using different pours of asphalt or concrete in a single survey unit; layering asphalt over
- 7 concrete
- 8 • layering different thicknesses of asphalt, concrete, rock, or gravel
- 9 • covering or burying old features, such as railroad beds or building footings

10 Background variability may also increase due to the concentration of fallout in low areas of
11 parking lots or under downspouts, where runoff water collects and evaporates. Variations in
12 background of a factor of five or more can occur in the space of a few meters.

13 There are a number of possible actions to address these concerns. NUREG-1505 (NRC 1998a)
14 provides a methodology for considering variability in reference area concentrations. Reviewing
15 and reassessing the selection of reference areas may also be necessary. Selecting different
16 reference areas to represent individual survey units is another possibility. More attention may
17 also be needed in selecting survey units and their boundaries with respect to different areas of
18 potential or actual background variability. More detailed scoping or characterization surveys
19 may be needed to better understand background variability. Using radionuclide-specific
20 measurement techniques instead of gross radioactive material measurement techniques may
21 also be necessary. If a background reference area that satisfies the above recommendations is
22 not available, consultation with the regulatory agency is recommended. Alternate approaches
23 may include using published studies of radionuclide distributions. However, published reports
24 may not truly reflect the conditions at the site.

25 Verifying that a background reference area is appropriate for a survey can be accomplished
26 using the techniques described or referenced in **Chapter 8**. Verification provides assurance that
27 assumptions used to design the survey are appropriate and defensible. This approach can also
28 prevent decision errors that may result from selecting an inappropriate background reference
29 area.

30 If the radionuclides of interest do not occur in background, or the background levels are known
31 to be a small fraction of the DCGL_w (e.g., < 10 percent), the survey unit radiological conditions
32 may be compared directly to the specified DCGL_w, and reference area background surveys are
33 not necessary. If the background is not well defined at a site and the decision maker is willing to
34 accept the increased probability of incorrectly failing to release a survey unit (Type II error), the
35 reference area measurements can be eliminated and the Sign test performed as described in
36 **Section 8.3**.

37 **4.7 Statistical Considerations**

38 The primary practical objective of an FSS survey is to answer the question, “Can this survey unit
39 be released to the satisfaction of the regulator?” In other words, the design team needs to be
40 able to *confidently* demonstrate compliance (or non-compliance) with the dose- or risk-based
41 release criteria expressed as a measurable quantity (DCGL). This need for a demonstrable,
42 quantitative confidence necessitates planning for statistical hypothesis testing.

1 The statistical concepts used in MARSSIM were introduced in **Section 2.5**. This chapter
2 reinforces and builds on those concepts with respect to the design of an FSS. The MARSSIM
3 user should be familiar with the statistical discussions throughout **Chapters 2, 5, and 8** and
4 **Appendices D and I**. Consultations with statisticians can be very valuable for surveys that rely
5 on statistical methods for their design and assessment of the collected data.

6 **4.7.1 Basic Terms**

7 Before designing an FSS, the planning team should be familiar with the following statistical
8 terms:

- 9 • sample⁴ mean
- 10 • sample standard deviation
- 11 • sample median
- 12 • parametric and nonparametric tests
 - 13 ○ Sign test
 - 14 ○ Wilcoxon Rank Sum⁵ (WRS) test
 - 15 ○ Student's *t* test
- 16 • Type I and Type II errors
- 17 • statistical power
- 18 • lower boundary of the gray region (LBGR)
- 19 • upper boundary of the gray region (UBGR)
- 20 • relative shift (Δ/σ)
- 21 • null and alternative hypotheses

22 The MARSSIM user will encounter these and other statistical terms many times in this
23 document and while designing, performing, and assessing the results of an FSS. The use of
24 these terms will be kept to a minimum in this chapter, but this in no way diminishes their
25 importance. For this chapter, statistical terms will be defined when they are introduced.

26 **4.7.2 Recommended Statistical Tests**

27 How well a statistical test meets its objective depends on the difference between the
28 assumptions used to develop the test and the actual conditions being measured. Parametric
29 tests, such as the Student's *t* test, rely upon the results fitting some known distribution, like a

⁴ The term "sample" here is a statistical term and should not be confused with laboratory samples. For the calculation of basic statistical quantities above, data may consist of scan data, direct measurement data, or laboratory sample data. See also the glossary definition of sample.

⁵ This test is also called the Mann-Whitney U test, Mann-Whitney-Wilcoxon test, or Wilcoxon-Mann-Whitney test.

1 normal distribution. Nonparametric statistics are recommended in MARSSIM because they are
2 based on less restrictive assumptions than parametric tests. MARSSIM recommends the use of
3 the WRS test if the radionuclides of concern are present in the background or if gross activity
4 measurements are made. If the radionuclides of concern are not present in the background or
5 present only to a slight degree, then the Sign test is recommended.

6 **4.7.3 Considerations on the Choice of a Statistical Test**

7 The choice of a statistical test should be part of the DQO process during the design phase of
8 the FSS. The choice of the statistical test is influenced by how the DCGLs are expressed (gross
9 activity, radionuclide-specific, sum or ratios [unity rule]), the distribution of residual radioactive
10 material in the survey unit (relatively uniform vs. small areas of elevated activity), number of
11 reference units needed, etc. Concurrently, the number of samples needed depends on the
12 DCGL, the standard deviation of the residual radioactive material in both the survey and
13 reference units, the desired confidence in the conclusions (Type I and Type II errors), and the
14 statistical test under consideration (see **Sections 5.3.3 and 5.3.4** for details, and see example
15 calculations in **Sections 4.12.3 and 4.12.4**). Ensuring a reasonable level of confidence that any
16 areas of elevated activity are detected might require additional samples.

17 Once the FSS is completed, the assumptions used to select the statistical test are examined to
18 determine whether the conditions are met for the test. As part of the DQO process, the design
19 team should plan for the possibility that the initial assumptions were not correct.

20 **4.7.4 Deviations from MARSSIM Statistical Test Recommendations**

21 The guidance and recommendations in MARSSIM are meant to be a set of practices generally
22 acceptable for use in designing an FSS. However, the flexibility of the DQO process allows for
23 the use of more cost-effective methods, if they are acceptable to the regulator. An example is
24 presented in **Section 4.12.7**.

25 **4.7.5 An Important Statistical Note**

26 For FSSs, the parameter of interest is the mean concentration of residual radioactive material in
27 a survey unit. The nonparametric statistical tests recommended in MARSSIM are tests of the
28 median value. For data that are from a skewed right distribution, the mean could significantly
29 exceed the median. Therefore, the team planning the FSS should include a comparison step in
30 the survey to ensure that mean is less than the $DCGL_w$. See **Section 8.2.2**.

31 **4.8 Measurements**

32 Based on the potential radionuclides of interest, their associated radiations, how the DCGLs are
33 expressed, the types of media (e.g., soil, structure surfaces), and number of measurements to
34 be evaluated, the detection capabilities of various measurement methods (which consist of a
35 combination of a measurement technique and instrument) must be determined and
36 documented. Note that “measurements” includes both direct (field) measurements and
37 laboratory analyses.

38 **4.8.1 Quality Control and Quality Assurance**

39 For both field measurements (**Chapter 6**) and laboratory analyses (**Chapter 7**), the FSS design
40 team must plan to collect data to evaluate the performance of measurement and analytical
41 methods (including data collection). These data are called measurement and instrument
42 performance indicators. The DQO and MQO processes are used to determine which indicators

1 are important and included in the QAPP. Examples of measurement and instrument
2 performance indicators are shown below:

- 3 • *Instrument background readings*: Background readings before and after a series of
4 measurements are used as part of the process to ensure that an instrument was functioning
5 properly.
- 6 • *Instrument response checks*: Checking the instrument response with the same source in the
7 same geometry over the course of surveying can help ensure that the instrument was
8 working properly during the survey.
- 9 • *Field blanks*: These are samples prepared in the field using certified clean sand, soil, or
10 other media and sent to the laboratory for analysis. Field blanks are used to assess
11 contamination associated with sampling and laboratory procedures.
- 12 • *Performance evaluation samples*: These are used to assess the overall bias and errors in
13 the laboratory's analytical processes.

14 **4.8.2 Measurement Quality Objectives**

15 Although specifically for laboratory analyses, the performance characteristics discussed in the
16 Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP) (NRC 2004)
17 should be considered when establishing Measurement Quality Objectives (MQOs). This list is
18 not intended to be exhaustive:

- 19 • the method's uncertainty at a specified concentration, usually at the UBGR (expressed as a
20 standard deviation)
- 21 • the method's detection capability (expressed as the minimum detectable concentration, or
22 MDC)
- 23 • the method's quantification capability (expressed as the minimum quantifiable concentration,
24 or MQC)
- 25 • the method's range, which defines the method's ability to measure the radionuclide of
26 concern over some specified range of concentration
- 27 • the method's specificity, which refers to the ability of the method to measure the
28 radionuclide of concern in the presence of interferences
- 29 • the method's ruggedness, which refers to the relative stability of method performance for
30 small variations in method parameter values

31 Project-specific method performance characteristics should be developed as necessary and
32 may or may not include the characteristics listed here. When lists of performance characteristics
33 that affect measurability have been identified, the planning team should develop MQOs
34 describing the project-specific objectives for potential measurement techniques. Potential
35 measurement techniques should then be evaluated against the MQOs to determine whether
36 they are capable of meeting the objectives for measurability.

37 The International Organization for Standardization *Guide to the Expression of Uncertainty in*
38 *Measurement* (ISO 1993), National Institute of Standards and Technology Technical Note 1297
39 (NIST 1994), MARLAP (NRC 2004), Multi-Agency Radiation Survey and Assessment of

1 Materials and Equipment Manual (MARSAME) (NRC 2009), and **Chapter 6** of this manual
2 provide information on determining measurement uncertainty. **Chapter 6** of this manual and
3 NRC report NUREG-1507 (NRC 1997a) discuss the concept of detection capabilities and
4 provide guidance on determining detection capabilities and selecting appropriate measurement
5 methods. Although MARSAME and MARLAP include the concept of quantification capability,
6 MARSSIM takes a different approach by incorporating requirements for quantification capability
7 into detection capability with the requirement that the MDC be less than the UBGR and by
8 recommending that the MDC be less than 50 percent of the UBGR (See **Chapter 6**). **Chapter 6**
9 also discusses instruments and survey techniques for scans and direct measurements, and
10 **Chapter 7** provides information on sampling and laboratory analysis. **Appendix H** describes
11 typical field and laboratory equipment, plus associated cost and instrument capabilities.

12 **4.8.3 Selecting a Measurement Technique**

13 Instruments should be identified for each of the three types of measurement techniques planned
14 for the FSS: (1) scanning, (2) direct, and (3) laboratory measurements. Scanning and direct
15 measurements are referred to as field measurements. In some cases, the same instrument or
16 type of instrument may be used for performing several measurement techniques. For example,
17 a gas proportional counter can be used for surface scanning measurements and laboratory
18 measurements of smear samples. Once the instruments are selected, appropriate
19 measurement techniques and standard operating procedures (SOPs) should be developed and
20 documented. The measurement techniques describe how the instrument will be used to perform
21 the required measurements.

22 **4.8.3.1 Scanning Measurements**

23 Scanning is an in situ measurement technique performed by moving a portable radiation
24 detector at a specified speed and distance next to a surface to detect radiation. Scanning
25 measurements are generally used to locate areas that exceed investigation levels and areas of
26 elevated activity that might be missed (e.g., measurements made with a systematic grid). In
27 general, MARSSIM does not recommend “scan-only” FSSs. However, through the DQO
28 process and consultation with the regulator, an FSS based on scanning measurements alone
29 might be allowed. Items that should be kept in mind while investigating a scan-only survey are—

- 30 • data and location logging
- 31 • reproducibility of the measurements (e.g., fixing a detector at a constant distance from a
32 surface)
- 33 • MDCs
- 34 • scanning speed and operator training
- 35 • data integrity and security
- 36 • selecting an appropriately sized area for elevated measurement comparison calculations

37 Additional information can be found in **Chapter 6**.

38 **4.8.3.2 Direct Measurements**

39 A direct measurement is an in situ measurement of radioactive material obtained by placing the
40 detector near the surface or media being surveyed for a prescribed amount of time. An

1 indication of the resulting concentration of radioactive material is read out directly. Making direct
2 measurements is analogous to collecting samples, and the results are often treated in a similar
3 manner. Direct measurement of alpha, beta, and gamma radiation for an FSS requires that
4 instruments and techniques be used that meet the DQOs and MQOs (e.g., MDC). When
5 selecting instruments and techniques, the design team needs to consider—

- 6 • type and amounts of radionuclides potentially present
- 7 • required detection limits
- 8 • distance from the surface being monitored and field of view
- 9 • type of measurement—rate or scaler (integrated) (e.g., counts in 5 minutes)
- 10 • duration of integrated counts
- 11 • radiation background (including interferences from nearby radiation sources)

12 All direct measurements and their locations should be recorded. Additional information can be
13 found in **Chapter 6**.

14 *4.8.3.3 Laboratory Measurements*

15 When planning for collecting samples as part of an FSS, the design team should use the DQO
16 process to determine the need for sample collection and laboratory analyses. All laboratories
17 under consideration to analyze samples should have written procedures that document their
18 analytical capabilities for the radionuclides of concern and a QA/QC program that documents
19 adherence to established criteria. The survey design team should also consider any appropriate
20 laboratory accreditation. Accreditation, QA/QC, and other appropriate documentation should be
21 available for review by the survey design team (with appropriate restrictions for proprietary or
22 other controlled information). Once a qualified laboratory has been chosen, the design team
23 should involve the laboratory early in the design process and maintain communication
24 throughout execution and data evaluation and interpretation. **Chapter 7** contains more
25 information on the sampling and preparation for laboratory measurements.

26 Additionally, MARLAP (NRC 2004) contains extensive information “for the planning,
27 implementation, and assessment of projects that require laboratory analysis of radionuclides.”
28 Like MARSSIM, MARLAP aims to provide a flexible approach to ensure that the radioanalytical
29 data are of the right quality and appropriate for the needs of the user.

30 Some items that should be considered when planning for laboratory analyses include the
31 following:

- 32 • sample media
- 33 • number of samples
- 34 • type and number of QC samples
- 35 • amount of material needed by the laboratory
- 36 • analytical bias and precision
- 37 • detection limits

- 1 • costs
- 2 • required turnaround time
- 3 • sample preservation and shipping requirements
- 4 • measurement documentation requirements
- 5 • sample tracking needs (e.g., chain of custody requirements)

6 *4.8.3.4 Selecting a Radioanalytical Laboratory*

7 It is advisable to select a radiochemical laboratory as early as possible in the survey planning
8 process so that it may be consulted on the analytical methodology and the sampling activities.
9 Federal procurement procedures may require additional considerations beyond the method
10 described here. The procurement of laboratory services usually starts with the development of a
11 request for proposal that includes a statement of work describing the analytical services to be
12 procured. The careful preparation of the statement of work is essential to the selection of a
13 laboratory capable of performing the required services in a technically competent and timely
14 manner.

15 Six criteria that should be considered are:

- 16 • well-documented procedures, instrumentation, and trained personnel to perform the
17 necessary analyses
- 18 • surveyors who are experienced in performing the same or similar analyses
- 19 • satisfactory performance evaluation results from formal monitoring or accreditation programs
- 20 • adequate capacity to perform all analyses within the desired timeframe
- 21 • internal QC program
- 22 • protocols for method performance documentation, sample tracking and security, and
23 documentation of results

24 The design team should review that laboratory's documentation concerning MDC calculations,
25 reporting procedures, calibrations, QA/QC, and accreditation to ensure that the FSS DQOs will
26 be met. More details can be found in **Section 7.4**.

27 When samples are collected for laboratory analyses, communications between the project
28 manager, field personnel, and laboratory personnel are vital to a successfully executed FSS.
29 The survey design team should strive to establish communications with the laboratory early in
30 the design process; when this is not possible, a radiochemist or health physicist with
31 radiochemical training should be consulted. Additional information on laboratory
32 communications is in **Section 7.3**.

33 *4.8.4 Selection of Instruments for Field Measurements*

34 *4.8.4.1 Reliability and Robustness*

35 Choose reliable instruments that are suited to the physical and environmental conditions at the
36 site and capable of meeting the MQOs. The MQOs should include the measurement method

1 uncertainty, which is typically established at the UBGR (usually the DCGL_w). The required
2 measurement method uncertainty is perhaps the most important MQO to be established during
3 the planning process. Determining a realistic value for the measurement method uncertainty for
4 field measurements is a challenging calculation, typically requiring the use of specialized
5 software. However, ensuring that the measurement method uncertainty meets the requirement
6 set for it at the UBGR will ensure that the measurement method can reliably perform
7 measurements at the most critical concentration level for the survey.

8 *4.8.4.2 Detection Capability*

9 The detection capability (sensitivity) or the ability to detect radiation or radioactive material with
10 some quantifiable level of confidence is a critical factor in the design of an FSS. This capability
11 is most often referred to as the MDC for direct measurements, or the scan MDC for scanning
12 measurements. The formal MARSSIM definition of the MDC is “the a priori activity concentration
13 that a specific instrument and technique that has a specified probability (typically 95 percent) of
14 producing a net count (or count rate) above the critical level.” Informally, the MDC is the
15 concentration of radioactive material that can be reliably detected; if radioactive material is
16 present at the MDC with a specified probability of 95 percent, then the measurement process
17 will determine its presence 95 percent of the time. The MDC is a factor of both the
18 instrumentation and the technique or procedure being used. For scanning, human factors also
19 need to be taken into account. Details on how to calculate MDCs are given in **Section 6.3**. The
20 design team should be aware that there are other methods to calculate MDCs (especially for
21 direct and laboratory measurements) discussed in the scientific literature. The DQO process
22 should be used to determine which method best suits the needs of the FSS. This method and
23 results should be approved by the appropriate regulatory agency.

24 Having low MDCs is valuable when designing the FSS. If measured values are less than the
25 MDC, then the values can be quite variable and lead to high values for the standard deviation
26 (σ) of the measured values in the survey unit or reference area. High values for σ can be
27 accommodated in the statistical tests described in **Chapter 8** for the FSS, but a large number of
28 measurements are needed to account for the variability.

29 Early in the project, low MDCs help in the identification of areas that can be classified as non-
30 impacted or Class 3 areas. These decisions are usually based on fewer numbers of samples,
31 and each measurement is evaluated individually. Using an optimistically low estimation of the
32 MDC (see **Section 2.3.5**) for these surveys may result in the misclassification of a survey unit
33 and cleaning up an area with no residual radioactive material or, alternatively, performing an
34 FSS in an area with residual radioactive material. Selecting a measurement technique with a
35 well-defined MDC or a conservative estimate of the MDC ensures the usefulness of the data for
36 making decisions for planning the FSS. For these reasons, MARSSIM recommends that a
37 realistic or conservative estimate of the MDC be used instead of an optimistic estimate.

38 *4.8.4.3 Dynamic Range*

39 The expected concentration range for a radionuclide of concern can be an important factor in
40 the overall measurement method performance. Most radiation measurement techniques are
41 capable of measuring over a wide range of radionuclide concentrations. However, if the
42 expected concentration range is large, the range should be identified as an important
43 measurement method performance characteristic, and an MQO should be developed. The MQO
44 for the acceptable range should be a conservative estimate. This will help prevent the selection
45 of measurement techniques that cannot accommodate the actual concentration range.

1 4.8.4.4 Calibration

2 Calibration refers to the determination and adjustment of the instrument response in a particular
3 radiation field of known intensity. Proper calibration procedures are essential to providing
4 confidence in measurements made to demonstrate compliance with release criteria. The FSS
5 design team should review and understand **Section 6.6.4**.

6 The instrument should be calibrated for the radiations and energies of interest at the site
7 (**Section 6.6.4**). Instrument calibrations should be traceable to an accepted standards
8 organization, such as the National Institute of Standards and Technology (NIST).⁶ Operational
9 checks of instrument performance should be conducted routinely and frequently to ensure that
10 the instrument response is maintained within acceptable ranges and that any changes in
11 instrument background are not attributable to radioactive contamination of the detector.

12 Considerations for the use and calibration of instruments include—

- 13 • the radiation type for which the instrument is designed
- 14 • the radiation energies within the range of energies for which the instrument is designed
- 15 • the environmental conditions for which the instrument is designed
- 16 • the influencing factors, such as magnetic and electrostatic fields, for which the instrument is
17 designed
- 18 • the orientation of the instrument, such that geotropic (gravity) effects are not a concern
- 19 • the manner the instrument is used, such that it will not be subject to mechanical or thermal
20 stress beyond that for which it is designed

21 As a minimum, each measurement system (detector/readout combination) should be calibrated
22 annually, and the response of the detector to a check source should be established following
23 calibration (ANSI 2013). Instruments may require more frequent calibration if recommended by
24 the manufacturer. Recalibration of field instruments is also required if an instrument fails a
25 performance check or if it has undergone repair or any modification that could affect its
26 response. The system should be calibrated to minimize potential errors during data transmission
27 and retransmission. The user may decide to perform calibrations following industry-recognized
28 procedures (ANSI 1997, NCRP 1978, NCRP 1985, NCRP 1991, ISO 1988, HPS 1994a, HPS
29 1994b), or the user can choose to obtain calibration by an outside service, such as a major
30 instrument manufacturer or a health physics services organization. Calibrations should include
31 devices used to determine the position or location of samples or measurements, as
32 recommended by the manufacturer.

33 Additional technical details about instrument efficiencies and example calculations are
34 contained in **Section 4.12.5**.

35 4.8.4.5 Specificity

36 Specificity is the ability of the measurement method to measure the radionuclide of concern in
37 the presence of interferences. To determine whether specificity is an important measurement

⁶ The NIST policy on traceability can be found here: <https://www.nist.gov/calibrations/traceability>.

1 method performance characteristic, the planning team will need information about expected
2 concentration ranges for the radionuclides of concern and other chemical and radionuclide
3 constituents, along with chemical and physical attributes of the soil or surface being measured.
4 The importance of specificity depends on—

- 5 • the chemical and physical characteristics of the soil or surface
- 6 • the chemical and physical characteristics of the residual radioactive material
- 7 • the expected concentration range for the radionuclides of concern

8 If potential interferences are identified (e.g., inherent radioactive material, similar radiations), an
9 MQO should be established for specificity.

10 *4.8.4.6 Instrumentation Examples*

11 **Table 4.2** presents a list of common radionuclides along with recommended instruments for
12 field measurement methods that have proven effective based on past survey experience in the
13 decommissioning industry. This table provides a general indication of the detection capability of
14 commercially available instruments for field measurements. As such, **Table 4.2** may be used to
15 provide an initial evaluation of instrument capabilities for some common radionuclides at the
16 example DCGLs listed in the table. For example, consider a surface with ²⁴¹Am. **Table 4.2**
17 indicates that ²⁴¹Am is detectable at the example DCGLs and that viable direct measurement
18 instruments include gas-flow proportional (alpha mode) and alpha scintillation detectors.

19 Many radiation detection instruments can be used for both direct and scanning measurements.
20 The example DCGLs in **Table 4.2** are given for direct measurements only. Issues of
21 detectability (MDC) for scanning are more complicated than for direct measurements and
22 depend on things such as human response, height above the surface, and scanning speed.

23 **Table 4.2** should not be interpreted as providing specific values for an instrument's detection
24 capability, which is discussed in **Section 6.7**. In addition, NRC draft report NUREG-1506 (NRC
25 1995) and NUREG-1507 (NRC 1997a) provide further information on factors that may affect
26 survey instrumentation selection.

27 *4.8.5 Selection of Sample Collection Methods*

28 Sample characteristics—such as sample depth, volume, area, moisture level, and composition,
29 as well as sample preparation techniques that may alter the sample—are important planning
30 considerations for DQOs. Sample preparation may include, but is not limited to, removing
31 extraneous material, homogenizing, splitting, drying, compositing, and doing final preparations
32 of samples. Dose or risk pathway modeling should be representative of actual survey
33 conditions, to the extent practical, and modeling limitations should be well documented and
34 assessed. The sampling method should then consider assumptions made in the dose or risk
35 pathway modeling used to determine radionuclide DCGLs. For example, the actual depth and
36 area of residual radioactivity in the survey unit should be reflected in the modeling, and
37 sampling should be compatible with how the source was represented in the modeling. If a direct
38 measurement or scanning technique is used, it should also consider the compatibility of the
39 technique with the assumptions made in the dose or risk pathway modeling.

1 **Table 4.2: Examples of Field Measurement Instruments**

Nuclide	Structure Surfaces		Land Areas		Example Instruments		
	Example DCGL ^a (Bq/m ²)	Detectable	Example DCGL ^a (Bq/kg)	Detectable	Surface Activity	Soil Activity	Exposure Rate
³ H	2.0×10 ⁸	No	4.1×10 ³	No	ND ^b	ND	ND
¹⁴ C	6.2×10 ⁶	Yes	4.4×10 ²	No	GP _β	ND	ND
⁵⁴ Mn	5.4×10 ⁴	Yes	5.6×10 ²	Yes	GP _β , GM	γS, IS _γ	PIC, γS, IS _γ
⁵⁵ Fe	7.5×10 ⁶	No	3.7×10 ⁵	No ^c	ND	ND (IS _γ)	ND (IS _γ)
⁶⁰ Co	1.2×10 ⁴	Yes	1.4×10 ²	Yes	GP _β , GM	γS, IS _γ	PIC, γS, IS _γ
⁶³ Ni	3.0×10 ⁶	Yes	7.8×10 ⁴	No	GP _β	ND	ND
⁹⁰ Sr	1.5×10 ⁴	Yes	6.3×10 ¹	No ^c	GP _β , GM	ND (GM, GP _β)	ND
⁹⁹ Tc	2.2×10 ⁶	Yes	7.0×10 ²	No	GP _β , GM	ND	ND
¹³⁷ Cs	4.7×10 ⁴	Yes	4.1×10 ²	Yes	GP _β , GM	γS, IS _γ	PIC, γS, IS _γ
¹⁵² Eu	—	Yes	3.2×10 ²	Yes	GP _β , GM	γS, IS _γ	PIC, γS, IS _γ
²²⁶ Ra (C) ^d	—	Yes	2.6×10 ¹	Yes	GP _α , αS	γS, IS _γ	PIC, γS, IS _γ
²³² Th (C) ^d	—	Yes	4.1×10 ¹	Yes	GP _α , αS, GP _β	γS, IS _γ	PIC, γS, IS _γ
²³⁸ U (C)	—	Yes	1.9×10 ¹	Yes	GP _α , αS, GP _β , IS _γ	γS, IS _γ , GP _β	PIC, γS, IS _γ
²³⁹ Pu	—	Yes	8.5×10 ¹	No ^c	GP _α , αS	ND (IS _γ)	ND
²⁴¹ Am	—	Yes	7.8×10 ¹	Yes	GP _α , αS	γS, IS _γ	PIC, γS, IS _γ

Abbreviations: Bq = becquerels; m² = square meters; kg = kilograms; GP_α = gas-flow proportional counter (α mode); GM = Geiger-Mueller survey meter; GP_β = gas-flow proportional counter (β mode); PIC = pressurized ionization chamber; αS = alpha scintillation survey meter; γS = gamma scintillation (gross); IS_γ = in situ gamma spectrometry.

^a Example DCGLs are provided only for discussion and are based on values given in NRC Report NUREG-1757 (Rev. 2), Volume 1, Tables B.1 and B.2 (NRC 2006). Example DCGLs should not be used in place of approved DCGLs.

^b ND = Not detectable.

^c Possibly detectable at limits for areas of elevated activity.

^d For decay chains having two or more radionuclides of significant half-life that reach secular equilibrium, the notation "(C)" indicates the direct measurement techniques assume the presence of decay products in the chain.

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1 Conceptual models reflected in commonly used codes used to derive DCGLs should be
2 understood. For example, if surficial residual radioactive material exists at a thickness less than
3 15 cm (6 inches), commonly used codes either assume or allow the residual radioactive
4 material to be uniformly mixed throughout a larger thickness to simulate such processes as soil
5 mixing due to plowing. Yu et al. (1993) allows both the thickness of contamination and the
6 mixing depth to be specified. NRC (1992b) assumes the residual radioactivity is located in the
7 top 15 cm of soil. Similarly, models may be based on dry weight, which may necessitate either
8 drying samples or data transformation to account for dry weight. The DQOs and subsequent
9 direction to the laboratory for analysis might include removal of material not relevant for
10 characterizing the sample, such as pieces of glass, twigs, rocks, pebbles, or leaves. In all
11 cases, it is important to understand the modeling assumptions and how the data collected will
12 be compared to DCGLs derived from the modeling to ensure the fidelity of the statistical survey
13 results.

14 Both sample depth and area are considerations in determining appropriate sample volume, and
15 sample volume is a key consideration for determining the laboratory MDC. The depth should
16 also correlate with the conceptual model developed in **Chapter 3** and upgraded throughout the
17 RSSI process. For example, if data collected during the HSA indicate that residual radioactive
18 material may exist to a certain depth, then samples should be deep enough to support the
19 survey objectives, such as for the scoping or characterization survey. Taking samples as a
20 function of depth might also be a survey design objective, such as for scoping, characterization,
21 or remediation support. Although some models and codes may allow for the input of (or can be
22 manipulated to consider) heterogeneous radionuclide distributions, other models and codes
23 may assume uniform residual radioactivity. In cases where the models are incapable of
24 representing the complexity of the sources, data may need to be processed for use in the
25 model. Impacts associated with the modeling simplifications should be well understood and
26 documented.

27 Additionally, the design team needs to consider sampling both data needs and data quality
28 indicators as determined from the DQO process. The design team should review the information
29 in **Section 7.2** when designing the sampling portion of the FSS plan. The decision maker and
30 the survey planning team need to identify the data needs for the survey being performed,
31 including—

- 32 • type of samples to be collected or measurements to be performed (**Chapter 5**)
- 33 • radionuclide(s) of interest (**Section 4.3**)
- 34 • number of samples to be collected (**Sections 5.3.3–5.3.5**)
- 35 • type and frequency of field QC samples to be collected (**Section 4.9**)
- 36 • amount of material to be collected for each sample (**Sections 4.7.3 and 7.5**)
- 37 • sampling locations and frequencies (**Section 5.3.7**)
- 38 • SOPs to be followed or developed
- 39 • measurement method uncertainty (**Section 6.4**)
- 40 • target detection capabilities for each radionuclide of interest (**Section 6.3**)
- 41 • cost of the methods being evaluated (cost per analysis and total cost) (**Appendix H**)

- 1 • necessary turnaround time
- 2 • sample preservation and shipping requirements (**Section 7.6**)
- 3 • specific background for each radionuclide of interest (**Section 4.5**)
- 4 • DCGL for each radionuclide of interest (**Section 4.3**)
- 5 • measurement documentation requirements (**Section 5.3.11**)
- 6 • sample tracking requirements (**Section 7.8**)

7 In addition to the above items, the design team needs to consider the following data quality
8 indicators:

- 9 • precision
- 10 • bias
- 11 • representativeness
- 12 • comparability
- 13 • completeness
- 14 • others as discussed in **Section 7.2.2.6**

15 See **Section 7.2** for a detailed discussion of the DQOs and MQOs for sampling.

16 Under some circumstances, it might be useful to assess the radionuclide concentrations on
17 different size fractions to better assess transport processes assumed in some dose models.
18 **Chapters 6 and 7** present more detail regarding the application of these survey planning
19 considerations.

20 **4.8.6 Selection of Measurement Techniques**

21 In practice, the DQO process is used to obtain a proper balance among the use of various
22 measurement techniques (scanning, direct, and laboratory). In general, there is an inverse
23 correlation between the cost of a specific measurement technique and the detection levels
24 being sought. Depending on the survey objectives, important considerations include survey
25 costs and choosing an appropriate measurement method.

26 A certain minimum number of direct measurements or samples may be needed to demonstrate
27 compliance with the release criteria based on certain statistical tests (see **Section 5.3.2**).
28 Alternatively, if there is sufficient detection capability and an acceptable level of measurement
29 method uncertainty, a scan-only survey technique can (with the proper application of the DQO
30 process and regulatory approval) be used to demonstrate compliance with the DCGL_w. The
31 potential for areas of elevated residual radioactive material may also have to be considered for
32 designing scanning surveys, as the need to identify areas of elevated activity may affect the
33 number of measurements. Some measurements may provide information of a qualitative nature
34 to supplement other measurements. An example of such an application is in situ gamma
35 spectrometry to demonstrate the absence (or presence) of specific radionuclides.

1 Assuming the residual radioactive material can be detected, either directly or by measuring a
2 surrogate radionuclide in the mixture, the next decision point depends on whether the
3 radionuclide being measured is present in background. Gross measurement methods will likely
4 be more appropriate for measuring concentrations of radioactive materials on surfaces in
5 structures, scanning for locations of elevated activity, and determining exposure rates.
6 Radionuclide-specific measurement techniques, such as gamma spectrometry, provide a
7 marked increase in detection capability over gross measurements because of their ability to
8 screen out contributions from other sources. **Figure 4.2** illustrates the sequence of steps in
9 determining the type of survey design needed—that is, whether field measurement techniques
10 can be applied at a particular site along with sampling or if a scan-only design is more
11 appropriate. The selection of appropriate instruments for scanning, direct measurement, and
12 sampling and analysis should be survey specific.

13 **4.8.7 Data Conversion**

14 Radiation survey data are usually obtained in units, such as the number of counts per unit time,
15 which have no intrinsic meaning relative to DCGLs. For comparison of survey data to DCGLs,
16 the survey data from field and laboratory measurements should be converted to DCGL units.
17 Alternatively, the DCGL can be converted into the same units used to record survey results.
18 Either method relies on understanding the instrument response (efficiency). The FSS design
19 team should use the DQO process to determine and document the proper methods used to
20 compare instrument results and DCGLs. Additional details are provided in **Sections 4.12.6 and**
21 **6.7.**

22 **4.8.8 Additional Planning Considerations Related to Measurements**

23 **4.8.8.1 Selecting a Field Service Provider**

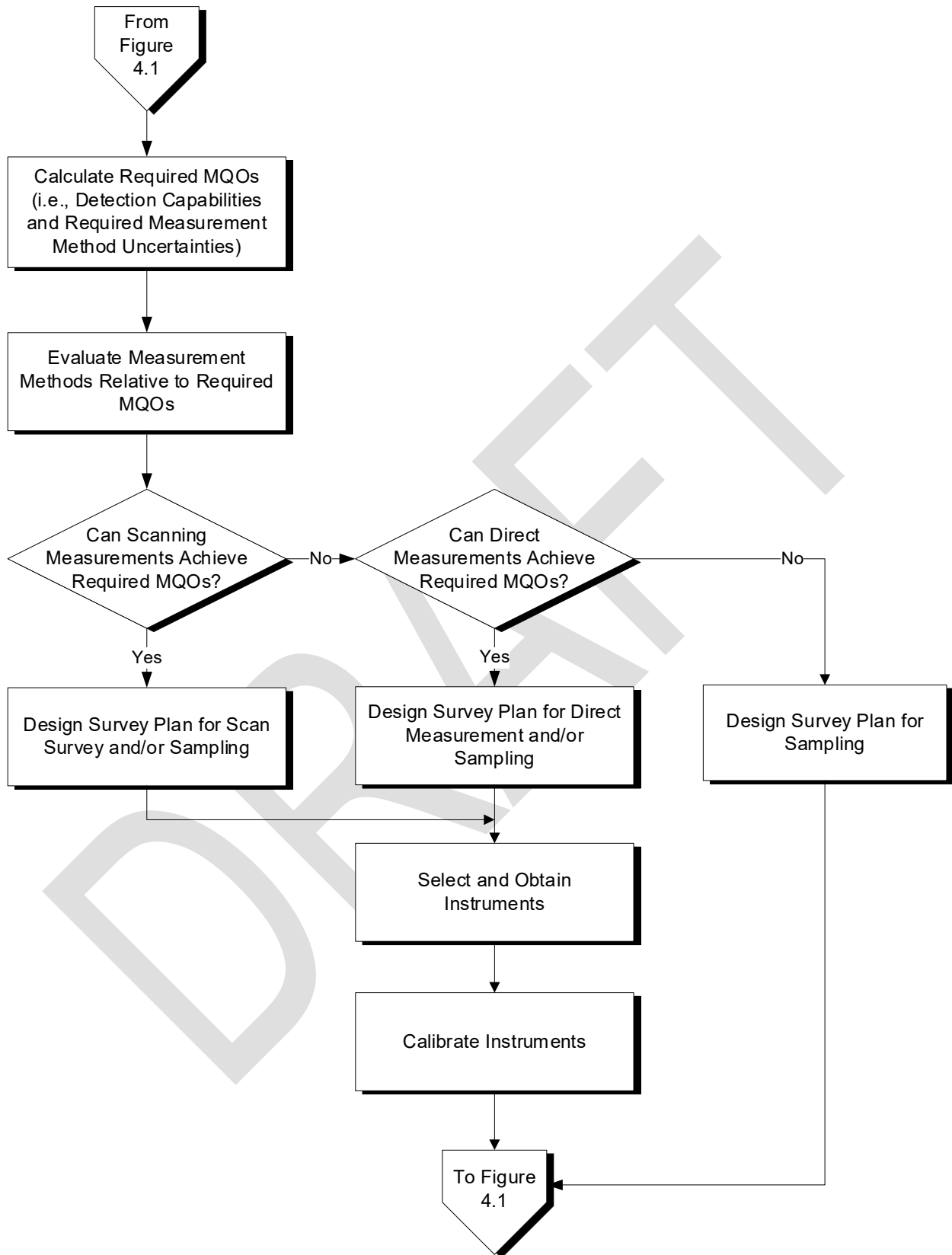
24 The survey design team should start the process of selecting a service provider to perform field
25 data collection early in the planning process. Six criteria that should be considered are—

- 26 • validated SOPs
- 27 • experience with similar data collection activities
- 28 • satisfactory performance evaluations or technical review results
- 29 • adequate capacity to perform the all the data collection activities
- 30 • internal QC program
- 31 • protocols for method performance documentation, sample tracking and security, and
32 documentation of results

33 More details can be found in **Section 6.5.**

34 **4.8.8.2 Radon Measurements**

35 In some cases, radon may be detected within structures that do not contain residual radioactive
36 material; conversely, some structures that contain residual radioactive material may not yield
37 detectable radon or thoron. Consult with your regulator for the applicability of radon or thoron
38 measurements as part of a site survey.



1

2 **Figure 4.2: Flow Diagram for Field Survey Design**

1 If radon is a concern for the FSS, the design team should work with the appropriate regulatory
2 agency to determine the applicability of radon or thoron measurements. Because of the
3 widespread nature of indoor air radon, many states have developed requirements for
4 certification/qualification of people who perform radon services. Therefore, as part of the
5 qualifications for the service provider, determine whether the measurement provider or the
6 laboratory analyzing the measurements is required to be certified by the state or locality where
7 the work is being performed. State radon contacts can be found at
8 [https://www.epa.gov/radon/find-information-about-local-radon-zones-and-state-contact-](https://www.epa.gov/radon/find-information-about-local-radon-zones-and-state-contact-information)
9 [information.](https://www.epa.gov/radon/find-information-about-local-radon-zones-and-state-contact-information)

10 More details can be found in **Section 6.8**.

11 *4.8.8.3 Specialized Equipment*

12 The survey team must plan for using any specialized equipment other than radiation detectors
13 (e.g., global positioning systems [GPS], local microwave or sonar beacons and receivers, laser
14 positioning systems, etc.). Because these specialized systems are continuously being modified
15 and developed for site-specific applications, it is not possible to provide detailed descriptions of
16 every system. **Section 6.9** provides examples of specialized equipment that have been applied
17 to radiation surveys and site investigations.

18 **4.9 Site Preparation**

19 Site preparation involves obtaining consent for performing the survey, establishing the property
20 boundaries, evaluating the physical characteristics of the site, accessing surfaces and land
21 areas of interest, and establishing a reference coordinate system. Site preparation may also
22 include removing equipment and materials that restrict access to surfaces. The presence of
23 furnishings or equipment will restrict access to building surfaces and add additional items that
24 the survey should address.

25 *4.9.1 Consent for Survey*

26 When facilities or sites are not owned by the organization performing the surveys, consent from
27 the site or equipment owner should be obtained before conducting the surveys. All appropriate
28 Federal, State, Tribal, and local officials, as well as the site owner and other affected parties,
29 should be notified of the survey schedule. **Section 3.6** discusses consent for access, and
30 additional information based on the Comprehensive Environmental Response, Compensation,
31 and Liability Act is available from EPA (EPA 1987c).

32 *4.9.2 Property Boundaries*

33 Property boundaries may be determined from property survey maps furnished by the owners or
34 from plat maps obtained from city or county tax maps. Large-area properties and properties with
35 obscure boundaries or missing survey markers may require the services of a professional land
36 surveyor. A professional land surveyor can also tie a site radiological survey grid into the
37 existing land survey of the site or to an official State or municipal survey grid. Such a tie-in has
38 the advantage of making the radiological survey grid reproducible in the future.

39 If the radiological survey is only performed inside buildings, a tax map with the buildings
40 accurately located will usually suffice for site/building location designation.

1 **4.9.3 Physical Characteristics of the Site**

2 The physical characteristics of the site will have a significant impact on the complexity,
3 schedule, and cost of a survey. These characteristics include the number and size of structures,
4 type of building construction, wall and floor penetrations, pipes, building condition, total area,
5 topography, soil type, and ground cover. In particular, the accessibility of structures and land
6 areas (**Section 4.9.4**) has a significant impact on the survey effort. In some cases, survey
7 techniques (e.g., in situ gamma spectrometry or scanning surveys discussed in **Chapter 6**) can
8 preclude or reduce the need to gain physical access or use intrusive techniques. This should be
9 considered during survey planning.

10 **4.9.3.1 Structures**

11 Building design and condition will have a marked influence on the survey efforts. The time
12 involved in conducting a survey of building interior surfaces is essentially directly proportional to
13 the total surface area, recognizing that upper wall and ceiling areas require more time than floor
14 and lower wall surveys. For this reason, the degree of survey coverage decreases as the
15 potential for residual radioactive material decreases. Judgment measurements and sampling,
16 which are performed in addition to the measurements performed for certain survey designs, are
17 recommended in areas likely to have accumulated deposits of residual radioactive material. As
18 discussed in **Section 8.5**, judgment measurements and samples are compared directly to the
19 appropriate DCGL.

20 The condition of surfaces after remedial action may affect the survey process. Removing
21 radioactive material that has penetrated a surface usually involves removing the surface
22 material. As a result, the floors and walls of remediated facilities are frequently badly scarred or
23 broken up and are often very uneven. Such surfaces are more difficult to survey, because it is
24 not possible to maintain a fixed distance between the detector and the surface. In addition,
25 scabbled or porous surfaces may significantly attenuate radiations—particularly alpha and low-
26 energy beta particles. Use of monitoring equipment on wheels is precluded by rough surfaces,
27 and such surfaces also pose an increased risk of damage to fragile detector probe faces. These
28 factors should be considered during the calibration of survey instruments; NRC report NUREG-
29 1507 (NRC 1997a) provides additional information on how to address these surface conditions.
30 The condition of the building should also be considered from a safety and health standpoint
31 before a survey is conducted. A structural assessment may be needed to determine whether the
32 structure is safe to enter.

33 Expansion joints, stress cracks, drains, and penetrations into floors and walls for piping, conduit,
34 anchor bolts, etc., are potential sites for accumulation of residual radioactive material and
35 pathways for migration into subfloor soil and hollow wall spaces. Drains, sewers, and septic
36 systems can contain residual radioactive material, and wall/floor interfaces are also likely
37 locations for residual radioactive material. Coring, drilling, or other such methods may be
38 necessary to gain access for surveying. Intrusive surveying may require permitting by local
39 regulatory authorities. Additionally, suspended ceilings may cover areas of potential residual
40 radioactive material, such as ventilation ducts and fixtures. There may be other materials
41 introduced that were not part of the original construction—such as floor tiles, partitions,
42 insulation, additional concrete slabs, and paint—that may cover residual radioactive material.

43 Exterior building surfaces will typically have a low potential for residual radioactive material;
44 however, there are several locations that should be considered during survey planning. If there
45 are roof exhausts or roof accesses that allow for radioactive material movement, or if the facility
46 is proximal to the air effluent discharge points, the possibility for residual radioactive material on

1 the roof should be considered. Because roofs are periodically resurfaced, radioactive material
2 may be trapped in roofing material, and sampling this material may be necessary. Such roof
3 drainage points as driplines along overhangs, downspouts, and gutters are also important
4 survey locations. Roofs may also accumulate radioactive material from fallout, or roof materials
5 may contain elevated levels of naturally occurring radioactive material (e.g., elevated uranium in
6 roof tar). Wall penetrations for process equipment, piping, and exhaust ventilation are potential
7 locations for exterior residual radioactive material. Window ledges and outside exits (doors,
8 doorways, landings, stairways, etc.) are also building exterior surfaces that should be
9 addressed.

10 *4.9.3.2 Building Materials*

11 In addition to radiological surveys of the building surfaces described in **Section 4.8.3.1**, it may
12 also be necessary to survey any building materials removed from the building as part of its
13 demolition, remediation, or renovation. Guidance for the design and implementation of
14 radiological surveys of these materials is provided in MARSAME (NRC 2009).

15 *4.9.3.3 Land Areas*

16 Depending on site processes and operating history, the radiological survey may include varying
17 portions of the land areas. Open land or paved areas with a potential for residual radioactive
18 material should include storage areas (e.g., equipment, product, waste, and raw material), liquid
19 waste collection lagoons and sumps, areas downwind (based on predominant wind directions
20 on an average annual basis, if possible) of stack release points, and surface drainage
21 pathways. Additionally, roadways and railways that may have been used for transport of
22 improperly contained radioactive materials could also have an accumulation of residual
23 radioactive material.

24 Building modifications should be reviewed to assess any expansions that might cover former
25 land disposal areas. Other land areas—such as wetlands, marshlands, or low-lying surface
26 areas—where waste material was used as fill material need to be assessed for potential
27 residual radioactive material. In some instances, the waste material is covered with clean
28 backfill material to grade to ground surface. Archived aerial photos, historical maps, and
29 interviews can be used to assess the potential presence of such areas.

30 Buried piping, underground tanks, fill areas, sewers, spill areas, and septic leach fields that may
31 have received radioactive liquids are locations of possible residual radioactive material that may
32 necessitate sampling of subsurface soil (**Section 7.5.3**). Information regarding soil type
33 (e.g., clay, sand) may provide insight into the retention or migration characteristics of specific
34 radionuclides. The need for special sampling by coring or split-spoon equipment should be
35 anticipated for characterization surveys.

36 If radioactive waste has been removed, surveys of excavated areas will be necessary before
37 backfilling with clean fill. If the waste is to be left in place, subsurface sampling around the burial
38 site perimeter to assess the potential for future migration may be necessary.

39 Additionally, rivers, harbors, shorelines, and other outdoor areas with a potential for residual
40 radioactive material may require survey activities including environmental media (e.g., sediment
41 and biota) associated with these areas.

1 **4.9.4 Clearing to Provide Access**

2 In addition to the physical characteristics of the site, a major consideration is how to address
3 difficult-to-access areas that have a potential for residual radioactive material. Difficult-to-access
4 areas may need significant effort and resources to perform adequate surveys. This section
5 provides a description of common difficult-to-access areas that may have to be considered. The
6 level of effort expended to access such areas should be commensurate with the potential for
7 residual radioactive material. For example, the potential for the presence of residual radioactive
8 material behind walls should be established before significant effort is expended to remove
9 drywall.

10 **4.9.4.1 Structures**

11 When necessary, structures and indoor areas should be sufficiently cleared to permit
12 completion of the survey. Clearing includes providing access to interior surfaces (e.g., drains,
13 ducting, tanks, pits, ceiling areas, and equipment) by removing covers, disassembly, or other
14 means of producing adequate openings.

15 Such building features as ceiling height, construction materials, ducts, pipes, etc., will determine
16 the ease of accessibility of various surfaces. Scaffolding, cranes, lifts, or ladders may be
17 necessary to reach some surfaces, and dismantling portions of the building may be required.

18 The presence of furnishings and equipment will restrict access to building surfaces and add
19 additional items that the survey should address. Any remaining equipment indirectly involved in
20 the process may need to be dismantled to evaluate the radiological status, particularly of
21 difficult-to-access parts of the equipment. Removing or relocating certain furnishings, such as
22 laboratory benches and hoods, to obtain access to floors and walls may also be necessary. The
23 amount of effort and resources dedicated to such removal or relocation activities should be
24 commensurate with the potential for residual radioactive material. Where the potential is low, a
25 few spot-checks may be sufficient to provide confidence that covered areas are free of residual
26 radioactive material. In other cases, complete removal may be warranted. Guidance for the
27 survey and assessment of materials and equipment is included in the MARSAME Manual.

28 Piping, drains, sewers, sumps, tanks, and other components of liquid-handling systems present
29 special difficulties because of the difficulty in accessing interior surfaces. Process information,
30 operating history, and preliminary monitoring at available access points will assist in evaluating
31 the extent of sampling and measurements included in the survey. Some specialized survey
32 techniques for drains and sewers have been developed and are effective for the measurement
33 of some radionuclides.

34 If the building is constructed of porous materials (e.g., wood, concrete, masonry, etc.) and the
35 surfaces were not sealed, residual radioactive material may be found in the walls, floors, and
36 other surfaces. It may be necessary to obtain cores of these surfaces for laboratory analysis.

37 Another accessibility problem is the presence of residual radioactive material beneath tile or
38 other floor coverings. This often occurs because the covering was placed over surfaces
39 containing residual radioactive material, or the joints in tile were not sealed to prevent
40 penetration. The practice in some facilities has been to "fix" radioactive material (particularly
41 alpha emitters) by painting over the surface of the affected area. Thus, actions to obtain access
42 to surfaces, such as removing wall and floor coverings (including paint, wax, or other sealer)
43 and opening drains and ducts, may be necessary to enable representative measurements of the
44 residual radioactive material. This material may also require a radiation survey to ensure no

1 radioactive material was transferred during the removal process. If alpha radiation or very low
2 energy beta radiation is to be measured, the surface should be free of overlying material, such
3 as dust and water, which may significantly attenuate the radiations.

4 *4.9.4.2 Land Areas*

5 If ground cover needs to be removed or if other obstacles limit access by survey personnel or
6 necessary equipment, the time and expense of making land areas accessible should be
7 considered. In addition, contamination control procedures need to be developed to prevent the
8 spreading of radioactive material during ground cover removal or the use of heavy equipment.

9 Whenever possible, the property owner should perform the removal or relocation of equipment
10 and materials that require special precautions to prevent damage or maintain inventory
11 accountability. Clearing open land of brush and weeds will usually be performed by a
12 professional land-clearing organization under subcontract arrangements. However, survey
13 personnel may perform minor land-clearing activities as needed.

14 An important consideration prior to clearing is the possibility of bio-uptake of radionuclides in the
15 plant material to be cleared. Special precautions to avoid exposure of personnel involved in
16 clearing activities may be necessary. Radiological screening surveys should be performed to
17 ensure that cleared material or equipment does not contain residual radioactive material.

18 The extent of site clearing in specific areas depends primarily on the potential for residual
19 radioactive material to exist in those areas where—

- 20 • The radiological history or results of previous surveys indicate a low potential for residual
21 radioactive material in an area; it may be sufficient to perform only minimum clearing to
22 establish a reference coordinate system.
- 23 • Residual radioactive material is known to exist, or a high potential for it necessitates
24 completely clearing an area to provide access to all surfaces.
- 25 • New findings as the survey progresses indicate that additional clearing is needed.

26 Open land areas may be cleared by heavy machinery (e.g., bulldozers, bushhogs, and
27 hydroaxes). However, care should be exercised to prevent relocation of surface radioactive
28 material or damage to such site features as drainage ditches, utilities, fences, and buildings.
29 Minor land clearing may be performed using manually operated equipment, such as brush
30 hooks, power saws, knives, and string trimmers. Brush and weeds should be cut to the
31 minimum practical height necessary to facilitate measurement and sampling activities
32 (approximately 15 cm). Care should be exercised to prevent unnecessary damage to or removal
33 of mature trees, shrubs, or historical or cultural resources.

34 Potential ecological or cultural damage that might result from an extensive survey should be
35 considered. If a survey is likely to result in significant or permanent damage to environmental or
36 cultural resources, appropriate environmental and cultural analyses should be conducted prior
37 to initiating the survey.

38 *4.9.5 Reference Coordinate System*

39 *4.9.5.1 Establishment*

40 Reference coordinate systems are established at the site to—

- 1 • Facilitate the selection of measurement and sampling locations.
 - 2 • Provide a mechanism for referencing a measurement to a specific location so that the same
3 survey point can be located again.
- 4 A survey reference coordinate system consists of a grid of intersecting lines referenced to a
5 fixed site location or benchmark. Typically, the lines are arranged in a perpendicular pattern,
6 dividing the survey location into squares or blocks of equal area; however, other types of
7 patterns (e.g., three-dimensional, polar) have been used.
- 8 The reference coordinate system used for a particular survey should provide a level of
9 reproducibility consistent with the objectives of the survey. For example, commercially available
10 single-frequency GPS devices can typically locate a position to within approximately 5 m, while
11 dual-frequency receivers and augmentation systems can provide real-time precision on the
12 order of a few centimeters. On the other hand, a metal bar can be driven into the ground to
13 provide a long-term reference point for establishing a local reference coordinate system. Some
14 States have official grid systems, and if such a system exists in a particular State, consideration
15 should be given to tying a site grid into the official State grid.
- 16 Reference coordinate system patterns on horizontal surfaces are usually identified numerically
17 on one axis and alphabetically on the other axis, or in distances in different compass directions
18 from the grid origin. Examples of structure interior and land area grids are shown in
19 **Figures 4.3–4.5**. Grids on vertical surfaces may include a third designator, indicating position
20 relative to floor or ground level. Overhead measurement and sampling locations (e.g., ceiling
21 and overhead beams) are referenced to corresponding floor grids.
- 22 For surveys of Class 1 and Class 2 areas, basic coordinate system patterns at 1–2 m intervals
23 on structure surfaces and at 10–20 m intervals of land areas may be sufficient for the purpose of
24 identifying FSS locations with a reasonable level of effort. Gridding of Class 3 areas may also
25 be necessary to facilitate referencing of survey locations to a common system or origin but, for
26 practical purposes, may typically be at larger intervals (e.g., 5–10 m for large structural surfaces
27 and 20–50 m for land areas). For the FSS, the required scanning percentages, number of
28 discrete survey locations for direct measurements, and number of sample locations will depend
29 on the classification of the survey unit (see **Chapter 5**).
- 30 Reference coordinate systems on structure surfaces are usually marked by chalk lines or paint
31 along the entire grid line or at line intersections. Land area reference coordinate systems are
32 usually marked by wooden or metal stakes driven into the surface at reference line
33 intersections. The selection of an appropriate marker depends on the characteristics and routine
34 uses of the surface. Where surfaces prevent installation of stakes, the reference line
35 intersection can be marked by painting.
- 36 Three basic coordinate systems are used for identifying points on a reference coordinate
37 system. The reference system shown in **Figure 4.3** references grid locations using numbers on
38 the vertical axis and letters on the horizontal axis. The reference system shown in **Figure 4.4**
39 references distances from the (0,0) point using the compass directions N (north), S (south),
40 E (east), and W (west). The reference system shown in **Figure 4.5** references distances along
41 and to the R (right) or L (left) of the baseline.
- 42 In addition, a less frequently used reference system is the polar coordinate system, which
43 measures distances along transects from a central point. Polar coordinate systems are
44 particularly useful for survey designs to evaluate effects of stack emissions, where it may be

1 desirable to have a higher density of samples collected near the stack and fewer samples with
2 increasing distance from the stack.

3 **Figure 4.5** shows an example grid system for an outdoor land area. The first digit or set of digits
4 includes an L or R (separated from the first set by a comma) to indicate the distance from the
5 baseline in units (m) and the direction (left or right) from the baseline. The second digit or set of
6 digits refers to the perpendicular distance from the (0,0) point on the baseline and is measured
7 in hundreds of units. Point A in the example of a reference coordinate system for survey of site
8 grounds, **Figure 4.5**, is identified as (100R, 2+00) (i.e., 200 m from the baseline and 100 m to
9 the right of the baseline). Fractional distances between reference points are identified by adding
10 the distance beyond the reference point and are expressed in the same units used for the
11 reference coordinate system dimensions. Point B on **Figure 4.5** is identified as (25R, 1+30).

12 Open land reference coordinate systems should be referenced to a location on an existing State
13 or local reference system or to a U.S. Geological Survey (USGS) benchmark. (This may require
14 the services of a professional land surveyor.) GPS is capable of locating reference points in
15 terms of latitude and longitude (**Section 6.9.2** provides descriptions of positioning systems.)

16 Following the establishment of the reference coordinate system, a drawing is prepared by the
17 survey team or the land surveyor. This drawing indicates the reference lines, site boundaries,
18 and other pertinent site features and provides a legend showing the scale and a reference
19 compass direction.

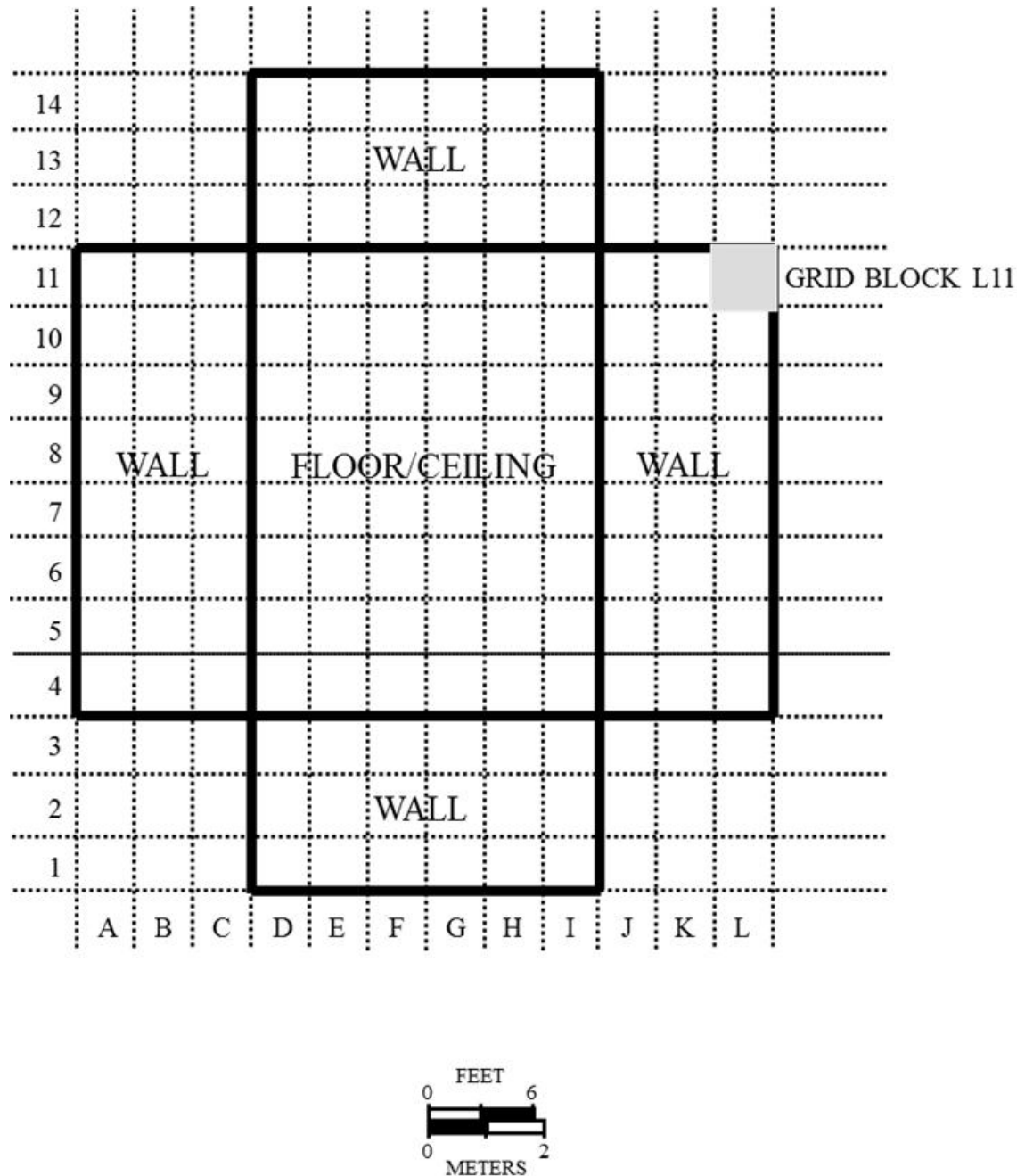
20 *4.9.5.2 Quality System Considerations*

21 The concept of the quality system was introduced in **Section 4.2.2**. The process used to
22 develop the reference coordinate system should be recorded in the survey planning
23 documentation (e.g., the QAPP). Any deviations from the requirements developed during
24 planning should be documented when the reference coordinate system is established.

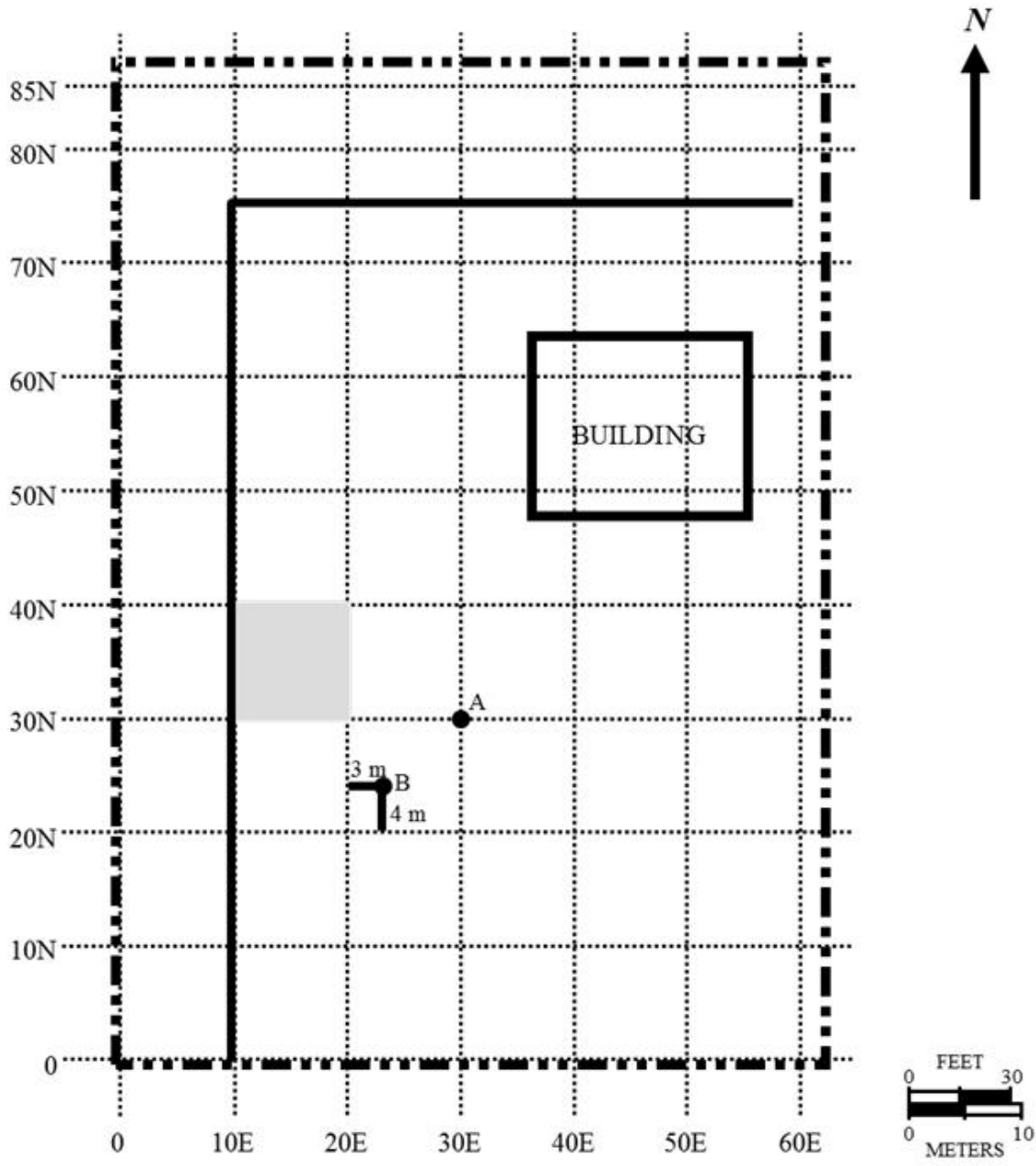
25 When the survey reference coordinate system is referenced to a fixed site location or
26 benchmark on a known geographic coordinate system (GCS) or projected coordinate system
27 (projection) (e.g., a State system), or the survey reference coordinate system itself uses a
28 known GCS or projection rather than one of the three basic coordinate systems described in
29 **Section 4.9.5.1**, then the following information should be provided about the actual GCS or
30 projection used:

- 31 • name
- 32 • units used (e.g., feet, meters, etc.)
- 33 • zone
- 34 • datum
- 35 • spheroid
- 36 • method used to determine/obtain the coordinates (e.g., GPS)
- 37 • estimates of the accuracy and precision of the coordinates
- 38 • transformations used to convert from coordinates from one system to another

- 1 Ideally, this information should be provided in the spatial reference section of the metadata for
- 2 the GIS layer containing the data. If a GPS was used to obtain the coordinates, then information
- 3 should be included about the differential corrections made to the original GPS measurements.
- 4 It should be noted that the reference coordinate systems described in this section are intended
- 5 primarily for reference purposes and do not necessarily dictate the spacing or location of survey
- 6 measurements or samples. Establishment of a measurement grid to demonstrate compliance
- 7 with the DCGLs is discussed in **Section 5.3.7** and **Chapter 8**.



8
 9 **Figure 4.3: Indoor Grid Layout with Alphanumeric Grid Block Designation: Walls and**
 10 **Floors are Diagrammed as Though They Lay Along the Same Horizontal Plane**

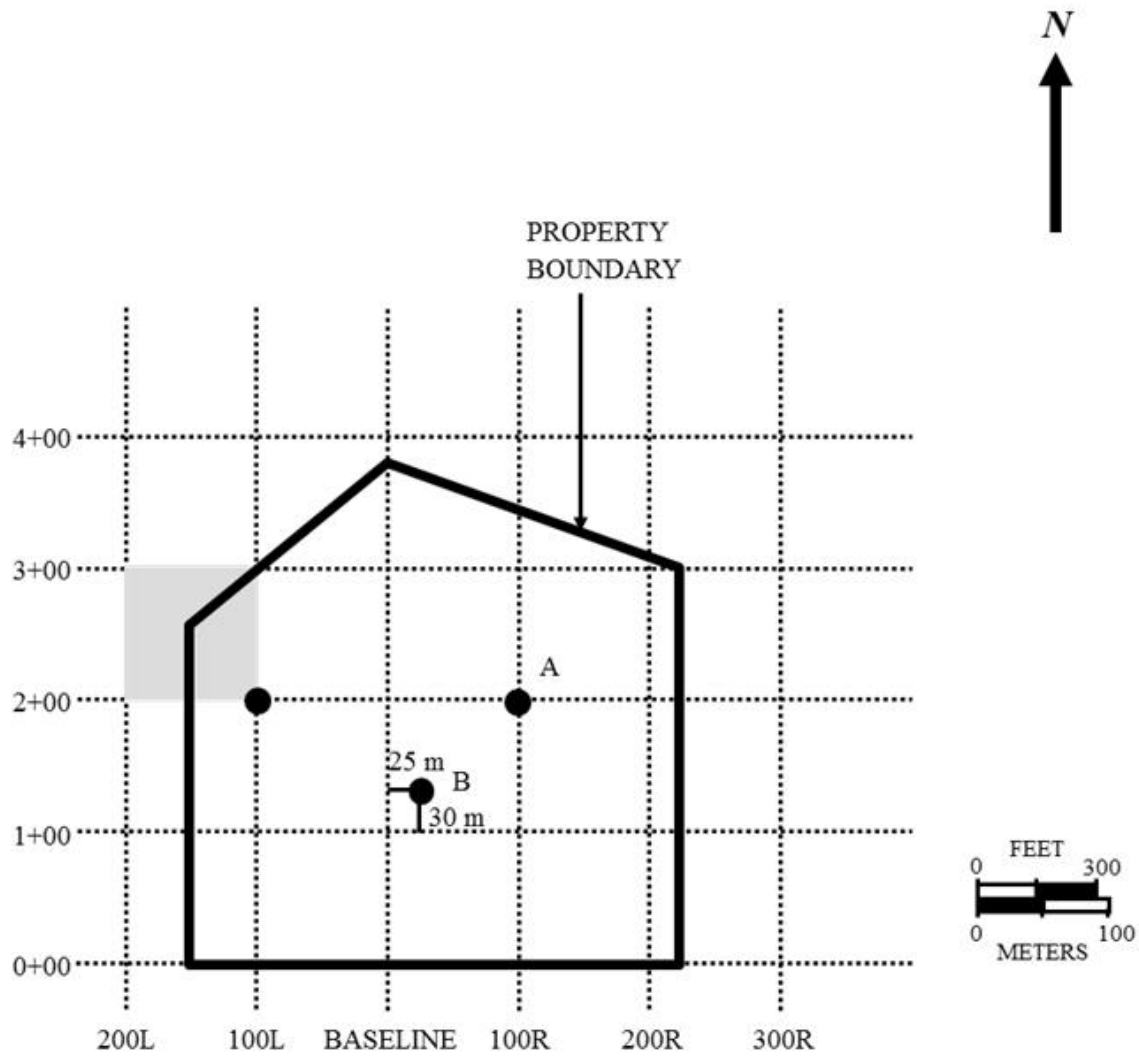


POINT A GRID COORDINATES 30E, 30N
POINT B GRID COORDINATES 23E, 24N
SHADED BLOCK GRID COORDINATES 10E, 30N

--- SURVEY UNIT BOUNDARY
— ONSITE FENCE

1

2 **Figure 4.4: Example of a Grid System for Survey of Site Grounds Using Compass**
3 **Directions**



POINT A GRID COORDINATES 100R, 2+00

POINT B GRID COORDINATES 25R, 1+30

SHADED BLOCK GRID COORDINATES 200L, 2+00

1

2 **Figure 4.5: Example of a Grid System for Survey of Site Grounds Using Distances Left or**
 3 **Right of the Baseline**

1 4.10 Health and Safety

2 Health and safety are emphasized as issues potentially affecting the implementation of
3 MARSSIM surveys. The focus of the health and safety program is minimizing environmental and
4 physical hazards (e.g., confined spaces, unstable surfaces, heat and cold stress) where these
5 issues may affect how a survey is designed and performed. Work areas and procedures that
6 present potential safety hazards must be identified and evaluated to warn personnel of potential
7 hazards. Personnel must be trained about potential physical and chemical safety hazards
8 (e.g., inhalation, adsorption, ingestion, injection/puncturing) and the potential for injury
9 (e.g., slips, trips, falls, burns). In addition, the presence or possibility of such environmental
10 hazards as poison ivy; ticks carrying Lyme disease; and poisonous snakes, spiders, rodents, or
11 insects should be noted. These hazards can affect the safety and health of the workers, as well
12 as the schedule for performing the survey. Some physical hazards require special procedures or
13 precautions. Steep slopes might require special gear for surveyors and instruments or might call
14 for dispensations from the regulatory agency to reduce or eliminate survey efforts in such areas.
15 The potential presence of unexploded ordnance (UXO) requires qualified explosive ordnance
16 disposal personnel to clear the survey unit of UXO and accompany survey personnel during the
17 survey.

18 A job safety analysis (JSA) should be performed prior to implementing a survey. The JSA offers
19 an organized approach to the task of locating problem areas for material handling safety (OSHA
20 2002). The JSA should be used to identify hazards and provide inputs for drafting a health and
21 safety plan (HASP). The HASP will address the potential hazards associated with survey
22 activities and should be prepared concurrently with the survey design. The HASP identifies
23 methods to minimize the threats posed by the potential hazards. The information in the HASP
24 may influence the selection of a measurement technique and disposition survey procedures.
25 Radiation work permits (RWPs) may be established to control access to radiologically controlled
26 areas. RWPs contain requirements from the JSA, such as dosimetry and personal protective
27 equipment (PPE), as well as survey maps illustrating predicted dose rates and related
28 radiological concerns (e.g., removable or airborne radioactive material). Hazard work permits
29 (HWPs) may be used in place of RWPs at sites with primarily physical or chemical hazards.

30 The JSA systematically carries out the basic strategy of accident prevention through the
31 recognition, evaluation, and control of hazards associated with a given job, as well as the
32 determination of the safest, most efficient method of performing that job. This process creates a
33 framework for deciding among engineering controls, administrative controls, and PPE for the
34 purpose of controlling or correcting unsafe conditions. Examples of these controls include—

- 35 • engineering controls, which are physical changes in processes or machinery (e.g., installing
36 guards to restrict access to moving parts during operation), storage configuration
37 (e.g., using shelves in place of piles or stacks)
- 38 • administrative controls, which are changes in work practices and organization
39 (e.g., restricted areas where it is not safe to eat, drink, smoke, etc.), including the placement
40 of signs to warn personnel of hazards
- 41 • PPE, which are clothing or devices worn by employees to protect against hazards
42 (e.g., gloves, respirator, full-body suits)

43 Correction measures may incorporate principles of all of the controls listed above. The preferred
44 method of control is through engineering controls, followed by administrative controls, and then
45 PPE.

1 Proper handling procedures for hazardous substances are documented in site-specific health
2 and safety plans. Compliance with all control requirements is mandatory to maintain a safe
3 working environment. Personnel must regard control requirements as a framework to facilitate
4 health and safety, while still taking responsibility for their own well-being. Being wary of safety
5 hazards remains an individual responsibility, and personnel must be aware of their surroundings
6 at all times in work areas.

7 **4.11 Documentation**

8 Concurrently with the FSS design, the design team should begin to draft the FSS report. In
9 many cases before the FSS is started, the regulator will require a report documenting the
10 proposed sampling and surveying plan, including ancillary documentation such as the QAPP.
11 The FSS report should present a complete and unambiguous record of the radiological status of
12 the survey unit, relative to the established DCGLs. To the extent possible, this should be
13 self-contained and contain a minimum of information incorporated by reference. Reporting
14 requirements for the FSS should be developed during planning and clearly documented in the
15 QAPP. The text below describes some of the information needed for review of an FSS:

Example 1: Information Needed for an FSS Review

A review by the U.S. Nuclear Regulatory Commission of the final status survey (FSS) documentation is undertaken to “verify that the results of the FSS demonstrate that the site, area, or building meet the radiological criteria for license termination” (NRC, 2006). The information needed by the NRC for a review is summarized below. For more details, see NRC (2006).

- an overview of the results of the FSS
- a summary of the derived concentration guideline levels
- a discussion of any differences from prior submissions
- a description of the method by which the number of samples was determined for each survey unit
- a summary of the values used to determine the number of samples and a justification for these values
- the results for each survey unit
- analytical methods used
- detection limits
- estimates of uncertainties or sample standard deviations
- a description of any changes in initial survey unit assumptions relative to the extent of residual radioactive material
- a description of how “as low as reasonably achievable” practices were employed to achieve final activity levels

In addition to the items above, the design team should have the following information available (NRC, 2006):

- the results of previously conducted in-process inspections and confirmatory surveys
- the licensee's quality assurance/quality control program
- confirmation that the changes to prior submissions are not significant and are technically correct
- issues (a) identified by intervenors and stakeholders and (b) raised in allegations to assure such issues have been satisfactorily resolved
- descriptions of the survey units to determine if any special survey situations are present
- results of elevated measurement comparisons
- results of the appropriate statistical tests (e.g., Wilcoxon Rank Sum and Sign tests) to confirm that results indicate compliance
- specific parts of the FSS and supporting data that affect the FSS but that were not available when the decommissioning or license termination plan was approved

1 4.12 Application of Survey Planning Concepts with Example Calculations

2 This section is intended to expand on the content presented in this chapter, provide a general
3 overview, and familiarize the MARSSIM user with the application of the concepts in
4 **Sections 4.4 through 4.7** to planning FSSs.⁷ Greater detail appears in the chapters that follow.

5 4.12.1 Scenario A or Scenario B?

6 Occasionally, the design team will need to determine the appropriate scenario for use in
7 statistical hypothesis testing as the basis for the FSS. Under Scenario A, it is assumed that the
8 concentration of residual radioactive material equals or exceeds the release criteria. For
9 Scenario B, it is assumed that the concentration of residual radioactive material meets the
10 release criteria (i.e., less than the action level [AL]). Historically, MARSSIM recommended the
11 use of Scenario A, which put the burden of proof that the survey unit met the release criteria on
12 the individuals designing the survey. In Scenario B, the burden of proof is no longer on the
13 individuals designing the survey and thus should be used with caution and only in those
14 situations where Scenario A is not an effective alternative.

15 The basic problem is one of being able to distinguish residual radioactive material from
16 background. If a radionuclide has a relatively small DCGL_w and is present in the background
17 with a relatively large variation, then it requires a large number of measurements to determine if
18 the residual concentration exceeds the DCGL_w. The choice of Scenario A or Scenario B should
19 be based on which null hypothesis is easier to live with if false (NRC 1998a). If the DCGL_w is
20 large relative to the measurement or background variation, then Scenario A should be chosen
21 (NRC 1998a). This is likely the more common situation. Conversely, if the DCGL_w is small

⁷ **Appendix A** contains a detailed example of MARSSIM applied to executing FSS for a single radionuclide. This example builds on examples in **Chapters 5 and 8**.

1 relative to the measurement or background variation, then Scenario B should be chosen
 2 (NRC 1998a).

3 The MARSSIM user should review the information in **Section 5.3.1** and NRC (1998a) for more
 4 information on selecting the appropriate scenario. The remainder of the examples in this section
 5 are based on Scenario A.

6 **4.12.2 DCGL Calculations**

7 **4.12.2.1 Decay Series**

8 In this example, the surface activity DCGL_W for natural thorium (Th-nat) is 1,000 Bq/m²
 9 (600 dpm/100 cm²), and all of its decay products are in secular equilibrium—that is, for each
 10 disintegration of thorium-232 (²³²Th), a total of six alpha and four beta particles are emitted in
 11 the thorium decay series. Note that in this example, the surface activity DCGL_W of 1,000 Bq/m²
 12 is assumed to apply to the total activity from all members of the decay chain. In this situation,
 13 the corresponding alpha activity DCGL_W should be adjusted to 600 Bq/m² (360 dpm/100 cm²),
 14 and the corresponding beta activity DCGL_W to 400 Bq/m² (240 dpm/100 cm²), in order to be
 15 equivalent to 1,000 Bq/m² of natural thorium surface activity. For a surface activity DCGL_W of
 16 1,000 Bq/m², the beta activity DCGL_W is calculated as shown in **Equation (4-16)**:

$$\begin{aligned}
 \text{DCGL}_{W, \beta} &= (\text{DCGL}_{W, \text{Total}}) \times (\text{fraction of decays that emit } \beta \text{ s}) \\
 &= \frac{\left(\frac{1,000 \text{ Bq of chain}}{\text{m}^2}\right) \times \left(\frac{4 \beta \text{ Bq}}{\text{Bq of } ^{232}\text{Th}}\right)}{\frac{10 \text{ Bq of chain}}{1 \text{ Bq of } ^{232}\text{Th}}} = \frac{400 \beta \text{ Bq}}{\text{m}^2} \quad (4-16)
 \end{aligned}$$

17 For this example, the beta activity DCGL_W corresponding to the DCGL_W for natural thorium is
 18 400 beta particles/second/square meter.

19 To demonstrate compliance with the beta activity DCGL_W for this example, measurements of
 20 beta count rates must be converted to activity using a weighted beta efficiency that accounts for
 21 the energy and yield of each beta particle. For decay chains that have not achieved secular
 22 equilibrium, the relative activities between the different chains of the decay chain can be
 23 determined as previously discussed for surrogate ratios.

24 **4.12.2.2 Surrogate DCGL**

25 This example illustrates and discusses the application of the surrogate method.

26 Determining the Surrogate Ratio

27 Ten soil samples within the survey unit were collected and analyzed for ¹³⁷Cs and ⁹⁰Sr to
 28 establish a surrogate ratio. The ratios of ⁹⁰Sr to ¹³⁷Cs were as follows: 6.6, 5.7, 4.2, 7.9, 3.0, 3.8,
 29 4.1, 4.6, 2.4, and 3.3. An assessment of this example data set results in a mean ⁹⁰Sr to ¹³⁷Cs
 30 surrogate ratio of 4.6, with a standard deviation of 1.7, as shown below using **Equations 8.1**
 31 **and 8.2**:

$$\begin{aligned}
 \text{Mean} &= \frac{6.6 + 5.7 + \dots + 2.4 + 3.3}{10} = 4.6 \\
 \sigma &= \frac{(6.6 - 4.6)^2 + (5.7 - 4.6)^2 + \dots + (2.4 - 4.6)^2 + (3.3 - 4.6)^2}{10 - 1} = 1.7
 \end{aligned}$$

1 There are various approaches that may be used to develop a surrogate ratio from this data, but
 2 each must consider the variability and level of uncertainty in the data. One may consider the
 3 variability in the surrogate ratio by selecting the 95 percent upper confidence level (UCL) of the
 4 surrogate ratio (to yield a conservative value of ^{90}Sr from the measured ^{137}Cs), which is 8.0 in
 5 this case, as shown below using **Equation 8.3**:

$$6 \quad \text{UCL} = 4.6 + 1.96 \times 1.7 = 8.0$$

7 Similarly, one may select the most conservative value from the data set (in this case, 7.9).

8 At sites where surrogates are used, a correlation coefficient should be calculated to validate the
 9 relationship between the radionuclides. In addition, the radioactive ingrowth and decay of
 10 radionuclides should be evaluated. Surrogates are most appropriate for sites where the
 11 radionuclides are contained in insoluble particulates. The sources of insoluble particulates
 12 include the following:

- 13 • *Sites processing minerals, such as monazite, thorite, thorianite, and zircon*: The gamma
 14 radiation from the decay products here are a useful surrogate for the decay chain, and the
 15 insolubility of the minerals precludes changes in the ratios of the parent and progeny.
- 16 • *Sites with residual radioactive material from corrosion products from nuclear reactors*: In this
 17 case, the gamma radiation from ^{60}Co is typically used as a surrogate for other radionuclides,
 18 including iron-59 (^{59}Fe), iron-55 (^{55}Fe), cobalt-57 (^{57}Co), chromium (^{51}Cr), manganese
 19 (^{54}Mn), nickel-57 (^{57}Ni), and nickel-63 (^{63}Ni). Note that at this kind of site, the shorter-lived
 20 radionuclides will decay more rapidly than the ^{60}Co , and appropriate decay corrections will
 21 need to be evaluated.
- 22 • *Sites with plutonium isotopes and americium-241 (^{241}Am)*: At these sites, the gamma
 23 radiation from ^{241}Am is a useful surrogate for plutonium-249 (^{239}Pu) and plutonium-240
 24 (^{240}Pu). Note that at this kind of site, plutonium-241 (^{241}Pu) will continue to decay to ^{241}Am ;
 25 therefore, the appropriate decay corrections will need to be made.
- 26 • *Sites with thoriated metal (e.g., nickel, tungsten, or magnesium)*: The gamma radiation from
 27 thorium progeny here can be used as a surrogate, but a thorough evaluation is required to
 28 verify that sufficient time has passed to permit the thorium and its progeny to be near a state
 29 of secular equilibrium.

30 Once an appropriate surrogate ratio is determined and approved by the appropriate regulatory
 31 agency, the planning team needs to consider how compliance will be demonstrated using
 32 surrogate measurements. That is, the planning team must modify the DCGL of the measured
 33 radionuclide to account for the inferred radionuclide. This calculation is shown below.

34 Surrogate DCGL Calculation

35 The modified DCGL for ^{137}Cs must be reduced using **Equation (4-9)**:

$$36 \quad \text{DCGL}_{\text{Cs-mod}} = \frac{1}{\left(\frac{1}{\text{DCGL}_{\text{Cs}}} + \frac{R_{\text{Sr/Cs}}}{\text{DCGL}_{\text{Sr}}} \right)}$$

37 where DCGL_{Cs} is the DCGL of ^{137}Cs ; DCGL_{Sr} is the DCGL of ^{90}Sr , and $R_{\text{Sr/Cs}}$ is the ratio of the
 38 concentrations of ^{90}Sr to ^{137}Cs . Assuming that the DCGL_{Sr} is 150 Bq/kg, the DCGL_{Cs} is

1 100 Bq/kg, and the ratio of ⁹⁰Sr to ¹³⁷Cs is 8 (e.g., from a post-remediation characterization
 2 survey), the modified DCGL for ¹³⁷Cs (DCGL_{Cs-mod}) can be calculated using **Equation (4-9)**:

3
$$DCGL_{Cs-mod} = \frac{1}{\left(\frac{1}{100 \text{ Bq kg}^{-1}} + \frac{8}{150 \text{ Bq kg}^{-1}}\right)} = 16 \text{ Bq kg}^{-1}$$

4 The modified DCGL for ¹³⁷Cs (DCGL_{Cs-mod}) is 16 Bq kg⁻¹.

5 *4.12.2.3 Gross Activity DCGL for Radionuclides in Known Ratios*

6 Determining the Radionuclide Ratios

7 As with the surrogate ratio method, the determination of the relative ratios should be determined
 8 through the DQO process and with regulatory approval. Care must be taken to ensure that
 9 ratios are applicable to the FSS conditions (e.g., ratio measurements are made just before
 10 starting the FSS).

11 General Gross Activity DCGL Calculation

12 For this example, assume that 40 percent of the total surface activity was contributed by a
 13 radionuclide with a DCGL of 8,300 Bq/m² (5000 dpm/100 cm²), 40 percent by a radionuclide
 14 with a DCGL of 1,700 Bq/m² (1000 dpm/100 cm²), and 20 percent by a radionuclide with a
 15 DCGL of 830 Bq/m² (500 dpm/100 cm²). Using **Equation (4-10)**,

16
$$DCGL_{gross} = \frac{1}{\frac{f_1}{DCGL_1} + \frac{f_2}{DCGL_2} + \frac{f_3}{DCGL_3}}$$

 17
$$= \frac{1}{\frac{0.40}{8,300 \text{ Bq/m}^2} + \frac{0.40}{1,700 \text{ Bq/m}^2} + \frac{0.20}{830 \text{ Bq/m}^2}}$$

 18
$$= 1,900 \text{ Bq/m}^2$$

21 the gross activity DCGL is 1,900 Bq/m² (1,100 dpm/100 cm²).

22 Note: If the relative amounts (ratios) were derived from data collected before
 23 remediation, then the relative amounts need to be confirmed or verified after
 24 remediation but before the FSS.

25 *4.12.2.4 Unity Rule DCGL for Radionuclides with Unrelated Concentrations*

26 For a given survey unit, data from previous surveys yield the radionuclide concentrations.

- 27 • Mean ⁶⁰Co concentration = 41 ± 32 (1σ) Bq/kg.
 28 • Mean ¹³⁷Cs concentration = 188 ± 153 (1σ) Bq/kg.

29 The DCGL_w values for ⁶⁰Co and ¹³⁷Cs are 130 Bq/kg (3.6 pCi/g) and 410 Bq/kg (11 pCi/g),
 30 respectively. Since the concentrations of the two radionuclides appear to be unrelated in the
 31 survey unit, the surrogate approach cannot be employed.

1 The weighted sum (calculated using **Equation (4-12)**) is

$$2 \quad T = \frac{C_{Co-60}}{DCGL_{Co-60}} + \frac{C_{Cs-137}}{DCGL_{Cs-137}} = \frac{41 \text{ Bq/kg}}{130 \text{ Bq/kg}} + \frac{188 \text{ Bq/kg}}{410 \text{ Bq/kg}} = 0.77$$

3 The standard deviation of the weighted sum (calculated using **Equation 4-13**) is

$$4 \quad \alpha(T) = \sqrt{\left[\frac{\alpha(C_{Co-60})}{DCGL_{Co-60}}\right]^2 + \left[\frac{\alpha(C_{Cs-137})}{DCGL_{Cs-137}}\right]^2} = \sqrt{\left[\frac{32 \text{ Bq/kg}}{130 \text{ Bq/kg}}\right]^2 + \left[\frac{153 \text{ Bq/kg}}{410 \text{ Bq/kg}}\right]^2} = 0.45$$

5 The weighted sum would be reported as 0.77 ± 0.45 (1σ). This weighted sum and standard
6 deviation can be used to determine the number of samples required for FSS based on the
7 statistical tests chose by the design team. See the example in **Section 4.12.4**.

8 **4.12.3 Required Number of Samples for a Single Radionuclide**

9 See **Sections 5.3.3 and 5.3.4** for detailed discussions on determining the required number of
10 data points for the WRS and Sign tests.

11 **4.12.3.1 WRS Test**

12 In this example the following data⁸ were collected for the survey unit and reference area. Under
13 consideration are a single radionuclide that is present in the background and a single survey
14 unit. This process would be repeated for each survey unit and reference area combination.
15 Because the actual activity units are irrelevant to the example, they will be omitted.

16 Data from a post-remediation survey are shown in **Table 4.3** below:

17 **Table 4.3: Sample Data from a Post-Remediation Survey**

	Reference Area	Survey Unit	Difference
Mean =	38.8	189.8	151.1
Median =	38.0	188.0	150.0
σ =	6.6	8.1	NA

18 The DCGL of concern is 160. The design team settled on alpha of 0.05 and beta of 0.10.

19 To determine the appropriate number of measurements, the relative shift must be calculated
20 using **Equation (4-17)**:

$$\text{Relative Shift} = \frac{DCGL - LBGR}{\sigma} \quad (4-17)$$

21

22 The LBGR is often set at the expected median concentration of the radionuclide. However, in
23 our example the mean is higher than the median. Because it is conservative to set the LBGR at

⁸ This example is based on data presented in NRC (1998a).

1 the higher value⁹ (i.e., the expected mean) and to choose the larger value for σ for the reference
 2 area or survey unit, that is what the design team does using **Equation (4-17)**:

3
$$\text{Relative Shift} = \frac{160 - 151.1}{8.1} = 1.1$$

4 Referring to **Table 5.2**, we see that the recommended number of measurements (N/2) is 22
 5 (given an alpha of 0.05 and beta of 0.10).¹⁰ This is the number of samples that must be
 6 collected in both the reference area and survey unit, for a total of 44 measurements. Also, this
 7 number accounts for missing or unusable data. The simplest approach is to assign half of those
 8 points to the survey unit and half to the reference area.

9 **4.12.3.2 Sign Test**

10 In this example, the following data were collected for the survey unit and reference area. Under
 11 consideration are a single radionuclide that is not present in the background or present an
 12 insignificant fraction of the DCGL_w and a single survey unit. The activity levels are compared
 13 directly to the DCGL. This process would be repeated for each survey unit. Because the actual
 14 activity units are irrelevant to the example, they will be omitted.

15 Data from a post-remediation survey are shown in **Table 4.4** below:

16 **Table 4.4: Sample Data from a Post-Remediation Survey**

	Survey Unit
Mean =	10.9
Median =	11.5
σ =	3.3

17 The DCGL of concern is 16. The design team settled on alpha of 0.05 and beta of 0.05.

18 To determine the appropriate number of measurements, the relative shift must be calculated
 19 using **Equation (4-17)**:

20
$$\text{Relative Shift} = \frac{\text{DCGL} - \text{LBGR}}{\sigma}$$

21 The LBGR is often set at the expected median concentration of the radionuclide. Because it is
 22 conservative to set the LBGR at the higher of the mean or median, the median is used (see
 23 **Equation (4-17)**):

24
$$\text{Relative Shift} = \frac{16 - 11.5}{3.3} = 1.4$$

25 Referring to **Table 5.2**, we see that the required number of measurements (N) is 20 (given the
 26 alpha of 0.05 and beta of 0.05). This number accounts for missing or unusable data.

⁹ Larger values for the LBGR and σ lead to a smaller relative shift that, in turn, leads to a larger number of required measurements.

¹⁰ Using the median value results in a relative shift of 1.2 and an N/2 value of 19.

1 **4.12.4 Required Number of Samples for the Multiple Radionuclides**

2 See **Sections 5.3.3–5.3.4** for detailed discussions on determining the required number of data
3 points for the WRS and Sign tests.

4 **4.12.4.1 Applying the Unity Rule**

5 A design team is tasked with classifying a survey unit according to the potential for
6 contamination and determining the appropriate number of soil samples to take during the FSS.
7 The contaminants are cobalt-60 (^{60}Co) and cesium-137 (^{137}Cs). The DCGL_W values are—

- 8 • $\text{DCGL}_{W,\text{Co-60}}$: 130 Bq/kg (3.5 pCi/g)
- 9 • $\text{DCGL}_{W,\text{Cs-137}}$: 410 Bq/kg (11 pCi/g)

10 During the DQO process and with approval of the regulator, the acceptable probability of a
11 Type I error¹¹ (α) is set to 0.05, and the acceptable probability of a Type II error¹² (β) set to 0.10.

12 Because compliance must be demonstrated for more than one radionuclide, and each
13 radionuclide will be measured separately, the unity rule will be used, wherein the concentration
14 of each contaminant is normalized to (divided by) its DCGL_W . When this is done, the collective
15 “concentration” of the multiple radionuclides is expressed as the weighted sum of ratios (T) or
16 sum of the ratios (SOR). See **Section 4.5.3.5** for details on the SOR.

17 The following data, obtained earlier during the characterization survey, are assumed to be
18 representative of the existing conditions in the survey unit. The data from the characterization
19 survey are shown in **Table 4.5**.

20 Sign test

21 Although ^{137}Cs is in the background, it is present at such a low concentration¹³ relative to the
22 DCGL that the planning team decides to “swallow” background and use the Sign test.¹⁴

23 Classification and General Observations

24 Both the mean (0.78) and median¹⁵ (0.66) of the SOR are less than 1. This indicates that the
25 survey unit might comply with the release criteria without further remediation. That the mean
26 and median differ indicates that the measurements might not be normally distributed. This
27 supports our decision to analyze the FSS data with a nonparametric test (Sign test).

28 That the value of the SORs for several samples (1, 4, 5, and 9) exceed 1 indicates that this
29 should be considered a Class 1 survey unit. Recall from the discussion of a Class 1 area that

¹¹ This is the probability that the statistical test will indicate that the survey unit meets the release criteria when, in fact, it does not.

¹² This is the probability that the statistical test will indicate that the survey unit does not meet the release criteria when, in fact, it does.

¹³ Cesium-137 appears in background soil at a concentration of about 37 Bq/kg (1 pCi/g).

¹⁴ The Sign test is a statistical test to demonstrate compliance with the release criteria when the radionuclide of concern is not present in background.

¹⁵ The median is the middle value of the data set when the number of data points is odd, and it is the average of the two middle values when the number of data points is even. Thus, 50 percent of the data points are above the median, and 50 percent are below the median.

1 **Table 4.5: Sample Results for Unity Rule Example**

Sample	Concentration (Bq/kg)		Normalized Concentration		T ^a
	C _{Co-60}	C _{Cs-137}	(C/DCGL) _{Co-60}	(C/DCGL) _{Cs-137}	
1	104	308	0.80	0.74	1.54
2	33	78	0.25	0.19	0.45
3	30	185	0.23	0.45	0.69
4	41	322	0.32	0.79	1.11
5	78	525	0.60	1.28	1.89
6	26	70	0.20	0.17	0.38
7	4	44	0.03	0.11	0.14
8	0	-11	0.00	-0.03	-0.03
9	59	229	0.45	0.56	1.02
10	37	137	0.28	0.33	0.62
Mean	41	188	0.32	0.46	0.78
Median	35	161	0.27	0.39	0.66
Sample	Sigma (Bq/kg)		Normalized Sigma		T ^a
	C _{Co-60}	C _{Cs-137}	(σ/DCGL) _{Co-60}	(σ/DCGL) _{Cs-137}	
N/A	32	162	0.25	0.39	N/A

2 Abbreviations: Bq = becquerel; kg = kilogram; DCGL = defined concentration guideline level; T = weighted sum of
 3 ratios (see **Equation 4-12**).

4 ^a To be conservative, all the ratios in the table have been rounded up.

5 “areas containing residual radioactive material in excess of the DCGL_w prior to remediation
 6 should be classified as Class 1 areas.” (See **Section 4.6.1**.) In this example, the survey unit has
 7 several individual locations where SOR exceeds 1, which is the unity rule DCGL. However, this
 8 does not mean that the survey unit fails to meet the release criteria.

9 Determining the Appropriate Number of Systematic Samples

10 To determine the appropriate number of soil samples, we must calculate the relative shift using
 11 **Equation (4-17)**:

12
$$\text{Relative Shift} = \frac{\text{DCGL} - \text{LBGR}}{\sigma}$$

13 Because we have two radionuclides (⁶⁰Co and ¹³⁷Cs), the unity rule is used, wherein the
 14 concentration of each radionuclide is divided by its DCGL. When this is done, the DCGL for the
 15 combined radionuclides effectively becomes 1, as shown in **Equation (4-18)**:

16
$$\text{Relative Shift} = \frac{1 - \text{LBGR}}{\sigma} \tag{4-18}$$

17 The LBGR is often set at the expected median concentration of the contaminant. However, in
 18 our example the mean is higher than the median. Because it is conservative to set the LBGR at
 the higher value (i.e., the expected mean), that is what we will do.

19 Given the fact that we have multiple contaminants, we divide the expected mean concentration
 20 of each radionuclide by its DCGL and use T or the SOR as our LBGR (**Equation (4-12)**):

$$\begin{aligned}
 \text{LBGR} &= \left(\frac{\text{Expected Mean Concentration}}{\text{DCGL}} \right)_{\text{Co-60}} + \left(\frac{\text{Expected Mean Concentration}}{\text{DCGL}} \right)_{\text{Cs-137}} \\
 &= \frac{41 \text{ Bq/kg}}{130 \text{ Bq/kg}} + \frac{188 \text{ Bq/kg}}{410 \text{ Bq/kg}} \\
 &= 0.32 + 0.46 \\
 &= 0.78
 \end{aligned}$$

Using **Equation (4-18)**, the relative shift calculation then becomes

$$\text{Relative Shift} = \frac{1 - 0.78}{\sigma}$$

Using **Equation (4-13)**, The combined sigma (σ) for ^{60}Co and ^{137}Cs using data from **Table 4.5** on previous page is

$$\begin{aligned}
 \sigma &= \sqrt{\left(\frac{\sigma}{\text{DCGL}} \right)_{\text{Co-60}}^2 + \left(\frac{\sigma}{\text{DCGL}} \right)_{\text{Cs-137}}^2} \\
 &= \sqrt{(0.25)^2 + (0.39)^2} \\
 &= 0.47
 \end{aligned}$$

The relative shift is then determined as follows, using **Equation (4-18)**:

$$\text{Relative Shift} = \frac{1 - 0.78}{0.47} = 0.47$$

Note that the relative shift and sigma have the same value (0.47), which is a coincidence.

Referring to **Table 5.3**, we see that the recommended number of samples is somewhere between 71 and 107 (given the alpha of 0.05 and beta of 0.10). When the relative shift falls between the values on two lines on **Table 5.3**, the number of samples can be conservatively estimated by using the number of samples corresponding to the smaller value of the relative shift. For this example, the number of required samples would be 107.

4.12.5 Instrument Efficiencies

The instrument efficiency (ϵ_i) is defined as the ratio of the net count rate of the instrument to the surface emission rate of a source for a specified geometry. The surface emission rate is defined as the number of particles of a given type above a given energy emerging from the front face of the source per unit time. The surface emission rate is the 2π particle fluence that embodies both the absorption and scattering processes that effect the radiation emitted from the source. Thus, the instrument efficiency is determined by the ratio of the net count rate and the surface emission rate.

The source efficiency (ϵ_s) is defined as the ratio of the number of particles of a given type emerging from the front face of a source to the number of particles of the same type created or released within the source per unit time. The source efficiency takes into account the increased particle emission due to backscatter effects, as well as the decreased particle emission due to self-absorption losses. For an ideal source (i.e., no backscatter or self-absorption), the value of the source efficiency is 0.5. Many real sources will exhibit values less than 0.5, although values greater than 0.5 are possible, depending on the relative importance of the absorption and backscatter processes.

1 For surface activity measurements, the product of the instrument and surface efficiencies is the
 2 total efficiency of the instrument (ϵ_t). The total efficiency is the net count rate of the instrument
 3 divided by the total (4π) emission rate in a specified geometry. It is usually the efficiency of
 4 ultimate interest when planning FSSs.

5 *4.12.5.1 Multiple Radionuclides*

6 Whatever approach is used to assess multiple radionuclides, the FSS design team needs to
 7 account for different instrument responses to the radionuclides of concern. It is important to use
 8 an appropriately weighted total efficiency to convert from instrument counts to activity units. This
 9 most frequently arises when measuring surface activity. When multiple radionuclides are being
 10 measured with the same instrument, a weighted efficiency must be used. Starting with the unity
 11 rule in its most general form (**Equation (4-1)**), the total number of counts is simply sum of the
 12 counts from each radionuclide j present:

$$\text{Total Number of Counts} = A_{\text{Total}}\epsilon_t = \sum_{j=1}^n A_j \epsilon_{s,j} \epsilon_{i,j} \quad (4-19)$$

13 where

- 14 • A_{Total} is the total activity of the n radionuclides.
- 15 • A_j is the activity of the j th radionuclide.
- 16 • $\epsilon_{s,j}$ is the source efficiency of the j th radionuclide.
- 17 • $\epsilon_{i,j}$ is the instrument efficiency of the j th radionuclide.

18 If the fraction f_j of each radionuclide in the mix is known, then, as shown in **Equation (4-20)**,

$$A_{\text{Total}}\epsilon_t = \sum_{j=1}^n (A_{\text{Total}}f_j)\epsilon_{s,j}\epsilon_{i,j} \quad (4-20)$$

19 Dividing both sides by A_{Total} yields the total efficiency for the mixture, as shown in
 20 **Equation (4-21)**:

$$\epsilon_t = \sum_{j=1}^n f_j \epsilon_{s,j} \epsilon_{i,j} \quad (4-21)$$

21 The example below illustrates the calculation of a weighted total efficiency for two radionuclides
 22 with different instrument efficiencies.

1 Consider a site contaminated with cesium-137 (^{137}Cs) and strontium/yttrium-90 ($^{90}\text{Sr/Y}$), with
 2 ^{137}Cs representing 60 percent of the total activity. Therefore, the relative fractions are 0.6 for
 3 ^{137}Cs and 0.4 for $^{90}\text{Sr/Y}$. The source efficiency for both ^{137}Cs and $^{90}\text{Sr/Y}$ is 0.5. The
 4 corresponding instrument efficiencies for ^{137}Cs and $^{90}\text{Sr/Y}$ are determined to be 0.38 and 0.45,
 5 respectively.

6 The total efficiency can be calculated using **Equation (4-21)**:

$$\begin{aligned} \varepsilon_t &= f_{\text{Cs}}\varepsilon_{s,\text{Cs}}\varepsilon_{i,\text{Cs}} + f_{\text{Sr/Y}}\varepsilon_{s,\text{Sr/Y}}\varepsilon_{i,\text{Sr/Y}} \\ &= (0.6)(0.5)(0.38) + (0.4)(0.5)(0.45) \\ &= 0.20 \end{aligned}$$

10 Alternatively, the total efficiencies for each radionuclide can be calculated by multiplying the
 11 surface efficiency by the instrument efficiency, as shown in the equations below, modified from
 12 **Equation (4-21)**:

$$\begin{aligned} \varepsilon_{t,\text{Cs}} &= \varepsilon_{s,\text{Cs}} \times \varepsilon_{i,\text{Cs}} = (0.5)(0.38) = 0.19 \\ \varepsilon_{t,\text{Sr/Y}} &= \varepsilon_{s,\text{Sr/Y}} \times \varepsilon_{i,\text{Sr/Y}} = (0.5)(0.45) = 0.22 \end{aligned}$$

15 The weighted total efficiency can then be calculated as follows using equations modified from
 16 **Equation (4-21)**:

$$\begin{aligned} \varepsilon_t &= f_{\text{Cs}}\varepsilon_{t,\text{Cs}} + f_{\text{Sr/Y}}\varepsilon_{t,\text{Sr/Y}} \\ &= (0.6)(0.19) + (0.4)(0.22) \\ &= 0.20 \end{aligned}$$

20 The weighted total efficiency is 0.20, or 20 percent.

21 When calculating the weighted total efficiency, one must account for the assumptions underlying
 22 the corresponding DCGL, particularly the relative ratios of the radionuclides present. In this
 23 case, the relative ratio of ^{137}Cs and $^{90}\text{Sr/Y}$ is needed to calculate the weighted total efficiency.
 24 This can be important when dealing with the naturally occurring radionuclide chains (e.g., ^{226}Ra
 25 and progeny). The state of secular equilibrium (disequilibrium) would need to be accounted for
 26 in determining the weighted total efficiency. An example of calculating the total weighted
 27 efficiency for a mixture of radionuclides is shown in **Section 4.12.6**.

28 This weighted efficiency discussion addresses considerations for fractional activity. However,
 29 more complex situations may be encountered, which must consider things such as radiation
 30 emission intensities and branching ratios of decay chains. MARSAME and NUREG-1507
 31 provide some additional examples of these more complex situations.

32 **4.12.6 Data Conversion**

33 This example illustrates the data conversion process along with another weighed total efficiency
 34 calculation. Additional details are provided in **Section 6.7**.

35 A radionuclide laboratory is being decommissioned. Options are being considered for the FSS
 36 of surfaces in the laboratory. The following radionuclide information is given in **Table 4.6**:

1 **Table 4.6: Sample Radionuclide Information**

Radionuclide	DCGL _w		Relative Fraction
	Bq m ⁻²	dpm (100 cm ²) ⁻¹	
¹⁴ C	5.77x10 ⁶	3.46x10 ⁶	0.12
⁶³ Ni	2.72x10 ⁶	1.63x10 ⁶	0.18
⁹⁹ Tc	1.95x10 ⁶	1.17x10 ⁶	0.40
²⁰⁴ Tl	1.33x10 ⁴	8.00x10 ³	0.02
⁹⁰ Sr/Y	1.30x10 ⁴	7.78x10 ³	0.13
¹⁰⁶ Ru/Rh	3.98x10 ⁴	2.39x10 ⁴	0.15

2 Abbreviations: DCGL_w = derived concentration guideline level determined for a wide area; Bq = Becquerels; m =
3 meters; dpm = decays per minute; cm = centimeters.

4 Because the relative ratios are well known, were determined through the DQO process, and
5 were approved by the regulatory agency, gross beta activity measurements will be used to
6 determine compliance with the release criterion for this survey. The gross activity DCGL_w can
7 be determined from **Equation (4-10)**.

$$DCGL_{gross} = \frac{1}{\left(\frac{0.18}{2.72 \times 10^6} + \frac{0.12}{5.77 \times 10^6} + \frac{0.40}{1.95 \times 10^6} + \frac{0.02}{1.33 \times 10^4} + \frac{0.13}{1.30 \times 10^4} + \frac{0.15}{3.98 \times 10^4} \right)}$$

$$= 6.42 \times 10^4 \text{ Bq m}^{-2} \text{ (} 3.85 \times 10^4 \text{ dpm (100 cm}^2\text{)}^{-1}\text{)}.$$

8 It has been decided to use a gas-flow proportional counter with a physical probe area of
9 126 cm² (0.0126 m²) in β particle-only mode for the survey. The design team has determined
10 the following total efficiencies for the detector (**Table 4.7**):

11 **Table 4.7: Sample Efficiencies for a Detector**

Radionuclide	Source Efficiency	Instrument Efficiency	Total Efficiency	Relative Fraction	Weighted Efficiency
¹⁴ C	0.25	0.16	0.04	0.12	0.0048
⁶³ Ni	0.25	0.00	0.00	0.18	0.000
⁹⁹ Tc	0.25	0.64	0.16	0.40	0.064
²⁰⁴ Tl	0.50	0.58	0.29	0.02	0.0058
⁹⁰ Sr/Y	0.50	0.72	0.36	0.13	0.047
¹⁰⁶ Ru/Rh	0.50	1.10	0.55	0.15	0.082
Total =				1.00	0.20

12 In general, the output of the counter is a gross counting rate or integrated counts in a set
13 counting interval. The relationship between the counter's output and surface activity (A_s)
14 concentration is given by **Equation 6-19**:

15
$$A_s = \frac{C_s/t_s}{\epsilon_t \times W}$$

16 where C_s is the integrated net counts recorded by the instrument; t_s is the time period over
17 which the counts were recorded; ε_t is the total efficiency of the instrument in counts per
18 disintegration, effectively the product of the instrument efficiency (ε_i) and the source efficiency

1 (ϵ_s); and W is the physical probe area. To account for background, **Equation (4-22)** (a slightly
2 modified form of **Equation 6-20**) is used:

$$A_s = \frac{C_{s+b}/t_s - C_b/t_b}{\epsilon_t \times W} = \frac{C_s/t_s}{\epsilon_t \times W} = \frac{R_{net}}{\epsilon_t \times W} \quad (4-22)$$

3

4 where C_b is the background counts¹⁶ recorded by the instrument, t_b is the time period over
5 which the background counts were recorded,¹⁷ and R_{net} is the net counting rate. The units for t_s ,
6 t_b , and W depend on the desired units for the FSS.

7 For this example, surface activity measurements are being made on drywall. Consider the
8 following data for one measurement location:

- 9 • $C_b = 1,626$ counts
- 10 • $t_b = 5$ minutes
- 11 • $C_s = 1,210$ counts
- 12 • $t_s = 1$ minute

13 The net counting rate is calculated using **Equation (4-23)**:

$$R_{net} = C_{s+b}/t_s - C_b/t_b \quad (4-23)$$

$$\begin{aligned} &= \frac{1,210 \text{ counts}}{1 \text{ minute}} - \frac{1,626 \text{ counts}}{5 \text{ minutes}} \\ &= (1,210 - 325.2) \text{ cpm} \\ &= 884.8 \text{ cpm} \end{aligned}$$

17 The net counting rate can be converted to the surface activity concentration, as shown below,
18 using **Equation (4-22)**:

$$\begin{aligned} A_s &= \frac{R_{net}}{\epsilon_T \times W} \\ &= \frac{884.8 \text{ cpm}}{0.20 \text{ (c/d)} \times 0.0126 \text{ m}^2} \\ &= 3.51 \times 10^5 \text{ dpm/m}^2 \end{aligned}$$

¹⁶ Background measurements should be made on uncontaminated material similar in composition to the material at the measurement location.

¹⁷ The sample and background counting intervals can be different, depending on the desired MDC. See **Section 6.3** and the professional literature for more discussion.

1 In general, either SI (Bq/m²) or conventional (dpm/100 cm²) units are desired. For SI units, the
 2 conversion is straightforward, because 60 dpm is equivalent to 1 Bq (see **Equation (4-22)**):

$$3 \quad A_s = \left(3.51 \times 10^5 \text{ dpm/m}^2 \right) \times \left(\frac{1 \text{ Bq}}{60 \text{ dpm}} \right)$$

$$4 \quad = 5.83 \times 10^3 \text{ Bq/m}^2$$

5 The conversion to conventional units is shown below, using **Equation (4-22)**:

$$6 \quad A_s = \left(3.51 \times 10^5 \text{ dpm/m}^2 \right) \times \left(\frac{0.01 \text{ m}^2}{100 \text{ cm}^2} \right)$$

$$7 \quad = 3.51 \times 10^3 \text{ dpm/100 cm}^2$$

8 The FSS design team should determine the desired units during the planning phase. After the
 9 desired units are chosen, the design team can create spreadsheets or other methods of
 10 analyzing the raw counting data to streamline the process. Similarly, any action or investigation
 11 levels chosen by the design team should be converted into the proper units. This process needs
 12 to be performed for each field measurement instrument and technique.

13 For example, if it is determined that units of dpm/100 cm² will be used, then the physical probe
 14 area should be measured in cm², and the following equation (**Equation (4-24)**) can be used for
 15 each instrument used:

$$A_s = \frac{C_s/t_s - C_b/t_b}{\epsilon_t \times (W/100)} = \frac{R_{net}}{\epsilon_t \times (W/100)} \quad (4-24)$$

16
 17 where t_s and t_b are recorded in minutes (R_{net} is expressed in cpm), and W is recorded in square
 18 centimeters instead of square meters.

19 For this example, the equation is shown below (see **Equation (4-22)**):

$$20 \quad A_s = \frac{884.8 \text{ cpm}}{0.20 \text{ (c/d)} \times \left(\frac{126}{100} \right)}$$

$$21 \quad = 3.51 \times 10^3 \text{ dpm/100 cm}^2$$

22 The result is the same as in the earlier example, as expected.

23 Additionally, action and investigation levels and the DCGL can be converted to detector outputs
 24 to facilitate timely actions (i.e., expressing action levels in terms of net counting rate might allow
 25 the field survey team to alert supervisors about measurements exceeding action levels in near-
 26 real time). In this case, the net counting rate corresponding to an action level can be expressed
 27 by the following equation (**Equation (4-25)**):

$$R_{net}^{AL} = \epsilon_t \times W \times A_s^{AL} \quad (4-25)$$

1

2 Suppose the design team set an action level at 10 percent of the $DCGL_{gross}$. The net counting
3 rate corresponding to this value is found as shown below, keeping in mind that 1 Bq is
4 equivalent to 1 disintegration per second (dps), using (**Equation (4-25)**):

$$5 \quad R_{net}^{AL} = 0.20 \times 0.0126 \text{ m}^2 \times (6.42 \times 10^3 \text{ Bq/m}^2) = 16.2 \text{ cps} = 971 \text{ cpm}$$

6 Thus, any net count exceeding about 970 counts per minute (cpm) would be flagged for
7 investigation. If background rates are relatively constant, an action level can be expressed as a
8 gross counting rate, as well.

9 **4.12.7 Example of a Deviation from a Recommended Statistical Test**

10 Consider the case of a survey unit that contains many different surfaces with potentially different
11 backgrounds (e.g., drywall panels, concrete floor, glass windows, metal doors, wood trim, and
12 plastic fixtures) and gross activity measurements are being considered. In this case, MARSSIM
13 recommends the use of the WRS test when gross activity measurements are used; however,
14 the use of the WRS test might require several survey and associated reference units, resulting
15 in an inordinately large number of measurements. Furthermore, “it is not appropriate to make
16 each material a separate survey unit because the dose modeling is based on the dose from the
17 room as a whole and because a large number of survey units in a room would require an
18 inappropriate number of samples” (NRC 2006). In this situation, the design team should use the
19 DQO process and determine the best approach.

20 Instead of attempting to use the WRS test and multiple reference units, the design team might
21 investigate the materials to determine if material-specific backgrounds are needed or whether
22 materials with similar background could be grouped and considered as a unit. If this is done, it
23 might be “acceptable to perform a one-sample test (Sign test) on the difference between the
24 paired measurements from the survey unit and from the appropriate reference material”
25 (NRC 2006). Chapter 2 of NUREG-1505 (NRC 1998a) contains details on this method.

26 In addition to the alternative statistical approach discussed above, the NRC (2006) discusses
27 two additional approaches to resolve this issue. First, if the materials in the survey unit have
28 substantially different backgrounds, then a reference unit containing a similar mix of material
29 might be used, and the WRS test can then be applied. Second, if the materials in the survey unit
30 have similar backgrounds, or if one material predominates, then a reference background from a
31 single material might suffice. See NRC (2006) for more details.

32 The design team should use the DQO process to investigate any deviations from usual methods
33 and get approval from the regulatory agency before executing the FSS.

34 **4.12.8 Release Criteria for Discrete Radioactive Particles**

35 With the installation in the mid- and late-1980s of very sensitive portal monitors, many nuclear
36 power plants detected residual radioactive material on individuals and their clothing, present as
37 small—usually microscopic—highly radioactive particles having relatively high specific activity.
38 These particles became known as “discrete radioactive particles” and sometimes “hot particles.”
39 Discrete radioactive particles are small (usually on the order of millimeters or micrometers),
40 distinct, highly radioactive particles capable of delivering extremely high doses to a localized
41 area in a short period of time.

1 To prove compliance with requirements for discrete radioactive particles, some surveys have
2 used the MARSSIM EMC process (see **Section 8.6.1**); however, that process is not valid when
3 instrumentation dose-to-rate conversion factor modeling assumes a “point source” as opposed
4 to an “area source” or “plane source.” This violates the assumption inherent in the dose or risk
5 model of an activity concentration averaged over some definable area. Therefore, it is not
6 acceptable to use the MARSSIM EMC process when the distance to the detector is greater than
7 three times the longest dimension of the area of elevated activity, as represented by
8 **Equation (4-26)**:

$$d > 3L \quad (4-26)$$

9 where L is the estimated longest dimension of the area of elevated activity, and d is the distance
10 to the detector.

11 To address discrete radioactive particles in surface soils or building surfaces—

- 12 • Include discrete radioactive particles as a consideration during the DQO process for
13 MARSSIM surveys.
- 14 • When a regulatory agency sets requirements on the concentration of discrete radioactive
15 particles in a survey unit, use the DQO process to develop a survey to assess whether
16 requirements are met.
- 17 • When appropriate, apply ALARA by addressing discrete radioactive particles during the
18 RAS survey.
- 19 • If discrete radioactive particles do not contribute significantly to dose or risk at a site, it is a
20 reasonable assumption that they will not affect the outcome of a wide-area FSS. If an FSS
21 fails due to discrete radioactive particles, investigate the reasons for survey failure (see
22 **Section 8.6.3**).

23 **4.12.9 Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA) Sites**

24 At UMTRCA sites, the U.S. Environmental Protection Agency’s Health and Environmental
25 Protection Standards for Uranium and Thorium Mill Tailings (in 40 CFR 192) are applicable.
26 However, the technical requirements in these standards are not always consistent with some of
27 the recommendations in MARSSIM. Specifically, the soil cleanup standards for ^{226}Ra and ^{228}Ra
28 are specified as averages over an area of 100 m². (In the 40 CFR 192 rulemaking, an averaging
29 area of 100 m² was used as a reasonable footprint for a home. One goal of the 40 CFR 192
30 standards was to protect future homes from indoor radon, and the specified averaging area was
31 a component implemented for the protection of health.) The rules at 40 CFR 192 do not
32 establish specific requirements for small areas of elevated radioactive material. At sites where
33 the uranium or thorium mill tailings standards are applicable, the following approach for FSSs is
34 acceptable:

- 35 • A survey unit of no greater than 100 m² sections of land should be used, consistent with the
36 regulatory standards.
- 37 • The systematic sampling for performance of statistical tests, normally required under the
38 MARSSIM approach, is not required for each survey unit. Instead, compliance with the
39 standard can be demonstrated through the analysis of soil samples or composite soil
40 samples from each survey unit in conjunction with gamma radiation scanning or in situ

- 1 gamma radiation measurements of each survey unit. When appropriate, gamma radiation
2 scanning or in situ measurements correlated to soil sampling may be used in place of soil
3 sampling.
- 4 • Survey units may be classified, as appropriate, and the percentage of the survey unit that is
5 scanned may be adjusted accordingly for Class 1, Class 2, or Class 3 survey units.
- 6 • EMC criteria for small elevated areas of activity may be developed but are not required for
7 the purposes of MARSSIM.
- 8 These minor modifications to the standard MARSSIM radiological survey approach are
9 acceptable for those sites to which the UMTRCA standards are applicable.

DRAFT

5 SURVEY PLANNING AND DESIGN

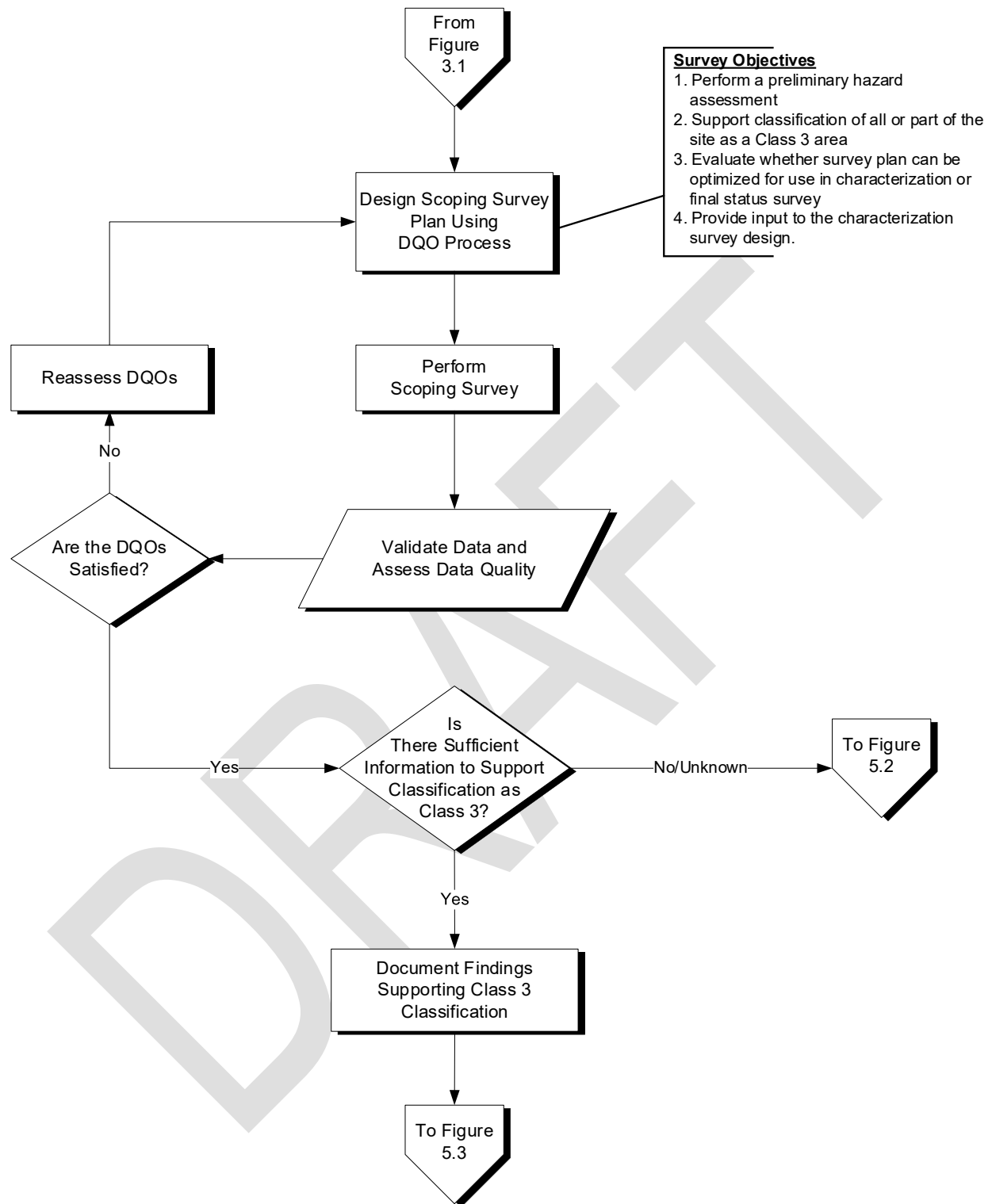
5.1 Introduction

This chapter is intended to assist the user in planning radiological surveys with a particular emphasis on conducting a final status survey (FSS), with the ultimate objective being to demonstrate compliance with the derived concentration guideline levels (DCGLs).¹ The survey types that make up the Radiation Survey and Site Investigation (RSSI) process include scoping, characterization, remedial action support (RAS), and FSSs; depending on the regulatory framework, the process may also include confirmatory or independent verification surveys. Although the scoping, characterization, and RAS surveys have multiple objectives, this manual focuses on those aspects related to supporting the FSS and demonstrating compliance with DCGLs. In general, each of these survey types expands upon the data collected during the previous survey (e.g., the characterization survey is planned with information collected during the scoping survey) up through the FSS. The conduct and extent of scoping and characterization surveys will depend on the available information from the Historical Site Assessment (HSA) and site-specific conditions. The purpose of the FSS is to demonstrate that the release criteria established by the regulatory agency have not been exceeded. This final release objective should be kept in mind throughout the design and planning phases for each of the other survey types. For example, scoping surveys may be designed to meet the objectives of the FSS such that the scoping survey report is also the FSS report. The survey and analytical procedures referenced in this chapter are described in **Chapters 6–7** and **Appendix H**. An example of an FSS, as described in **Section 5.3**, appears in **Appendix A**. In addition, example checklists are provided for each type of survey to assist the user in obtaining the necessary information for planning an FSS.

Scoping surveys—used to augment the HSA and provide input to future survey designs—and survey unit characterization and classification are described in **Section 5.2.1**. **Section 5.2.2** describes characterization surveys performed to determine the following: nature and extent of residual radioactive material; potential remediation alternatives and technologies; the inputs to pathway analysis and dose or risk assessment models; occupational and public health and safety impacts; and inputs to the FSS design. RAS surveys, performed to support remedial activities, update estimates of site-specific parameters used in FSS planning, and determine when a site or survey unit is ready for an FSS are described in **Section 5.2.3**. **Section 5.3** covers FSSs, which are performed to demonstrate that a site or survey unit meets the residual radioactive material release criteria.

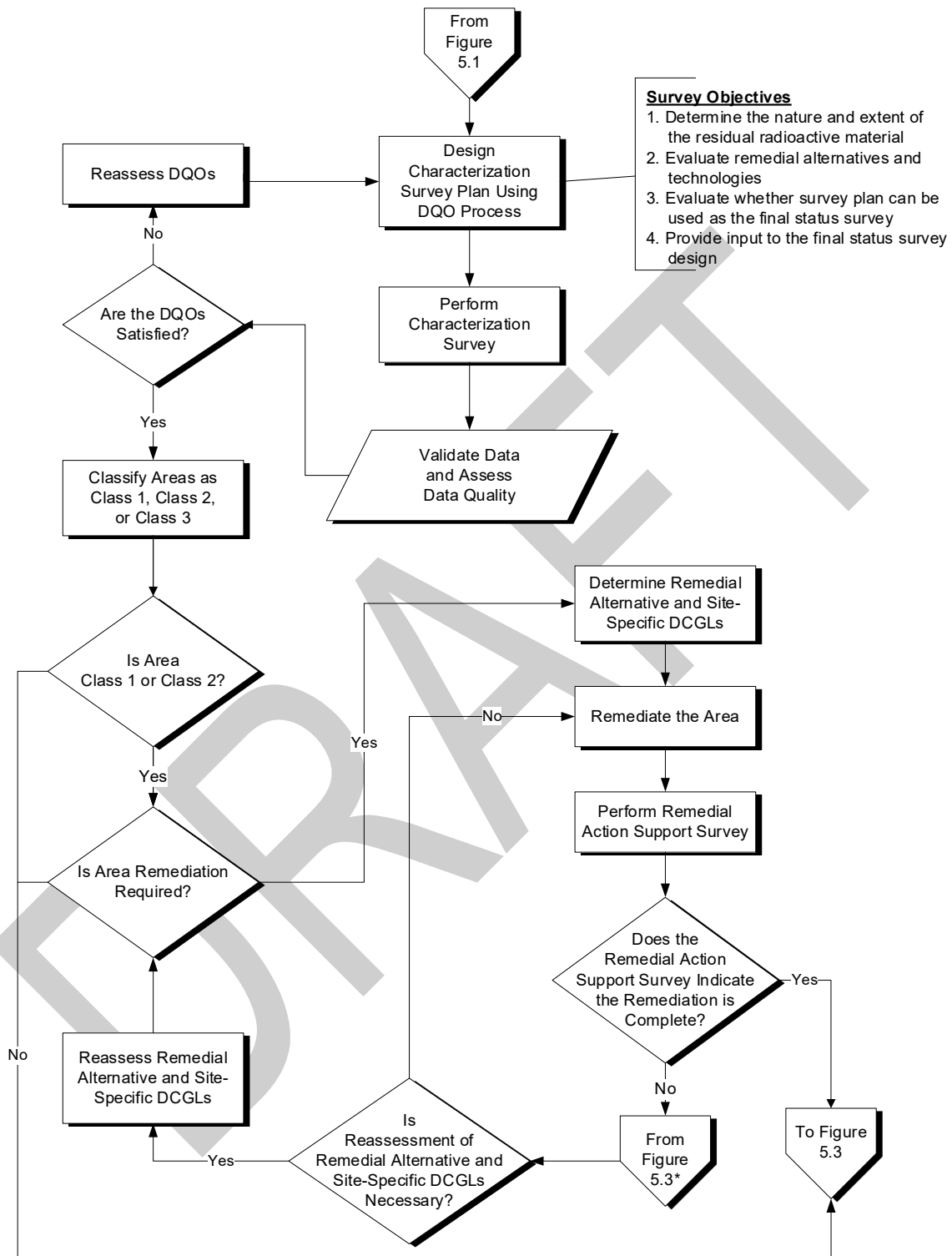
A flowchart diagram illustrating the Survey Planning and Design Process, broken up by survey type, is provided in **Figures 5.1–5.3**.

¹ MARSSIM uses the word “should” as a recommendation, not as a requirement. Each recommendation in this manual is not intended to be taken literally and applied at every site. MARSSIM’s survey planning documentation will address how to apply the process on a site-specific basis.



1
2
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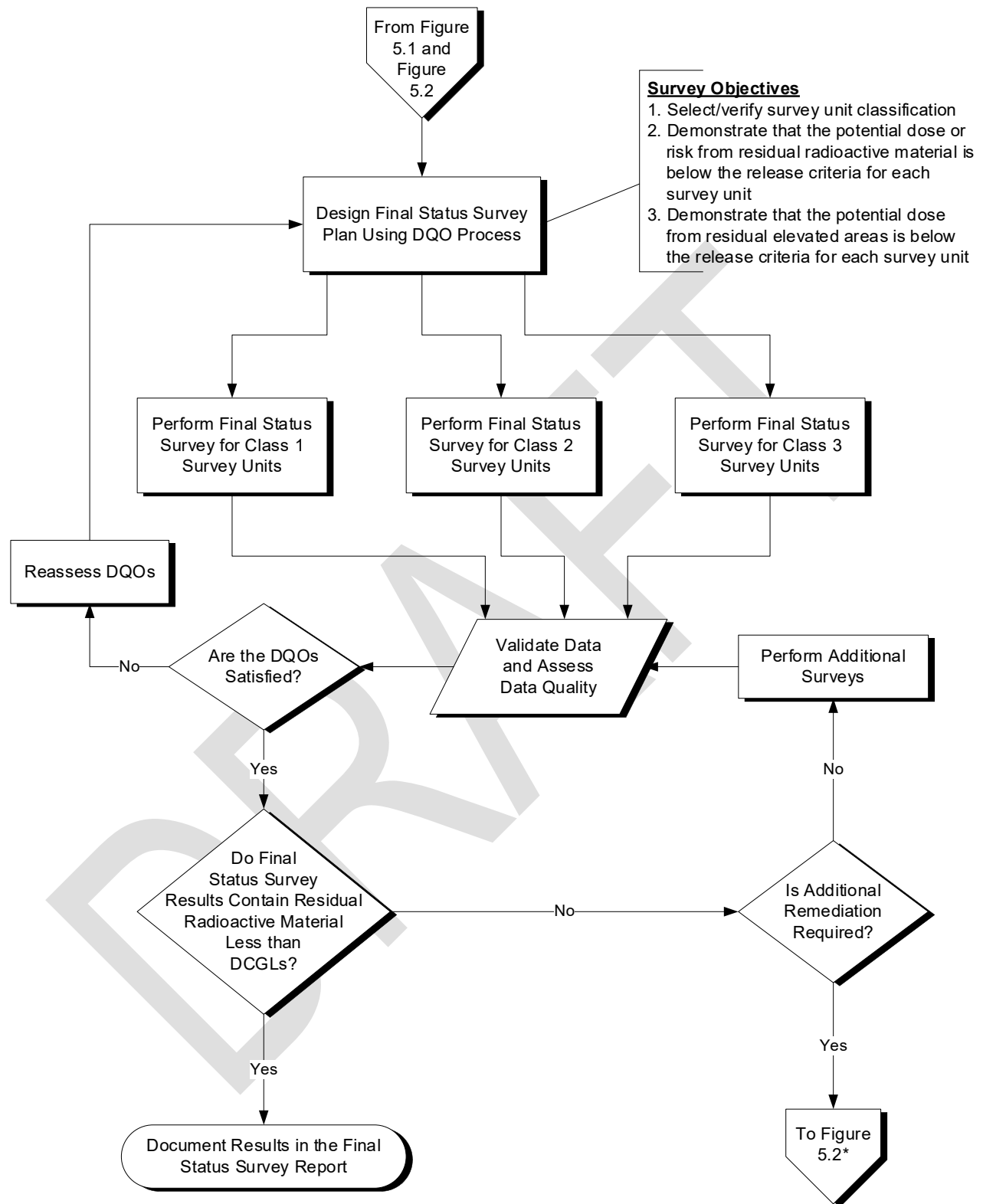
Figure 5.1: The Scoping Survey Portion of the Radiation Survey and Site Investigation Process



1

* The point where survey units that fail to demonstrate compliance in the final status survey in Figure 5.3 re-enter the process

2 **Figure 5.2: The Characterization and Remedial Action Support Survey Portions of the**
 3 **Radiation Survey and Site Investigation Process**



1 * Connects with the Remedial Action Support Survey portion of the process in Figure 5.2

2 **Figure 5.3: The Final Status Survey Portion of the Radiation Survey and Site Investigation**
 3 **Process**

1 **5.2 Preliminary Surveys**

2 **5.2.1 Scoping Surveys**

3 If the data collected during the HSA indicate that a site or area is impacted, a scoping survey
4 may be performed. The objective of this survey is to augment the HSA for sites with potential
5 residual radioactive material. Specific objectives may include—

- 6 • performing a preliminary risk assessment and providing data to complete the site
7 prioritization scoring process for Comprehensive Environmental Response, Compensation,
8 and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) sites
9 only (EPA 1992c)
- 10 • providing input to the characterization survey design, if necessary
- 11 • supporting the classification of all or part of the site as a Class 3 area for planning the FSS
- 12 • obtaining an estimate of the variability in the residual radioactive material concentration for
13 the site
- 14 • identifying non-impacted areas that may be appropriate for reference areas and estimating
15 the variability in radionuclide concentrations when the radionuclide of interest is present in
16 background

17 A scoping survey is not a requirement if HSA information meets the needs for designing
18 subsequent surveys, including the FSS. Alternatively, scoping surveys and characterization
19 surveys may be combined, if one survey can be designed to meet the requirements of both
20 survey types. See **Section 5.2.2** for a description of characterization surveys.

21 Scoping survey information about the general radiation levels at the site, including gross levels
22 of residual radioactive material on building surfaces and in environmental media, is needed
23 when conducting a preliminary risk assessment (as noted above for CERCLA and RCRA sites).
24 If unexpected conditions are identified that prevent the completion of the survey, the Multi-
25 Agency Radiation Survey and Site Investigation Manual (MARSSIM) user should contact the
26 regulatory agency for further guidance. Sites that meet the National Contingency Plan (NCP)
27 criteria for a removal should be referred to the Superfund Removal program (EPA 1988b).

28 If the HSA indicates that residual radioactive material above release levels is likely, a scoping
29 survey could be performed to provide initial estimates of the level of effort for remediation and
30 information for planning a more detailed survey, such as a characterization survey. Not all
31 radiological parameters need to be assessed when planning for additional characterization,
32 because total surface activity or limited sample collection may be sufficient to meet the
33 objectives of the scoping survey.

34 Once a review of pertinent site history indicates that an area is impacted, the minimum survey
35 coverage at the site will include a Class 3 area FSS before the site's being released. For
36 scoping surveys with this objective, identifying radiological decision levels is necessary for
37 selecting instruments and procedures with the necessary instrument capabilities to demonstrate
38 compliance with the release criteria. A methodology for planning, conducting, and documenting
39 scoping surveys is described in the following sections.

1 5.2.1.1 Survey Design

2 Planning a scoping survey involves reviewing the HSA for a site (**Chapter 3**). This process
3 considers available information concerning locations of spills or other releases of radioactive
4 material. Reviewing the radioactive materials license or similar documentation provides
5 information on the identity, locations, and general quantities of radioactive material used at the
6 site. This information helps determine which areas are likely to contain residual radioactive
7 material and, thus, areas where scoping survey activities will be concentrated. The information
8 may also identify one or more non-impacted areas as potential reference areas when
9 radionuclides of concern are present in background (**Section 4.5**). Following the review of the
10 HSA, appropriate DCGLs for the site are selected. The DCGLs may be adjusted later if a
11 determination is made to use site-specific information to support the development of DCGLs.

12 If residual radioactive material is identified during the scoping survey, the area may be classified
13 as Class 1 or Class 2 for FSS planning (refer to **Section 4.6.1** for information on initial
14 classification), and a characterization survey is subsequently performed. For scoping surveys
15 that are designed to provide input for characterization surveys, measurements and sampling
16 may not be as comprehensive or performed to the same level of sensitivity necessary for FSSs.
17 The design of the scoping survey should be based on specific Data Quality Objectives (DQOs).
18 See **Section 2.3.1** and **Appendix D** for the information to be collected.

19 For scoping surveys that potentially serve to release the site or portions of the site from further
20 consideration, the scoping survey design for the Class 3 area should consist of sampling based
21 on the HSA data, and professional judgment and must be consistent with the requirements for
22 an FSS. If residual radioactive material is *not* identified, it may be appropriate to characterize
23 the area as non-impacted. Refer to **Section 5.3** for a description of FSSs. However, collecting
24 additional information during subsequent surveys (e.g., characterization surveys) may be
25 necessary to make a final determination as to area classification.

26 5.2.1.2 Conducting Surveys

27 Scoping survey activities performed for preliminary risk assessment or to provide input for
28 additional characterization include a limited amount of surface scanning, surface activity
29 measurements, and sample collection (smears, soil, water, vegetation, paint, building materials,
30 subsurface materials). In this case, scans, direct measurements, and samples are used to
31 examine areas likely to contain residual radioactive material. These activities are conducted
32 based on HSA data, preliminary investigation surveys, and professional judgment.

33 Background activity and radiation levels for the area should be determined, including direct
34 radiation levels on building surfaces and radionuclide concentrations in media. Survey locations
35 should be referenced to grid coordinates, if appropriate, or fixed site features. This may be
36 accomplished by establishing a reference coordinate system in the event that residual
37 radioactive material is detected above the DCGLs (**Section 4.8.5**). Samples collected as part of
38 a scoping survey should be maintained under custody from collection through analysis and
39 reporting to ensure the integrity of the results. Sample tracking may include use of a chain of
40 custody, which is the unbroken trail of accountability that ensures the physical security of
41 samples, data, and records (**Section 7.8**).

42 Scoping surveys that are expected to be used as Class 3 area FSSs should be designed
43 following the procedure in **Section 5.3**. Scoping surveys should also include judgment
44 measurements and sampling in areas likely to have accumulated residual radioactive material
45 (**Section 5.3.9**). However, when performing a scoping survey as a Class 3 FSS, judgment

1 samples should not be used as part of the statistical sampling population utilized to make a
2 release decision on a site or survey unit.

3 *5.2.1.3 Evaluating Survey Results*

4 Survey data are converted to the same units as the DCGLs (**Section 6.6**). Identification of
5 potential radionuclides of concern at the site is performed using direct measurements or
6 laboratory analysis of samples. The data are compared to the appropriate regulatory DCGLs.

7 For scoping survey activities that provide an initial assessment of the radiological hazards at the
8 site or input for additional characterization, the survey data are used to identify locations and the
9 general extent of residual radioactive material. Scoping surveys that are expected to be used as
10 Class 3 area FSSs should follow the methodology presented in **Chapter 8** to determine whether
11 the release criteria have been exceeded.

12 *5.2.1.4 Documentation*

13 How the results of the scoping survey are documented depends on the specific objectives of the
14 survey. For scoping surveys that provide additional information for characterization surveys, the
15 documentation should provide general information on the radiological status of the site. Survey
16 results should include identification of the potential radionuclides of concern (including the
17 methods used for radionuclide identification), general extent of residual radioactive material
18 (e.g., activity levels, area, and depth), and possibly even relative ratios of radionuclides to
19 facilitate DCGL application. A narrative report or a report in the form of a letter may suffice for
20 scoping survey data that is used to provide input for characterization surveys. Sites being
21 released from further consideration should provide a level of documentation consistent with FSS
22 reports (**Section 5.3.11**). **Example 1** includes an illustration of a scoping survey checklist,
23 including survey design, conduct of the survey, and evaluation of survey results.

Example 1: Example Scoping Survey Checklist

Survey Design

_____ Enumerate Data Quality Objectives (DQOs) and Measurement Quality Objectives (MQOs). State the objectives of the survey; survey instrumentation capabilities should be appropriate for the specified survey objectives. Document survey requirements in a project-specific Quality Assurance Project Plan (QAPP).

_____ Review the Historical Site Assessment (HSA) for the following:

_____ Operational history (e.g., problems, spills, releases, or notices of violation) and available documentation (e.g., radioactive materials license)

_____ Other available resources—site personnel, former workers, residents, etc.

_____ Types and quantities of materials that were handled and where radioactive materials were stored, handled, moved, relocated, and disposed

_____ Release and migration pathways

_____ Areas that are potentially affected and likely to contain residual radioactive material (Note: Survey activities will be concentrated in these areas.)

_____ Types and quantities of materials likely to remain onsite—consider radioactive decay

_____ Select derived concentration guideline levels (DCGLs) for the site based on the HSA review. (It may be necessary to assume appropriate regulatory DCGLs in order to permit selection of survey methods and instrumentation for the expected radioactive material and quantities.)

Conducting Surveys

_____ Follow the survey design documented in the QAPP. Record deviations from the stated objectives or documented standard operating procedures, and document additional observations made when conducting the survey.

_____ Select instrumentation based on the specific DQOs and MQOs of the survey. Consider instrumentation capabilities for the expected residual radioactive material and quantities.

_____ Determine background activity and radiation levels for the area; include direct radiation levels on building surfaces, radionuclide concentrations in media, and exposure rates.

_____ Record measurement and sample locations referenced to grid coordinates or fixed site features.

_____ For scoping surveys that are conducted as Class 3 area final status surveys (FSSs), follow FSS procedure.

_____ Conduct scoping survey, which involves judgment measurements and sampling based on HSA results:

_____ Perform investigatory surface scanning.

_____ Conduct limited surface activity measurements.

_____ Perform limited sample collection (smears, soil, water, vegetation, paint, building materials, subsurface materials).

_____ Maintain sample tracking.

Evaluating Survey Results

_____ Compare survey results with the DQOs and MQOs.

_____ Identify radionuclides of concern.

_____ Identify impacted areas and the general extent of residual radioactive material.

_____ Estimate the variability in the residual radioactive material levels for the site.

- _____ Adjust DCGLs based on survey findings (the DCGLs initially selected may not be appropriate for the site).
- _____ Determine the need for additional action (e.g., none, remediate, more surveys)
- _____ Prepare report for regulatory agency (determine if letter report is sufficient).

1 **5.2.2 Characterization Surveys**

2 Characterization surveys may be performed to satisfy a number of specific objectives. Examples
3 of characterization survey objectives include—

- 4 • determining the nature and extent of residual radioactive material
- 5 • evaluating remediation alternatives (e.g., unrestricted use, restricted use, onsite disposal,
6 off-site disposal, etc.)
- 7 • input to pathway analysis/dose or risk assessment models for determining site-specific
8 DCGLs (becquerel [Bq]/kilogram [kg], Bq/square meter [m²])
- 9 • estimating the occupational and public health and safety impacts during decommissioning
- 10 • evaluating remediation technologies
- 11 • providing input to FSS design
- 12 • meeting Remedial Investigation/Feasibility Study (RI/FS) requirements (under a CERCLA
13 program) or RCRA Facility Investigation/Corrective Measures Study (RFI/CMS)
14 requirements (under an RCRA program).

15 A characterization survey is not a requirement if HSA and scoping survey information meets the
16 needs for designing subsequent surveys, including FSSs. Alternatively, scoping surveys and
17 characterization surveys may be combined if one survey can be designed to meet the
18 requirements of both survey types. The scope of this manual precludes detailed discussions of
19 characterization survey design for each of these objectives; therefore, the user should consult
20 other references for specific characterization survey objectives not covered. For example, the
21 *Decommissioning Handbook* (DOE 1994a) is a good reference for characterization objectives
22 that are concerned with evaluating remediation technologies or unrestricted/restricted use
23 alternatives. Other references (e.g., Abelquist 2014; EPA 1988b, 2006c; NRC 1994a) should be
24 consulted for planning decommissioning actions, including remediation techniques, projected
25 schedules, costs, waste volumes, and health and safety considerations during remedial action.
26 Also, the types of characterization data needed to support risk or dose modeling should be
27 determined from the specific modeling code documentation. This manual concentrates on
28 providing information for the FSS design, with limited coverage on determining the specific
29 nature and extent of residual radioactive material. The specific objectives for providing
30 information to the FSS design include—

- 31 • estimating the projected radiological status at the time of the FSS, in terms of radionuclides
32 present, concentration ranges and variances, spatial distribution, etc.

- 1 • evaluating potential reference areas to be used for background measurements, if necessary
- 2 • reevaluating the initial classification of survey units
- 3 • selecting instrumentation based on the necessary Measurement Quality Objectives (MQOs)
- 4 • establishing acceptable Type I and Type II errors with the regulatory agency (**Appendix D**
- 5 provides information on establishing acceptable decision error rates.)

6 Many of these objectives are satisfied by determining the specific nature and extent of residual
7 radioactive material in structures, residues, and environmental media. Additional detail on the
8 performance of characterization surveys designed to determine the general extent of residual
9 radioactive material can be found in the U.S. Nuclear Regulatory Commission's (NRC's)
10 *Consolidated Decommissioning Guidance* (NUREG-1757) (NRC 2006), *Performance and*
11 *Documentation of Radiological Surveys* (HPS/ANSI 13.49-2001) (HPS 2001), *Characterization*
12 *in Support of Decommissioning Using the Data Quality Objectives Process* (HPS/ANSI N13.59)
13 (HPS 2008), and the U.S. Environmental Protection Agency's (EPA's) RI/FS guidance (EPA
14 1988b; EPA 1993b).

15 Results of the characterization survey should include—

- 16 • the identification and distribution of residual radioactive material in buildings, structures, and
17 other site facilities
- 18 • the concentration and distribution of radionuclides of concern in surface and subsurface
19 soils
- 20 • the distribution and concentration of residual radioactive material in surface water, ground
21 water, and sediments
- 22 • the distribution and concentration of radionuclides of concern in other impacted media, such
23 as vegetation or paint

24 The characterization should include sufficient information on the physical characteristics of the
25 site, including surface features, meteorology and climatology, surface water hydrology, geology,
26 demography and land use, and hydrogeology. This survey should also address environmental
27 conditions that could affect the rate and direction of radionuclide transport in the environment,
28 depending on the extent of residual radioactive material identified above.

29 The following sections describe a method for planning, conducting, and documenting
30 characterization surveys. Alternative methodologies may also be acceptable to the regulatory
31 agencies.

32 *5.2.2.1 Survey Design*

33 The design of the site characterization survey is based on the specific DQOs for the information
34 to be collected, and it is planned using the HSA and scoping survey results. The DQO process
35 ensures that adequate data with sufficient quality are collected for the purpose of
36 characterization. The site characterization process typically begins with a review of the HSA,
37 which includes available information on site description, operational history, and the type and
38 extent of residual radioactive material (from the scoping survey, if performed). The site
39 description, or conceptual site model as first developed in **Section 3.6.4**, consists of the general
40 area, dimensions, and locations of affected areas on the site. A site map should show site

- 1 boundaries, roads, hydrogeological features, major structures, and other features that could
2 affect decommissioning activities. When available, Global Positioning System (GPS)
3 coordinates should be recorded for major features.
- 4 The operational history includes records of site conditions before operational activities,
5 operational activities of the facility, effluents and on-site disposal, and significant incidents—
6 including spills or other unusual occurrences—involving the spread of residual radioactive
7 material around the site and on areas previously released from radiological controls. This review
8 should include other available resources, such as site personnel, former workers, residents, etc.
9 Historic aerial photographs and site location maps may be particularly useful in identifying
10 potential areas of residual radioactive material.
- 11 The types and quantities of materials that were handled and the locations and disposition of
12 radioactive materials should be reviewed using available documentation (e.g., the radioactive
13 materials license). Release and migration pathways of radionuclides should be identified, as
14 well as areas that are potentially affected and are likely to contain residual radioactive material.
15 The types and quantities of materials likely to remain onsite, considering radioactive decay,
16 should be determined.
- 17 The characterization survey should clearly identify those portions of the site (e.g., soil,
18 structures, and water) that have been affected by site activities and potentially contain residual
19 radioactive material. The survey should also identify the portions of the site that have not been
20 affected by these activities. In some cases where no remediation is anticipated, results of the
21 characterization survey may indicate compliance with DCGLs established by the regulatory
22 agency. When planning for the potential use of characterization survey data as part of the FSS,
23 the characterization data must be of sufficient quality and quantity for that use (see
24 **Section 5.3**).
- 25 Several processes are likely to occur in conjunction with characterization. These include
26 considering and evaluating remediation alternatives and calculating site-specific DCGLs.
- 27 The survey should also provide information on variability in the radionuclide distribution in the
28 survey area. The radionuclide variability in each survey unit contributes to determining the
29 number of data points based on the statistical tests used during the FSS (**Sections 5.3.3–5.3.4**)
30 and the required scan coverage for Class 2 areas. Additionally, characterization data may be
31 used to justify reclassification for some survey units (e.g., from Class 1 to Class 2).
- 32 In some cases, judgment sampling is the most appropriate for meeting the data needs.
33 Judgment sampling includes measurements performed at locations selected using professional
34 judgment based on unusual appearance, location relative to known contaminated areas, high
35 potential for residual radioactive material, general supplemental information, etc. Examples of
36 situations in which judgment sampling may be the most appropriate include those where
37 residual radioactive material is isolated to locations that can be defined by individual
38 measurements, or in which biased results will provide the data from the areas of highest
39 suspected concentration of residual radioactive material. It should be understood, however, that
40 use of a judgment characterization survey will produce data that is considered biased and which
41 can generally only be used to draw conclusions about individual samples or specific locations
42 rather than provide quantifiable estimates about a larger aggregate population. As a result,

1 averages of judgment samples (i.e., biased) should not be used to determine the mean
2 concentration of the residual radioactive material in the survey unit.

3 For those characterization survey objectives that require statistical evaluation of the data, the
4 sampling plan should be designed to produce unbiased data. Unbiased sampling makes use of
5 random sample selection, whereby each sample has an equal probability of being selected.
6 Unbiased data can be used to provide a measure of the population characteristics, such as the
7 average or mean radioactive material concentration and variance on that mean. One example of
8 when unbiased sample data may be required is the use of a data set in assessing compliance
9 with dose- or risk-based criteria. Most human health risk assessment protocols (e.g., EPA
10 1989d) require the computation of a mean and upper confidence limit (UCL) as the best
11 measure of residual radioactive material in identifying excess lifetime cancer risk or radiation
12 dose to a target population (EPA 2002b; 2006b).

13 The characterization survey may be used as an FSS for Class 3 areas under the following
14 conditions:

- 15 • The characterization survey was planned as an FSS.
- 16 • Site or survey unit conditions warrant the use of the characterization survey as the FSS.
- 17 • Only randomly selected samples are utilized as part of the statistical evaluation of the site or
18 survey unit. Any judgment samples collected may not be used as part of the statistical
19 sample count or as part of the statistical evaluation of results.

20 It may be also appropriate to combine the principles of judgment and unbiased sampling
21 strategies in designing a sample plan that provides the most representative data but also meets
22 all of the DQOs.

23 Note that because of site-specific characteristics of residual radioactive material, performing all
24 types of measurements described here may not be relevant at every site. For example, detailed
25 characterization data may not be needed for areas with residual radioactive material well above
26 the DCGLs that clearly require remediation. Judgment should be used in determining the types
27 of characterization information needed to provide an appropriate basis for remediation
28 decisions.

29 A number of software programs have been developed over the years to facilitate the design of
30 surveys, an example of which is Visual Sample Plan, developed by the Pacific Northwest
31 National Laboratory. These software programs can perform calculations to determine the
32 number of locations where measurements should be made or where samples should be
33 collected.

34 *5.2.2.2 Conducting Surveys*

35 Characterization survey activities often involve the detailed assessment of various types of
36 building and environmental media, including building surfaces, surface and subsurface soil,
37 surface water, and ground water. The HSA data should be used to identify the media onsite with
38 a potential for residual radioactive material (see **Section 3.6.3**). Identifying the media that may
39 contain residual radioactive material is useful for preliminary survey unit classification and for
40 planning subsequent survey activities. Selection of survey instrumentation and analytical
41 techniques are typically based on knowledge of the appropriate DCGLs, because remediation
42 decisions are made based on the level of the residual radioactive material as compared to the

1 DCGL. Exposure rate measurements may be needed to assess occupational and public health
2 and safety.

3 Structure Surveys

4 Surveys of building surfaces and structures can include surface scanning, surface activity
5 measurements, exposure rate measurements, and sample collection (e.g., smears, subfloor
6 soil, water, paint, and building materials). Both field survey instrumentation (**Chapter 6**) and
7 analytical laboratory equipment and procedures (**Chapter 7**) are selected based on their
8 instrumentation capabilities for the expected residual radioactive material and their quantities.
9 Field and laboratory instruments are described in **Appendix H**.

10 Background activity and radiation levels for the area should be determined from appropriate
11 background reference areas. Background assessments include surface activity measurements
12 on building surfaces, exposure rates, and radionuclide concentrations in various media (refer to
13 **Section 4.5**). Building reference area measurements should be collected in non-impacted areas
14 within the same building, or in another similar building, provided that the reference area has
15 been constructed with materials of the same type and age. This ensures that the reference area
16 has the same inherent radioactive material and decay time, and therefore background
17 radioactivity, as the impacted area.

18 Measurement locations should be documented using reference system coordinates, if
19 appropriate, or fixed site features. A typical reference system spacing for building surfaces is
20 1 m. This is chosen to facilitate identifying survey locations and small areas of elevated activity.

21 Scans should be conducted in areas likely to contain residual radioactive material, based on the
22 results of the HSA and scoping survey.

23 Both systematic and judgment surface activity measurements are performed. Judgment direct
24 measurements are performed at locations of elevated direct radiation, as identified by surface
25 scans, to provide data on the upper ranges of residual radioactive material levels. Judgment
26 measurements may also be performed in sewers, air ducts, storage tanks, and septic systems
27 and on roofs of buildings, if necessary. Each surface activity measurement location should be
28 carefully recorded on the appropriate survey form.

29 Exposure rate measurements and media sampling are performed as necessary. For example,
30 subfloor soil samples may provide information on the horizontal and vertical extent of residual
31 radioactive material. Similarly, concrete core samples are necessary to evaluate the depth of
32 activated concrete in a reactor facility. Note that one type of radiological measurement may be
33 sufficient to determine the extent of residual radioactive material. For example, surface activity
34 measurements alone may be all that is needed to demonstrate that remediation of an area is
35 necessary; exposure rate measurements would add little to this determination.

36 Lastly, the measuring and sampling techniques should be commensurate with the intended use
37 of the data, as characterization survey data may be used to guide the FSS survey design or
38 supplement FSS data, provided that the data meet the selected DQOs and the FSS design
39 requirements.

1 Land Area Surveys

2 Characterization surveys for surface and subsurface soils and media involve employing
3 techniques to determine the lateral and vertical extent and radionuclide concentrations in the
4 soil. This may be performed using either sampling and laboratory analyses or in situ gamma
5 spectrometry analyses, depending on the instrumentation capabilities of each methodology for
6 the expected radionuclides and concentrations. Note that in situ gamma spectrometry analyses
7 or any direct surface measurement cannot easily be used to determine distributions of
8 radionuclides as a function of depth. Sample collection followed by laboratory analysis
9 introduces several additional sources of uncertainty that need to be considered during survey
10 design. In many cases, a combination of direct measurements and samples is required to meet
11 the objectives of the survey.

12 Radionuclide concentrations in background soil samples should be determined for a sufficient
13 number of soil samples that are representative of the soil in terms of soil type, soil depth, etc. It
14 is important that the background samples be collected in non-impacted areas. Consideration
15 should be given to spatial variations in the background radionuclide concentrations as
16 discussed in **Section 4.6** and NRC draft report NUREG-1501 (NRC 1994a).

17 Sample locations should be documented using GPS; reference system coordinates (see
18 **Section 4.9.5**), if appropriate; or fixed site features. A typical reference system spacing for open
19 land areas is 10 m (NRC 1992a). This spacing is somewhat arbitrary and is chosen to facilitate
20 determining survey unit locations and identifying areas of elevated concentrations of radioactive
21 material.

22 Surface scans for gamma activity should be conducted in areas likely to contain residual
23 radioactive material. Selection of instrumentation should be appropriate to detect the
24 radionuclide(s) of interest. Beta scans may be appropriate if the residual radioactive material is
25 near the surface and beta is the dominant radiation emitted from the residual radioactive
26 material. The detection capability and measurement uncertainty of the scanning technique
27 should be appropriate to meet the DQOs and MQOs.

28 Both systematic and judgment surface activity measurements are performed. Judgment direct
29 measurements are performed at locations of elevated direct radiation, as identified by surface
30 scans, to provide data on upper ranges of residual radioactive material levels. Judgment
31 measurements may also be performed in areas where radioactive materials might have
32 accrued, such as in swales, under downspouts, near access roads, etc., if necessary. Each
33 surface activity measurement location should be carefully recorded on the appropriate survey
34 form.

35 Both surface and subsurface soil and media samples may be necessary. Subsurface soil
36 samples should be collected where residual radioactive material is present on the surface and
37 where residual radioactive material is known or suspected in the subsurface. Boreholes should
38 be constructed to provide samples representing subsurface deposits.

39 Exposure rate measurements at 1 m (~3 feet) above the sampling location may also be
40 appropriate. Each surface and subsurface soil sampling and measurement location should be
41 carefully recorded.

42 Surface Water and Sediments

43 Surface water and sediment sampling may be necessary, depending on the potential for these
44 media to contain residual radioactive material, which depends on several factors, including the

1 proximity of surface water bodies to the site, size of the drainage area, total annual rainfall, and
2 spatial and temporal variability in surface water flow rate and volume. Refer to **Section 3.6.3.3**
3 for further criteria to determine the necessity for surface water and sediment sampling.

4 Characterizing surface water involves techniques that determine the extent and distribution of
5 residual radioactive material. This may be performed by collecting grab samples of the surface
6 water in a well-mixed zone. At certain sites, it may be necessary to collect stratified water
7 samples to provide information on the vertical distribution of residual radioactive material.
8 Sediment sampling should also be performed to assess the relationship between the
9 composition of the suspended sediment and the bedload sediment fractions (i.e., suspended
10 sediments compared to deposited sediments). When judgment sampling is used to find
11 radionuclides in sediments, radioactive sediments are more likely to be accumulated on fine-
12 grained deposits found in low-energy environments (e.g., deposited silt on inner curves of
13 streams).

14 Radionuclide concentrations in background water samples should be determined for a sufficient
15 number of water samples that are upstream of the site or in areas unaffected by site operations.
16 Consideration should be given to any spatial or temporal variations in the background
17 radionuclide concentrations.

18 Sampling locations should be documented using reference system coordinates, if appropriate,
19 or scale drawings of the surface water bodies. Effects of variability of surface water flow rate
20 should be considered. Surface scans for gamma activity may be conducted in areas likely to
21 contain residual radioactive material (e.g., along the banks) based on the results of the
22 document review or preliminary investigation surveys.

23 Surface water sampling should be performed in areas of runoff from active operations, at plant
24 outfall locations, upstream and downstream of the outfall, and any other areas likely to contain
25 residual radioactive material (see **Section 3.6.3.3**). Measurements of radionuclide
26 concentrations in water should include gross alpha and gross beta radioactivity concentration
27 assessments, as well as any necessary radionuclide-specific analyses. Non-radiological
28 parameters—such as specific conductance, pH, and total organic carbon—may be used as
29 surrogate indicators of potential radioactive material, if a specific relationship exists between the
30 radionuclide concentration and the level of the indicator (e.g., if a linear relationship between pH
31 and the radionuclide concentration in water is found to exist, then the pH may be measured
32 such that the radionuclide concentration can be calculated based on the known relationship
33 rather than performing an expensive nuclide-specific analysis). The use of surrogate
34 measurements is discussed in **Section 4.5.3**.

35 Each surface water and sediment sampling location should be carefully recorded on the
36 appropriate survey form. Additionally, surface water flow models may be used to illustrate
37 radionuclide concentrations and migration rates.

38 Ground Water

39 Ground water sampling may be necessary, depending on the local geology, potential for
40 residual radioactive material in the subsurface, and the regulatory framework. Because different
41 agencies handle ground water compliance in different ways (e.g., EPA's Superfund program
42 and some States require compliance with maximum contaminant levels specified in the Safe
43 Drinking Water Act), the regulatory agency should be contacted if residual radioactive material

1 in ground water is expected. The need for ground water sampling is described in
2 **Section 3.6.3.4.**

3 If residual radioactive material in ground water is identified, the regulatory agency should be
4 contacted at once, because (1) ground water release criteria and DCGLs should be established
5 by the appropriate agency (**Section 4.5.2**), and (2) the default DCGLs for soil may be
6 inappropriate, because they are usually based on ground water without any residual radioactive
7 material.

8 Characterization of residual radioactive material in ground water should determine the extent
9 and distribution of residual radioactive material, rates and direction of ground water migration,
10 and the assessment of potential effects of ground water withdrawal on the migration of residual
11 radioactive material in ground water. This may be performed by designing a suitable monitoring
12 well network. The actual number and location of monitoring wells depends on the size of the
13 affected area, the type and extent of the residual radioactive material, the hydrogeological
14 system, and the objectives of the monitoring program.

15 When ground water samples are taken, background radiation levels should be determined by
16 collecting samples from the same aquifer upgradient of the site and then analyzing them. Any
17 tidal effects and effects of additional wells in the upgradient zone on ground water flow should
18 be evaluated to aid in selecting the proper location of upgradient background samples. The
19 background samples should not be affected by site operations and should be representative of
20 the quality of the ground water that would exist if the site had not been affected by the residual
21 radioactive material. Consideration should be given to any spatial or temporal variations in the
22 background radionuclide concentrations.

23 Sampling locations should be referenced to grid coordinates, if appropriate, or to scale drawings
24 of the ground water monitoring wells. Construction specifications on the monitoring wells should
25 also be provided, including elevation, internal and external dimensions, types of casings, type of
26 screen and its location, borehole diameter, and other necessary information about the wells.

27 In addition to organic and inorganic constituents, ground water sampling and analyses should
28 include all significant radiological constituents. Measurements in potential sources of drinking
29 water should include gross alpha and gross beta assessments, as well as any other
30 radionuclide-specific analyses deemed appropriate based on the HSA. Non-radiological
31 parameters—such as specific conductance, pH, and total organic carbon—may be used as
32 surrogate indicators of the potential presence of certain radionuclides, provided that a specific
33 relationship exists between the radionuclide concentration and the level of the indicator.

34 Each ground water monitoring well location should be carefully recorded on the appropriate
35 survey form. Additionally, radionuclide concentrations and sources should be plotted on a map
36 to illustrate the relationship among radionuclides, sources, hydrogeological features and
37 boundary conditions, and property boundaries (EPA 1993f).

38 Other Media

39 Air sampling may be necessary at some sites, depending on the local geology and the
40 radionuclides of potential concern. This may include collecting air samples or filtering the air to
41 collect resuspended particulates. Air sampling is often restricted to monitoring activities for
42 occupational and public health and safety, and it is not required to demonstrate compliance with
43 risk- or dose-based regulations. **Section 3.6.3.5** describes examples of sites where air sampling
44 may provide information useful to designing an FSS. At some sites, radon measurements may

1 be used to indicate the presence of radium, thorium, or uranium in the soil. **Section 6.8** and
2 **Appendix H** provide information on this type of sampling.

3 In rare cases, vegetation samples may be collected as part of a characterization survey to
4 provide information in preparation for an FSS. Because most risk- and dose-based regulations
5 are concerned with potential future land use that may differ from the current land use,
6 vegetation samples are unsuitable for demonstrating compliance with regulations. There is a
7 relationship between radionuclide concentrations in plants and those in soil (the soil-to-plant
8 transfer factor is used in many models to develop DCGLs), and the plant concentration could be
9 used as a surrogate measurement of the soil concentration. In most cases, a measurement of
10 the soil itself as the parameter of interest is more appropriate and introduces less uncertainty in
11 the result.

12 *5.2.2.3 Evaluating Survey Results*

13 Survey data are converted to the same units as those in which DCGLs are expressed
14 (**Section 6.7**). Laboratory and in situ analyses are performed to identify potential residual
15 radioactive material at the site. Appropriate regulatory DCGLs for the site are selected, and the
16 data are then compared to the DCGLs. For characterization data that are used to supplement
17 FSS data, the statistical methodology in **Chapter 8** should be followed to determine if a survey
18 unit satisfies the release criteria.

19 For characterization data that are used to help guide remediation efforts, the survey data are
20 used to identify locations and the general extent of residual radioactivity. The survey results are
21 first compared with DCGLs. Surfaces and environmental media are then differentiated as
22 exceeding DCGLs, not exceeding DCGLs, or not affected, depending on the measurement
23 results relative to the DCGL value. Direct measurements indicating areas of elevated activity are
24 further evaluated, and the need for additional measurements is determined.

25 *5.2.2.4 Documentation*

26 Documentation of the site characterization survey should provide a complete and unambiguous
27 record of the radiological status of the site. In addition, sufficient information to characterize the
28 extent of residual radioactive material, including all possible affected environmental media,
29 should be provided in the report. This report should also provide sufficient information to support
30 reasonable approaches or alternatives to site remediation. **Example 2** includes an example of a
31 characterization survey checklist.

Example 2: Example Characterization Survey Checklist

Survey Design

_____ Enumerate Data Quality Objectives (DQOs) and Measurement Quality Objectives (MQOs): State the objective of the survey; survey instrumentation capabilities should be appropriate for the specific survey objective.

_____ Review the Historical Site Assessment (HSA) and scoping survey results, if performed, for—

- _____ Operational history (e.g., any problems, spills, or releases) and available documentation (e.g., radioactive materials license).
- _____ Other available resources—site personnel, former workers, residents, etc.
- _____ Types and quantities of materials that were handled and where radioactive materials were stored, handled, and disposed of.
- _____ Release and migration pathways.
- _____ Information on the potential for residual radioactive material that may be useful during area classification for final status survey (FSS) design. Note: Survey activities will be concentrated in Class 1 and Class 2 areas.
- _____ Types and quantities of materials likely to remain onsite—consider radioactive decay and ingrowth of decay products.
- _____ Document the survey plan (e.g., Quality Assurance Project Plan, standard operating procedures, etc.)

Conducting Surveys

- _____ Select instrumentation based on its capabilities for the expected residual radioactive material and quantities and knowledge of the appropriate derived concentration guideline levels (DCGLs).
- _____ Define background locations and determine background activity and radiation levels for the area; include surface activity levels on building surfaces, radionuclide concentrations in environmental media, and exposure rates.
- _____ Establish a reference coordinate system. Prepare scale drawings for surface water and ground water monitoring well locations.
- _____ Perform thorough surface scans of all areas potentially containing residual radioactive material. Examples of indoor areas include expansion joints, stress cracks, penetrations into floors and walls for piping, conduits, anchor bolts, and wall/floor interfaces. Examples of outdoor areas include radioactive material storage areas, areas downwind of stack release points, dripline and downspout areas, surface drainage pathways, and roadways that may have been used for transport of radioactive materials.
- _____ Perform systematic surface activity measurements.
- _____ Perform systematic smear, surface and subsurface soil and media, sediment, surface water, and ground water sampling, if appropriate for the site.
- _____ Perform judgment direct measurements and sampling of elevated areas to provide data on the upper ranges of levels of the concentration of radioactive material.
- _____ Document survey and sampling locations.
- _____ Maintain chain of custody of samples when necessary.

Note: One category of radiological data (e.g., radionuclide concentration, direct radiation level, or surface radioactivity) may be sufficient to determine the extent of residual radioactive material; other measurements may not be necessary (e.g., removable surface radioactive material or exposure rate measurements).

Note: Measuring and sampling techniques should be commensurate with the intended use of the data, because characterization survey data may be used to supplement FSS data.

Evaluating Survey Results

_____ Compare survey results with DCGLs. Differentiate surfaces or areas as exceeding DCGLs, not exceeding DCGLs, or not affected.

_____ Evaluate all locations of elevated direct measurements, and determine the need for additional measurements or samples.

_____ Prepare site characterization survey report.

1 **5.2.3 Remedial Action Support Surveys**

2 RAS surveys are conducted to (1) support remediation activities, (2) determine when a site or
3 survey unit is ready for the FSS, and (3) provide updated estimates of site-specific parameters
4 to use for planning the FSS. This manual does not discuss the routine operational surveys
5 (e.g., air sampling, dose rate measurements, environmental sampling) conducted for health and
6 safety purposes to support remediation activities.

7 A RAS survey serves to monitor the effectiveness of remediation efforts to reduce residual
8 radioactive material to acceptable levels. The RAS survey also ensures that remediation is
9 targeted to only those areas requiring remediation, which in turn ensures a cost-effective
10 remediation. This type of survey guides the cleanup in a real-time mode. The RAS survey
11 typically relies on a simple radiological parameter, such as direct radiation near the surface, as
12 an indicator of effectiveness. The investigation level for the RAS survey (established as the
13 DCGL) is determined and used for immediate, in-field decisions (**Section 5.3.8**).

14 Such a survey is intended for expediency and cost-effectiveness and does not provide thorough
15 or accurate data describing the radiological status of the site. Note that this survey typically
16 does not provide information that can be used to demonstrate compliance with the DCGLs;
17 rather, it is an interim step in the compliance demonstration process. Areas that are determined
18 to likely satisfy the DCGLs on the basis of the RAS survey will then be surveyed in detail by the
19 FSS. Alternatively, the RAS survey can be designed to meet the objectives of an FSS as
20 described in **Section 5.3**.

21 Remedial activities result in changes to the distribution of residual radioactive material within a
22 survey unit. The site-specific parameters used during FSS planning (e.g., variability in the
23 radionuclide concentration within a survey unit or the probability of small areas of elevated
24 activity) will change during remediation. For most survey units, values for these parameters will
25 need to be re-established following remediation. Obtaining updated values for these critical
26 planning parameters should be considered when designing a RAS survey.

1 *5.2.3.1 Survey Design*

2 The objective of the RAS survey is to determine whether remediation was adequate to remove
3 radioactive material to levels at or below the DCGL criteria. Although the presence of small
4 areas of elevated concentrations of radioactive material may satisfy the elevated measurement
5 criteria, it may be more efficient to design the RAS survey to identify residual radioactive
6 material at the radionuclide-specific release limit based on the spatial distribution of the
7 radionuclide within a survey unit (DCGL_w) and to remediate small areas of elevated activity that
8 may potentially satisfy the release criteria. Survey instrumentation and techniques are therefore
9 selected based on the instrumentation capabilities for the known or suspected radionuclides and
10 DCGLs to be achieved.

11 There will be radionuclides and media that cannot be evaluated at the DCGL_w using field
12 monitoring techniques. For these cases, it may be feasible to collect and analyze samples by
13 methods that are quicker and less costly than radionuclide-specific laboratory procedures. Field
14 laboratories and screening techniques may be acceptable alternatives to more expensive
15 analyses. Reviewing remediation plans may be required to get an indication of the location and
16 amount of residual radioactive material remaining following remediation.

17 *5.2.3.2 Conducting Surveys*

18 Field survey instruments and procedures are selected based on their ability to detect and
19 quantify the expected radionuclides. Survey methods typically include scans of surfaces
20 followed by direct measurements to identify residual radioactive material. The surface activity
21 levels are compared to the investigation levels, and a determination is made on the need for
22 further remediation efforts.

23 Survey activities for soil excavations include surface scans using field instrumentation sensitive
24 to beta and gamma activity. Because it can be difficult to correlate scanning results to
25 radionuclide concentrations in soil, judgment should be exercised carefully when using scan
26 results to guide the cleanup efforts. Field laboratories and screening techniques may provide a
27 better approach for determining whether further soil remediation is necessary.

28 *5.2.3.3 Evaluating Survey Results*

29 Survey data (e.g., surface activity levels and radionuclide concentrations in various media) are
30 converted to standard units and compared to the DCGLs (**Section 6.7**). If results of these
31 survey activities indicate that remediation has been successful in meeting the DCGLs, remedial
32 actions are ceased, and FSS activities are initiated. Alternatively, further remediation may be
33 needed if results indicate the presence of residual radioactive material in excess of the DCGLs.

34 DCGLs may be recalculated based on the results of the remediation process as the regulatory
35 program allows or permits.

36 *5.2.3.4 Documentation*

37 The RAS survey should guide the cleanup and alert those performing remedial activities that
38 (1) additional remediation is needed or (2) the site may be ready to initiate an FSS. Data that
39 indicate an area has been successfully remediated could be used to estimate the variance for
40 the survey units in that area. Information identifying areas of elevated activity that existed before
41 remediation may be useful for planning FSSs. **Example 3** includes an example of a RAS survey
42 checklist, including survey design, conduct of surveys, and evaluation of survey results.

Example 3: Example Remedial Action Support Survey Checklist**Survey Design**

_____ Enumerate Data Quality Objectives and Measurement Quality Objectives: State the objectives of the survey; survey instrumentation capabilities should be appropriate for the specific survey objective.

_____ Document the survey plan (e.g., Quality Assurance Project Plan, standard operating procedures, *etc.*)

_____ Review the remediation plans.

_____ Determine applicability of monitoring surfaces/soils for the radionuclides of concern.

Note: RAS surveys may not be feasible for residual radioactive materials with very low-energy beta emitters or for soils or media containing pure alpha emitters.

_____ Select simple radiological parameters (e.g., surface activity) that can be used to make immediate in-field decisions on the effectiveness of the remedial action.

Conducting Surveys

_____ Select instrumentation based on its capabilities for measuring the expected radionuclides.

_____ Perform scanning and surface activity measurements near the surface being remediated.

_____ Survey soil excavations and perform field evaluation of samples (e.g., gamma spectrometry of undried/non-homogenized soil) as remedial actions progress.

Evaluating Survey Results

_____ Compare survey results with DCGLs using survey data as a field decision tool to guide the remedial actions in a real-time mode.

_____ Document survey results.

1 **5.3 Final Status Surveys**

2 An FSS is performed to demonstrate that residual radioactive material in each survey unit
 3 satisfies the predetermined criteria for release for unrestricted use or, where appropriate, for use
 4 with designated limitations. The survey provides data to demonstrate that all radiological
 5 parameters do not exceed the established DCGLs. For these reasons, more detailed
 6 information is provided for this category of survey. For the FSS, survey units represent the
 7 fundamental elements for demonstrating that the property is less than the DCGL_w by using a
 8 combination of direct measurements or sampling and scanning (see **Sections 5.3.3–5.3.5**) or
 9 by a scan-only survey of the property (if warranted by the scanning instrumentation detection
 10 capability and measurement uncertainty; see **Section 5.3.6**). The percentage of the area

1 scanned is dependent upon the classification of the property or survey units within the property
2 as well as the relative shift for the site. The documentation specified in the following sections
3 helps ensure a consistent approach among different organizations and regulatory agencies.
4 This allows for comparisons of survey results between sites or facilities.

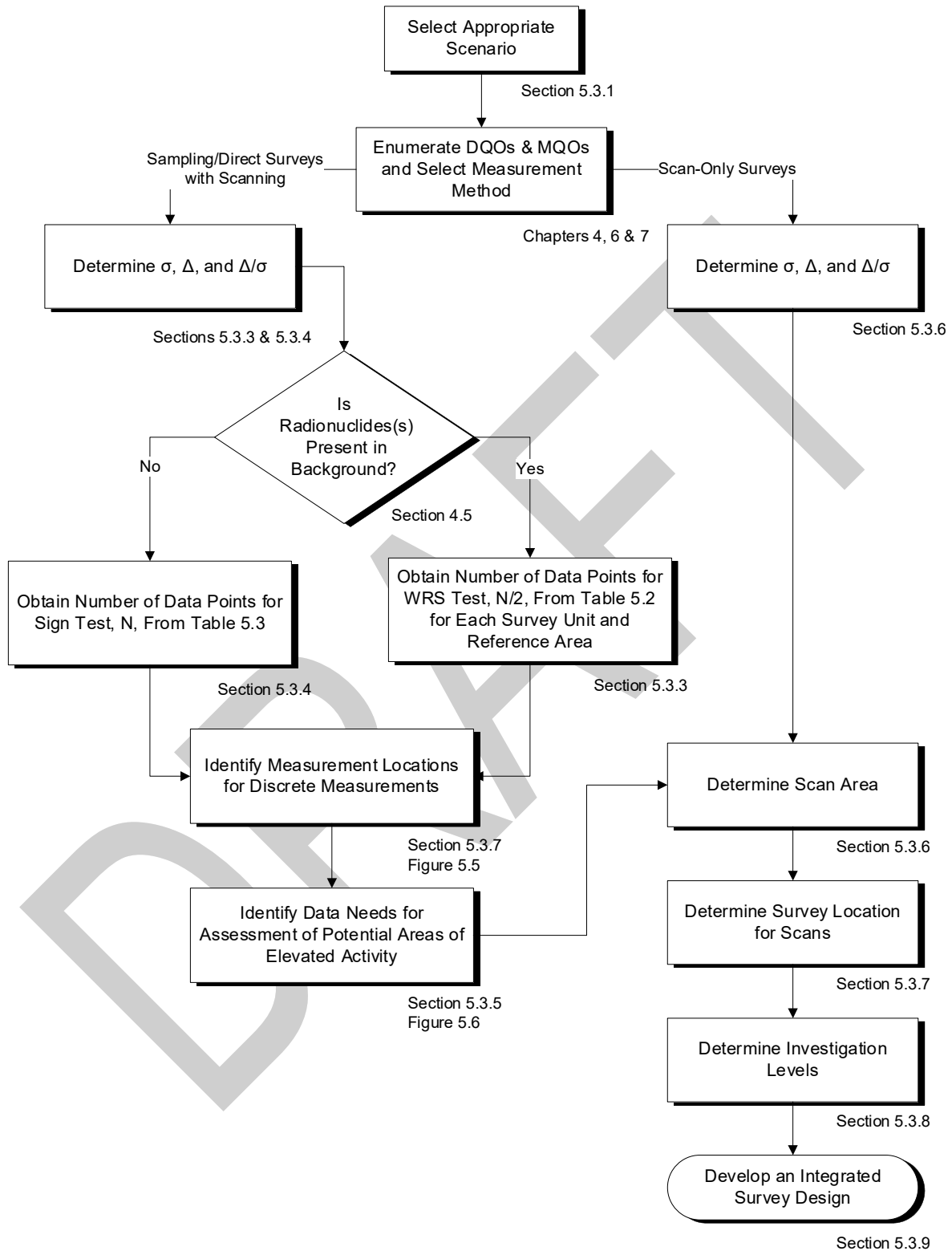
5 The MARSSIM approach recognizes that alternative methods may be acceptable to different
6 regulatory agencies. Flow diagrams and a checklist to assist the user in planning a survey are
7 included in this section.

8 **Figures 5.4–5.6** illustrate the process of designing an FSS. This process begins with
9 development of DQOs and MQOs. The first decision after developing the DQOs and MQOs is to
10 establish whether a scan-only or traditional MARSSIM approach (scanning with direct
11 measurements and/or samples) will be used. Based on these objectives and the known or
12 anticipated radiological conditions at the site, the numbers and locations of measurement and
13 sampling points used and amount of scanning to demonstrate compliance with the release
14 criteria are then determined. Finally, survey techniques appropriate to develop adequate data
15 (see **Chapters 6 and 7**) are selected and implemented.

16 The elements of an FSS discussed in **Section 5.3** consist of the following subsections:

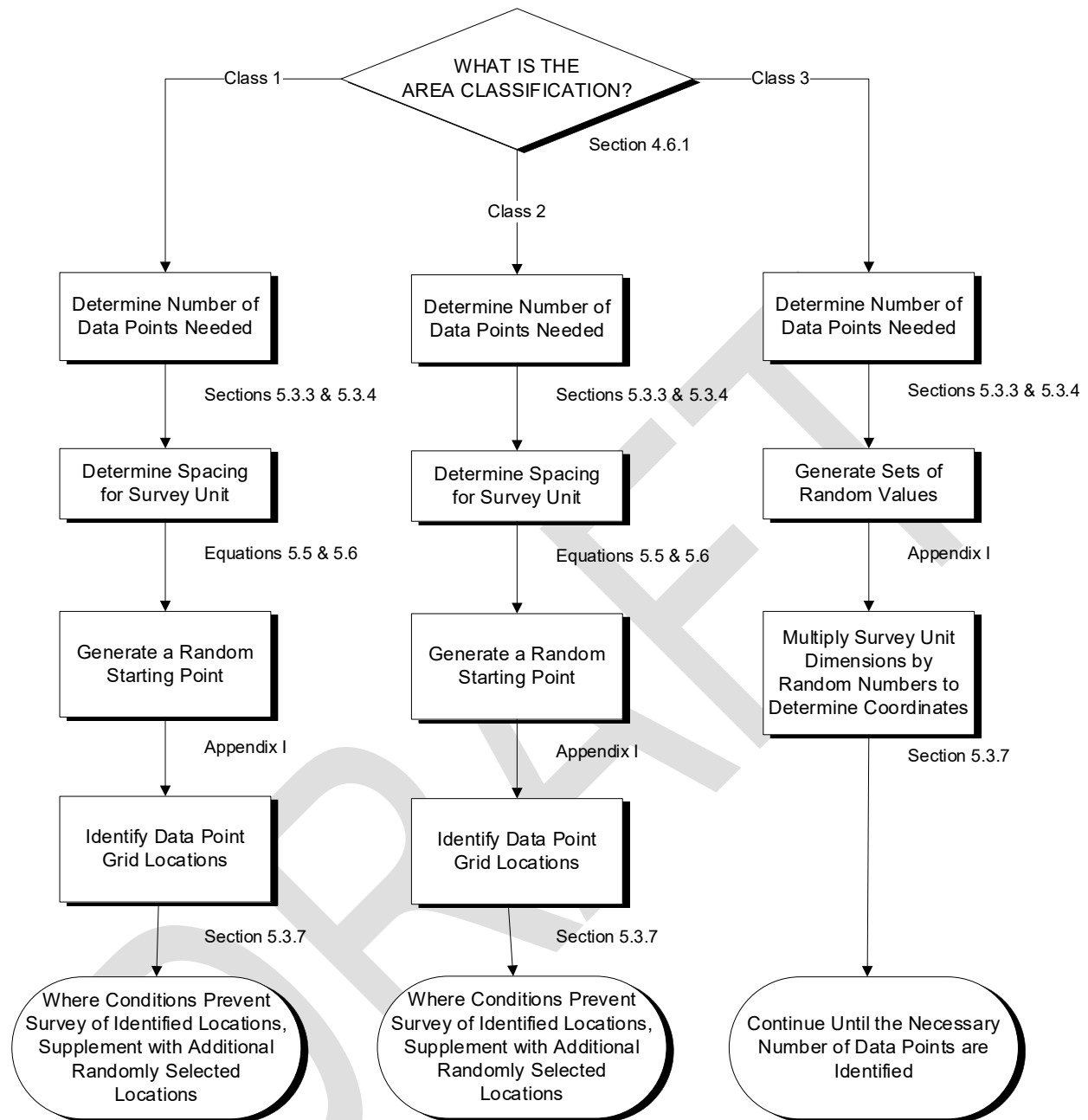
- 17 • selecting either Scenario A or Scenario B as a basis of the survey design (**Section 5.3.1**)
- 18 • determining the appropriate release criteria based on whether radionuclides of concern are
19 present in the background (**Section 5.3.2**)
- 20 • determining the appropriate number of data points for statistical tests when residual
21 radioactive materials are present in the background (**Section 5.3.3**)
- 22 • determining the appropriate number of data points for statistical tests when residual
23 radioactive materials are not present in the background (**Section 5.3.4**)
- 24 • establishing procedures for determining data points for small areas of elevated activity
25 (**Section 5.3.5**)
- 26 • determining the scan area (**Section 5.3.6**)
- 27 • determining the survey locations (**Section 5.3.7**)
- 28 • establishing the appropriate investigation level for a survey (**Section 5.3.8**)
- 29 • developing an integrated survey design (**Section 5.3.9**)
- 30 • evaluating the survey results (**Section 5.3.10**)
- 31 • documenting the results (**Section 5.3.11**)

32 Another important consideration during planning for an FSS is the performance of confirmatory
33 surveys. Planning for the FSS should include early discussions with the regulatory agency
34 concerning logistics for confirmatory or verification surveys. A confirmatory survey (also known
35 as an independent verification survey) may be performed by the regulatory agency or by an
36 independent third party (e.g., a party contracted by the regulatory agency) to provide data to
37 substantiate results of the FSS. Actual field measurements and sampling may be performed.



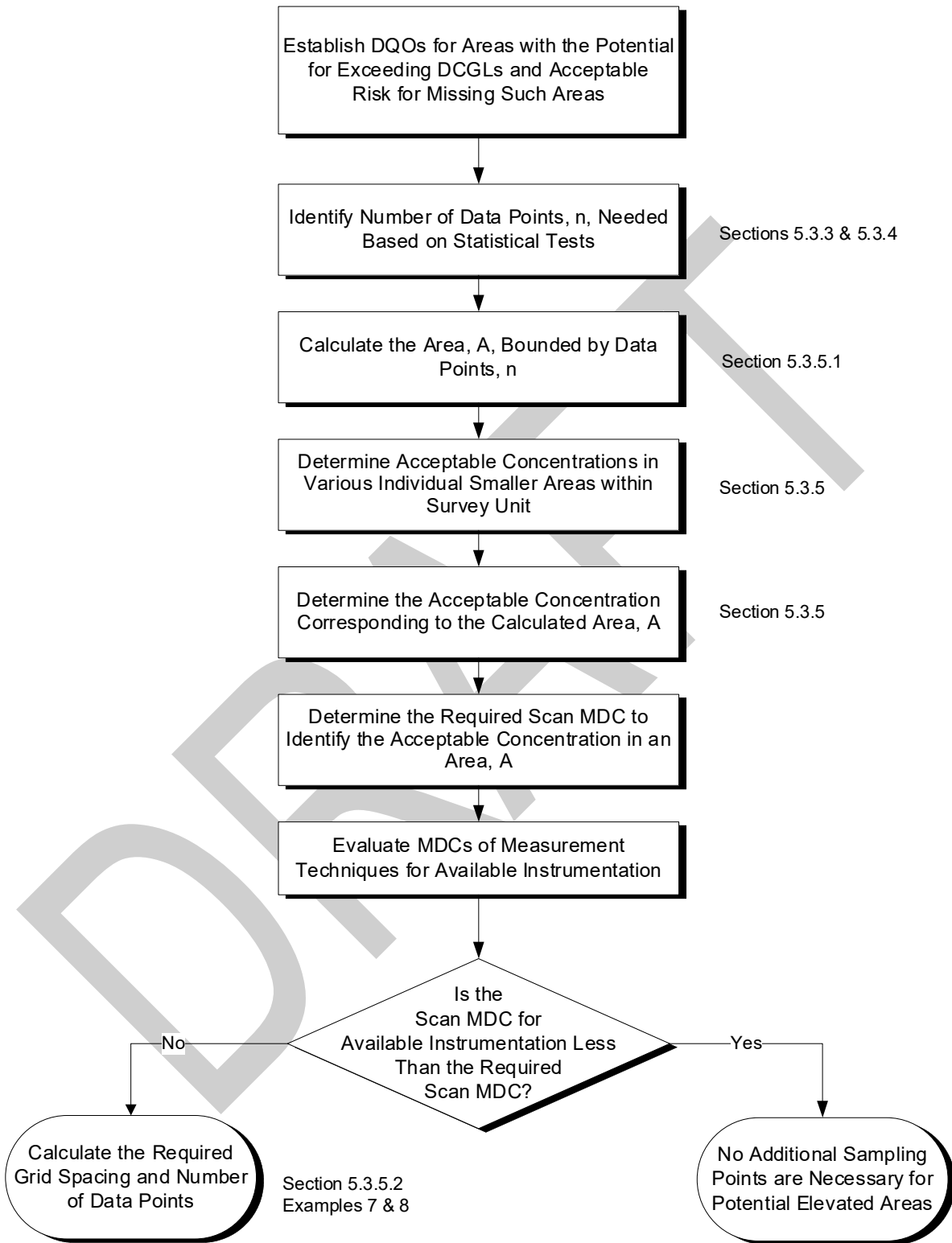
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2 **Figure 5.4: Process for Designing an Integrated Survey Plan for a Final Status Survey**



1

2 **Figure 5.5: Process for Identifying Discrete Measurement Locations**



1
 2 **Figure 5.6: Identifying Data Needs for Assessment of Potential Areas of Elevated Activity**
 3 **in Class 1 Survey Units**

1 Independent confirmatory survey activities are usually limited in scope to spot-checking
 2 conditions at selected locations, comparing findings with those of the FSS and performing
 3 independent statistical evaluations of the data developed from the confirmatory survey and the
 4 FSS. Another purpose of the confirmatory activities may be to identify any deficiencies in the
 5 FSS documentation based on a thorough review of survey procedures and results. Finally,
 6 reviewing the results of confirmatory surveys performed on other sites may provide insight into
 7 possible survey deficiencies, which can then be corrected before the FSS is performed (Roberts
 8 2008).

9 **5.3.1 Selecting the Appropriate Scenario**

10 The DQO process, as it is applied to FSSs, is described in more detail in **Appendix D** of this
 11 manual and in EPA and NRC guidance documents (EPA 1987b, 1987c, 2006c; NRC 1998a). As
 12 part of this process, the objective of the survey and the null and alternative hypotheses should
 13 be clearly stated. The objective of FSSs is typically to demonstrate that residual radioactive
 14 material levels meet the release criteria. One of two approaches is used to demonstrate that this
 15 objective is met; the two approaches differ in the selection of the null hypothesis (i.e., what is
 16 assumed to be the true state of nature), as summarized in **Table 5.1**.

17 **Table 5.1: Null and Alternative Hypothesis for Scenarios A and B**

Scenario	Null Hypothesis (H_0)	Alternative Hypothesis (H_1)
A	The concentration of residual radioactive material is equal to or exceeds the release criteria.	The concentration of residual radioactive material is less than the release criteria.
B	The concentration of residual radioactive material is equal to or less than the release criteria.	The concentration of residual radioactive material exceeds the release criteria.

18 Historically, MARSSIM recommended the use of Scenario A, which put the burden of proof that
 19 the survey unit met the release criteria on the individuals designing the survey. However,
 20 Scenario A requires that survey designers choose a discrimination limit (DL), the lower bound of
 21 the gray region (LBGR), at some radioactive material concentration less than the DCGL. This is
 22 effectively impossible when the AL corresponding to the release criteria is “zero residual
 23 radioactive material” or “zero residual radioactive material above background.” The only way to
 24 design a survey for these kinds of release criteria is to establish a DL at some radioactive
 25 material concentration greater than the AL.

26 In Scenario B, the burden of proof is no longer on the individuals designing the survey and,
 27 thus, should be used with caution and only in those situations where Scenario A is not an
 28 effective alternative. The consequence of inadequate power is an increased Type II decision
 29 error (β) rate. For Scenario A, this means that a survey unit that does meet the release criteria
 30 has a higher probability of being incorrectly determined not to meet the release criteria. For
 31 Scenario B, this means that a survey unit that does not meet the release criteria has a higher
 32 probability of being incorrectly determined to meet the release criteria. For this reason,
 33 individuals designing a MARSSIM Survey using Scenario B should make conservative
 34 assumptions for the estimate of the standard deviation (σ) (see **Section 5.3.3.2**) so that even if
 35 the variability in the survey unit is higher than expected, the power of the resulting survey
 36 ($1 - \beta$) (see **Section 5.3.2**) will still be sufficient to ensure that survey units with residual
 37 radioactive material in excess of the AL will be discovered $1 - \beta$ percent of the time. As a result,
 38 a retrospective power analysis needs to be performed following the completion of Scenario B

1 MARSSIM surveys indicating that regulatory agency requirements on β at the DL were met. See
2 **Chapter 8** and **Appendix M** for more information on performing a retrospective power analysis.

3 **5.3.2 Application of Release Criteria**

4 The statistical test used to evaluate data for FSSs where direct measurements or sampling and
5 analysis is performed depend on the scenario selected. For radionuclides that are present in
6 background, the Wilcoxon Rank Sum (WRS) test is typically used in Scenario A. In Scenario B
7 two nonparametric statistical tests are performed: the WRS test and the Quantile test. The WRS
8 and Quantile tests are both used because each test detects different residual radioactive
9 material patterns in the survey unit. When radionuclides of concern are not present in
10 background, the Sign test is used for both scenarios. For scan-only surveys, a comparison to an
11 upper confidence level (UCL) is performed. The Sign, WRS, UCL, and Quantile tests are
12 discussed in **Chapter 8**.

13 To determine data needs for these tests, the acceptable probability of making Type I decision
14 errors (α) and Type II decision errors (β) should be established (see **Appendix D, Section**
15 **D.1.6**). The acceptable decision error rates are defined at the LBGR and the DCGL_w for
16 Scenario A and the action level (AL) and the DL for Scenario B. Acceptable decision error rates
17 are determined during survey planning using the DQO process.

18 The final step of the DQO process includes selecting a survey design that satisfies the DQOs.
19 For some sites or survey units, the information provided in this section may result in a survey
20 design that cannot be accomplished with the available resources. For these situations, the
21 planning team may be able to relax one or more of the constraints used to develop the survey
22 design as described in **Appendix D**. For example—

- 23 • increasing the decision error rates, considering the risks associated with making an incorrect
24 decision
- 25 • increasing the width of the gray region, as long as the LBGR is not set lower than the
26 estimate of the residual radioactive material remaining in the survey unit in Scenario A
- 27 • changing the boundaries—it may be possible to reduce measurement costs by changing or
28 eliminating survey units that may require different decisions

29 **5.3.3 Determining Numbers of Data Points for Statistical Tests for Residual Radioactive** 30 **Material Present in Background**

31 The comparison of measurements from the reference area and survey unit is made using the
32 WRS test, which is usually conducted for each survey unit. In addition, the Elevated
33 Measurement Comparison (EMC) may need to be performed against each measurement to
34 ensure that the measurement result does not exceed a specified investigation level. If any
35 measurement in the remediated survey unit exceeds the specified investigation level, then
36 additional investigation is recommended, at least locally, regardless of the outcome of the WRS
37 test.

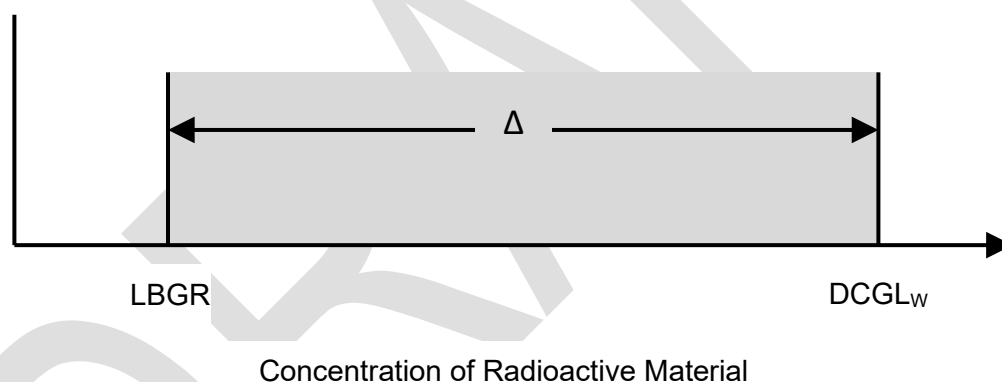
38 The WRS test is most effective when residual radioactive material is uniformly present
39 throughout a survey unit. The test is designed to detect whether the median concentration
40 exceeds the DCGL_w. The advantage of this nonparametric test is that it does not assume the

1 data are normally or log-normally distributed. The WRS test also allows for “less than”
 2 measurements to be present in the reference area and the survey units. This test can generally
 3 be used with up to 40 percent “less than” measurements in either the reference area or the
 4 survey unit. However, the use of “less than” values in data reporting is not recommended (NRC
 5 2004). Wherever possible, the actual result of a measurement, together with its uncertainty,
 6 should be reported.

7 This section introduces several terms and statistical parameters that will be used to determine
 8 the number of data points needed to apply the nonparametric tests. An example is provided
 9 below to better illustrate the application of these statistical concepts.

10 5.3.3.1 Define the Gray Region

11 In Scenario A, the upper bound of the gray region (UBGR) is equal to the $DCGL_w$. The gray
 12 region is defined as the interval between the LBGR and the $DCGL_w$ (**Figure 5.7**). For
 13 Scenario A, the LBGR is typically chosen to represent a conservative (slightly higher) estimate
 14 of the mean concentration of residual radioactive material remaining in the survey unit at the
 15 beginning of the FSS. If there is no information with which to estimate the residual radioactive
 16 material concentration remaining, the LBGR may be initially set to equal one-half of the $DCGL_w$.

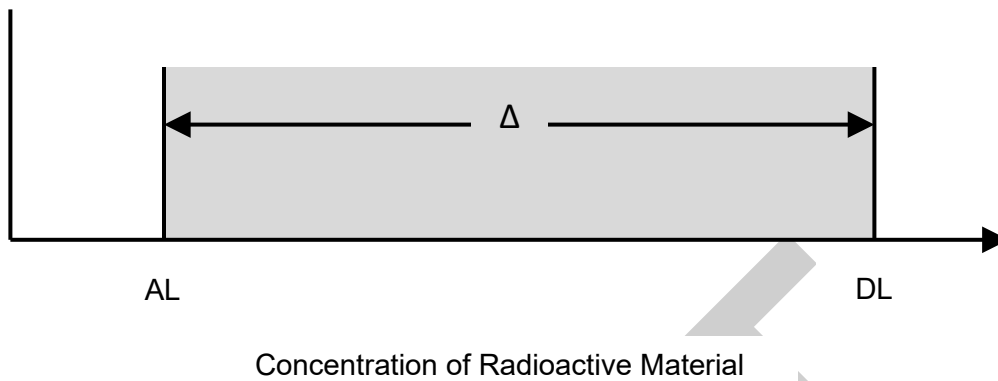


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18 **Figure 5.7: Gray Region for Scenario A**

19 In Scenario B, the UBGR is equal to the DL, and the LBGR is equal to the AL. The gray region
 20 is defined as the interval between the AL and the DL (**Figure 5.8**).² The AL is the concentration
 21 of radioactive material that causes a decision maker to choose one of the alternative actions,
 22 such as releasing a survey unit or requiring additional investigation. The planning team also
 23 chooses the DL. The DL is the concentration of radioactive material or level of radioactivity that
 24 can be reliably distinguished from the action level by performing measurements with the devices
 25 selected for the survey (i.e., direct measurements, scans, in situ measurements, samples with
 26 laboratory analyses) and defines the rigor of the survey. It is determined through negotiations
 27 with the regulator, and, in some cases, the DL will be set equal to a regulatory limit (e.g.,
 28 10 CFR 36.57 and DOE 2011c). The DL and the AL should be reported in the same units. The
 29 selection of the appropriate null hypothesis is further discussed in **Chapter 8** and **Appendix D**.

² This description of Scenario B is based on information contained in the Multi-Agency Radiation Survey and Assessment of Materials and Equipment (MARSAME) Manual and the Multi-Agency Radiation Laboratory Analytical Protocols and is fundamentally different from the description of Scenario B found in NUREG-1505 (NRC 1998a).



1

2 **Figure 5.8: Gray Region for Scenario B**

3 When Scenario B is being used, the variability in the data may be such that a decision may be
 4 "too close to call" when the true but unknown value of the residual radioactivity concentration is
 5 very near the DL. In this situation, consultation with the appropriate regulator may be required to
 6 determine the AL and DL. As an example, the U.S. NRC discusses methods in NUREG-1505
 7 (NRC 1998a), Chapter 13, to establish the gray region and a concentration level that is
 8 considered indistinguishable from background when the WRS test is used³.

9 **5.3.3.2 Calculate the Relative Shift**

10 The width of the gray region is a parameter that is essential for planning all statistical tests; it is
 11 also referred to as the shift, Δ . In Scenario A, the shift is the difference between the LBGR and
 12 the DCGL_W ($\Delta = \text{DCGL}_W - \text{LBGR}$). In Scenario B, the shift is the difference between the AL
 13 and the DL ($\Delta = \text{DL} - \text{AL}$). The absolute size of the shift is less important than the relative shift,
 14 Δ/σ , where σ is an estimate of the standard deviation of the measured values in the survey unit.
 15 This estimate of σ includes both the real spatial variability in the quantity being measured and
 16 the uncertainty of the chosen measurement method. The relative shift is an expression of the
 17 resolution of the measurements in units of measurement uncertainty.

18 The shift and the estimated standard deviation in the measurements of the radioactive material
 19 in the survey unit (σ_s) and reference area (σ_r) are used to calculate the relative shift (Δ/σ) (see
 20 **Appendix D, Section D.1.7.3**). The standard deviations in the radionuclide level will likely be
 21 available from previous systematic and non-judgment survey data (e.g., scoping or
 22 characterization survey data for un-remediated survey units or RAS surveys for remediated
 23 survey units). If they are not available, it may be necessary to (1) perform some limited
 24 preliminary measurements (about 5–20) to estimate the distributions or (2) to make a
 25 reasonable estimate based on available site knowledge. If the first approach above is used, the
 26 scoping or characterization survey data or preliminary measurements used to estimate the
 27 standard deviation should use the same technique as the FSS will. When preliminary data are
 28 not obtained, it may be reasonable to assume a coefficient of variation (CV) on the order of

³ Chapter 8 in NUREG-1505 [NRC 1998] provides additional information on the WRS test.

1 30 percent, based on experience. The CV is a measure of the dispersion of the data and is
2 defined by the ratio of the standard deviation to the mean.

3 The value selected as an estimate of σ for a survey unit may be based on data collected only
4 from within that survey unit or from data collected from a much larger area of the site. Note that
5 survey units are not finalized until the planning stage of the FSS. This means that there may be
6 some difficulty in determining which individual measurements from a preliminary survey may
7 later represent a particular survey unit. For many sites, the most practical solution is to estimate
8 σ for each area classification (i.e., Class 1, Class 2, and Class 3) for both interior and exterior
9 survey units. This will result in all exterior Class 3 survey units using the same estimate of σ , all
10 exterior Class 2 survey units using a second estimate for σ , and all exterior Class 1 survey units
11 using a third estimate for σ . If there are multiple types of surfaces within an area classification,
12 additional estimates of σ may be required. For example, a Class 2 concrete floor may require a
13 different estimate of σ than a Class 2 cinder block wall, or a Class 3 unpaved parking area may
14 require a different estimate of σ than a Class 3 lawn. In addition, a separate estimate of σ
15 should be obtained for every reference area.

16 The importance of choosing appropriate values for σ_r and σ_s must be emphasized. If the value
17 is grossly underestimated, the number of data points will be too few to obtain the desired power
18 level for the test, and a resurvey may be recommended (see **Chapter 8**). If, on the other hand,
19 the value is overestimated, the number of data points determined will be unnecessarily large.

20 Values for the relative shift that are less than 1 will result in a large number of measurements
21 needed to demonstrate compliance. The number of data points will also increase as Δ becomes
22 smaller. Because the DCGL is fixed, this means that the LBGR also has a significant effect on
23 the estimated number of measurements needed to demonstrate compliance in Scenario A. The
24 DL selected during the DQO process will have a similar effect in Scenario B. When the
25 estimated standard deviations in the reference area and survey units are different, the larger
26 value should be used to calculate the relative shift (Δ/σ). There is little benefit, in terms of
27 reduced number of measurements, for relative shift values greater than 3. Because of this and
28 the large number of measurements resulting from relative shift values less than 1, in
29 Scenario A, the LBGR may be adjusted to ensure the relative shift is greater than 1, as long as
30 the LBGR is not set lower than the estimate of the residual radioactive material remaining in the
31 survey unit. For Scenario B, the planning team may wish to adjust the DL to achieve a similar
32 effect with approval from the regulator. However, it is extremely important that such adjustments
33 be supported by data. Additional considerations related to adjusting the relative shift are
34 provided in **Appendix D, Section D.1.7.3**.

35 In practice, the DQO process is used to obtain a proper balance among the use of various
36 measurement techniques. In general, there is an inverse correlation between the cost of a
37 specific measurement method and the detection levels being sought. Depending on the survey
38 objectives, there are many important considerations when selecting a measurement method
39 that will ultimately affect both the survey costs and the statistical power of the sampling design.
40 Statistical power is defined as the probability that a statistical test will correctly reject the null
41 hypothesis (i.e., under Scenario A, accepting that a site that meets the release criteria truly
42 does, and under Scenario B, accepting that a site that does not meet the release criteria truly
43 does not). A general example approach that might be undertaken for a Scenario A planning
44 session is discussed below.

45 N is the total number of data points for each survey unit/reference area combination. The N data
46 points are divided between the survey unit, n , and the reference area, m . The simplest method

1 for distributing the N data points is to assign half the data points to the survey unit and half to
2 the reference area, so $n = m = N/2$. This means that $N/2$ measurements are performed in
3 each survey unit, and $N/2$ measurements are performed in each reference area. If more than
4 one survey unit is associated with a particular reference area, $N/2$ measurements should be
5 performed in each survey unit, and $N/2$ measurements should be performed in the reference
6 area.

7 **Table 5.2** provides a list of the number of data points needed to demonstrate compliance using
8 the WRS test for selected values of α , β , and Δ/σ . The values listed in **Table 5.2** represent the
9 number of measurements to be performed in each survey unit and in the corresponding
10 reference area. **Example 4** illustrates the use of the WRS Test under Scenario A.

Example 4: Use of WRS Test under Scenario A

A site has 14 survey units and 1 reference area in a building, and the same measurement method is used to perform measurements in each survey unit and the reference area. The radionuclide has a wide-area derived concentration guideline level of 400 becquerels/square meter (Bq/m^2) (240 decays per minute [dpm]/100 square centimeters [cm^2]). The radionuclide is present in background at a level of $100 \pm 15 \text{ Bq}/\text{m}^2$ (1σ). The standard deviation of the radionuclide in the survey area is $\pm 40 \text{ Bq}/\text{m}^2$ (24 dpm/100 cm^2), based on previous survey results for the same or similar radionuclide distribution. When the estimated standard deviation in the reference area and the survey units are different, the larger value, 40 Bq/m^2 in this example, is used to calculate the relative shift. During the Data Quality Objective process, Scenario A is selected. The LBGR is selected to be 240 Bq/m^2 . This is based on a conservative estimate of the concentration of residual radioactive material in the survey unit. Type I and Type II error values (α and β) of 0.05 are selected. Determine the number of data points to be obtained from the reference area and from each of the survey units for the statistical tests.

The value of the relative shift for the survey unit, Δ/σ , is $(400 - 240)/40$, or 4.0. The number of data points can be obtained directly from **Table 5.2**. For $\alpha = 0.05$, $\beta = 0.05$, and $\Delta/\sigma = 4.0$, a value of 9 is obtained for $N/2$. The table value has already been increased by 20 percent to account for missing or unusable data.

11

Table 5.2: Values of $N/2$ for Use with the Wilcoxon Rank Sum Test^{4,5}

Δ/σ	$\alpha = 0.01$					$\alpha = 0.025$					$\alpha = 0.05$					$\alpha = 0.10$					$\alpha = 0.25$				
	β					β					β					β					β				
	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25
0.1	5,452	4,627	3,972	3,278	2,268	4,627	3,870	3,273	2,646	1,748	3,972	3,273	2,726	2,157	1,355	3,278	2,646	2,157	1,655	964	2,268	1,748	1,355	964	459
0.2	1,370	1,163	998	824	570	1,163	973	823	665	440	998	823	685	542	341	824	665	542	416	243	570	440	341	243	116
0.3	614	521	448	370	256	521	436	369	298	197	448	369	307	243	153	370	298	243	187	109	256	197	153	109	52
0.4	350	297	255	211	146	297	248	210	170	112	255	210	175	139	87	211	170	139	106	62	146	112	87	62	30
0.5	227	193	166	137	95	193	162	137	111	73	166	137	114	90	57	137	111	90	69	41	95	73	57	41	20
0.6	161	137	117	97	67	137	114	97	78	52	117	97	81	64	40	97	78	64	49	29	67	52	40	29	14
0.7	121	103	88	73	51	103	86	73	59	39	88	73	61	48	30	73	59	48	37	22	51	39	30	22	11
0.8	95	81	69	57	40	81	68	57	46	31	69	57	48	38	24	57	46	38	29	17	40	31	24	17	8
0.9	77	66	56	47	32	66	55	46	38	25	56	46	39	31	20	47	38	31	24	14	32	25	20	14	7
1.0	64	55	47	39	27	55	46	39	32	21	47	39	32	26	16	39	32	26	20	12	27	21	16	12	6
1.1	55	47	40	33	23	47	39	33	27	18	40	33	28	22	14	33	27	22	17	10	23	18	14	10	5
1.2	48	41	35	29	20	41	34	29	24	16	35	29	24	19	12	29	24	19	15	9	20	16	12	9	4
1.3	43	36	31	26	18	36	30	26	21	14	31	26	22	17	11	26	21	17	13	8	18	14	11	8	4
1.4	38	32	28	23	16	32	27	23	19	13	28	23	19	15	10	23	19	15	12	7	16	13	10	7	4
1.5	35	30	25	21	15	30	25	21	17	11	25	21	18	14	9	21	17	14	11	7	15	11	9	7	3
1.6	32	27	23	19	14	27	23	19	16	11	23	19	16	13	8	19	16	13	10	6	14	11	8	6	3
1.7	30	25	22	18	13	25	21	18	15	10	22	18	15	12	8	18	15	12	9	6	13	10	8	6	3
1.8	28	24	20	17	12	24	20	17	14	9	20	17	14	11	7	17	14	11	9	5	12	9	7	5	3
1.9	26	22	19	16	11	22	19	16	13	9	19	16	13	11	7	16	13	11	8	5	11	9	7	5	3
2.0	25	21	18	15	11	21	18	15	12	8	18	15	13	10	7	15	12	10	8	5	11	8	7	5	3
2.25	22	19	16	14	10	19	16	14	11	8	16	14	11	9	6	14	11	9	7	4	10	8	6	4	2
2.5	21	18	15	13	9	18	15	13	10	7	15	13	11	9	6	13	10	9	7	4	9	7	6	4	2
2.75	20	17	15	12	9	17	14	12	10	7	15	12	10	8	5	12	10	8	6	4	9	7	5	4	2
3.0	19	16	14	12	8	16	14	12	10	6	14	12	10	8	5	12	10	8	6	4	8	6	5	4	2
3.5	18	16	13	11	8	16	13	11	9	6	13	11	9	8	5	11	9	8	6	4	8	6	5	4	2
4.0	18	15	13	11	8	15	13	11	9	6	13	11	9	7	5	11	9	7	6	4	8	6	5	4	2

⁴ In Scenario B the sample size for the WRS test is also used for the Quantile test.

⁵ The values were calculated using Equation O-1 and increased by 20 percent for the reasons discussed in Appendix O.

1 **Example 5** illustrates the use of the WRS Test under Scenario B.

Example 5: Use of WRS Test under Scenario B

A site has 14 survey units and 1 reference area in a building, and the same measurement method is used to perform measurements in each survey unit and the reference area. The radionuclide is present in background at a level of 100 ± 15 becquerels/meter squared (Bq/m^2) (1σ). The standard deviation of the radionuclide in the survey area is 40 Bq/m^2 , based on previous survey results for the same or similar radionuclide distribution. When the estimated standard deviation in the reference area and the survey units are different, the larger value, 40 Bq/m^2 in this example, should be used to calculate the relative shift. During the Data Quality Objective process, Scenario B is selected because the release criterion for the site is no residual radioactive material above background. The discrimination limit is selected to be 220 Bq/m^2 as a stakeholder agreed-upon starting point for developing an acceptable survey design, and Type I and Type II error values (α and β) of 0.05 are selected. Determine the number of data points to be obtained from the reference area and from each of the survey units for the statistical tests.

The value of the relative shift for the reference area, Δ/σ , is $(220 - 100)/40$, or 3.0. The number of data points can be obtained directly from **Table 5.2**. For $\alpha = 0.05$, $\beta = 0.05$, and $\Delta/\sigma = 3.0$, a value of 10 is obtained for $N/2$. The table value has already been increased by 20 percent to account for missing or unusable data.

2 **5.3.4 Determining Numbers of Data Points for Statistical Tests for Residual Radioactive** 3 **Material Not Present in Background**

4 For the situation where the residual radioactive material is not present in background or is
5 present at such a small fraction of the DCGL_w as to be considered insignificant, a background
6 reference area is not necessary. Instead, the radionuclide levels are compared directly with the
7 DCGL value. The general approach closely parallels that used for the situation when the
8 radionuclide is present in background as described in **Section 5.3.3**. However, the statistical
9 tests differ slightly. The Sign test replaces the WRS test described above.

10 **5.3.4.1 Define the Gray Region**

11 In Scenario A, the UBGR is equal to the DCGL_w (**Figure 5.7**). The LBGR is typically chosen to
12 represent a conservative (slightly higher) estimate of the residual radioactive material
13 concentration remaining in the survey unit at the beginning of the FSS. If there is no information
14 with which to estimate the residual radioactive material concentration remaining, the LBGR may
15 be initially set to equal one-half of the DCGL_w . In Scenario B, the LBGR is equal to zero or the
16 DCGL_w , and the UBGR is defined as the DL (**Figure 5.8**). The DL is a concentration or level of
17 radioactive material that can be reliably distinguished from the LBGR by performing
18 measurements with the devices selected for the survey. The DL defines the rigor of the survey
19 and is determined through negotiations with the regulator. The selection of the appropriate null
20 hypothesis is further discussed in **Chapter 8** and **Appendix D**.

1 5.3.4.2 Calculate the Relative Shift

2 In Scenario A, the shift is the distance between the LBGR and the DCGL_W ($\Delta = \text{DCGL}_W -$
3 LBGR). In Scenario B, the shift is the distance between the AL and the DL ($\Delta = \text{DL} - \text{AL}$).
4 The absolute size of the shift is less important than the relative shift, Δ/σ , where σ is an
5 estimate of the variability in the survey unit. The value of σ may be obtained from earlier
6 surveys, limited preliminary measurements, or a reasonable estimate. This estimate of
7 σ includes both the real spatial variability in the quantity being measured and the uncertainty of
8 the measurement method. The relative shift, Δ/σ , is an expression of the resolution of the
9 measurements in units of measurement uncertainty. Values of the relative shift that are less
10 than 1 will result in a large number of measurements needed to demonstrate compliance.
11 **Section 5.3.3.2** provides more detail on the relative shift.

12 **Table 5.3** provides a list of the number of data points used to demonstrate compliance using the
13 Sign test for selected values of α , β , and Δ/σ . The values listed in **Table 5.3** represent the
14 number of measurements to be performed in each survey unit. These values were calculated
15 using **Equation O-1** in **Appendix O** and increased by 20 percent to account for missing or
16 unusable data and uncertainty in the calculated value of N . **Example 6** illustrates the use of the
17 Sign Test under Scenario A.

Example 6: Use of Sign Test Under Scenario A

A site has one survey unit. The wide-area derived concentration guideline level for the radionuclide of interest is 140 becquerels/kilogram (Bq/kg) (3.9 picocuries/gram [pCi/g]) in soil. The radionuclide is not present in background; data from previous investigations indicate average residual radioactive material at the survey unit of 110 ± 3.7 (1σ) Bq/kg (3.7 ± 0.1 pCi/g). Using Scenario A, the lower bound of the gray region was selected to be 110 Bq/kg. A value of 0.05 is next selected for the probability of Type I decision errors (α), and a value of 0.01 is selected for the probability of Type II decision errors (β) based on the survey objectives. Determine the number of data points to be obtained from the survey unit for the statistical tests.

The value of the relative shift, Δ/σ , is $(140 - 110)/3.7$, or 8.1. The number of data points can be obtained directly from **Table 5.3**. For $\alpha = 0.05$, $\beta = 0.01$, and $\Delta/\sigma > 3.0$, a value of 20 is obtained for N . The table value has already been increased by 20 percent to account for missing or unusable data and uncertainty in the calculated value of N .

18

Table 5.3: Values of N for Use with the Sign Test⁶

Δ/σ	$\alpha = 0.01$					$\alpha = 0.025$					$\alpha = 0.05$					$\alpha = 0.10$					$\alpha = 0.25$				
	β					β					β					β					β				
	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25
0.1	4,095	3,476	2,984	2,463	1,704	3,476	2,907	2,459	1,989	1,313	2,984	2,459	2,048	1,620	1,018	2,463	1,989	1,620	1,244	725	1,704	1,313	1,018	725	345
0.2	1,035	879	754	623	431	879	735	622	503	333	754	622	518	410	258	623	503	410	315	184	431	333	258	184	88
0.3	468	398	341	282	195	398	333	281	227	150	341	281	234	185	117	282	227	185	143	83	195	150	117	83	40
0.4	270	230	197	162	113	230	1921	162	131	87	197	162	136	107	68	162	131	107	82	48	113	87	68	48	23
0.5	178	152	130	107	75	152	126	107	87	58	130	107	89	71	45	107	87	71	54	33	75	58	45	33	16
0.6	129	110	94	77	54	110	92	77	63	42	94	77	65	52	33	77	63	52	40	23	54	42	33	23	11
0.7	99	83	72	59	41	83	70	59	48	33	72	59	50	40	26	59	48	40	30	18	41	33	26	18	9
0.8	80	68	58	48	34	68	57	48	39	26	58	48	40	32	21	48	39	32	24	15	34	26	21	15	8
0.9	66	57	48	40	28	57	47	40	33	22	48	40	34	27	17	40	33	27	21	12	28	22	17	12	6
1.0	57	48	41	34	24	48	40	34	28	18	41	34	29	23	15	34	28	23	18	11	24	18	15	11	5
1.1	50	42	36	30	21	42	35	30	24	17	36	30	26	21	14	30	24	21	16	10	21	17	14	10	5
1.2	45	38	33	27	20	38	32	27	22	15	33	27	23	18	12	27	22	18	15	9	20	15	12	9	5
1.3	41	35	30	26	17	35	29	24	21	14	30	24	21	17	11	26	21	17	14	8	17	14	11	8	4
1.4	38	33	28	23	16	33	27	23	18	12	28	23	20	16	10	23	18	16	12	8	16	12	10	8	4
1.5	35	30	27	22	15	30	26	22	17	12	27	22	18	15	10	22	17	15	11	8	15	12	10	8	4
1.6	34	29	24	21	15	29	24	21	17	11	24	21	17	14	9	21	17	14	11	6	15	11	9	6	4
1.7	33	28	24	20	14	28	23	20	16	11	24	20	17	14	9	20	16	14	10	6	14	11	9	6	4
1.8	32	27	23	20	14	27	22	20	16	11	23	20	16	12	9	20	16	12	10	6	14	11	9	6	4
1.9	30	26	22	18	14	26	22	18	15	10	22	18	16	12	9	18	15	12	10	6	14	10	9	6	4
2.0	29	26	22	18	12	26	21	18	15	10	22	18	15	12	8	18	15	12	10	6	12	10	8	6	3
2.5	28	23	21	17	12	23	20	17	14	10	21	17	15	11	8	17	14	11	9	5	12	10	8	5	3
3.0	27	23	20	17	12	23	20	17	14	9	20	17	14	11	8	17	14	11	9	5	12	9	8	5	3

⁶ The values were calculated using Equation O-2 and increased by 20 percent for the reasons discussed in Appendix O.

1 **5.3.5 Determining the Number of Discrete Data Points for Small Areas of Elevated**
 2 **Activity**

3 As described in **Section 4.2.5**, the treatment of elevated areas of radioactive material is
 4 determined strictly through requirements of regulatory agencies and is beyond the scope of
 5 MARSSIM. A technically sound approach should be used for the derivation of the DCGL for the
 6 Elevated Measurement Comparison (DCGL_{EMC}) values. The methodology presented in
 7 MARSSIM of using the unity rule to consider the combined impact of each elevated area is one
 8 conservative approach to assess areas of elevated radioactive materials. See **Figure 5.6** for a
 9 summary of data needs for areas of elevated activity.

10 The statistical tests described throughout **Sections 5.3.3 and 5.3.4** (see also **Chapter 8**)
 11 evaluate whether the residual radioactive material in an area exceeds the DCGL_W for
 12 radionuclide concentrations that are approximately uniform across the survey unit. In addition,
 13 there should be a reasonable level of assurance that any small areas of elevated concentrations
 14 of residual radioactive material that could be significant relative to the DCGL_{EMC} are not missed
 15 during the FSS. The statistical tests introduced in the previous sections may not successfully
 16 detect small areas of elevated concentrations of radioactive material. Instead, systematic
 17 measurements or samples are made at locations defined by a systematic grid, in conjunction
 18 with surface scanning. These results are used to obtain adequate assurance that small areas of
 19 elevated concentrations of radioactive material are below the DCGL_{EMC} and the release criteria
 20 are met. The procedure is applicable for all radionuclides, regardless of whether they are
 21 present in background and is implemented for Class 1 survey units.

22 **5.3.5.1 Determine if Additional Data Points are Needed**

23 Identify the number of survey data points needed for the statistical tests discussed in
 24 **Sections 5.3.3 or 5.3.4** (the appropriate section is determined by whether the radionuclide is
 25 present in background). These data points are then positioned throughout the survey unit by
 26 randomly selecting a start point and establishing a systematic pattern. This systematic sampling
 27 grid may be either triangular or rectangular. The triangular grid is generally more efficient for
 28 locating small areas of elevated activity. **Appendix D** includes a brief discussion on the
 29 efficiency of triangular and rectangular grids for locating areas of elevated activity. A more
 30 detailed discussion is provided by EPA (EPA 1994b).

31 The number of calculated survey locations, n , and the total area of the survey unit, A , are used
 32 to determine the grid spacing, L , of the systematic sampling pattern, using **Equations 5-1**
 33 **and 5-2**.

$$L = \sqrt{\frac{A \text{ (survey unit)}}{0.866 n}} \text{ for a triangular grid} \quad (5-1)$$

$$L = \sqrt{\frac{A \text{ (survey unit)}}{n}} \text{ for a rectangular grid} \quad (5-2)$$

1 The grid area that is bounded by these survey locations is given by **Equations 5-3 and 5-4**. The
 2 risk of not sampling a circular area—equal to A (grid area)—of elevated activity by use of a
 3 random-start grid pattern is illustrated in **Figure D.7** in **Appendix D**.

$$A \text{ (grid area)} = 0.866 L^2 \text{ for a triangular grid} \quad (5-3)$$

$$A \text{ (grid area)} = L^2 \text{ for a rectangular grid} \quad (5-4)$$

4 The $DCGL_{EMC}$ that corresponds to this size of the area of elevated activity (A_{EA}) is obtained from
 5 specific regulatory agency guidance. After using the grid area calculated in **Equation 5-3 or 5-4**
 6 to determine the $DCGL_{EMC}$ for a specific radionuclide, the required minimum detectable
 7 concentration (MDC) of the scan procedure needed to detect an area of elevated activity is
 8 given by **Equation 5-5**.

$$\text{Scan MDC (required)} = DCGL_{EMC} \quad (5-5)$$

9 The actual scan MDCs of scanning techniques are then determined for the available
 10 instrumentation (see **Sections 6.3.2 and 6.6**). The actual scan MDC of the selected scanning
 11 technique is compared to the required scan MDC. If the actual scan MDC is less than the
 12 required scan MDC, no additional sampling points are necessary for assessment of small areas
 13 of elevated activity. In other words, the scanning technique exhibits adequate detection
 14 capability to detect small areas of elevated activity.

15 Revisions 0 and 1 of MARSSIM (published in 1998 and 2000, respectively) included the
 16 calculation of an area factor⁷ as an intermediate step in the determination of the required scan
 17 MDC. The use of an area factor is not necessary if $DCGL_{EMC}$ is tabulated directly as a function
 18 of the area of radioactive material. To simplify the determination of the required scan MDC, the
 19 use of the area factor as an intermediate calculation is not included in this revision of
 20 MARSSIM. The area factor can still be used if the ratio of the $DCGL_{EMC}$ to the $DCGL_W$ is known
 21 and will produce the same results as the approach described in the current revision of
 22 MARSSIM.

23 *5.3.5.2 Calculate the Required Grid Spacing and Number of Data Points*

24 If the actual scan MDC is greater than the required scan MDC (i.e., the available scan detection
 25 capability is not sufficient to detect small areas of elevated activity), then it is necessary to
 26 calculate the $DCGL_{EMC}$ that corresponds to the actual scan MDC using **Equation 5-6**.

$$DCGL_{EMC} = \text{Scan MDC (actual)} \quad (5-6)$$

27 The size of the area of elevated activity (A_{EA}) that corresponds to this $DCGL_{EMC}$ is then obtained
 28 from specific regulatory agency guidance. The required number of data points for assessing

⁷ The area factor, A_m , is defined as the ratio of the $DCGL_{EMC}$ to the $DCGL_W$ as a function of the grid area and relates the required scan MDC to the $DCGL_W$ using the equation: $\text{Scan MDC (required)} = A_m \times DCGL_W$.

- 1 small areas of elevated activity (n_{EA}) can then be determined by dividing the area of elevated
2 activity (A_{EA}) into the survey unit area using **Equation 5-7**.

$$n_{EA} = \frac{A \text{ (survey unit)}}{A_{EA} \text{ (grid unit)}} \quad (5-7)$$

- 3 The calculated number of measurement or sampling locations, n_{EA} , is used to determine a
4 revised spacing, L_{EA} , of the systematic pattern, using **Equations 5-8 and 5-9**.

$$L_{EA} = \sqrt{\frac{A \text{ (survey unit)}}{0.866 n_{EA}}} \text{ for a triangular grid} \quad (5-8)$$

$$L_{EA} = \sqrt{\frac{A \text{ (survey unit)}}{n_{EA}}} \text{ for a rectangular grid} \quad (5-9)$$

- 5 The distance between measurement/sampling locations should generally be rounded *down* to
6 the nearest distance that can be conveniently measured in the field. This value of L_{EA} is then
7 used to determine the measurement locations as described in **Section 5.3.7**. The Sign, WRS,
8 and quantile tests are performed using the larger number of data points, n_{EA} . **Figure 5.6**
9 provides a concise overview of the procedure used to identify data needs for the assessment of
10 small areas of elevated activity.

- 11 If residual radioactive material is found in an isolated area of elevated activity in addition to
12 residual radioactive material distributed relatively uniformly across the survey unit, the
13 information in **Section 8.6.2** can be used to ensure that the total dose or risk does not exceed
14 the release criteria. If there is more than one area of elevated activity, a conservative method is
15 to include a separate term in the formula for each; however, this method may violate
16 assumptions used in the pathway modeling process if adjustments are not made to the
17 modeling. Specifically, if a receptor is assumed to be located directly above one area of
18 elevated activity for the full occupancy period, that same receptor cannot realistically also be
19 assumed to be located directly above a separate area of elevated activity for the full occupancy
20 period associated with the exposure scenario⁸. As an alternative, the dose or risk due to the
21 actual residual radioactive material can be modeled if there is an appropriate exposure pathway
22 model available. Note that these considerations generally apply only to Class 1 survey units,
23 since areas of elevated activity should not exist in Class 2 or Class 3 survey units.

- 24 When the detection limit of the scanning technique is very large relative to the $DCGL_{EMC}$, the
25 number of measurements estimated to demonstrate compliance using the statistical tests may
26 become unreasonably large. In this situation, evaluate the survey objectives and considerations.
27 These considerations may include the survey design and measurement methodology, exposure

⁸ By default, RESRAD assumes that the receptor spends 50 percent of the time indoors and 25 percent of his time outdoors; without further adjustment, and if two areas are considered, the receptor would spent 100 percent of the time indoors and another 50 percent of the time outdoors for a total time of 150 percent of what would typically be assumed for the exposure scenario.

- 1 pathway modeling assumptions and parameter values used to determine the DCGLs, HSA
 2 conclusions concerning source terms and radionuclide distributions, and the results of scoping
 3 and characterization surveys. In most cases, the result of this evaluation is not expected to
 4 justify an unreasonably large number of measurements. **Example 7** provides an example of
 5 how to determine whether additional data points are required to ensure the actual scan MDC is
 6 less than or equal to the required scan MDC.

Example 7: Example Determination Whether Additional Data Points Are Required

A Class 1 land area survey unit of 1,500 square meters (m²) is potentially affected by residual radioactive material consisting of cobalt-60 (⁶⁰Co). The wide-area derived concentration guideline level value for ⁶⁰Co is 110 becquerels/kilogram (Bq/kg; 3 picocuries/gram [pCi/g]), and the scan detection capability for this radionuclide has been determined to be 150 Bq/kg (4 pCi/g). The table below provides the derived concentration guideline level obtained using the Elevated Measurement Comparison for different grid areas:

Grid Area (m ²)	DCGL _{EMC} (Bq/kg)
1	1,070
3	480
10	230
30	160
100	130
300	120
1,000	120
3,000	110
10,000	110

Abbreviations: m = meter; DCGL_{EMC} = derived concentration guideline level obtained using the Elevated Minimum Comparison; Bq = becquerel; kg = kilogram.

Calculations indicate the number of data points needed for statistical testing is 27. The distance between measurement locations for this number of data points and the given land area is 8 m, as illustrated in the application of **Equation 5-1**:

$$L = \sqrt{\frac{A \text{ (survey unit)}}{0.866 n}} = \sqrt{\frac{1,500 \text{ m}^2}{0.866 \times 27}} = 8.0 \text{ m for a triangular grid}$$

The grid area encompassed by a triangular sampling pattern of 8 m is approximately 55.4 m² as calculated using **Equation 5-3**:

$$A \text{ (grid area)} = 0.866 L^2 = 0.866 (8.0 \text{ m})^2 = 55.4 \text{ m}^2$$

The DCGL_{EMC} for a grid area of 55.4 m² is determined by interpolation to be 150 Bq/kg:

$$160 \text{ Bq/kg} + \left(\frac{55.4 \text{ m}^2 - 30 \text{ m}^2}{100 \text{ m}^2 - 30 \text{ m}^2} \right) (130 \text{ Bq/kg} - 160 \text{ Bq/kg}) = 150 \text{ Bq/kg}$$

The acceptable minimum detectable concentration (MDC) of the scan procedure needed to detect an area of elevated activity in a 55.4 m² area is therefore given by **Equation 5-5**:

$$\text{Scan MDC (required)} = \text{DCGL}_{\text{EMC}} = 150 \text{ Bq/kg}$$

Because the detection capability of the procedure to be used (150 Bq/kg) is equal to or less than the required Scan MDC, no additional data points are needed to demonstrate compliance with the elevated measurement comparison criteria.

- 1 **Example 8** provides another example of how to determine if additional data points are required
 2 to ensure the actual scan MDC is less than or equal to the required scan MDC, including how to
 3 calculate the number of required data points when the actual scan MDC is greater than the
 4 required scan MDC.

5 **Example 8: Example Determination Whether Additional Data Points Are Required**

- 6 A Class 1 land area survey unit of 1,500 square meters (m²) is potentially affected by residual
 7 radioactive material consisting of ⁶⁰Co. The wide-area derived concentration guideline level for
 8 cobalt-60 (⁶⁰Co) is 110 becquerels/kilogram (Bq/kg; 3 picocuries/gram [pCi/g]). The table below
 9 provides the derived concentration guideline level obtained using the Elevated Measurement
 10 Comparison for different grid areas:

11

Grid Area (m ²)	DCGL _{EMC} (Bq/kg)
1	1,070
3	480
10	230
30	160
100	130
300	120
1,000	120
3,000	110
10,000	110

Abbreviations: m = meter; DCGL_{EMC} = derived concentration guideline level obtained using the Elevated Minimum Comparison; Bq = becquerel; kg = kilogram.

In contrast to **Example 7**, the scan detection capability for this radionuclide has been determined to be 170 Bq/kg (4.6 pCi/g). Calculations indicate the number of data points needed for statistical testing is 15. The distance between measurement locations for this number of data points and the given land area is 10 m, as illustrated in the application of **Equation 5-1**:

$$L = \sqrt{\frac{A \text{ (survey unit)}}{0.866 n}} = \sqrt{\frac{1,500 \text{ m}^2}{0.866 \times 15}} = 10.7 \text{ m for a triangular grid}$$

The grid area encompassed by a triangular sampling pattern of 10 m is approximately 86.6 m², as calculated using **Equation 5-3**:

$$A \text{ (grid area)} = 0.866 L^2 = 0.866 (10.7 \text{ m})^2 = 99.1 \text{ m}^2$$

The DCGL_{EMC} for a grid area of 99.1 m² is determined by interpolation to be 130 Bq/kg:

$$160 \text{ Bq/kg} + \frac{99.1 \text{ m}^2 - 30 \text{ m}^2}{100 \text{ m}^2 - 30 \text{ m}^2} (130 \text{ Bq/kg} - 160 \text{ Bq/kg}) = 130 \text{ Bq/kg}$$

The required scan minimum detectable concentration (MDC) for that grid area is therefore also 130 Bq/kg:

$$\text{Scan MDC (required)} = \text{DCGL}_{\text{EMC}} = 130 \text{ Bq/kg}$$

Because the actual scan MDC of the procedure to be used (170 Bq/kg) is greater than the required scan MDC, the data points obtained for the statistical testing may not be sufficient to demonstrate compliance using the elevated measurement comparison. The grid area corresponding to a DCGL_{EMC} of 170 Bq/kg is determined by interpolation to be 27 m²:

$$30 \text{ m}^2 + \left(\frac{170 \text{ Bq/kg} - 160 \text{ Bq/kg}}{230 \text{ Bq/kg} - 160 \text{ Bq/kg}} \right) (10 \text{ m}^2 - 30 \text{ m}^2) = 27 \text{ m}^2$$

The number of samples required to account for areas of elevated activity (n_{EA}) is calculated using **Equation 5-7**:

$$n_{EA} = \frac{A \text{ (survey unit)}}{A_{EA} \text{ (grid unit)}} = \frac{1,500 \text{ m}^2}{27 \text{ m}^2} = 56 \text{ measurements}$$

The triangular grid spacing required to account for areas of elevated activity (L_{EA}) is calculated using **Equation 5-8**:

$$L_{EA} = \sqrt{\frac{A \text{ (survey unit)}}{0.866 n_{EA}}} = \sqrt{\frac{1500 \text{ m}^2}{0.866 \times 56}} = 5.5 \text{ m for a triangular grid}$$

The number of data points required increased from 15 to 56, and the grid spacing decreased from 10.7 m to 5.5 m.

1 **5.3.6 Determining the Scan Area**

2 The use of direct measurements or sampling in combination with separate scans of the area is
 3 necessary when the scanning instrument and technique have sufficient detection capability to
 4 identify areas of elevated concentrations of radioactive material, but insufficient detection
 5 capability to quantify the average concentration of radioactive material in the survey unit. In
 6 instances where the measurement method has sufficient detection capability to meet the MQOs
 7 to both quantify the average concentration of radioactive material in the survey unit and identify
 8 areas of elevated concentrations of radioactive material, a scan-only survey can be considered.
 9 Similar in principle to a scan-only survey is a series of direct measurements that have the
 10 detection capability to meet the MQOs to both quantify the average concentration of radioactive
 11 material in the survey unit and identify areas of elevated concentrations of radioactive material.

12 **5.3.6.1 Scan-Only Surveys**

13 During scan-only surveys, a large number of discrete scan measurements are taken and
 14 analyzed; this approach is greatly facilitated by the use of scan systems that automatically
 15 record scan measurements and location. These systems typically utilize GPS or other position
 16 determinations in conjunction with radiological measurements, with both the radiological and
 17 locational data being automatically recorded. These techniques permit the convenient
 18 accumulation, storage, and display of hundreds or thousands of scan data points for a survey
 19 unit.

20 Scan-only surveys will likely require site-specific validation samples to ensure that the method
 21 can reliably detect concentrations at the DCGL_w under the conditions expected at the site. This
 22 validation can be accomplished at any point in the RSSI process (post-remediation, if
 23 remediation is performed). Consult with your regulator for guidance on the level of effort needed
 24 to validate scan-only surveys.

25 Scan-only surveys generally cover a much larger portion of the survey unit than traditional
 26 discrete sampling or measurement. A similar concept is found in a series of direct

1 measurements, where the field of view of the direct measurements covers a statistically
2 significant portion of the survey unit (i.e., 10 percent or more).⁹

3 However, a scan-only approach should be used only for circumstances where the measurement
4 method has sufficient detection capability to meet the MQOs to both quantify the average
5 concentration of radioactive material in the survey unit and identify areas of elevated
6 concentrations of radioactive material. To ensure that this is the case, the scan MDC (for the
7 scan system) should be less than 50 percent of the DCGL_w. The scan-only methodology will
8 require validation, which likely requires collecting some percentage of samples for laboratory
9 analysis to compare with results from the same location. Other MQOs should be met as well,
10 including the MQO for measurement method uncertainty at the DCGL_w.

11 In general, when utilizing a scan-only survey approach, the anticipated measurement method
12 uncertainty is expected to be higher than traditional scan and sampling procedures. Therefore, a
13 maximum scan coverage (e.g., 100 percent) should always be achieved in Class 1 areas when
14 utilizing this approach. The percentages of Class 2 or Class 3 areas that should be scanned is
15 10 percent or the result using **Equation 5-10**, whichever is larger:

$$\text{Scan Area} = \frac{(10 - \Delta/\sigma)}{10} \times 100\% \quad (5-10)$$

16 Scanning a greater percentage than that calculated above is always acceptable. When
17 performing scan-only surveys, the following must be considered and addressed in survey plans:

- 18 • Perform quality control procedures, such as evaluating measurement method uncertainty by
19 performing replicate scans over a prescribed portion of the site and performing reference
20 standard checks at a prescribed frequency.
- 21 • Evaluate the extent to which alpha and beta radiation in the surface may impact scan-only
22 survey results.
- 23 • Determine the number and type of validation samples to establish a correlation between
24 scan-only and laboratory results.

25 *5.3.6.2 Scanning and Sampling*

26 When scanning is done in combination with direct measurements or sampling, the scanning
27 instrument and technique must have detection capabilities to meet the MQOs to identify areas
28 of elevated concentrations of radioactive material. This differs from the requirements for scan-
29 only surveys that must have detection capabilities to both identify areas of elevated
30 concentrations of radioactive material and quantify the average concentration of radioactive
31 material in the survey unit.

⁹ In the Multi-Agency Radiation Survey and Assessment of Materials and Equipment (MARSAME) Manual, a direct measurement survey covering a statistically significant portion of the survey unit was referred to as an "in situ" survey type; in MARSSIM, this survey type is incorporated into scan-only surveys.

1 The percentage of the area that needs to be scanned depends on the classification of the
2 survey unit. For Class 1 survey units, 100 percent of the area should be scanned. The
3 percentages of Class 2 or Class 3 areas are scanned according to **Equation 5-10**. Scanning a
4 greater percentage than that calculated above for Class 2 or Class 3 areas is always
5 acceptable.

6 The detection capability for scanning techniques used in Class 2 and Class 3 areas is not tied to
7 the area between measurement locations like they are in a Class 1 area (see **Section 5.3.5**).
8 The scanning techniques selected should represent the best reasonable effort based on the
9 survey objectives. Structure surfaces are generally scanned for alpha-, beta-, and gamma-
10 emitting radionuclides. In contrast, scanning for alpha or beta emitters for land area survey units
11 is generally not considered effective because of problems with attenuation and media
12 interferences. If one can reasonably expect to find any residual radioactive material, it is prudent
13 to perform a judgment scanning survey.

14 **5.3.7 Determining Survey Locations**

15 Like the required scanning percentages, the determination of discrete survey locations for the
16 direct measurements or the collection of samples depends on the classification of the survey
17 unit. The method for determining survey locations for land areas and structure surfaces is
18 described below.

19 **5.3.7.1 Survey Locations for Discrete Measurements and Samples**

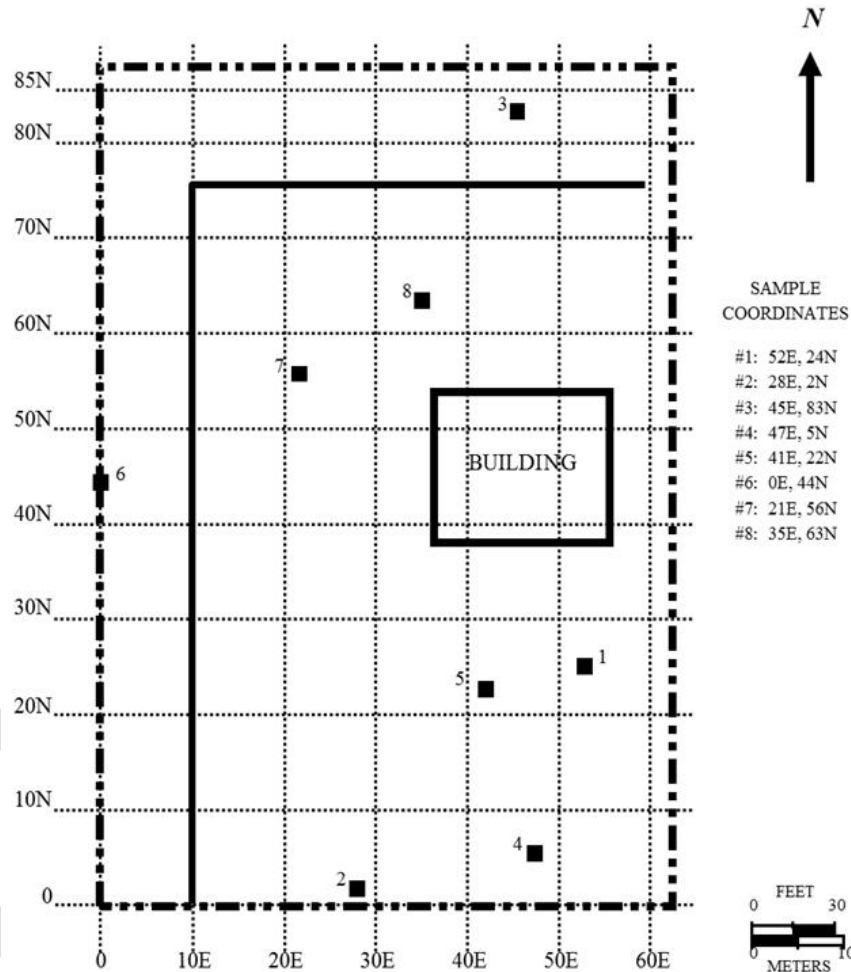
20 A scale drawing of the survey unit is prepared, along with the overlying planar reference
21 coordinate system or grid system. Any location within the survey area is thus identifiable by a
22 unique set of coordinates. The maximum length, X, and width, Y, dimensions of the survey unit
23 are then determined. Identifying and documenting a specific location for each measurement
24 performed is an important part of an FSS to ensure that measurements can be reproduced if
25 necessary. The reference coordinate system described in **Section 4.9.5** provides a method for
26 relating measurements to a specific location within a survey unit. Systems utilizing GPS
27 technology and data logging software are widely available to identify and track survey
28 dimensions, sampling locations, and locations associated with specific scan results.

29 Land Areas

30 Measurements and samples in Class 3 survey units and reference areas are usually taken at
31 random locations. These locations are determined by generating sets of random numbers
32 (two values, representing the X axis and Y axis distances). Random numbers can be obtained
33 from mathematical tables, including **Table I.11** in **Appendix I**, or generated by calculator or
34 computer. Sufficient sets of numbers will be needed to identify the total number of survey
35 locations established for the survey unit. Each set of random numbers is multiplied by the
36 appropriate survey unit dimension to provide coordinates, relative to the origin of the survey unit
37 reference grid pattern. Coordinates identified in this manner that do not fall within the survey unit
38 area or that cannot be surveyed because of site conditions are replaced with other survey points
39 determined in the same manner. **Example 9** provides an example of a random sampling
40 pattern.

Example 9: Random Sampling Pattern

In this example, eight data points were identified using the appropriate table (Table 5.2 or Table 5.3). The locations of these points were determined using the table of random numbers found in **Appendix I, Table I.11**.



- # ■ SURFACE SOIL MEASUREMENT/SAMPLING LOCATION
- - - - SURVEY UNIT BOUNDARY
- ONSITE FENCE

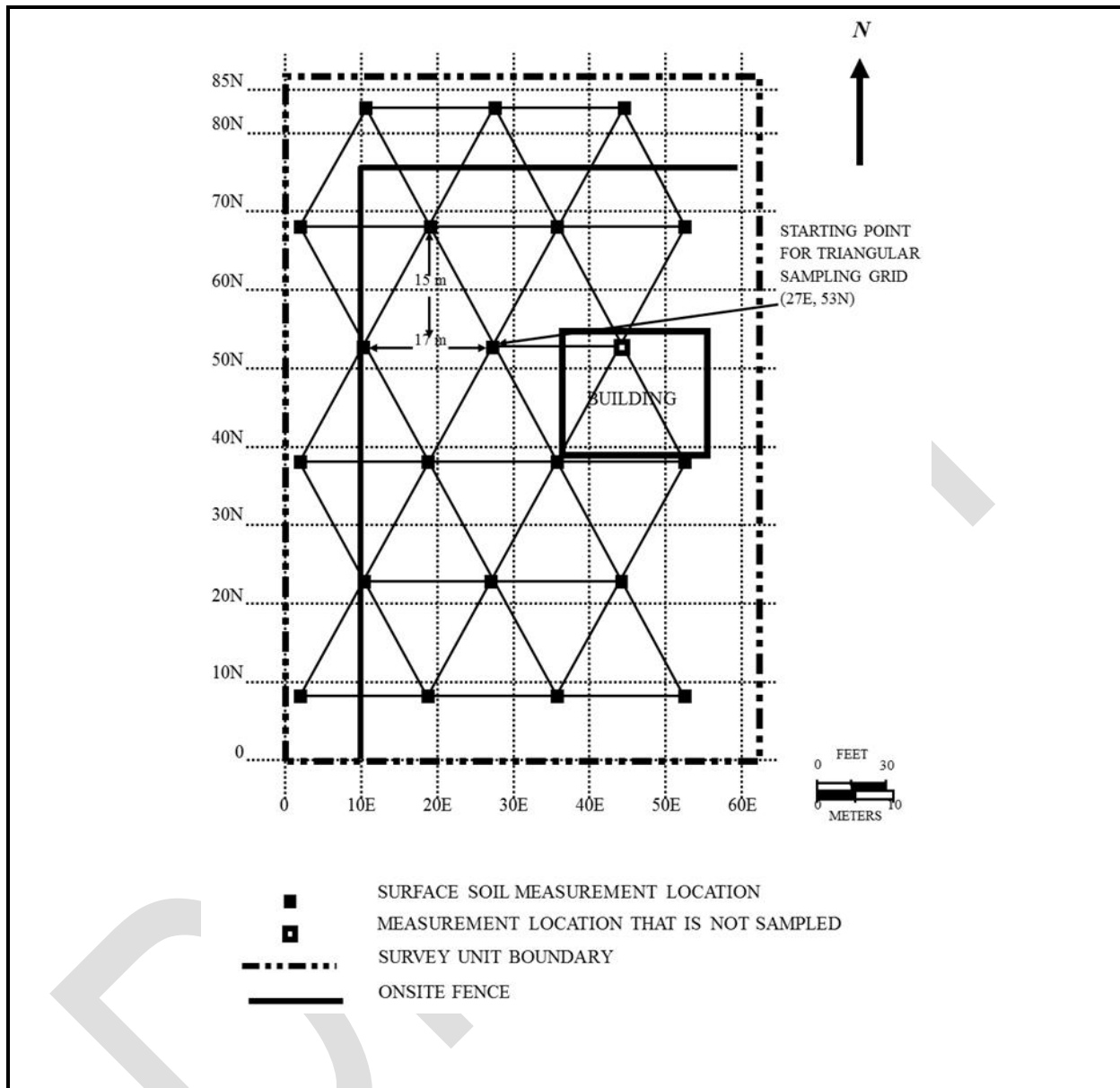
- 1 Class 2 areas are surveyed on a random-start systematic pattern. The number of calculated
2 survey locations, n , based on the statistical tests, is used to determine the spacing, L , of a
3 systematic pattern as specified in **Equations 5-1 and 5-2**.
- 4 After L is determined, a random start location is identified, as described previously, for a survey
5 pattern starting location. Beginning at the random start location, a row of points is identified
6 parallel to the X-axis at intervals of L .
- 7 For a triangular grid, a second row of points is then developed, parallel to the first row, at a
8 distance of $0.866 \times L$ from the first row. Survey points along that second row are midway (on the
9 X-axis) between the points on the first row. This process is repeated to identify a pattern of
10 survey locations throughout the affected survey unit. If identified points fall outside the survey
11 unit or at locations that cannot be surveyed, additional points are determined using the random
12 process described above until the desired total number of points is identified.
- 13 For Class 1 areas, a systematic pattern having dimensions determined in **Section 5.3.6** is
14 installed on the survey unit. The starting point for this pattern is selected at random, as
15 described above for Class 2 areas. The same process as described above for Class 2 areas
16 applies to Class 1. **Example 10** provides an illustration of a triangular systematic pattern in an
17 outdoor Class 2 survey unit.

Example 10: Illustration of a Triangular Systematic Pattern in an Outdoor Class 2 Survey Unit

An example of a triangular survey pattern is shown below. In this example, the statistical test calculations estimate 20 samples (**Table 5.3**, $\alpha = 0.01$, $\beta = 0.05$, $\Delta/\sigma > 3.0$). The random-start coordinates were 27E, 53N. The grid spacing (L) was calculated using **Equation 5-3**.

$$L = \sqrt{\frac{5,100 \text{ m}^2}{0.866 \times 20}} = 17 \text{ m}$$

Two points were identified on a row parallel to the X-axis, each 17 meters (m) from the starting point. The subsequent rows were positioned $0.866 \times L$, or 15 m, from the initial row. This random-start triangular sampling process resulted in 21 sampling locations, one of which was difficult to assess because of the building location, which yields the desired number of data points.



1 Structure Surfaces

2 All structure surfaces for a specific survey unit are included on a single reference grid system for
 3 purposes of identifying survey locations. The same methods as described above for land areas
 4 are then used to locate survey points for all classifications of areas.

5 In addition to the survey locations identified for statistical evaluations and elevated
 6 measurement comparisons, data may be obtained from judgment locations that are selected
 7 because of unusual appearance, location relative to areas affected by residual radioactive
 8 material, high potential for residual radioactive material, general supplemental information, etc.

1 Data points selected based on professional judgment are not included with the data points from
2 the random-start triangular grid for statistical evaluations; instead they are compared individually
3 with the established DCGLs and conditions. Measurement locations selected on the basis of
4 professional judgment cannot be considered representative of the survey unit, a necessary
5 condition if the statistical tests described in **Chapter 8** are used.

6 *5.3.7.2 Survey Locations for Scans*

7 Like the determination of the location of discrete measurements or samples, the determination
8 of survey locations for scans depends on the classification of the survey unit.

9 Class 1 Areas

10 For Class 1 areas, scans are intended to detect small areas of elevated activity that are not
11 detected by the measurements using the systematic pattern (**Section 5.3.5**). This is the reason
12 for recommending 100 percent coverage for the scanning survey. One-hundred percent
13 coverage means that the entire accessible surface area of the survey unit is covered by the field
14 of view of the scanning instrument. If the field of view is 2 m wide, the survey instrument can be
15 moved along parallel paths 2 m apart to provide 100 percent coverage. If the field of view of the
16 detector is 5 centimeters (cm), the parallel paths should be 5 cm apart.

17 Class 2 Areas

18 Class 2 survey units have a lower probability for areas of elevated activity than Class 1 survey
19 units, but some portions of the survey unit may have a higher potential than others. Judgment
20 scanning surveys focus on the portions of the survey unit with the highest probability for areas
21 of elevated activity. If the entire survey unit has an equal probability for areas of elevated
22 activity, or the judgment scans don't cover at the required scanning percentage of the area,
23 systematic scans along transects of the survey unit or scanning surveys of randomly selected
24 grid blocks are performed.

25 Class 3 Areas

26 Class 3 areas may be uniformly scanned for radiation emitted from the radionuclides of interest,
27 or the scanning may be performed in areas with the greatest potential for residual radioactive
28 material (e.g., corners, ditches, and drains) based on professional judgment and the objectives
29 of the survey. Such recommendations are typically provided by a health physics professional
30 with radiation survey experience. This provides a qualitative level of confidence that no areas of
31 elevated activity were missed by the random measurements or that there were no errors made
32 in the classification of the area. In some cases, a combination of these approaches may be the
33 most appropriate.

34 *5.3.8 Determining Investigation Levels*

35 An important aspect of the FSS is the design and implementation of investigation levels.
36 Investigation levels are radionuclide-specific levels of radioactive material used to indicate when
37 additional investigations may be necessary. Investigation levels also serve as a quality control
38 check to determine when a measurement process begins to get out of control. For example, a
39 measurement that exceeds the investigation level may indicate that the survey unit has been

1 improperly classified (see **Section 4.6**), or it may indicate a failing instrument. Typically,
2 investigation levels are set as part of the DQO process.

3 When an investigation level is exceeded, the first step is to confirm that the initial measurement
4 or sample actually exceeds the particular investigation level. This may involve taking further
5 measurements to determine that the area and level of the elevated residual radioactive material
6 are such that the resulting dose or risk meets the release criteria. Rather than—or in addition
7 to—taking further measurements, the investigation may involve assessing the adequacy of the
8 exposure pathway model used to obtain the DCGLs and area factors, as well as the consistency
9 of the results obtained with the HSA and the scoping, characterization, and RAS surveys.
10 Depending on the results of the investigation actions, the survey unit may require
11 reclassification, remediation, or resurvey. **Table 5.4** illustrates an example of how investigation
12 levels can be developed.

13 **Table 5.4: Example FSS Investigation Levels**

Survey Unit Classification	Flag Direct Measurement or Sample Result When...	Flag Scanning Measurement Result When...
Class 1	> DCGL _{EMC} or > DCGL _W and > a statistical parameter-based value	> DCGL _{EMC} for the area bounded by four adjacent systematic grid measurement points to determine the DCGL _{EMC} (when a traditional MARSSIM approach is utilized), or for the area bounded by an acceptable elevated area size (when a scan-only approach is utilized)
Class 2	> DCGL _W	> DCGL _W or > scan MDC
Class 3	> fraction of DCGL _W	> DCGL _W or > scan MDC

14 Abbreviations: DCGL_{EMC} is the derived concentration guideline level (DCGL) determined with the Elevated
15 Measurement Comparison; DCGL_W is the wide-area DCGL.

16 When determining an investigation level using a statistical-based parameter (e.g., standard
17 deviation) one should consider survey objectives, underlying radionuclide distributions, and an
18 understanding of corresponding types (e.g., normal, lognormal, non-parametric), descriptors
19 (e.g., standard deviation, mean, median), population stratifications (i.e., subgroups), and other
20 prior survey and historical information. For example, a level might be arbitrarily established at
21 the mean + 3s, where s is the standard deviation of the survey unit, assuming a normal
22 distribution. A higher value might be used if locating discrete sources of higher activity was a
23 primary survey objective. By the time the FSS is conducted, survey units should be defined.
24 Estimates of the mean, variance, and standard deviation of the radionuclide activity levels within
25 the survey units should also be available.

26 For a Class 1 survey unit, measurements above the DCGL_W are not necessarily unexpected.
27 However, a measurement above the DCGL_W at one of the discrete measurement locations
28 might be considered unusual if it were much higher than all of the other discrete measurements.
29 Thus, any discrete measurement that is both above the DCGL_W and above the statistical-based
30 parameter for the measurements should be investigated further. Any measurement, either at a
31 discrete location or from a scan that is above the DCGL_{EMC} should also be flagged for further
32 investigation. When a traditional MARSSIM approach (scanning with direct measurements
33 and/or samples) is utilized, the DCGL_{EMC} should be established for the largest (worst case)

1 potential elevated measurement area (the area bounded by four sampling grid measurement
2 points). This largest potential elevated area is also the survey unit area divided by the number of
3 measurements or samples (for the systematic sampling grid). When a scan-only approach is
4 utilized, it is important that an appropriate size for a potential elevated area and associated
5 $DCGL_{EMC}$ be established as a part of the DQO process and in agreement with the regulator.

6 In Class 2 or Class 3 areas, neither measurements above the $DCGL_W$ nor areas of elevated
7 activity are expected. Any measurement at a discrete location exceeding the $DCGL_W$ in these
8 areas should be flagged for further investigation. Because the survey design for Class 2 and
9 Class 3 survey units is not driven by the EMC, the scan MDC might exceed the $DCGL_W$. In this
10 case, any indication of residual radioactive material during the scan would warrant further
11 investigation.

12 When it is not feasible to obtain a scan MDC below the $DCGL_W$, the basis for using the
13 $DCGL_{EMC}$ or an investigation level above the $DCGL_W$ in **Table 5.4** for Class 2 and Class 3 areas
14 may be necessary but should be justified in survey planning documents. For example, where
15 there is high uncertainty in the reported scan MDC, more conservative criteria would be
16 warranted.

17 Similarly, data quality assessment (DQA) for scanning may warrant a more conservative flag, as
18 would greater uncertainty from HSA or other surveys on the size of potential areas of elevated
19 activity. In some cases, it may even be necessary to agree in advance with the regulatory
20 agency on which site-specific investigation will be used if other than those presented in
21 **Table 5.4**.

22 Because there is a low expectation for residual radioactive material in a Class 3 area, it may be
23 prudent to investigate any measurement exceeding even a fraction of the $DCGL_W$. The level
24 selected in these situations should be commensurate with the potential exposures at the site,
25 the radionuclides of concern, and the measurement and scanning methods chosen. This level
26 should be set using the DQO Process during the survey design phase of the Data Life Cycle. In
27 some cases, the user may also wish to follow this procedure for Class 2 and even Class 1
28 survey units.

29 **5.3.9 Developing an Integrated Survey Strategy**

30 The final step in survey design is to integrate the survey techniques (**Chapter 6**) with the
31 number of measurements and measurement spacing, with the amount of scanning determined
32 earlier in this chapter. This integration, along with the information provided in other portions of
33 this manual, produce an overall strategy for performing the survey. The survey design may
34 consist of scan-only, or a combination of scans with sampling or direct measurements.

35 **Table 5.5** provides a summary of the recommended survey coverage for structures and land
36 areas. This survey coverage for different areas is the subject of this section.

1 **Table 5.5: Recommended Survey Coverage for Structures and Land Areas**

Area Classification	Scanning and Direct Measurements and/or Sampling Survey		Scan-Only Survey
	Scanning	Direct Measurements or Samples)	Scanning
Class 1	100%	Number of data points from statistical tests (Sections 5.3.3 and 5.3.4); additional measurements may be necessary for small areas of elevated activity (Section 5.3.5)	100%
Class 2	10–100% Systematic and Judgment "Scan Area"= $\frac{(10 - \Delta/\sigma)}{10} \times 100\%$	Number of data points from statistical tests (Sections 5.3.3 and 5.3.4)	10–100% Systematic and Judgment "Scan Area"= $\frac{(10 - \Delta/\sigma)}{10} \times 100\%$
Class 3	Judgment	Number of data points from statistical tests (Sections 5.3.3 and 5.3.4)	"Scan Area"= $\frac{(10 - \Delta/\sigma)}{10} \times 100\%$ Judgment

2 Abbreviation: Δ/σ represents the relative shift.

3 For surveys in which discrete measurements or samples are taken, random measurement
 4 patterns are generally used for Class 3 survey units to ensure that the measurements are
 5 independent and support the assumptions of the statistical tests. Systematic grids are used for
 6 Class 2 survey units because there is an increased probability of small areas of elevated
 7 activity. The use of a systematic grid allows the decision maker to draw conclusions about the
 8 size of the potential areas of elevated activity based on the area between measurement
 9 locations. The random starting point of the grid provides an unbiased method for obtaining
 10 measurement locations to be used in the statistical tests. Class 1 survey units have the highest
 11 potential for small areas of elevated activity, so the areas between measurement locations
 12 might need to be adjusted to ensure that these areas can be detected by scanning techniques.

13 MARSSIM allows the use of both sampling (where a sample is collected and sent to an
 14 analytical laboratory, on-site or off-site) and direct measurements (fixed measurement taken in
 15 the field by an *in situ* gamma spectroscopy or beta scintillation meter, for example.) It is
 16 important to consider the required MQOs for the survey and ensure that the measurement
 17 method chosen meets those criteria. Some direct measurement methods may not be
 18 appropriate for some radionuclides in land areas.

1 The objectives of the scanning surveys are different. Scanning is used to identify locations
2 within the survey unit that exceed the investigation level. These locations are marked and/or
3 receive additional investigations to determine the concentration, area, and extent of the residual
4 radioactive material.

5 Scanning measurements can also be used in place of the sampling or direct measurements
6 when the detection capability is sufficient and a large number of discrete scan measurements
7 are taken and analyzed; this approach is greatly facilitated by the use of scan systems that
8 automatically record scan measurements and location. These systems typically utilize GPS or
9 other position determinations in conjunction with radiological measurements, with both the
10 radiological and locational data being automatically recorded. These techniques permit the
11 convenient accumulation, storage, and display of hundreds or thousands of scan data points for
12 a survey unit. However, a scan-only approach should only be used for circumstances where the
13 scan MDC (for the scan system) is less than 50 percent of the DCGL_w and other MQOs, such
14 as requirements for measurement method uncertainty, can be met. For scan-only surveys of
15 Class 2 or Class 3 survey units where the percentage of the area scanned is less than
16 100 percent, the survey must be designed so that average concentration of radioactive material
17 calculated from the survey data is an unbiased representative estimate of the true mean
18 concentration in the survey unit. In the event the scan-only survey option is feasible for a site or
19 survey unit, the sampling function of the FSS would not be applicable.

20 In addition to the building and land surface areas described above, there are numerous other
21 locations where measurements and/or sampling may be necessary independent from the FSS.
22 Examples include items of equipment and furnishings, building fixtures, drains, ducts, and
23 piping. Many of these items or locations have both internal and external surfaces with potential
24 residual radioactive material. An approach on conducting or evaluating these types of surveys is
25 contained in the Multi-Agency Radiation Survey and Assessment of Materials and Equipment
26 (MARSAME) Manual (NRC 2009), which is a supplement to MARSSIM. Subsurface
27 measurements or sampling may also be necessary.

28 Special situations may be evaluated by judgment sampling and measurements. Data from such
29 surveys should be compared directly with a limit developed for the specific situation and
30 approved by the regulator.

31 Quality control measurements are recommended for all surveys, as described in **Sections 4.8,**
32 **6.2, and 7.2.** Also, some regulatory programs require removable activity measurements
33 (e.g., DOE requirements in DOE Order 458.1 [DOE 2011c], 10 CFR 835). These additional
34 measurements should be considered during survey planning.

35 *5.3.9.1 Class 1 Areas*

36 For Class 1 areas, scanning surveys are designed to detect small areas of elevated activity
37 above the DCGL_w that are not detected by the measurements using the systematic pattern
38 (**Section 5.3.7**). For this reason, the measurement locations and the number of measurements
39 may need to be adjusted based on the sensitivity of the scanning technique (**Section 5.3.5.1**).
40 This is also the reason for recommending 100 percent coverage for the scanning survey.

- 1 As discussed in **Section 5.3.6.1**, scanning techniques can be used in lieu of discrete samples or
2 direct measurements when the scan MDC is less than 50 percent of the $DCGL_W$, and the scan
3 coverage is 100 percent. Note that, in a statistical sense, a scan of 100 percent of a survey unit
4 constitutes a sample of 100 percent of the survey unit. Other MQOs need to be met, as well,
5 including the MQO for required measurement method uncertainty.
- 6 Locations of direct radiation above an investigation level are identified and evaluated. Results of
7 initial and followup direct measurements and sampling at these locations are recorded and
8 documented in the FSS report. For structure surfaces, measurements of total and (when
9 applicable) removable radioactive material are performed at locations identified by scans and at
10 previously determined locations (**Section 5.3.7**). Soil sampling or direct measurements are
11 performed at locations identified by scans and at previously determined locations
12 (**Section 5.3.7**).
- 13 The development of direct measurement or sample investigation levels for Class 1 areas should
14 establish a course of action for individual measurements that exceed the investigation level.
15 Because measurements above the $DCGL_W$ are not necessarily unexpected in a Class 1 survey
16 unit, additional investigation levels may be established to identify discrete measurements that
17 are much higher than the other measurements. Any discrete measurement that both is above
18 the $DCGL_W$ and exceeds a statistical based parameter (e.g., three standard deviations above
19 the mean) should be investigated further (**Section 5.3.8**). Any measurement (direct
20 measurement, sample, or scan) that exceeds the $DCGL_{EMC}$ should be flagged for further
21 investigation.
- 22 The results of the investigation and any additional remediation that was performed should be
23 included in the FSS report. Data are reviewed as described in **Section 8.2.2**, additional data are
24 collected as necessary, and the final complete data set evaluated as described in **Section 8.3**
25 and **Section 8.4**.
- 26 **5.3.9.2 Class 2 Areas**
- 27 Scanning surveys in Class 2 areas are also primarily performed to find areas of elevated activity
28 not detected by the measurements using the systematic pattern. However, the number and
29 location of measurements are not adjusted based on sensitivity of the scanning technique, and
30 scanning is performed in portions of the survey unit. The level of scanning effort should be
31 proportional to the potential for finding areas of elevated activity based on the conceptual site
32 model developed and refined from **Section 3.6.4**. In other words, the farther the expected
33 residual radioactive material in the survey unit is from the $DCGL_W$ in units of uncertainty (the
34 larger the Δ/σ), the less scanning is needed. Surface scans are performed over 10–100 percent
35 of structure surfaces or open land surfaces, as calculated in **Equation 5-10**. A larger portion of
36 the survey unit would be scanned in Class 2 survey units that have residual radioactive material
37 close to the release criteria, but for survey units that are closer to background scanning, a
38 smaller portion of the survey unit may be appropriate.
- 39 As discussed in **Section 5.3.6.1**, scanning techniques for Class 2 survey units might be used in
40 lieu of discrete samples or direct measurements when the scan MDC is less than 50 percent of
41 the $DCGL_W$ and the scan coverage is between 10 and 100 percent. Note that, in a statistical
42 sense, a scan of 10–100 percent of a survey unit constitutes a sample of 10–100 percent of the

- 1 survey unit. Other MQOs need to be met, as well, including the MQO for required measurement
2 method uncertainty. The area scanned should be selected in an unbiased manner.
- 3 Locations of scanning survey results greater than the investigation level are identified and
4 investigated. If small areas of elevated activity are confirmed by this investigation, all or part of
5 the survey unit should be reclassified as Class 1 and the survey strategy for that survey unit
6 redesigned accordingly. Investigation levels for Class 2 areas should establish levels for
7 investigation of individual measurements close to but less than the $DCGL_w$. Investigation levels
8 for Class 2 areas should also establish a course of action for individual measurements that
9 exceed or approach the $DCGL_w$. The results of the investigation of the positive measurements
10 and basis for reclassifying all or part of the survey unit as Class 1 should be included in the FSS
11 report.
- 12 The results of the investigation should be included in the FSS report. Data are reviewed as
13 described in **Section 8.2.2**, additional data are collected as necessary, and the final complete
14 data set evaluated as described in **Section 8.3** and **Section 8.4**.
- 15 **5.3.9.3 Class 3 Areas**
- 16 Class 3 areas have the lowest potential for areas of elevated activity. Locations exceeding the
17 scanning survey investigation level should be flagged for further investigation. If the presence of
18 residual radioactive material occurring at concentrations greater than a small fraction of the
19 $DCGL_w$ is identified, reevaluation of the classification of the survey unit should be performed.
- 20 As discussed in **Section 5.3.6.1**, scanning techniques for Class 3 survey units can be used in
21 lieu of sampling and statistical testing when the scan MDC is less than 50 percent of the
22 $DCGL_w$. Other MQOs need to be met, as well, including the MQO for required measurement
23 method uncertainty.
- 24 Sampling or direct measurements are performed at randomly selected locations
25 (**Section 5.3.7**). Survey results are tested for compliance with DCGLs, and additional data are
26 collected and tested as necessary. For structure surfaces, measurements of total and (when
27 applicable) removable radioactive material are performed at the locations identified by the scans
28 and at the randomly selected locations that are chosen in accordance with **Section 5.3.7**.
- 29 Investigation levels for Class 3 areas should be established to identify areas of elevated activity
30 that may indicate the presence of residual radioactive material. Because there is a low
31 expectation for residual radioactive material in a Class 3 area, it may be prudent to investigate
32 any measurement exceeding even a fraction of the $DCGL_w$. The investigation level selected will
33 depend on the site, the radionuclides of concern, and the measurement and scanning methods
34 chosen. This level should be commensurate with the potential exposures and should be
35 determined using the DQO Process during survey planning. In some cases, the user may wish
36 to follow this procedure for Class 2 survey units.
- 37 The data are tested relative to the preestablished criteria. If additional data are needed, they
38 should be collected and evaluated as part of the entire data set. Identification of residual
39 radioactive material suggests that the area may be incorrectly classified. If so, a reevaluation of

1 the Class 3 area classification should be performed and, if appropriate, all or part of the survey
2 unit should be resurveyed as a Class 1 or Class 2 area.

3 The results of the investigation of the measurements that exceed the investigation level and the
4 basis for reclassifying all or part of the survey unit as Class 1 or Class 2 should be included in
5 the FSS report.

6 As discussed in **Section 5.3.8**, investigation levels are determined and used to indicate when
7 additional investigations may be necessary or when a measurement process begins to get out
8 of control. The results of all investigations should be documented in the FSS report, including
9 the results of scan surveys that may have potentially identified areas of elevated direct radiation.

10 **5.3.10 Evaluating Survey Results**

11 **Chapter 8** describes detailed procedures for evaluating survey results. After data are converted
12 to the same units as the DCGL, the process of comparing the results to the DCGLs and
13 objectives begins. Individual measurements and sample concentrations are first compared to
14 DCGL levels for evidence of small areas of elevated activity and not to determine if
15 reclassification is necessary. Additional data or additional remediation and resurveying may be
16 necessary. Data are then evaluated using statistical methods to determine if they exceed the
17 release criteria. If the release criteria have been exceeded or if results indicate the need for
18 additional data points, appropriate further actions will be determined by the site management
19 and the regulatory agency. The scope of further actions should be agreed upon and developed
20 as part of the DQO Process before the survey begins (**Appendix D**). Finally, the results of the
21 survey are compared with the DQOs established during the planning phase of the project. Note
22 that DQOs may identify a need for a report of the evaluation of removable radioactive material
23 resulting from the analysis of smears. These results may be used to satisfy regulatory
24 requirements or to evaluate the need for additional ALARA procedures.

25 **5.3.11 Documentation**

26 Documentation of the FSS should provide a complete and unambiguous record of the
27 radiological status of the survey unit relative to the established DCGLs. In addition, sufficient
28 data and information should be provided to enable an independent re-creation and evaluation at
29 some future time. Much of the information in the FSS report will be available from other site
30 remediation documents; however, to the extent practicable, this report should be a stand-alone
31 document with minimum information incorporated by reference. The report should be
32 independently reviewed (see **Section 8.7**) and should be approved by a designated person (or
33 persons) who are capable of evaluating all aspects of the report before release, publication, or
34 distribution. **Example 11** includes an example of a final status survey checklist, including survey
35 preparations, survey design, conduct of surveys, and evaluation of survey results.

Example 11: Example Final Status Survey Checklist**Survey Preparations**

- _____ Ensure that residual radioactive material limits have been determined for the radionuclides present at the site, typically performed during earlier surveys associated with the release process.
- _____ Identify the radionuclides of concern. Determine whether the radionuclides of concern exist in background.
- _____ Segregate the site into Class 1, Class 2, and Class 3 areas, based on the presence of potential residual radioactive material.
- _____ Identify the survey units.
- _____ Select representative reference (background) areas for both indoor and outdoor survey areas. Reference areas are selected from non-impacted areas and—
 - _____ are free of residual radioactive material from site operations
 - _____ exhibit similar physical, chemical, and biological characteristics of the survey area
 - _____ have similar construction, but have no history of radioactive operations
- _____ Select measurement method, based on the required Measurement Quality Objectives (MQOs).
 - _____ Determine minimum detectable concentrations (MDCs; select instrumentation based on the radionuclides present) and match between instrumentation and derived concentration guideline levels (DCGLs)—the selected instruments should be capable of detecting the radionuclides of concern at less than 50 percent of the DCGLs.
 - _____ Determine measurement method uncertainty and compared to required measurement method uncertainty.
 - _____ Determine ruggedness, specificity, and range and compare to requirements.
- _____ Prepare the area if necessary—clear and provide access to areas to be surveyed.
- _____ Establish reference coordinate systems (as appropriate).

Survey Design

- _____ Enumerate Data Quality Objectives (DQOs) and MQOs: State the objective of the survey, state the null and alternative hypotheses, specify the acceptable decision

error rates (Type I [α] and Type II [β]) and requirements for MDC, measurement method uncertainty, ruggedness, specificity, and range.

- _____ Specify sample collection and analysis procedures.
- _____ Determine numbers of data points for statistical tests, depending on whether the radionuclide is present in background. Alternatively, design a scan-only survey using automated equipment recording both data and location.
 - _____ Specify the number of samples/measurements to be obtained, if applicable.
 - _____ Evaluate the power of the statistical tests to determine whether the number of samples is appropriate.
 - _____ Ensure that the sample size is sufficient for detecting areas of elevated activity.
 - _____ Add additional samples/measurements for quality control and to allow for possible loss.
 - _____ Establish the percentage of the survey unit to be surveyed by scanning.
- _____ Specify sampling locations, if appropriate.
- _____ Specify areas and percentage of areas subject to scanning survey.
- _____ Provide information on the survey measurement method.
- _____ Specify methods of data reduction and comparison of survey units to reference areas.
- _____ Provide quality control procedures and Quality Assurance Project Plan (QAPP) for ensuring validity of survey data:
 - _____ properly calibrated instrumentation
 - _____ necessary replicate, reference, and blank measurements
 - _____ comparison of field measurement results to laboratory sample analyses
- _____ Document the survey plan (e.g., QAPP, standard operating procedures [SOPs], etc.)

Conducting Surveys

- _____ Perform reference (background) area measurements and sampling.
- _____ Conduct survey activities:
 - _____ Perform surface scans of the Class 1, Class 2, and Class 3 areas.

_____ Conduct surface activity measurements and sampling at previously selected sampling locations, if applicable.

_____ Conduct additional direct measurements and sampling at locations based on professional judgment.

_____ Perform and document any necessary investigation activities, including survey unit reclassification, remediation, and resurvey.

_____ Document measurement and sample locations; provide information on measurement system MDC and measurement method uncertainty.

_____ Document any observations, abnormalities, and deviations from the QAPP or SOPs.

Evaluating Survey Results

_____ Review DQOs and MQOs.

_____ Perform data reduction on the survey results.

_____ Conduct a preliminary data review.

_____ Select the statistical test(s).

_____ Verify the assumptions of statistical tests.

_____ Compare survey results with regulatory DCGLs:

_____ Conduct an elevated measurement comparison, if appropriate.

_____ Determine the area-weighted average, if appropriate.

_____ Conduct Wilcoxon Rank Sum or Sign tests, if appropriate.

_____ Conduct quantile test or retrospective power analysis, if appropriate.

_____ Conduct Upper Level Comparison, if appropriate.

_____ Prepare FSS report.

_____ Obtain an independent review of the report.

6 FIELD MEASUREMENT METHODS AND INSTRUMENTATION

6.1 Introduction

“Measurement” is used in the Multi-Agency Radiation Survey and Investigation Manual (MARSSIM) to mean (1) the act of using a detector to determine the level or quantity of radioactive material on a surface or in a sample of material removed from a medium being evaluated, or (2) the quantity obtained by the act of measuring.¹ Three methods are available for collecting radiation data while performing a survey: direct measurements, scanning, and sampling. This chapter discusses direct measurement methods, scanning, and instrumentation. The collection and analysis of media samples are presented in **Chapter 7**. Information on the operation and use of individual field and laboratory instruments is provided in **Appendix H**.

Total surface activities, removable surface activities, and radionuclide concentrations in various environmental media are the radiological parameters typically determined using field measurements and laboratory analyses. Certain radionuclides or radionuclide mixtures may necessitate the measurement of alpha, beta, and gamma radiations. In addition to assessing each survey unit as a whole, any small areas of elevated activity should be identified to the extent practicable and their extent and activities determined. Due to numerous detector requirements, multiple measurement methods (survey technique and instrument combination) may be needed to adequately measure all of the parameters required to satisfy the release criteria or meet all the objectives of a survey.

Selecting an appropriate measurement method requires evaluation of both Data Quality Objectives (DQOs) and Measurement Quality Objectives (MQOs). Instruments should be stable and reliable under the environmental and physical conditions where they are used, and their physical characteristics (size and weight) should be compatible with the intended application. Numerous commercial firms offer a wide variety of instruments appropriate for the radiation measurements described in this manual. These firms can provide thorough information regarding capabilities, operating characteristics, limitations, etc., of specific equipment.

If the available field measurement methods do not achieve the MQOs, laboratory methods discussed in **Chapter 7** are typically used. There are certain radionuclides that are difficult to measure at some derived concentration guideline levels (DCGLs) typically encountered *in situ* using current state-of-the-art instrumentation and techniques because of the types, energies, and abundances of their radiations. Examples of such radionuclides include such very low-energy, pure beta emitters as tritium (³H) and nickel-63 (⁶³Ni) and low-energy photon emitters as iron-55 (⁵⁵Fe) and iodine-125 (¹²⁵I). Pure alpha emitters dispersed in soil or covered with some absorbing layer may not be measurable, because alpha radiation will not penetrate through the media or covering to reach the detector. A common example of such a condition would be thorium-230 (²³⁰Th) surface contamination covered by paint, dust, oil, or moisture. The U.S. Nuclear Regulatory Commission (NRC) report NUREG-1507 (NRC 1997a) provides information on the extent to which these surface conditions may affect detection capability. In

¹ MARSSIM uses the word “should” as a recommendation, not as a requirement. Each recommendation in this manual is not intended to be taken literally and applied at every site. MARSSIM’s survey planning documentation will address how to apply the process on a site-specific basis.

1 such circumstances, the survey design will usually rely on sampling and laboratory analysis to
2 measure residual activity levels. **Appendix E** provides information on using a ranked set
3 sampling procedure to reduce sampling requirements for hard-to-detect radionuclides.

4 **Section 6.2** includes a discussion of DQOs and MQOs. Two important MQOs, detection
5 capability and measurement uncertainty, are covered in more detail in **Sections 6.3 and 6.4**,
6 respectively. **Section 6.5** discusses the selection of a service provider to perform field data
7 collection activities. The selection of a measurement method is discussed in **Section 6.6**.

8 **Section 6.7** includes information on the data conversion needed to make comparisons with the
9 applicable DCGLs. Radon measurements are covered in **Section 6.8**. **Section 6.9** includes
10 information about special equipment.

11 **6.2 Data Quality Objectives**

12 The third step of the DQO Process (EPA 2006c) involves identifying the data needs for a
13 survey. One decision that can be made at this step is the selection of field measurement
14 methods that meet the MQOs or determining that sample collection and subsequent laboratory
15 analysis is required.

16 **6.2.1 Identifying Data Needs for Field Measurement Methods**

17 The decision maker and the survey planning team need to identify the data needs for the survey
18 being performed, including the following:

- 19 • type of measurements to be performed (**Chapter 5**)
- 20 • radionuclide(s) of interest (**Section 4.5**)
- 21 • number of direct measurements to be performed (**Sections 5.3.3–5.3.4**)
- 22 • area of survey coverage for surface scans based on survey unit classification
23 (**Section 5.3.6**)
- 24 • type and frequency of field QC measurements to be performed (**Section 4.8**)
- 25 • standard operating procedures (SOPs) to be followed or developed (**Chapter 6**)
- 26 • measurement method uncertainties (**Section 6.4**)
- 27 • detection capabilities for each radionuclide of interest (**Section 6.3**)
- 28 • cost of the measurement methods being evaluated (both cost per measurement and total
29 cost) (**Appendix H**)
- 30 • necessary turnaround time (a potential health and safety concern for situations involving
31 excavations)
- 32 • specific background for the radionuclide(s) of interest (**Section 4.5**)

- 1 • DCGL for each radionuclide of interest (**Section 4.10**)
- 2 • measurement documentation requirements
- 3 • measurement tracking requirements

4 Some of this information will be supplied by subsequent steps in the DQO process, and several
5 iterations of the process may be needed to identify all of the data needs. Consulting with a
6 health physicist or radiochemist may be necessary to properly evaluate the information before
7 deciding between field measurement methods or sampling followed by laboratory analytical
8 methods to perform the survey. Many surveys will involve a combination of field measurements
9 and sampling methods to demonstrate compliance with the release criteria.

10 **6.2.2 Measurement Performance Indicators**

11 Measurement performance indicators are used to evaluate the performance of the
12 measurement method. These indicators describe how the measurement method is performing
13 to ensure the survey results are of sufficient quality to meet the survey objectives.

14 **6.2.2.1 Background Measurements/Blanks**

15 Background measurements are direct measurements or scans of materials with little or no
16 radioactive material, other than that present in the natural background of the material; or the
17 response of the instrument to ambient radiation when the instrument is moved away from the
18 surface being surveyed. These measurements are performed to determine whether the
19 measurement process introduces any increase in instrument signal rate that could impact the
20 measurement method detection capability. Background measurements should be representative
21 of all measurements performed using a specific measurement method (i.e., combination of
22 instrumentation and measurement technique). When practical, the background measurements
23 should consist of the same or equivalent material(s) as the area being surveyed.

24 Background measurements typically are performed before and after a series of measurements
25 to demonstrate the measurement method was performing adequately throughout the survey. At
26 a minimum, background measurements should be performed at the beginning and end of each
27 shift. When large quantities of data are collected (e.g., scanning measurements) or there is an
28 increased potential for radionuclide contamination of the instrument (e.g., removable or airborne
29 radionuclides), background measurements may be performed more frequently. In general,
30 background measurements should be performed before too many measurements have been
31 performed such that it is not practical to repeat those measurements if a problem is identified.

32 A sudden change in the measured background indicates a condition requiring immediate
33 attention. Sudden changes can be caused by the introduction of a radionuclide, a change in
34 ambient background, instrument instability, or contamination of the detector. Gradual changes in
35 the measured background indicate a need to inspect all survey areas for sources of radioactive
36 material. Gradual buildup of removable radionuclides over time or instrument drift and
37 deterioration can result in slowly increasing background measurements. High variability in
38 background measurements can result from instrument instability or improper classification

1 (i.e., high-activity and low-activity areas combined into a single survey unit). It is important to
2 correct any problems with blanks to ensure that the detection capability (see **Section 6.3**) is not
3 compromised.

4 If smears or swipes, described in more detail in **Section 6.6.1.4**, are used to estimate the
5 amount of removable radioactive material on the surface, measurement of an unused smear, or
6 blank, provides a background measurement of the instrument used to test the smears

7 **6.2.2.2 Replicate Measurements**

8 Replicate measurements are two or more measurements performed at the same location or on
9 the same sample that are performed primarily to provide an estimate of the random uncertainty
10 for the measurement method. The reproducibility of measurement results should be evaluated
11 by replicates to establish this component of measurement uncertainty (see **Section 6.4**).

12 Replicates typically are performed at specified intervals during a survey (e.g., 5 percent of all
13 measurements or once per day) and should be employed to evaluate each batch of data used
14 to support a decision (e.g., one replicate per survey unit). For scan-only surveys, where
15 decisions are made based on logged and geolocated measurements, typically 5 percent of all
16 measurements are replicated (e.g., 5 percent of the scanned area is scanned twice).

17 Estimates of random uncertainty exhibit a range of values and depend in part on the surface
18 being measured and the activity level. Small changes in the random uncertainty are expected,
19 and the acceptable range of variability should be established before initiating data collection
20 activities. The main causes for high random uncertainty include problems with repeating
21 measurements on irregular surfaces, the surface being measured, counting statistics when the
22 activity levels are low, and instrument contamination.

23 **6.2.2.3 Spikes and Standards**

24 Spikes and standards are materials with known composition and amounts of radioactive
25 material; they are used to evaluate bias in the measurement method and typically performed
26 periodically during a survey (e.g., 5 percent of all measurements or once per day). When spikes
27 and standards are available, they should be used to evaluate each batch of data used to
28 support a release decision (i.e., at least one spike or standard per survey unit).

29 Tracking results of measurements with known activity can provide an indication of the
30 magnitude of the systematic uncertainty or drift of the measurement system. In general, activity
31 levels near the DCGLs (or discrimination limits in Scenario B) will provide adequate information
32 on the performance of the measurement system.

33 **6.2.3 Instrument Performance Indicators**

34 Evaluating instrument performance indicators provides information on the operation of the
35 instruments and how they are performing.

1 *6.2.3.1 Performance Tests*

2 Performance tests should be carried out periodically and after any maintenance to ensure that
3 the instruments continue to meet performance requirements for measurements. An example of
4 a performance test is a test for response time. Performance requirements should be met as
5 specified in the applicable sections of the American National Standards Institute (ANSI)
6 publications ANSI N323AB (ANSI 2013), ANSI N42.17A (ANSI 2004), and ANSI N42.17C (ANSI
7 1990). These tests may be conducted as part of the calibration procedure.

8 *6.2.3.2 Functional Tests*

9 Functional tests should be performed before initial use of an instrument and after periods when
10 the instrument was stored for a relatively long time or transported over a long distance. These
11 functional tests should include—

- 12 • general condition
- 13 • battery condition
- 14 • verification of current calibration (i.e., check to see that the date due for calibration has not
15 passed)
- 16 • source and background response checks (and other tests as applicable to the instrument)
- 17 • constancy check

18 The effects of environmental conditions (temperature, humidity, etc.) and interfering radiation on
19 an instrument should be established before use. The performance of functional tests should be
20 appropriately documented. This may be as simple as a checklist on a survey sheet, or it may
21 include more detailed statistical evaluation, such as a chi-square test (Gilbert 1987).

22 *6.2.3.3 Instrument Background*

23 All radiation detection instruments have a background response, even in the absence of a
24 sample or radiation source. Inappropriate background correction will result in measurement
25 error and increase the uncertainty of data interpretation.

26 *6.2.3.4 Efficiency Calibrations*

27 Knowing the detector efficiency is critical for converting the instrument response to activity (see
28 MARSSIM **Section 6.7**, Multi-Agency Radiation Survey and Assessment of Materials and
29 Equipment [MARSAME] Section 7.8.2.2, and Multi-Agency Radiological Laboratory Analytical
30 Protocols [MARLAP] Chapter 16). Routine performance checks may be used to demonstrate
31 that the system's operational parameters are within acceptable limits, and these measurements
32 typically are included in the assessment of systematic uncertainty. The system's operational
33 parameters may be tracked using control charts.

1 **6.2.3.5 Energy Calibrations (Spectrometry Systems)**

2 Spectrometry systems identify radionuclides based on the energy of the detected radiations. A
3 correct energy calibration is critical to accurately identify radionuclides. An incorrect energy
4 calibration may result in misidentification of peaks or failure to identify radionuclides present.

5 **6.2.3.6 Peak Resolution and Tailing (Spectrometry Systems)**

6 The shape of the full energy peak is important for identifying radionuclides and quantifying their
7 activity with spectrometry systems. Poor peak resolution and peak tailing may result in larger
8 measurement uncertainty or in failure to identify the presence of peaks based on shape.
9 Consistent problems with peak resolution indicate the presence of an analytical bias.

10 **6.2.3.7 Voltage Plateaus (Proportional Counters, Geiger-Mueller Detectors)**

11 The accuracy of results using a proportional counter or Geiger-Mueller (GM) detector can be
12 affected if the system is not operated with its detector's high voltage adjusted such that it is on a
13 stable portion of the operating plateau.

14 **6.2.3.8 Self-Absorption, Backscatter, and Crosstalk**

15 Alpha and beta measurement results can be affected through self-absorption and backscatter.
16 Measurement systems using an electronic discriminator (e.g., gas flow proportional detectors)
17 that simultaneously detect alpha and beta particles can be affected by crosstalk
18 (i.e., identification of alpha particles as beta particles and vice versa). Accurate differentiation
19 between alpha and beta activity depends on the assessment and maintenance of information on
20 self-absorption and crosstalk.

21 **6.3 Detection Capability**

22 The detection capability (sometimes referred to as sensitivity) of a measurement system refers
23 to a radiation level or quantity of radioactive material that can be measured or detected with
24 some known or estimated level of confidence. This quantity is a factor of both the
25 instrumentation and the technique or procedure being used.

26 The primary parameters that affect a measurement system's detection capability are the
27 background count rate, the instrument's detection efficiency, and the counting time interval.
28 When making field measurements, the detection capability will usually be less than what can be
29 achieved in a laboratory due to increased background and, often, significantly lower detection
30 efficiency. It is often impossible to guarantee that pure alpha emitters can be detected in situ,
31 because the weathering of aged surfaces will often completely absorb the alpha emissions.
32 NUREG-1507 (NRC 1997a) contains data on many of the parameters that affect detection
33 efficiencies in situ, such as absorption, surface smoothness, and particulate radiation energy.

34 **6.3.1 Detection Capability for Direct Measurements**

35 Prior to performing field measurements using scalers, an investigator must evaluate the
36 detection capability of the equipment proposed for use to ensure that levels below the DCGL
37 can be detected. After a direct measurement has been made, it is then necessary to determine

1 whether the result can be distinguished from the instrument background response of the
2 measurement system. The terms that are used in this manual to define detection capability for
3 fixed point counts and sample analyses are—

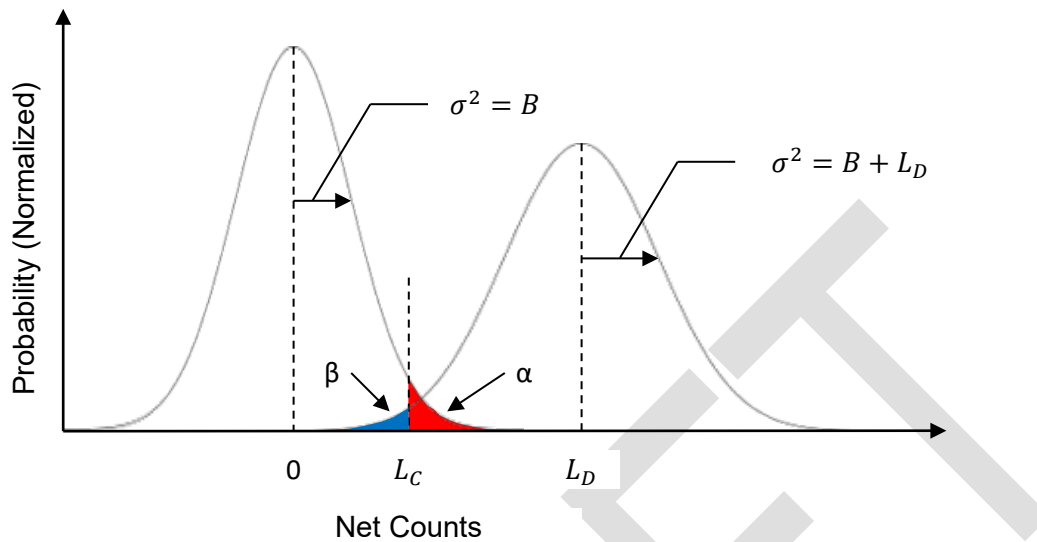
- 4 • *Critical level*: The critical level (L_C) is the level at which there is a statistical probability (with a
5 predetermined confidence) of correctly identifying a measurement as greater than
6 background.
- 7 • *Detection limit*: The detection limit (L_D) is the net response level that can be expected to be
8 seen with a detector with a fixed level of confidence.
- 9 • *Minimum detectable concentration*: The minimum detectable concentration (MDC) is the a
10 priori activity concentration that a specific instrument and technique that has a specified
11 probability (typically 95 percent) of producing a net count (or count rate) above the critical
12 level. When stating the detection limit of an instrument, this value should be used. The MDC
13 is the detection limit multiplied by an appropriate conversion factor to give units of activity.

14 The following discussion provides an overview of the derivation contained in the well-known
15 publication by Currie (1968) followed by a description of how the resulting formulas should be
16 used. Publications by Currie (1968) and Altshuler and Pasternack (1963) provide details of the
17 derivations involved. The two parameters of interest for a detector system with a background
18 response greater than zero are—

- 19 1. The critical level is the lower bound on the 95 percent detection interval defined for L_D and is
20 the level at which there is a 5 percent chance of calling a background value “greater than
21 background.” This value should be used when counting samples or making direct radiation
22 measurements. Any response above this level should be considered as above background
23 (i.e., a net positive result). This will ensure 95 percent detection capability for L_D .
- 24 2. The detection limit is the net response level, in counts, that can be expected to be seen with
25 a detector with a fixed level of confidence, which is assumed to be 95 percent.

26 Assuming that a system has a background response, and that random uncertainties and
27 systematic uncertainties are accounted for separately, these parameters can be calculated
28 using Poisson statistics. For these calculations, two types of decision errors should be
29 considered. A Type I error occurs when a detector response is considered to be above
30 background when, in fact, only background radiation is present. A Type II error occurs when a
31 detector response is considered to be background when, in fact, radiation is present at levels
32 above background. The probability of a Type I error is referred to as α (alpha) and is associated
33 with L_C ; the probability of a Type II error is referred to as β (beta) and is associated with L_D .
34 **Figure 6.1** graphically illustrates the relationship of these terms with respect to each other and
35 to a normal background distribution.²

² Note that the values of α and β chosen here are for the detection hypothesis test and are always chosen to be 5% for comparability purposes. These α and β values are separate and distinct from the values of α and β chosen by the planning team for use in designing site surveys.



B = Background Counts (mean)
 L_C = Critical Level (net counts above background)
 L_D = Detection Limit (net counts above background)
 α = Probability of Type I Error
 β = Probability of Type II Error

1

2 **Figure 6.1: Graphically Represented Probabilities for Type I and Type II Errors in**
 3 **Detection Capability for Instrumentation with a Background Response**

4 If α and β are assumed to be equal, the variance (σ^2) of all measurement values is assumed to
 5 be equal to the values themselves. If the background of the detection system is not well known,
 6 then the critical level and the detection limit can be calculated by using the following formulas:

$$L_C = k\sqrt{2B} \quad (6-1)$$

$$L_D = k^2 = 2k\sqrt{2B} \quad (6-2)$$

7 where L_C is the critical level (counts), L_D is the detection limit (counts), k is the Poisson
 8 probability sum for α and β (assuming α and β are equal), and B is the number of background
 9 counts that are expected to occur while performing an actual measurement.

10 The curve to the left in **Figure 6.1** is the background distribution. The result is a Poisson
 11 distribution with a mean equal to the number of background counts, B , and a variance, σ^2 , equal
 12 to B . Note that the distribution accounts only for the expected statistical variation due to the
 13 stochastic nature of radioactive decay. Currie assumed "paired blanks" when deriving the above
 14 stated relationships (Currie 1968), which is interpreted to mean that the sample and background
 15 count times are the same.

1 If values of 0.05 for both α and β are selected as acceptable, then $k = 1.645$ (from **Appendix I,**
 2 **Table I.1**), and **Equations 6-1 and 6-2** can be written as—

$$L_C = 2.33\sqrt{B} \quad (6-3)$$

$$L_D = 3 + 4.65\sqrt{B} \quad (6-4)$$

3 Note: In Currie's derivation, the constant factor of 3 in the L_D formula was stated
 4 as being 2.71, but since that time it has been shown (Brodsky 1992) and
 5 generally accepted that a constant of 3 is more appropriate. If the sample count
 6 times and background count times are different, a slightly different formulation is
 7 used.

8 The MDC value should be used when stating the detection capability of an instrument. Again,
 9 this value is used before any measurements are made and is used to estimate the level of
 10 activity that can be detected using a given measurement method.

11 For an integrated measurement over a preset time, the MDC can be obtained from
 12 **Equation 6-4** by multiplying by the factor C . This factor is used to convert from counts to
 13 concentration, as shown in **Equation 6-5**:

$$\text{MDC} = C \times (3 + 4.65\sqrt{B}) \quad (6-5)$$

14 The total detection efficiency and other constants or factors represented by the variable C are
 15 usually not truly constants, as shown in **Equation 6-5**. It is likely that at least one of these
 16 factors will have a certain amount of variability associated with it, which may or may not be
 17 significant. These varying factors are gathered together into the single constant, C , by which the
 18 net count result will be multiplied when converting the final data. If C varies significantly between
 19 measurements, then it might be best to select a value, C' , from the observed distribution of C
 20 values that represents a conservative estimate. For example, a value of C might be selected to
 21 ensure that at least 95 percent of the possible values of C are less than the chosen value, C' .
 22 The MDC calculated in this way helps assure that the survey results will meet the DQOs. This
 23 approach for including uncertainties into the MDC calculation is recommended in both
 24 NUREG/CR-4007 (NRC 1984) and Appendix A to ANSI N13.30 (ANSI 1996). Underestimating
 25 an MDC can have adverse consequences, especially if activity is later detected at a level above
 26 the stated MDC.

27 From a conservative point of view, it is better to overestimate the MDC for a measurement
 28 method. Therefore, when calculating MDC and L_C values, a measurement system background
 29 value should be selected that represents the high end of what is expected for a particular
 30 measurement method. For direct measurements, probes will be moved from point to point; as a
 31 result, it is expected that the background will most likely vary significantly because of variations
 32 in background, source materials, and changes in geometry and shielding. Ideally, the MDC
 33 values should be calculated for each type of area, but it may be more economical to simply
 34 select a background value from the highest distribution expected and use this for all

1 calculations. For the same reasons, realistic values of detection efficiencies and other process
 2 parameters should be used when possible and should be reflective of the actual conditions, as
 3 adopting an overly conservative MDC may sometimes lead to difficulties in implementation. To a
 4 great degree, the selection of these parameters will be based on judgment and will require
 5 evaluation of site-specific conditions. **Example 1** illustrates the calculation of an MDC in
 6 becquerels per square meter (Bq/m²) for an instrument with a 15 cm² probe area when the
 7 measurement and background counting times are each 1 minute.

Example 1: Calculation of a Minimum Detectable Concentration (MDC)

This example illustrates the calculation of an MDC in becquerels per square meter (Bq/m²) for an instrument with a 15 square centimeter (cm²) probe area when the measurement and background counting times are each 1 minute. Note that the count rate is reported in units of disintegrations per minute (dpm). The background counts, B , is 40 counts.

If the total efficiency of the probe is 20 percent, then 1 count will be recorded during a 1-minute timeframe for every 5 dpm. The concentration $C =$

$$C = \left(\frac{5 \text{ dpm}}{\text{count}} \right) \left(\frac{\text{Bq}}{60 \text{ dpm}} \right) \left(\frac{1}{15 \text{ cm}^2} \right) \left(\frac{10,000 \text{ cm}^2}{\text{m}^2} \right) = 55.6 \text{ Bq/m}^2$$

The MDC is calculated using **Equation 6-5**:

$$\text{MDC} = (55.6 \text{ Bq/m}^2) \times (3 + 4.65\sqrt{40}) = 1,800 \text{ Bq/m}^2 (1,100 \text{ dpm}/100 \text{ cm}^2)$$

The critical level, L_C , for this example is calculated from **Equation 6-3**:

$$L_C = 2.33\sqrt{B} = 2.33\sqrt{40} = 15 \text{ counts}$$

Given the above scenario, if a person asked what level of residual radioactive material could be detected 95 percent of the time using this method, the answer would be 1,800 Bq/m² (1,100 dpm/100 cm²). When performing measurements using this method, any count yielding greater than 55 total counts, or greater than 15 net counts (55 - 40 = 15) during a period of 1 minute, would be regarded as greater than background.

8 MDC values for other counting conditions may be derived from **Equation 6-5**, depending on the
 9 detector and radionuclides of concern. For example, it may be required to determine what level
 10 of residual radioactive material, distributed over 100 square centimeters (cm²), can be detected
 11 with a 500 cm² probe or what level of residual radioactive material can be detected with any
 12 probe when the area is smaller than the probe active area. **Table 6.1** lists several common field
 13 survey detectors with estimates of MDC values for uranium-238 (²³⁸U) on a smooth, flat plane.
 14 As such, these represent minimum MDC values and may not be applicable at all sites.
 15 Appropriate site-specific MDC values should be determined using the DQO Process.

6.3.2 Detection Capability for Scans

Unless data logging is employed, the ability to identify a small area of elevated levels of radioactive material during surface scanning is dependent upon the surveyor's skill in recognizing an increase in the output of an instrument. For notation purposes, the term detection capability (sometimes referred to as scanning sensitivity) is used throughout this section to describe the ability of a surveyor to detect a pre-determined level of residual radioactive material with a detector. The greater the detection capability, the lower the level of residual radioactive material that can be detected. **Table 6.1** provides examples of a set of detection capabilities.

Table 6.1: Examples of Estimated Detection Capabilities for Alpha and Beta Survey Equipment (Static 1-Minute Counts for ^{238}U Calculated Using Equations 6-3, 6-4, and 6-5)

Detector	Probe Area (cm ²)	Background (cpm)	Efficiency (cpm/dpm)	Approximate Detection Capability		
				L_C (counts)	L_D (counts)	MDC (Bq/m ²) ^a
Alpha proportional	50	1	0.15	2	7	150
Alpha proportional	100	1	0.15	2	7	83
Alpha proportional	600	5	0.15	5	13	25
Alpha scintillation	50	1	0.15	2	7	150
Beta proportional	100	300	0.20	40	83	700
Beta proportional	600	1,500	0.20	90	183	250
Beta GM pancake	15	40	0.20	15	32	1,800

Abbreviations: cm = centimeter; cpm = counts per minute; dpm = decays per minute; L_C = critical level; L_D = detection limit; Bq = becquerels; m = meters; GM = Geiger-Mueller.

^a Assumes that the size of the area of radioactive material is at least as large as the probe area.

Many of the radiological instruments and monitoring techniques typically used for occupational health physics activities may not provide the detection capabilities necessary to demonstrate compliance with the DCGLs. The detection capability for a given application can be improved (i.e., lower the MDC) by (1) selecting an instrument with a higher detection efficiency or a lower background, (2) decreasing the scanning speed, or (3) increasing the size of the effective probe area without significantly increasing the background response.

1 Scanning is usually performed during radiological surveys to identify the presence of any areas
2 of elevated activity. The probability of detecting residual radioactive material in the field not only
3 depends on the detection capability of the survey instrumentation when used in the scanning
4 mode of operation, but also is affected by the surveyor's ability (i.e., human factors). The
5 surveyor must make a decision whether the signals represent only the background activity or
6 residual radioactive material in excess of background. Lower levels of residual radioactive
7 material can be detected by increasing the detection capability (i.e., detection of residual
8 radioactive material is inversely proportional to the detection capability). Accounting for these
9 human factors represents a significant change from the methods of estimating detection
10 capabilities for scans used in the past.

11 An empirical method for evaluating the detection capability for surveys is by actual
12 experimentation or, as it is certainly feasible, by simulating an experimental setup using
13 computer software. The following steps provide a simple example of how one can perform this
14 empirical evaluation:

- 15 1. A desired radionuclide activity level is selected.
- 16 2. The response of the detector to be used is determined for the selected radionuclide activity
17 level.
- 18 3. A test source is constructed that will give a detector count rate equivalent to the detector
19 response, determined in Step 2. The count rate is equivalent to what would be expected
20 from the detector when placed on an actual area with residual radioactive material equal in
21 value to that selected in Step 1.
- 22 4. The detector of choice is then moved over the source at different scan rates until an
23 acceptable speed is determined.

24 The most useful aspect of this approach is that the source can then be used to show surveyors
25 what level of residual radioactive material is expected to be targeted with the scan. They, in
26 turn, can gain experience with what the expected response of the detector will be and how fast
27 they can survey and still feel confident about detecting the target residual radioactive material
28 level. The person responsible for the survey can then use this information when developing a
29 fixed point measurement and sampling plan.

30 The remainder of this section provides the reader with information regarding the underlying
31 processes involved when performing scanning surveys for alpha-, beta-, and gamma-emitting
32 radionuclides. The purpose is to provide relevant information that can be used for estimating
33 realistic detection capabilities for scans.

34 *6.3.2.1 Scanning for Beta and Gamma Emitters*

35 The scan MDC depends on several factors:

- 36 • the intrinsic characteristics of the detector (efficiency, physical probe area, etc.)

- 1 • the nature (type and energy of emissions) and relative distribution of residual radioactive
- 2 material (point versus distributed source and depth of residual radioactive material)
- 3 • scan rate
- 4 • other characteristics of the surveyor

5 Some factors may affect the surveyor's performance (e.g., fatigue, noise, level of training,
6 experience) and the surveyor's a priori expectation of the likelihood of residual radioactive
7 material present. For example, if the surveyor believes that the potential for residual radioactive
8 material is very low, as in a Class 3 area, a relatively large signal may be required for the
9 surveyor to conclude that residual radioactive material is present.

10 Signal Detection Theory

11 Personnel conducting radiological surveys for residual radioactive material at sites must
12 interpret the audible output of a portable survey instrument to determine when the signal
13 ("clicks") exceeds the background level by a margin sufficient to conclude that residual
14 radioactive material is present. It is difficult to detect low levels of residual radioactive material,
15 because both the signal and the background vary widely. Signal detection theory provides a
16 framework for the task of deciding whether the audible output of the survey meter during
17 scanning is due to background or signal plus background levels. An index of sensitivity (d') that
18 represents the distance between the means of the background and background plus signal
19 (refer to **Figure 6.1** for determining L_D), in units of their common standard deviation can be
20 calculated for various decision errors (correct detection and false positive rate).

21 As an example, for a correct detection rate of 95 percent (complement of a false negative rate of
22 5 percent) and a false positive rate of 5 percent, d' is 3.28 (similar to the static MDC for the
23 same decision error rates). The index of sensitivity is independent of human factors; therefore,
24 the ability of an ideal observer (theoretical construct) may be used to determine the minimum d'
25 that can be achieved for particular decision errors. The ideal observer makes optimal use of the
26 available information to maximize the percent correct responses, providing an effective upper
27 bound against which to compare actual surveyors. **Table 6.2** lists selected values of d' .

28 Two Stages of Scanning

29 The framework for determining the scan MDC is based on the premise that there are two stages
30 of scanning. That is, surveyors do not make decisions based on a single indication; rather, upon
31 noting an increased number of counts, they pause briefly and then decide whether to move on
32 or take further measurements. Thus, scanning consists of two components: continuous
33 monitoring and stationary sampling. In the first component, characterized by continuous
34 movement of the probe, the surveyor has only a brief "look" at potential sources, determined by
35 the scan speed. The surveyor's willingness to decide that a signal is present at this stage is
36 likely to be liberal, in that the surveyor should respond positively on scant evidence, because
37 the only "cost" of a false positive is a little time. The second component occurs only after a
38 positive response was made at the first stage. This response is marked by the surveyor
39 interrupting his or her scanning and holding the probe stationary for a period of time while

1 comparing the instrument output signal during that time to the background counting rate. Owing
 2 to the longer observation interval, detection capability is relatively high. For this decision, the
 3 criterion should be stricter, as the cost of a “yes” decision is to spend considerably more time

4 **Table 6.2: Index of Sensitivity (d') Values for Selected True Positive and False Positive**
 5 **Proportions**

False Positive Proportion	True Positive Proportion							
	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
0.05	1.90	2.02	2.16	2.32	2.48	2.68	2.92	3.28
0.10	1.54	1.66	1.80	1.96	2.12	2.32	2.56	2.92
0.15	1.30	1.42	1.56	1.72	1.88	2.08	2.32	2.68
0.20	1.10	1.22	1.36	1.52	1.68	1.88	2.12	2.48
0.25	0.93	1.06	1.20	1.35	1.52	1.72	1.96	2.32
0.30	0.78	0.91	1.05	1.20	1.36	1.56	1.80	2.16
0.35	0.64	0.77	0.91	1.06	1.22	1.42	1.66	2.02
0.40	0.51	0.64	0.78	0.93	1.10	1.30	1.54	1.90
0.45	0.38	0.52	0.66	0.80	0.97	1.17	1.41	1.77
0.50	0.26	0.38	0.52	0.68	0.84	1.04	1.28	1.64
0.55	0.12	0.26	0.40	0.54	0.71	0.91	1.15	1.51
0.60	0.00	0.13	0.27	0.42	0.58	0.82	1.02	1.38

6 taking a static measurement or a sample. Because scanning can be divided into two stages, it is
 7 necessary to consider the survey’s scan detection capability for each stage. Typically, the
 8 minimum detectable count rate (MDCR) associated with the first scanning stage will be greater
 9 due to the brief observation intervals of continuous monitoring—provided that the length of the
 10 pause during the second stage is significantly longer. Typically, observation intervals during the
 11 first stage are on the order of 1 or 2 seconds, while the second stage pause may be several
 12 seconds longer. The greater value of MDCR from each of the scan stages is used to determine
 13 the detection capability for the surveyor.

14 Determination of MDCR and Use of Surveyor Efficiency

15 The minimum detectable number of net source counts in the time interval is given by s_i .
 16 Therefore, for an ideal observer, the number of source counts required for a specified level of
 17 performance can be arrived at by multiplying the square root of the number of background
 18 counts by the detectability value associated with the desired performance (as reflected in d') as
 19 shown in **Equation 6-6**:

$$s_i = d' \sqrt{b_i} \quad (6-6)$$

- 1 where the value of d' is selected from **Table 6.2** based on the required true positive and false
 2 positive rates and b_i is the number of background counts in the interval. The MDCR can be
 3 calculated using the **Equation 6-7**:

$$\text{MDCR} = \frac{s_i}{\Delta t_i} \quad (6-7)$$

- 4 where Δt_i is the observation interval. **Example 2** illustrates the calculation of the MDCR for a
 5 probe with a background count rate of 1,500 counts per minute (cpm) for a 1-second interval.

Example 2: Calculation of the Minimum Detectable Count Rate for the First Stage of Scanning

Estimate the minimum detectable count rate (MDCR) by scanning in an area with a background of 1,500 counts per minute (cpm). Note that the MDCR must be considered for both scan stages, and the more conservative value is selected as the minimum count rate that is detectable. It will be assumed that a typical source remains under the probe for 1 second (s) during the first stage, therefore, the average number of background counts in the observation interval is—

$$b_i = (1500 \text{ cpm})(1 \text{ s}) \left(\frac{\text{minute}}{60 \text{ s}} \right) = 25 \text{ counts}$$

where b_i is the average number of background counts in an observation interval. Furthermore, it can be assumed that at the first scanning stage, a high rate (e.g., 95 percent) of correct detections is required and that a correspondingly high rate of false positives (e.g., 60 percent) will be tolerated. From **Table 6.2**, the value of d' , representing this performance goal is 1.38. The net source counts needed to support the specified level of performance (assuming an ideal observer) will be estimated by multiplying 5 (the square root of 25) by 1.38. Thus, the net source counts, s_i in interval Δt_i (in seconds), needed to yield better than 95 percent detections with about 60 percent false positives is given by **Equation 6-6**:

$$s_i = 1.38 \times \sqrt{25} = 6.9$$

The MDCR, in cpm, may be calculated using **Equation 6-7**:

$$\text{MDCR} = \frac{s_i}{\Delta t_i} = \left(\frac{6.9 \text{ counts}}{1 \text{ s}} \right) \left(\frac{60 \text{ s}}{\text{minute}} \right) = 414 \text{ cpm}$$

where s_i is the minimum detectable number of net source counts and is over a time interval specified by t_i . For this example, MDCR is equivalent to 414 cpm above a background of 1,500 cpm (1,914 cpm gross).

- 1 **Example 3** illustrates the determination of the detection limit for the ideal observer (MDCR) at
 2 the first scanning stage for various background levels for a true positive proportion of 95 percent
 3 and false positive proportion of 60 percent.

Example 3: Determination of the Detection Limit for the Ideal Observer

The table below provides the minimum detection count rate and detection limit for the ideal observer at the first scanning stage for various background levels, based on an index of sensitivity (d') of 1.38 for a true positive proportion of 95 percent, a false positive proportion of 60 percent, and a 2-second observation interval.

Detection Capability of the Ideal Observer for Various Background Levels

Background (cpm)	MDCR (net cpm)	Scan Sensitivity (gross cpm) ^a
45	50	95
60	60	120
260	120	380
300	130	430
350	140	490
400	150	550
1,000	240	1,240
3,000	410	3,410
4,000	480	4,480

Abbreviations: cpm = counts per minute; MDCR = minimum detectable count rate.

^aThe detection capability of the ideal observer during the first scanning stage is based on an index of sensitivity (d') of 1.38 and a 2-second observational interval.

- 4 The minimum number of source counts required to support a given level of performance for the
 5 final detection decision (second scan stage) can be estimated using the same method. As
 6 explained earlier, the performance goal at this stage will be more demanding. **Example 4**
 7 illustrates the calculation of the MDCR for the probe from **Example 2** but with an interval of
 8 4 seconds instead of 1 second.

Example 4: Calculation of the Minimum Detectable Count Rate for the Second Stage of Scanning

The required rate of true positives remains high (e.g., 95 percent), but fewer false positives (e.g., 20 percent) can be tolerated, such that the index of sensitivity (d') (from **Table 6.2**) is now 2.48. One will assume that the surveyor typically stops the probe over a suspect location for about 4 seconds (s) before making a decision so that the average number of background counts in an observation interval is

$$b_i = (1,500 \text{ cpm})(4 \text{ s}) \left(\frac{\text{minute}}{60 \text{ s}} \right) = 100 \text{ counts}$$

where b_i is the average number of background counts in an observation interval. Therefore, the minimum detectable number of net source counts, s_i , needed will be estimated by multiplying 10 (the square root of b_i) by 2.48 (the d' value) using **Equation 6-6**:

$$s_i = d' \sqrt{b_i} = 2.48 \times \sqrt{100} = 24.8$$

The minimum detectable count rate (MDCR) is calculated using **Equation 6-7**:

$$\text{MDCR} = \frac{s_i}{\Delta t_i} = \left(\frac{24.8 \text{ counts}}{4 \text{ s}} \right) \left(\frac{60 \text{ s}}{\text{minute}} \right) = 372 \text{ cpm}$$

where s_i is the minimum detectable number of net source counts and is over a time interval specified by t_i . The MDCR is 372 counts per minute (cpm) net, or 1,872 cpm gross. The value associated with the first scanning stage (**Example 2**: 414 cpm net or 1,914 cpm gross) will typically be greater, owing to the relatively brief intervals assumed.

- 1 Laboratory studies using simulated sources and backgrounds were performed to assess the
- 2 abilities of surveyors under controlled conditions. The methodology and analysis of results for
- 3 these studies are described in NUREG-1507 (NRC 1997a). The surveyor's actual performance
- 4 as compared with the ideal possible performance (using the ideal observer construct) provided
- 5 an indication of the efficiency of the surveyors. Based on the results of the confidence rating
- 6 experiment, this surveyor efficiency (p) was estimated to be between 0.5 and 0.75.
- 7 MARSSIM recommends assuming a surveyor efficiency value at the lower end of the observed
- 8 range (i.e., 0.5) when making MDC estimates. Thus, the required number of net source counts,
- 9 $\text{MDCR}_{\text{surveyor}}$, is determined by dividing the MDCR by the square root of p , as in **Equation 6-8**:

$$\text{MDCR}_{\text{surveyor}} = \frac{\text{MDCR}}{\sqrt{p}} \quad (6-8)$$

- 10 **Example 5** shows the calculation of the surveyor MDCR for **Example 1**:

Example 5: Calculation of the Surveyor Minimum Detectable Count Rate for Example 1

Using the data from Example 1, the surveyor minimum detectable count rate (MDCR) is calculated using **Equation 6-8**:

$$\text{MDCR}_{\text{surveyor}} = \frac{\text{MDCR}}{\sqrt{p}} = \frac{414 \text{ cpm}}{\sqrt{0.5}} = 585 \text{ cpm}$$

The surveyor MDCR is 585 counts per minute (cpm) net (2,085 cpm gross).

1 Scan MDCs for Structure Surfaces and Land Areas

2 The survey design for determining the number of data points for areas of elevated activity (see
 3 **Section 5.3.5**) depends on the scan MDC for the selected instrumentation. In general, alpha or
 4 beta scans are performed on structure surfaces to satisfy the elevated activity measurements
 5 survey design, and gamma scans are performed for land areas. Because of low background
 6 levels for alpha emitters, the approach described here is not generally applied to determining
 7 scan MDCs for alpha emitters; rather, the reader is referred to **Section 6.3.2.2** for an
 8 appropriate method for determining alpha scan MDCs for building surfaces. In any case, the
 9 data requirements for assessing potential elevated areas of direct radiation depend on the scan
 10 MDC of the survey instrument (e.g., floor monitor, GM detector, sodium iodide [NaI] scintillation
 11 detector).

12 Scan MDCs for Building/Structure Surfaces

13 The scan MDC is determined from the MDCR by applying conversion factors that account for
 14 detector and surface characteristics and surveyor efficiency. As discussed above, the MDCR
 15 accounts for the background level, performance criteria (d'), and observation interval. The
 16 observation interval during scanning is the actual time that the detector can respond to the
 17 source of residual radioactive material—this interval depends on the scan speed, detector size
 18 in the direction of the scan, and area of elevated activity. Because the actual dimensions of
 19 potential areas of elevated activity in the field cannot be known a priori, MARSSIM recommends
 20 postulating a certain area (e.g., perhaps 50–200 cm²) and then selecting a scan rate that
 21 provides a reasonable observation interval.

22 Finally, the scan MDC in units of decays per minute (dpm)/100 cm² for structure surfaces may
 23 be calculated using **Equation 6-9**:

$$\text{Scan MDC} = \frac{\text{MDCR}}{\sqrt{p} \varepsilon_i \varepsilon_s \frac{W}{100}} \quad (6-9)$$

24 where

- 25 • MDCR is the minimum detectable count rate
- 26 • ε_i is the instrument efficiency
- 27 • ε_s is the surface efficiency
- 28 • p is the surveyor efficiency
- 29 • W is the physical probe area in square centimeters
- 30 • 100 is a units conversion from (cm²)⁻¹ to (100 cm²)⁻¹

- 1 Consideration may need to be given to the size of the detector probe relative to the size of the
 2 postulated hot spot size. For example, a large area floor monitor with a probe area of
 3 approximately 600 cm² would fully cover the area of the postulated hot spot in the scenario
 4 presented above (i.e., 50–200 cm²). In this situation, a probe area correction is likely not
 5 appropriate. **Example 6** illustrates the calculation of the scan MDC for the probe in **Example 3**
 6 for technetium-99 (⁹⁹Tc).

Example 6: Calculation of the Scan Minimum Detectable Concentration for the Probe in Example 3

As an example, the scan minimum detectable concentration (MDC) (in disintegrations per minute [dpm]/100 square centimeters [cm²]) for technetium-99 (⁹⁹Tc) on a concrete surface may be determined for a background level of 300 counts per minute (cpm) and a 2-second observation interval using a hand-held gas proportional detector (126 cm² probe area). For a specified level of performance at the first scanning stage of 95 percent true positive rate and 60 percent false positive rate (and assuming the second stage pause is long enough to ensure that the first stage is more limiting), d' equals 1.38 (**Table 6.2**), and the minimum detectable count rate (MDCR) is 130 cpm (**Example 3**). Using a surveyor efficiency of 0.5, and assuming instrument and surface efficiencies of 0.36 and 0.54, respectively, the scan MDC is calculated using **Equation 6-9**:

$$\text{Scan MDC} = \frac{\text{MDCR}}{\sqrt{p} \varepsilon_i \varepsilon_s \frac{W}{100}} = \frac{130 \text{ cpm}}{\sqrt{0.5} (0.36 \times 0.54 \text{ cpm/dpm}) \left(\frac{126 \text{ cm}^2}{100} \right)} = 750 \text{ dpm/100 cm}^2$$

The scan MDC for ⁹⁹Tc is 750 dpm/100 cm².

- 7 Additional examples for calculating the scan MDC may be found in NUREG-1507 (NRC 1997a).
- 8 Scan MDCs for Land Areas
- 9 In addition to the MDCR and detector characteristics, the scan MDC for land areas is based on
 10 the area of elevated activity, depth of contamination, and the radionuclide (i.e., energy and yield
 11 of gamma emissions).
- 12 Thallium-infused NaI (NaI(Tl)) scintillation detectors are generally used for scanning land areas.
 13 Typically, the detectors are placed just above the surveyed area. By hand, this can be done by
 14 suspending the detector from the surveyor's hand by a rope. By mechanical means, the
 15 detector can be fixed from an automated device.
- 16 An overview of the approach used to determine scan MDCs for land areas follows. The NaI(Tl)
 17 scintillation detector background level and scan rate (observation interval) are postulated, and
 18 the MDCR for the ideal observer, for a given level of performance, is obtained. After a surveyor
 19 efficiency is selected, the relationship between the surveyor MDCR (MDCR_{surveyor}) and the
 20 radionuclide concentration in soil, in Bq/kilogram (kg) or picocuries/gram (pCi/g) is determined.

1 This correlation requires two steps: First, the relationship between the detector's net count rate
 2 to net exposure rate (cpm per microrentgens/hour [$\mu\text{R}/\text{h}$]) is established, and second, the
 3 relationship between the concentration of residual radioactive material and exposure rate is
 4 determined.

5 For a particular gamma energy, the relationship of NaI(Tl) scintillation detector count rate and
 6 exposure rate may be determined analytically (in cpm per $\mu\text{R}/\text{h}$). The approach used to
 7 determine the gamma fluence rate necessary to yield a fixed exposure rate (1 $\mu\text{R}/\text{h}$)—as a
 8 function of gamma energy—is provided in NUREG-1507 (NRC 1997a). The NaI(Tl) scintillation
 9 detector response (in cpm) is related to the fluence rate at specific energies, considering the
 10 detector's efficiency (probability of interaction) at each energy. From this, the NaI(Tl) detector
 11 count rate versus exposure rates for varying gamma energies are determined. After the
 12 relationship between the NaI(Tl) detector response and the exposure rate is established, the
 13 $\text{MDCR}_{\text{surveyor}}$ (in cpm) of the NaI(Tl) detector can be related to the minimum detectable exposure
 14 rate (MDER) using **Equation 6-10**:

$$\text{MDER} = \frac{\text{MDCR}_{\text{surveyor}}}{\text{Ratio of Count Rate to Exposure Rate}} \quad (6-10)$$

15 The MDER is used to determine the minimum detectable radionuclide concentration (i.e., the
 16 scan MDC) by modeling a specified small area of elevated activity and then dividing the MDER
 17 by the exposure rate conversion factor using **Equation 6-11**:

$$\text{Scan MDC} = \frac{\text{MDER}}{\text{Exposure Rate Conversion Factor}} \quad (6-11)$$

18 **Example 7** illustrates the calculation of the scan MDC for cesium-137 (^{137}Cs) using a 38
 19 millimeter (mm; 1.5 inch [in.]) by 32 mm (1.25 in.) NaI(Tl) scintillation detector.

Example 7: Calculation of a Scan Minimum Detectable Concentration for ^{137}Cs

Modeling (using MicroShield 5.05™) of the small area of elevated activity (soil concentration) is used to determine the net exposure rate produced by a radionuclide concentration at a distance 10 centimeters (cm) above the source. This position is selected because it relates to the average height of the NaI(Tl) scintillation detector above the ground during scanning. The factors considered in the modeling include the following:

- radionuclide of interest (considering all gamma emitters for decay chains)
- expected concentration of the radionuclide of interest
- areal dimensions of the area of elevated activity
- depth of the area of elevated activity
- location of dose point (NaI(Tl) scintillation detector height above the surface)
- density and moisture content of soil

Modeling analyses are conducted by selecting a radionuclide (or radioactive material decay series) and then varying the concentration of the radionuclide. The other factors are held

constant—the areal dimension of a cylindrical area of elevated activity is 0.25 square meters (m^2 ; radius of 28 cm), the depth of the area of elevated activity is 15 cm, the dose point is 10 cm above the surface, and the density of soil is 1.6 g/cm^3 . The soil was modeled as 50 percent aluminum and 50 percent carbon by weight. The objective is to determine the radionuclide concentration that is correlated to the minimum detectable net exposure rate.

The scan MDC for cesium-137 (^{137}Cs) using a 38 millimeter (mm; 1.5 inch [in.]) by 32 mm (1.25 in.) NaI(Tl) scintillation detector is considered in detail. Assume that the background level is 4,000 counts per minute (cpm) and that the desired level of performance, 95 percent correct detections and 60 percent false positive rate, results in a d' of 1.38. The scan rate of 0.5 m/second (s) provides an observation interval of 1 second (based on a diameter of about 56 cm for the area of elevated activity). The $\text{MDCR}_{\text{surveyor}}$ may be calculated assuming a surveyor efficiency (p) of 0.5, as follows:

$$b_i = (4,000 \text{ cpm}) \times (1 \text{ s}) \times (1 \text{ min}/60 \text{ s}) = 66.7 \text{ counts}$$

$$\text{MDCR} = d' \sqrt{b_i} \times (60 \text{ s}/1 \text{ min}) = (1.38) \times (\sqrt{66.7}) \times (60 \text{ s}/1 \text{ min}) = 680 \text{ cpm}$$

$$\text{MDCR}_{\text{surveyor}} = \frac{\text{MDCR}}{\sqrt{p}} = \frac{680 \text{ cpm}}{\sqrt{0.5}} = 960 \text{ cpm}$$

The corresponding minimum detectable exposure rate (MDER) is determined for this detector and radionuclide. The manufacturer of this particular 38 mm (1.5 in.) by 32 mm (1.25 in.) NaI(Tl) scintillation detector quotes a count rate to exposure rate ratio for ^{137}Cs of 350 cpm per $\mu\text{R}/\text{hour}$ (h), which is equivalent to the Standard International System of Units of 1.36 cpm per picocoulomb (pC) per kilogram (kg) per hour (cpm/(pC/kg)/h). MDER can be calculated by dividing the $\text{MDCR}_{\text{surveyor}}$ by the exposure rate ratio for ^{137}Cs , as shown below:

$$\text{MDER} = \frac{960 \text{ cpm}}{1.36 \text{ cpm}/(\text{pCi}/\text{kg})/\text{h}} = 706 \text{ (pCi}/\text{kg})/\text{h} \text{ (2.74 } \mu\text{R}/\text{h)}$$

Both ^{137}Cs and its short-lived progeny, $^{137\text{m}}\text{Ba}$, are chosen from the MicroShield® library. The source activity and other modeling parameters are entered into the modeling code. The source activity is selected based on an arbitrary concentration of 185 Bq/kg (5 picocuries [pCi]/g). The modeling code performed the appropriate calculations and determined an exposure rate of 337 (pCi/kg)/h (1.307 $\mu\text{R}/\text{h}$), which accounts for buildup.

Finally, the radionuclide concentrations of ^{137}Cs and $^{137\text{m}}\text{Ba}$ (scan MDC) necessary to yield the minimum detectable exposure rate of 706 (pCi/kg)/h (2.74 $\mu\text{R}/\text{h}$) may be calculated using the following formula:

$$\text{scan MDC} = \frac{706 \text{ (pCi/kg)/h}}{\left(\frac{337 \text{ (pCi/kg)/h}}{185 \text{ Bq/kg}}\right)} = 390 \text{ Bq/kg}$$

The scan MDC for ^{137}Cs using a 38 mm (1.5 in.) by 32 mm (1.25 in.) NaI(Tl) scintillation detector, rounded to the appropriate number of significant digits, is 390 Bq/kg (11 pCi/g).

1 It must be emphasized that although a single scan MDC value can be calculated for a given
2 radionuclide, other scan MDC values may be equally justifiable, depending on the values
3 chosen for the various factors, including the MDCR (background level, acceptable performance
4 criteria, observation interval), surveyor efficiency, detector parameters, and the modeling
5 conditions of the residual radioactive material. It should also be noted that determination of the
6 scan MDC for radioactive materials—such as uranium and thorium—must consider the gamma
7 radiation emitted from the entire decay series. NUREG-1507 (NRC 1997a) provides a detailed
8 example of how the scan MDC can be determined for enriched uranium.

9 **Example 7** uses ^{137}Cs as the radionuclide, which is the same radionuclide that is used to
10 calibrate the instrument. When doing gamma surveys for other radionuclides than ^{137}Cs —the
11 most common instrument calibration source—instruments may underestimate or overestimate
12 the source strength because of the different energies of the gamma rays that are emitted. This
13 uncertainty can be reduced or eliminated by cross calibrating the detector to energy
14 compensated detectors, such as pressurized ion chambers, or the instrument can be calibrated
15 to the specific radionuclide of concern.

16 **Table 6.3** provides scan MDCs for common radionuclides and radioactive materials in soil. It is
17 important to note that the variables used in the above examples to determine the scan MDCs for
18 the 38 mm (1.5 in.) by 32 mm (1.25 in.) NaI(Tl) scintillation detector (i.e., the $\text{MDCR}_{\text{surveyor}}$
19 detector parameters (e.g., cpm per $\mu\text{R/h}$), and the characteristics of the area of elevated
20 activity) have all been held constant to facilitate the calculation of scan MDCs provided in
21 **Table 6.3**. The benefit of this approach is that generally applicable scan MDCs are provided for
22 different radionuclides. Additionally, the relative detectability of different radionuclides is evident
23 because the only variable in **Table 6.3** is the nature of the radionuclide.

24 As noted above, the scan MDCs calculated using the approach in this section are dependent on
25 several factors. One way to validate the appropriateness of the scan MDC is by tracking the
26 levels of residual radioactive material (both surface activity and soil concentrations) identified
27 during investigations performed as a result of scanning surveys. The measurements performed
28 during these investigations may provide an a posteriori estimate of the scan MDC that can be
29 used to validate the a priori scan MDC used to design the survey.

30

1 **Table 6.3: NaI(Tl) Scintillation Detector Scan MDCs for Common Radionuclides and**
 2 **Radioactive Materials**

Radionuclide/Radioactive Material	1.25 in. by 1.5 in. NaI Detector ^a		2 in. by 2 in. NaI Detector ^a	
	Scan MDC (Bq/kg)	Weighted cpm/ μ R/h	Scan MDC (Bq/kg)	Weighted cpm/ μ R/h
²⁴¹ Am	1,650	5,830	1,170	13,000
⁶⁰ Co	215	160	126	430
¹³⁷ Cs	385	350	237	900
²³⁰ Th	111,000	4,300	78,400	9,580
²²⁶ Ra (Individual radionuclide, in equilibrium with progeny)	167	300	104	760
²³² Th decay series (Sum of all radionuclides in the thorium decay series)	1,050	340	677	830
Th-232 (Individual radionuclide, in equilibrium with progeny in decay series)	104	340	66.6	830
Depleted U ^b (0.34% U-235)	2,980	1,680	2,070	3,790
U in natural isotopic abundance ^b	4,260	1,770	2,960	3,990
3% Enriched U ^b	5,070	2,010	3,540	4,520
20% Enriched U ^b	5,620	2,210	3,960	4,940
50% Enriched U ^b	6,220	2,240	4,370	5,010
75% Enriched U ^b	6,960	2,250	4,880	5,030

3 Abbreviations: in. = inch; MDC = minimum detectable concentration; Bq = becquerel; kg = kilogram; cpm = counts per
 4 minute; μ R/h = microrentgens/hour.

5 ^a Refer to text for complete explanation of factors used to calculate scan MDCs. For example, the background level
 6 for the 1.25 in. by 1.5 in. NaI detector was assumed to be 4,000 cpm, and 10,000 cpm for the 2 in. by 2 in. NaI
 7 detector. The observation interval was 1 second, and the level of performance was selected to yield a performance
 8 criteria (d') of 1.38.

9 ^b Scan MDC for uranium includes the sum of ²³⁸U, ²³⁵U, and ²³⁴U.

10 6.3.2.2 Scanning for Alpha Emitters

11 Scanning for alpha emitters differs significantly from scanning for beta and gamma emitters in
 12 that the expected background response of most alpha detectors is very close to zero. The
 13 following discussion covers scanning for alpha emitters and assumes that the surface being

1 surveyed is similar in nature to the material on which the detector was calibrated. In this respect,
 2 the approach is purely theoretical. Surveying surfaces that are dirty, non-planar, or weathered
 3 can significantly affect the detection efficiency and therefore introduce bias to the expected
 4 MDC for the scan. The use of reasonable detection efficiency values instead of optimistic values
 5 is highly recommended. **Appendix J** contains a complete derivation of the alpha scanning
 6 equations used in this section.

7 Because the time an area is under the probe varies and the background count rate of some
 8 alpha instruments is less than 1 cpm, it is not practical to determine a fixed MDC for scanning.
 9 Instead, it is more useful to determine the probability of detecting an area of residual radioactive
 10 material at a predetermined DCGL for given scan rates.

11 For alpha survey instrumentation with backgrounds ranging from less than 1 to 3 cpm, a single
 12 count provides a surveyor sufficient cause to stop and investigate further. Assuming this to be
 13 true, the probability of detecting given levels of alpha-emitting radioactive materials on a surface
 14 can be calculated by use of Poisson summation statistics.

15 Given a known scan rate and a DCGL for residual radioactive material on a surface, the
 16 probability of detecting a single count while passing over the contaminated area is calculated
 17 using **Equation 6-12**:

$$P(n \geq 1) = 1 - e^{-\frac{G \epsilon_t d}{60v}} \quad (6-12)$$

18 where

- 19 • $P(n \geq 1)$ is the probability of observing one or more counts
- 20 • G is the activity in disintegrations per minute (dpm)
- 21 • ϵ_t is the detector efficiency (4π)
- 22 • d is width of the detector in the direction of the scan in centimeters
- 23 • v is the scan speed in centimeters/second

24 **Equation 6-12** may be solved for a minimum detectable alpha concentration by assessing
 25 the probability of detection using Poisson summation statistics. Specifically, by defining a
 26 certain probability of detection, the alpha scan minimum detectable activity (MDA) may be
 27 estimated by solving **Equation 6-12** for G , as shown in **Equation 6-13**, where i is the
 28 observation interval (in seconds) that can be calculated as d / v from **Equation 6-12**:

$$\text{Alpha Scan MDA} = \frac{[-\ln(1 - P(n \geq 1))] \times (60/i)}{\epsilon_t} \quad (6-13)$$

29 The scan MDC calculation may be written to account for the probe area, as shown in
 30 **Equation 6-14**:

$$\text{Alpha Scan MDC} = \frac{[-\ln(1 - P(n \geq 1))] \times (60/i)}{\varepsilon_t \times \frac{W}{100}} \quad (6-14)$$

1 where A is the physical probe area (cm^2) and the Alpha Scan MDC is in units of $\text{dpm}/100 \text{ cm}^2$.

2 Note: This evaluation is shown for the situation where a surveyor is expected to
 3 respond to one single count and would become more complex for 2 or more
 4 counts. It is also necessary to define an acceptable probability of detection,
 5 which should be considered during the DQO process and may require
 6 consultation with the regulator.

7 After a count is recorded and the guideline level of residual radioactive material is present, the
 8 surveyor should stop and wait until the probability of getting another count is at least 90 percent.
 9 This time interval can be calculated by using **Equation 6-15**:

$$t = \frac{[-\ln(1 - P(n \geq 1))] \times 60 \times 100}{C \times W \times \varepsilon_t} = \frac{13,800}{C \times W \times \varepsilon_t} \quad (6-15)$$

10 where

- 11 • t is the time period for static count in seconds
- 12 • C is the DCGL in $\text{dpm}/100 \text{ cm}^2$
- 13 • W is the physical probe area (in cm^2)
- 14 • ε_t is the detector efficiency (4π)

15 Many portable proportional counters have background count rates on the order of 5–10 cpm,
 16 and a single count should not cause a surveyor to investigate further. A counting period long
 17 enough to establish that a single count indicates that an elevated level would be prohibitively
 18 inefficient. For these types of instruments, the surveyor usually will need to get at least 2 counts
 19 while passing over the source area before stopping for further investigation.

20 Assuming this to be a valid assumption, the probability of getting two or more counts can be
 21 calculated using **Equation 6-16**:

$$\begin{aligned} P(n \geq 2) &= 1 - P(n = 0) - P(n = 1) \\ &= 1 - \left(1 + \frac{(G\varepsilon_t + B)t}{60}\right) \left(e^{-\frac{(G\varepsilon_t + B)t}{60}}\right) \end{aligned} \quad (6-16)$$

22 where $P(n \geq 2)$ is probability of getting 2 or more counts during the time interval t ; $P(n = 0)$ is
 23 the probability of not getting any counts during the time interval t ; $P(n = 1)$ is the probability of

1 getting exactly 1 count during the time interval t ; and B is the background count rate (cpm). All
2 other variables are the same as in **Equation 6-10**.

3 **Appendix J** provides a complete derivation of **Equations 6-12 through 6-16** and a detailed
4 discussion of the probability of detecting residual alpha-emitting radioactive material on surfaces
5 for several different variables. Several probability charts are included at the end of **Appendix J**
6 for common detector sizes. **Table 6.4** provides estimates of the probability of detecting
7 300 dpm/100 cm² for some commonly used alpha detectors.

8 **Table 6.4: Probability of Detecting 300 dpm/100 cm² of Alpha Activity While Scanning**
9 **with Alpha Detectors Using an Audible Output (Calculated Using Equation 6-16)**

Detector Type	Detection Efficiency (cpm/dpm)	Probe Dimension in Direction of Scan (cm)	Scan Rate (cm/s)	Probability of detecting 300 dpm/100 cm ²
Proportional	0.20	5	3	80%
Proportional	0.15	15	5	90%
Scintillation	0.15	5	3	70%
Scintillation	0.15	10	3	90%

10 Abbreviations: cpm = counts per minute; dpm = decays per minute; cm = centimeters; s = seconds.

11 **6.4 Measurement Uncertainty**

12 The quality of measurement data will be directly affected by the magnitude of the measurement
13 uncertainty associated with it. Some uncertainties, such as statistical counting uncertainties, can
14 be easily calculated from the count results using mathematical procedures. Evaluation of other
15 sources of uncertainty requires more effort and in some cases is not possible. For example, if
16 an alpha activity measurement is made on a porous concrete surface, the observed instrument
17 response when converted to units of activity will probably not exactly equal the true activity
18 under the probe. Variations in the absorption properties of the surface for particulate radiation
19 will vary from point to point and therefore will create some level of variation in the expected
20 detection efficiency. This variability in the expected detector efficiency results in uncertainty in
21 the final reported result.

22 The measurement uncertainty for every analytical result or series of results, such as for a
23 measurement system, should be reported. This uncertainty, although not directly used for
24 demonstrating compliance with the release criteria, is used for survey planning and data
25 assessment throughout the Radiation Survey and Site Investigation (RSSI) process. In addition,
26 the uncertainty is used for evaluating the performance of measurement systems using quality
27 control (QC) measurement results. QC measurement results provide an estimate of random and
28 systematic uncertainties associated with the measurement process. Uncertainty can also be
29 used for comparing individual measurements to the DCGL. This is especially important in the
30 early stages of remediation (i.e., scoping, characterization, remedial action support) when
31 decisions are made based on a limited number of measurements.

32 Finally, where controlling uncertainty is important, a required uncertainty can be specified or a
33 minimum quantifiable concentration (MQC) can be defined. The MQC could, for example, be

1 that concentration of residual radioactive material that can be quantified with an uncertainty no
2 greater than some limit (e.g., 10 percent) at some specified concentration (e.g., the DCGL).

3 For most sites, evaluations of uncertainty associated with field measurements are important
4 only for data being used as part of the final status survey (FSS) documentation. The FSS data,
5 which is used to document the final radiological status of a site, should state the uncertainties
6 associated with the measurements. Conversely, detailing the uncertainties associated with
7 measurements made during scoping or characterization surveys may or may not be of value,
8 depending on what the data will be used for, as defined by the DQOs. From a practical
9 standpoint, if the observed data are obviously greater than the DCGL and will be eventually
10 cleaned up, then the uncertainty may be relatively unimportant. Conversely, data collected
11 during early phases of a site investigation that may eventually be used to show that the area is
12 below the DCGL, and therefore does not require any cleanup action, will need the same
13 uncertainty evaluation as the FSS data. In summary, the level of effort needed to evaluate the
14 uncertainty should match the intended use of the data.

15 **6.4.1 Systematic and Random Uncertainties**

16 Measurement uncertainties are often broken into two subclasses: systematic uncertainty
17 (e.g., methodical) and random uncertainty (e.g., stochastic). Systematic uncertainties derive
18 from a lack of knowledge about the true distribution of values associated with a numerical
19 parameter and result in data that are consistently higher or lower than the true value. An
20 example of a systematic uncertainty would be the use of a fixed counting efficiency value
21 without knowledge of the frequency, even though it is known that the efficiency varies from
22 measurement to measurement. If the fixed counting efficiency value is higher than the true but
23 unknown efficiency—as would be the case for an unrealistically optimistic value—then every
24 measurement result calculated using that efficiency would be biased low. Random uncertainties
25 refer to fluctuations associated with a known distribution of values. An example of a random
26 uncertainty would be a well-documented chemical separation efficiency that is known to
27 fluctuate with a regular pattern about a mean. A constant recovery value is used during
28 calculations, but the true value is known to fluctuate from sample to sample with a fixed and
29 known degree of variation.

30 To minimize the need for estimating potential sources of uncertainty, the sources of uncertainty
31 themselves should be reduced to a minimal level by using such practices as the following:

- 32 • The detector used should minimize the potential uncertainty. For example, when making
33 field surface activity measurements for ^{238}U on concrete, a beta detector—such as a thin-
34 window GM “pancake” probe—may provide better quality data than an alpha detector,
35 depending on the circumstances. Less random uncertainty would be expected between
36 measurements with a beta detector, such as a pancake probe, because beta emissions
37 from the uranium will be affected much less by thin, absorbent layers than the alpha
38 emissions will.
- 39 • Calibration factors should accurately reflect the efficiency of the detector used on the
40 surface material being measured for the radionuclide or mixture of radionuclides of concern

1 (see **Section 6.6.4**). For most field measurements, variations in the counting efficiency on
2 different types of materials will introduce the largest amount of uncertainty in the final result.

3 • Uncertainties should be reduced or eliminated by using standardized measurement
4 protocols (e.g., SOPs) when possible. Special effort should be made to reduce or eliminate
5 systematic uncertainties, or uncertainties that are the same for every measurement simply
6 due to an error in the process. If the systematic uncertainties are reduced to a negligible
7 level, then the random uncertainties, or those uncertainties that occur on a somewhat
8 statistical basis, can be dealt with more easily.

9 • Instrument operators should be trained and experienced with the instruments used to
10 perform the measurements.

11 • Quality assurance/quality control (QA/QC) should be conducted.

12 Uncertainties that cannot be eliminated need to be evaluated such that the effect can be
13 understood and properly propagated into the final data and uncertainty estimates. As previously
14 stated, nonstatistical uncertainties should be minimized as much as possible using good work
15 practices.

16 Overall random uncertainty can be evaluated using the methods described in the following
17 sections:

18 • **Section 6.4.2** describes a method for calculating random counting uncertainty.

19 • **Section 6.4.3** discusses how to combine this counting uncertainty with other uncertainties from the
20 measurement process using uncertainty propagation.

21 Systematic uncertainty is derived from calibration errors, incorrect yields and efficiencies,
22 nonrepresentative survey designs, and “blunders.” It is difficult—and sometimes impossible—to
23 evaluate the systematic uncertainty for a measurement process, but bounds should always be
24 estimated and made small compared to the random uncertainty, if possible. If no other
25 information on systematic uncertainty is available, Currie (NRC 1984) recommends using
26 16 percent as an estimate for systematic uncertainties (1 percent for blanks, 5 percent for
27 baseline, and 10 percent for calibration factors).

28 **6.4.2 Statistical Counting Uncertainty**

29 When performing an analysis with a radiation detector, the result will have an uncertainty
30 associated with it because of the statistical nature of radioactive decay. To calculate the total
31 uncertainty associated with the counting process, both the background measurement
32 uncertainty and the sample measurement uncertainty must be accounted for. The standard
33 deviation of the net count rate, or the statistical counting uncertainty, can be calculated using
34 **Equation 6-17**:

$$\sigma_n = \sqrt{\frac{C_{s+b}}{t_{s+b}^2} + \frac{C_b}{t_b^2}} \quad (6-17)$$

1 where

- 2 • σ_n is the standard deviation of the net count rate result
- 3 • C_{s+b} is the number of gross counts (sample)
- 4 • t_{s+b} is the gross count time
- 5 • C_b is the number of background counts
- 6 • t_b is the background count time

7 **6.4.3 Uncertainty Propagation**

8 Most measurement data will be converted to different units or otherwise included in a calculation
 9 to determine a final result. The standard deviation associated with the final result, or the total
 10 uncertainty, can then be calculated. Assuming the individual uncertainties are relatively small,
 11 symmetric about zero, and independent of one another, then the total uncertainty for the final
 12 calculated result can be determined by solving the following partial differential equation:

$$\sigma_y = \sqrt{\left(\frac{\partial y}{\partial x_1}\right)^2 \sigma_{x_1}^2 + \left(\frac{\partial y}{\partial x_2}\right)^2 \sigma_{x_2}^2 + \dots + \left(\frac{\partial y}{\partial x_n}\right)^2 \sigma_{x_n}^2} \quad (6-18)$$

13 where $y = f(x_1, x_2, \dots, x_n)$ is a formula that defines the calculation of a final result as a function of
 14 the collected data. All variables in this equation (i.e., x_1, x_2, \dots, x_n) are assumed to have a
 15 measurement uncertainty associated with them and do not include numerical constants. σ_y is
 16 the standard deviation, or uncertainty, associated with the final result, and $\sigma_{x_1}, \sigma_{x_2}, \dots, \sigma_{x_n}$ are the
 17 standard deviations, or uncertainties, associated with the parameters x_1, x_2, \dots, x_n , respectively.
 18 **Equation 6-18**, generally known as the error propagation formula, can be solved to determine
 19 the standard deviation of a final result from calculations involving measurement data and their
 20 associated uncertainties. The solutions for common calculations along with their uncertainty
 21 propagation formulas are included in **Table 6.5**.

22 Note: In the above examples, x_1 and x_2 are measurement values with associated
 23 standard deviations, or uncertainties, equal to σ_{x_1} and σ_{x_2} , respectively. The
 24 symbol c is used to represent a numerical constant which has no associated
 25 uncertainty. The symbol σ_y is used to denote the standard deviation, or
 26 uncertainty, of the final calculated value, y .

1 **Table 6.5: Common Uncertainty Propagation Equations**

Data Calculation	Uncertainty Propagation
$y = x_1 + x_2$ or $y = x_1 - x_2$	$\sigma_y = \sqrt{\sigma_{x_1}^2 + \sigma_{x_2}^2}$
$y = x_1/x_2$ or $y = x_1 \times x_2$	$\sigma_y = y \sqrt{\left(\frac{\sigma_{x_1}}{x_1}\right)^2 + \left(\frac{\sigma_{x_2}}{x_2}\right)^2}$
$y = cx_1$ where c is a positive constant	$\sigma_y = c\sigma_{x_1}$
$y = x_1/c$ where c is a positive constant	$\sigma_y = \frac{\sigma_{x_1}}{c}$

2 **6.4.4 Reporting Confidence Intervals**

3 Throughout **Section 6.4**, the term “measurement uncertainty” is used interchangeably with the
4 term “standard deviation.” In this respect, the uncertainty is qualified as numerically identical to
5 the standard deviation associated with a normally distributed range of values. When reporting a
6 confidence interval for a value, one provides the range of values that represent a predetermined
7 level of confidence (i.e., 95 percent). To make this calculation, the final standard deviation—or
8 total uncertainty σ_y , as shown in **Equation 6-18**—is multiplied by a constant factor k ,
9 representing the area under a normal curve as a function of the standard deviation. The values
10 of k representing various intervals about a mean of normal distributions as a function of the
11 standard deviation are given in **Table 6.6**. The following example illustrates the use of this factor
12 in context with the propagation and reporting of uncertainty values. **Example 8** demonstrates
13 the calculation of the activity of a sample, along with its associated activity.

14 **Table 6.6: Areas Under Various Intervals About the Mean of a Normal Distribution**

Interval ($\bar{\mu} \pm k\sigma$)	Area Under the Interval
$\bar{\mu} \pm 0.674\sigma$	0.500
$\bar{\mu} \pm 1.00\sigma$	0.683
$\bar{\mu} \pm 1.65\sigma$	0.900
$\bar{\mu} \pm 1.96\sigma$	0.950
$\bar{\mu} \pm 2.00\sigma$	0.954
$\bar{\mu} \pm 2.58\sigma$	0.990
$\bar{\mu} \pm 3.00\sigma$	0.997

1

Example 8: Uncertainty Propagation and Confidence Interval

A measurement process with a zero background yields a count result of 28 ± 5 counts in 5 minutes, where the ± 5 counts represents one standard deviation about a mean value of 28 counts. The detection efficiency is 0.1 ± 0.01 counts per disintegration, again representing one standard deviation about the mean.

Calculate the activity of the sample, in decays per minute (dpm), total measurement uncertainty, and the 95 percent confidence interval for the result.

The total number of disintegrations is—

$$y = \frac{x_1}{x_2} = \frac{28 \text{ counts}}{0.1 \text{ counts/disintegration}} = 280 \text{ disintegrations}$$

Using the equation for error propagation for division, total uncertainty is—

$$\sigma_y = y \sqrt{\left(\frac{\sigma_{x_1}}{x_1}\right)^2 + \left(\frac{\sigma_{x_2}}{x_2}\right)^2} = 280 \sqrt{\left(\frac{5}{28}\right)^2 + \left(\frac{0.01}{0.1}\right)^2} = 57 \text{ disintegrations}$$

The activity will then be $280/5$ minutes = 56 dpm and the total uncertainty will be $57 \div 5$ minutes = 11 dpm. (Because the count time is considered to have trivial variance, this is assumed to be a constant.)

Referring to **Table 6.6**, a k value of ± 1.96 represents a confidence interval equal to 95 percent about the mean of a normal distribution. Therefore, the 95 percent confidence interval would be 1.96×11 dpm = 22 dpm. The final result would be that a 95 percent confidence interval for mean activity is 56 ± 22 dpm at a coverage factor of k equal to 1.96.

2 **6.5 Select a Service Provider to Perform Field Data Collection Activities**

3 Often, one of the first steps in designing a survey is to select a service provider to perform field
 4 data collection activities. MARSSIM recommends that this selection take place early in the
 5 planning process so that the service provider can provide information during survey planning
 6 and participate in the design of the survey. Service providers may include in-house experts in
 7 field measurements and sample collection, health physics companies, or environmental
 8 engineering firms, among others. See **Section 6.8** and **Appendix H** for important information
 9 concerning radon service providers.

10 Potential service providers should be evaluated to determine their ability to perform the
 11 necessary analyses. Consideration should be given to using a field survey company that is
 12 separate from the remediation company to preclude questions of independence and conflict of

1 interest. For large or complex sites, this evaluation may take the form of a pre-award audit. The
2 results of this audit provide a written record of the decision to use a specific service provider.
3 For less complex sites or facilities, a review of the potential service provider's qualifications is
4 sufficient for the evaluation.

5 Six criteria should be reviewed during this evaluation:

- 6 • Does the service provider possess the validated SOPs, appropriate instrumentation, and
7 trained personnel necessary to perform the field data collection activities, including
8 radon/thoron measurements? Field data collection activities (e.g., scanning surveys, direct
9 measurements, and sample collection) are defined by the data needs identified by the DQO
10 process.
- 11 • Is the service provider experienced in performing the same or similar data collection
12 activities?
- 13 • Does the service provider have satisfactory performance evaluation or technical review
14 results? The service provider should be able to provide a summary of QA audits and QC
15 measurement results to demonstrate proficiency. Equipment calibrations should be
16 performed using National Institute of Standards and Technology (NIST) traceable reference
17 radionuclide standards whenever possible.
- 18 • Is there adequate capacity to perform all field data collection activities within the desired
19 timeframe? This criterion considers the number of trained personnel and quantity of
20 calibrated equipment available to perform the specified tasks.
- 21 • Does the service provider conduct an internal QC review of all generated data that is
22 independent of the data generators?
- 23 • Are there adequate protocols for method performance documentation, sample tracking and
24 security (if necessary), and documentation of results?

25 Chapter 10 of MARLAP provides additional guidance related to field and sampling issues that
26 affect laboratory measurements (NRC 2004). Potential service providers should have an active
27 and fully documented quality system in place. The quality management system is typically
28 documented in one or more documents such as a Quality Management Plan (QMP) or Quality
29 Assurance Manual (QAM). This system should enable compliance with the objectives
30 determined by the DQO process in **Section 2.3** (see also EPA 2006c). The elements of a
31 quality management system are discussed in **Appendix D** and EPA QA/G-5 (EPA 2002a).

32 **6.6 Select a Measurement Method**

33 The combination of a measurement technique with instrumentation, or measurement method, is
34 selected to implement a radiological survey design based on the ability to meet the MQOs (see
35 **Section 6.1**). Note that measurement techniques are separate from survey designs. A realistic
36 determination of the measurement method uncertainty is critical to demonstrating a method
37 meets the MQOs. Other considerations when selecting a measurement method include—

- 1 • health and safety concerns (**Section 4.10**)
- 2 • required detection capability (**Section 6.3**)
- 3 • required measurement method uncertainty and/or required measurement quantifiability
- 4 (**Section 6.4**)
- 5 • DQOs for the project

6 Measurement techniques are discussed in **Section 6.6.1**. Instrumentation includes a
7 combination of a radiation detector (**Section 6.6.2**) and a display (**Section 6.6.3**). Evaluation of
8 a measurement method and comparison to MQOs also requires an understanding of the
9 instrument calibration (**Section 6.6.4**). Instrumentation for performing radiological
10 measurements is varied and constantly being improved. **Section 6.6.5** provides an overview of
11 some commonly used types of instruments and how they might be applied to FSSs. The
12 purpose of the discussions on instrumentation is not to provide an exhaustive list of acceptable
13 instruments, but to provide examples of how instrumentation and measurement techniques can
14 be combined to meet the survey objectives. Additional information on instrumentation is found in
15 **Appendix H**.

16 **Section 6.6.6** provides information on selecting a combination of measurement technique and
17 instrumentation to provide a measurement method. It is necessary that the selected
18 measurement method meet the MQOs established during survey design. Selecting
19 instrumentation can be an iterative process. Certain MQOs (e.g., MDC, required measurement
20 method uncertainty) may not be attainable with some measurement methods. In some cases,
21 selection of a different instrument may be all that is necessary, and in other cases a different
22 measurement technique or an entirely different measurement method will need to be
23 considered. Finally, in cases where the MQOs cannot be met with any available measurement
24 methods, consult with the regulator for acceptable options.

25 **6.6.1 Select a Measurement Technique**

26 A measurement technique describes how a measurement is performed. The detector can be
27 moved relative to the surface being measured (i.e., scanning), used to perform static
28 measurements at a specified location in the survey unit (i.e., in situ or direct measurements), or
29 some representative portion of the survey unit taken to a different location for analysis
30 (i.e., sampling). These three measurement techniques are described in **Section 6.6.1.1**,
31 **Section 6.6.1.2**, and **Section 6.6.1.3**, respectively. Smears are a type of sampling, where a
32 portion of the removable radioactive material is collected from the surface being investigated
33 (**Section 6.6.1.4**).

34 **6.6.1.1 Scanning Techniques**

35 Scanning techniques generally consist of moving portable radiation detectors at a specified
36 distance relative to the physical surface of a survey unit at some specified speed to meet the
37 MQOs. Scanning is used in surveys to locate radiation anomalies by searching for variations in
38 readings, indicating gross activity levels that may require further investigation or action.

1 Scanning techniques can more readily provide thorough coverage of a given survey unit and are
2 often relatively quick and inexpensive to perform.

3 Scanning techniques can be used alone to demonstrate that concentrations of radioactive
4 material do not exceed release criteria. These surveys are referred to as scan-only surveys and
5 are discussed in detail in **Section 5.3.6.1**. Important considerations include that the scan MDC
6 and measurement method uncertainty are sufficient to meet MQOs to both quantify the average
7 concentration of the radioactive material and to identify areas of elevated activity. Scanning
8 equipment coupled with GPS or other locational data is strongly recommended for scan-only
9 surveys.

10 Maintaining the specified distance and speed during scanning can be difficult, especially with
11 hand-held instruments and irregularly shaped surfaces. Variations in source-to-detector
12 distance and scan speed can result in increased total measurement method uncertainty.
13 Determining a calibration function for situations other than surficial radionuclides uniformly
14 distributed on a plane can be complicated and may also contribute to the total measurement
15 method uncertainty.

16 *6.6.1.2 Direct Measurements*

17 Direct measurements, also referred to as in situ measurements, are taken by placing the
18 instrument in a fixed position at a specified distance from the surface of a given survey unit and
19 taking a discrete measurement for a pre-determined time interval. Direct measurements may be
20 combined with scanning measurements in a FSS design. In situ measurements are used
21 generally to provide an estimate of the average radionuclide concentration or level of activity
22 over a certain area or volume defined by the calibration function. In situ techniques are not
23 typically used to identify or quantify small areas or volumes of elevated radionuclide
24 concentration or activity.

25 Determining a calibration function and the associated MDA/MDC can be complicated and may
26 contribute to the total measurement method uncertainty, especially for situations other than
27 radionuclides uniformly distributed on a plane or through a regularly shaped volume (e.g., a disk
28 or cylinder).

29 However, in applicable situations and at the concurrence of the regulator, direct measurements
30 may be substituted for laboratory analysis. For example, all or a fraction of the systematic soil
31 samples may be measured in situ rather than traditional laboratory analysis.

32 *6.6.1.3 Sampling*

33 Sampling consists of removing a representative portion of the survey unit for separate
34 laboratory analysis. This measurement method generally has greater detection capability and
35 less measurement uncertainty than techniques that may be implemented as scanning or direct
36 measurements. Sampling is discussed in more detail in **Chapter 7**.

1 *6.6.1.4 Smears*

2 Smears, sometimes referred to as smear tests, swipes, or wipes, are used to provide an
3 estimate of removable radioactive material on the surface. Smears are a type of sample where
4 a filter paper or other substance is used to wipe a specified area of a surface. The filter paper or
5 other substance is then tested for the presence of removable radioactive material. The amount
6 of removable radioactive material transferred to the smear will depend on a number of factors,
7 including the type of swipe or smear material, the method used, the physical and chemical
8 nature of the surface being tested, the surface roughness, and the physical and chemical nature
9 of the radioactive material. These factors result in the need to establish a removal factor that will
10 be subject to some uncertainty. For this reason, although smears with detectable radioactive
11 material provide a qualitative indication of removable radioactive material, caution should be
12 exercised when using any quantitative results from smears. EPA 600/R-11/122 (EPA 2011)
13 provides more detailed guidance on the use of smears.

14 *6.6.2 Select Instrumentation—Radiation Detectors*

15 The particular capabilities of a radiation detector will establish its potential applications in
16 conducting a specific type of survey. Radiation detectors can be divided into four general
17 classes based on the detector material or the application: (1) gas-filled detectors, (2) scintillation
18 detectors, (3) solid-state detectors, and (4) passive integrating detectors. See **Appendix H** for
19 more information on the detectors discussed in this section.

20 *6.6.2.1 Gas-Filled Detectors*

21 Radiation interacts with the fill gas, producing ion-pairs that are collected by charged electrodes.
22 Commonly used gas-filled detectors are categorized as ionization, proportional, or GM, referring
23 to the region of gas amplification in which they are operated. The fill gas varies, but the most
24 common are—

- 25 • air
- 26 • argon with a small amount of methane (usually 10 percent methane by mass, referred to as
27 P-10 gas)
- 28 • neon or helium with a small amount of a halogen (e.g., chlorine or bromine) added as a
29 quenching agent

30 *6.6.2.2 Scintillation Detectors*

31 Radiation interacts with a solid or liquid medium, causing electronic transitions to excited states
32 in a luminescent material. The excited states decay rapidly, emitting photons that, in turn, are
33 captured by a photomultiplier tube. The ensuing electrical signal is proportional to the scintillator
34 light output, which, under the right conditions, is proportional to the energy loss that produced
35 the scintillation. The most common scintillator materials are NaI(Tl), silver-activated zinc sulfide
36 (ZnS(Ag)), cadmium telluride (CdTe), thallium-activated cesium iodide (CsI(Tl)), and plastic

1 organic scintillators. The most traditional radiation survey instruments are the NaI(Tl) detector
2 used for gamma surveys and the ZnS(Ag) detector for alpha surveys.

3 *6.6.2.3 Solid-State Detectors*

4 Radiation interacting with a semiconductor material creates electron-hole pairs that are
5 collected by a charged electrode. The design and operating conditions of a specific solid-state
6 detector determines the types of radiations (alpha, beta, or gamma) that can be measured, the
7 detection limit of the measurements, and the ability of the detector to resolve the energies of the
8 interacting radiations. The common semiconductor materials in use are germanium, silicon, and
9 cadmium zinc telluride (CZT), which are available in both n and p types in various
10 configurations.

11 Spectrometric techniques using these detectors provide a marked increase in energy resolution
12 in many situations. When a particular radionuclide contributes only a fraction of the total particle
13 fluence, photon fluence, or both from all sources (natural or manmade background), gross
14 measurements are inadequate and nuclide-specific measurements are necessary.

15 Spectrometry provides the means to discriminate among various radionuclides based on
16 characteristic energies. Direct gamma spectrometry is particularly effective in field
17 measurements, because the penetrating nature of the radiation allows one to “see” beyond
18 immediate radioactive materials on the surface. The availability of large, high-efficiency
19 germanium detectors permits measurement of low-abundance gamma emitters, such as ^{238}U .

20 *6.6.2.4 Passive Integrating Detectors*

21 An additional class of instruments consists of passive, integrating detectors and associated
22 reading/analyzing instruments. The integrated ionization is read using a laboratory or hand-held
23 reader. This class includes thermoluminescent dosimeters (TLDs), optically stimulated
24 luminescence (OSL) dosimeters, and electret ion chambers (EICs). Because these detectors
25 are passive and can be exposed for relatively long periods of time, they can provide better
26 sensitivity for measuring low activity levels, such as free release limits, or for ongoing
27 surveillance. The ability to read and present data onsite is a useful feature, and such systems
28 are comparable to direct reading instruments.

29 The scintillation materials in **Section 6.6.2.2** are selected for their prompt fluorescence
30 characteristics. In another class of inorganic crystals, called TLDs, the crystal material and
31 impurities are chosen so that the free electrons and holes created following the absorption of
32 energy from the radiation are trapped by impurities in the crystalline lattice, thus locking the
33 excitation energy in the crystal. Such materials are used as passive, integrating detectors. After
34 removal from the exposure area, the TLDs are heated in a reader, which measures the total
35 amount of light produced when the energy is released. The total amount of light is proportional
36 to the number of trapped, excited electrons, which, in turn, is proportional to the amount of
37 energy absorbed from the radiation. The intensity of the light emitted from the
38 thermoluminescent crystals is thus directly proportional to the radiation dose. TLDs come in a
39 large number of materials, the most common of which are lithium fluoride (LiF), manganese-
40 activated calcium fluoride ($\text{CaF}_2:\text{Mn}$), dysprosium-activated calcium fluoride ($\text{CaF}_2:\text{Dy}$),

1 manganese-activated calcium sulfate ($\text{CaSO}_4:\text{Mn}$), dysprosium-activated calcium sulfate
2 ($\text{CaSO}_4:\text{Dy}$), and carbon-activated aluminum oxide ($\text{Al}_2\text{O}_3:\text{C}$).

3 OSL dosimeters are similar in principle to TLDs but use light instead of heat to release the free
4 electrons and holes trapped when radiation is absorbed. Advantages of OSL dosimeters over
5 TLDs include lower limits of detection and the fact that OSL dosimeters can be read multiple
6 times and can be reread later, if necessary.

7 The EIC consists of a very stable electret (a charged Teflon[®] disk) mounted inside a small
8 chamber made of electrically charged plastic. The ions produced inside this air-filled chamber
9 are collected onto the electret, causing a reduction of its surface charge. The reduction in
10 charge is a function of the total ionization during a specific monitoring period and the specific
11 chamber volume. This change in voltage is measured with a surface potential voltmeter.

12 **6.6.3 Display and Recording Equipment**

13 Radiation detectors are connected to electronic devices to (1) provide a source of power for
14 detector operation and (2) enable measurement of the quantity or quality of the radiation
15 interactions that are occurring in the detector. The quality of the radiation interaction refers to
16 the amount of energy transferred to the detector. In many cases, radiation interacts with other
17 material (e.g., air) before interacting with the detector or only partially interacts with the detector
18 (e.g., Compton scattering or pair production for photons). Because the energy recorded by the
19 detector is affected, there is an increased probability of incorrectly identifying the radionuclide.

20 The most common recording or display device used for portable radiation measurement
21 systems is a ratemeter. This device provides a display on either an analog meter representing
22 the number of events occurring over some time period (e.g., cpm), or, in the case of digital
23 ratemeters, on a digital display. The number of events can also be accumulated over a preset
24 time period using a digital scaling device. The resulting information from a scaling device is the
25 total number of events that occurred over a fixed period of time, where a ratemeter display
26 varies with time and represents a short-term average of the event rate. Determining the average
27 level on a ratemeter will require judgment by the user, especially when a low frequency of
28 events results in significant variations in the meter reading. The use of a ratemeter, although
29 acceptable for certain scanning applications, is discouraged for performing fixed measurements
30 (e.g., gross alpha/beta.)

31 Pulse height analyzers are specialized electronic devices designed to measure and record the
32 number of pulses or events that occur at different pulse height levels at specific energies. These
33 types of devices are used with detectors that produce output pulses proportional in height to the
34 energy deposited within them by the interacting radiation. They can be used to record only
35 those events occurring in a detector within a single band of energy or can simultaneously record
36 the events in multiple energy ranges. In the former case, the equipment is known as a single-
37 channel analyzer; the latter application is referred to as a multichannel analyzer. Both types of
38 analyzers can quantify specific radionuclides.

1 **6.6.4 Instrument Calibration**

2 Calibration refers to the determination and adjustment of the instrument response in a particular
3 radiation field of known intensity. Proper calibration procedures are an essential requisite toward
4 providing confidence in measurements made to demonstrate compliance with remediation
5 criteria. Certain factors, such as energy dependence and environmental conditions, require
6 consideration in the calibration process, depending on the conditions of use of the instrument in
7 the field. Considerations for the use and calibration of instruments include—

- 8 • the radiation type for which the instrument is designed
- 9 • the radiation energies within the range of energies for which the instrument is designed
- 10 • the environmental conditions for which the instrument is designed
- 11 • the influencing factors, such as magnetic and electrostatic fields, for which the instrument is
12 designed
- 13 • the orientation of the instrument, such that geotropic (gravity) effects are not a concern
- 14 • the manner the instrument is used, such that it will not be subject to mechanical or thermal
15 stress beyond that for which it is designed

16 Routine calibration commonly involves the use of one or more sources of a specific radiation
17 type and energy and of sufficient activity to provide adequate field intensities for calibration on
18 all ranges of concern.

19 Actual field conditions under which the radiation detection instrument will be used may differ
20 significantly from those present during routine calibration. Factors that may affect calibration
21 validity include—

- 22 • The energies of radioactive sources used for routine calibration may differ significantly from
23 those of radionuclides in the field.
- 24 • The source-detector geometry (e.g., point source or large area distributed source) used for
25 routine calibration may be different than that found in the field.
- 26 • The source-to-detector distance typically used for routine calibration may not always be
27 achievable in the field.
- 28 • The condition and composition of the surface being monitored (e.g., sealed concrete,
29 scabbled concrete, carbon steel, stainless steel, and wood) and the presence of overlaying
30 material (e.g., water, dust, oil, paint) may result in a decreased instrument response relative
31 to that observed during routine calibration.

32 If the actual field conditions differ significantly from the calibration assumptions, a special
33 calibration for specific field conditions may be required. Such an extensive calibration need only
34 be done once to determine the effects of the range of field conditions that may be encountered

- 1 at the site. If responses under routine calibration conditions and proposed use conditions are
2 significantly different, a correction factor or chart should be supplied with the instrument for use
3 under the proposed conditions.
- 4 As a minimum, each measurement system (detector/readout combination) should be calibrated
5 annually and response checked with a source following calibration (ANSI 2013). Instruments
6 may require more frequent calibration, if recommended by the manufacturer. Re-calibration of
7 field instruments is also required if an instrument fails a performance check or if it has
8 undergone repair or any modification that could affect its response. The system should be
9 calibrated to minimize potential errors during data transmission and re-transmission. The user
10 may decide to perform calibrations following industry recognized procedures (ANSI 1997, NCRP
11 1978, NCRP 1985, NCRP 1991, ISO 1988, HPS 1994a, HPS 1994b), or the user can choose to
12 obtain calibration by an outside service, such as a major instrument manufacturer or a health
13 physics services organization.
- 14 Calibration sources should be traceable to NIST. Where NIST-traceable standards are not
15 available, standards obtained from an industry-recognized organization (e.g., the New
16 Brunswick Laboratory for various uranium, thorium, and plutonium standards) may be used.
- 17 Calibration of instruments for measurement of residual radioactive material on surfaces should
18 be performed such that a direct instrument response can be accurately converted to the 4π
19 (total) emission rate from the source. An accurate determination of activity from a measurement
20 of count rate above a surface in most cases is an extremely complex task because of the need
21 to determine appropriate characteristics of the source, including decay scheme, geometry,
22 energy, scatter, and self-absorption. Proper calibration ensures that systematic errors in
23 measurements are controlled to help ensure that the MQO for measurement method uncertainty
24 is met.
- 25 The variables that affect instrument response should be understood. Therefore, the calibration
26 should account for the following factors (where necessary):
- 27 • Calibrations for point and large area source geometries may differ, and both may be
28 necessary if areas of activity smaller than the probe area and regions of activity larger than
29 the probe area are present.
 - 30 • Calibration should either be performed with the radionuclide of concern or with appropriate
31 correction factors developed for the radionuclide(s) present based on calibrations with
32 nuclides emitting radiations similar to the radionuclide of concern.
 - 33 • For portable instrumentation, calibrations should account for the substrate of concern
34 (i.e., concrete, steel) or appropriate correction factors developed for the substrates relative
35 to the actual calibration standard substrate. This is especially important for beta emitters
36 because backscatter is significant and varies with the composition of the substrate.
37 Conversion factors developed during the calibration process should be for the same
38 counting geometry to be used during the actual use of the detector.

1 For building surface DCGLs, the level of residual radioactive material is typically expressed in
2 terms of the activity per unit area, normally Bq/m² or dpm per 100 cm². In many facilities,
3 residual radioactive material on the surface is assessed by converting the instrument response
4 (in cpm) to surface activity using the overall total efficiency. The total efficiency may be
5 considered to represent the product of two factors: the instrument (detector) efficiency and the
6 source efficiency. Use of the total efficiency is not a problem, provided that the calibration
7 source exhibits characteristics similar to the residual radioactive material on the surface
8 (i.e., radiation energy, backscatter effects, source geometry, self-absorption). In practice, this is
9 rarely the case; more likely, instrument efficiencies are determined with a clean, stainless steel
10 source, and then those efficiencies are used to determine the level of residual radioactive
11 material on a dust-covered concrete surface. By separating the efficiency into two components,
12 the surveyor has greater ability to consider the actual characteristics of the residual radioactive
13 material on the surface.

14 The instrument efficiency is defined as the ratio of the net count rate of the instrument to the
15 surface emission rate of a source for a specified geometry. The surface emission rate is defined
16 as the number of particles of a given type above a given energy emerging from the front face of
17 the source per unit time. The surface emission rate is the 2π particle fluence that embodies both
18 the absorption and scattering processes that effect the radiation emitted from the source. Thus,
19 the instrument efficiency is determined by the ratio of the net count rate and the surface
20 emission rate.

21 The instrument efficiency is determined during calibration by obtaining a static count with the
22 detector over a calibration source that has a traceable activity or surface emission rate. In many
23 cases, a source emission rate is measured by the manufacturer and certified as NIST traceable.
24 The source activity is then calculated from the surface emission rate based on assumed
25 backscatter and self-absorption properties of the source. The maximum value of instrument
26 efficiency is 1.

27 The source efficiency is defined as the ratio of the number of particles of a given type emerging
28 from the front face of a source to the number of particles of the same type created or released
29 within the source per unit time. The source efficiency takes into account the increased particle
30 emission due to backscatter effects, as well as the decreased particle emission due to self-
31 absorption losses. For an ideal source (i.e., no backscatter or self-absorption), the value of the
32 source efficiency is 0.5. Many real sources will exhibit values less than 0.5, although values
33 greater than 0.5 are possible, depending on the relative importance of the absorption and
34 backscatter processes.

35 Source efficiencies may be determined experimentally. Alternatively, ISO-7503-1 (ISO 1988)
36 makes recommendations for default source efficiencies. A source efficiency of 0.5 is
37 recommended for beta emitters with maximum energies above 0.4 megaelectronvolts (MeV).
38 Alpha emitters and beta emitters with maximum beta energies between 0.15 and 0.4 MeV have
39 a recommended source efficiency of 0.25. Source efficiencies for some common surface
40 materials and overlaying material are provided in NUREG-1507 (NRC 1997a).

41 Instrument efficiency may be affected by detector-related factors, such as detector size (probe
42 surface area); window density thickness; geotropism; instrument response time; counting time

1 (in static mode); scan rate (in scan mode); and ambient conditions, such as temperature,
2 pressure, and humidity. Instrument efficiency also depends on solid angle effects, which include
3 source-to-detector distance and source geometry.

4 Source efficiency may be affected by source-related factors, such as the type of radiation and
5 its energy, source uniformity, surface roughness and coverings, and surface composition
6 (e.g., wood, metal, concrete).

7 The calibration of gamma detectors for the measurement of photon radiation fields should also
8 provide reasonable assurance of acceptable accuracy in field measurements. Use of these
9 instruments for demonstration of compliance with DCGLs is complicated by the fact that most
10 DCGLs produce exposure rates of at most a few $\mu\text{R/h}$. Several of the portable survey
11 instruments currently available in the United States for exposure rate measurements of $\sim 1 \mu\text{R/h}$
12 (often referred to as micro-R meters) have full scale intensities of $\sim 3\text{--}5 \mu\text{R/h}$ on the first range.
13 This is below the ambient background for most low radiation areas and most calibration
14 laboratories. A typical background exposure rate of 10 mR/h gives a background dose rate of
15 $100 \text{ millirem/year (mrem/y)}$. Even on the second range, the ambient background in the
16 calibration laboratory is normally a significant part of the range and must be taken into
17 consideration during calibration. The instruments commonly are not energy-compensated and
18 are very sensitive to the scattered radiation that may be produced by the walls and floor of the
19 room or additional shielding required to lower the ambient background.

20 Low-intensity sources and large distances between the source and detector can be used for
21 low-level calibrations if the appropriate precautions are taken. Field characterization of low-level
22 sources with traceable transfer standards can be difficult because of the poor signal-to-noise
23 ratio. To achieve adequate detector signal, the distance between the detector and the source
24 generally will be as small as possible while still maintaining good geometry (5–7 detector
25 diameters).

26 Corrections for scatter can be made using a shadow-shield technique in which a shield of
27 sufficient density and thickness is placed about midway between the source and the detector to
28 eliminate virtually all the primary radiation. The dimensions of the shield should be the minimum
29 required to reduce the primary radiation intensity at the detector location to less than 2 percent
30 of its unshielded value. The change in reading caused by the shield's removal is attributed to
31 the primary field from the source at the detector position.

32 In some instruments that produce pulses (GM counters or scintillation counters), the detector
33 can be separated electronically from the readout electronics, and the detector output can be
34 simulated with a suitable pulser. Caution must be exercised to ensure that either the high
35 voltage is properly blocked or that the pulser is designed for this application. If this can be
36 accomplished, the instrument can first be calibrated on a higher range that is not affected by the
37 ambient background and in a geometry where scatter is not a problem and, after disconnecting
38 the detector, to provide the pulse-rate from the pulser, which will give the same instrument
39 response. The pulse rate can then be related to field strength and reduced to give readings on
40 lower ranges (with the detector disconnected) even below the ambient background. This

1 technique does not take into account any inherent detector background independent of the
2 external background.

3 Ionization chambers are commonly used to measure radiation fields at very low levels. To
4 obtain the sensitivity necessary to measure these radiation levels, the instruments are
5 frequently very large and often pressurized. These instruments have some of the same
6 calibration problems as the more portable micro-R meters described above. The same
7 precautions (shadow shield) must be taken to separate the response of the instrument to the
8 source and to scattered radiation. Generally, it is not possible to substitute an electronic pulser
9 for the radiation field in these instruments.

10 For energy-dependent gamma scintillation instruments, such as NaI(Tl) detectors, calibration for
11 the gamma energy spectrum at a specific site may be accomplished by comparing the
12 instrument response to that of a pressurized ionization chamber, or equivalent detector, at
13 different locations on the site. Multiple radionuclides with various photon energies may also be
14 used to calibrate the system for the specific energy of interest.

15 In the interval between calibrations, the instrument should receive a daily performance check
16 when in use. In some cases, a performance check following use may also provide valuable
17 information. This calibration check is merely intended to establish whether the instrument is
18 operating within certain specified, rather large, uncertainty limits. The initial performance check
19 should be conducted following the calibration by placing the source in a fixed, reproducible
20 location and recording the instrument reading. The source should be identified along with the
21 instrument, and the same check source should be used daily in the same fashion to
22 demonstrate the instrument's operability when the instrument is in use. Location and other
23 specific conditions should be recorded as well (e.g., indoor, outdoor, inside trailer, inside
24 vehicle, on the roof, etc.). For analog readout (count rate) instruments, a variation of
25 ± 20 percent is usually considered acceptable. Optionally, instruments that integrate events and
26 display the total on a digital readout typically provide an acceptable average response range of
27 2 or 3 standard deviations. This is achieved by performing a series of repetitive measurements
28 (10 or more is suggested) of background and check source response and determining the
29 average and standard deviation of those measurements. From a practical standpoint, a
30 maximum deviation of ± 20 percent is usually adequate when compared with other uncertainties
31 associated with the use of the equipment. The amount of uncertainty allowed in the response
32 checks should be consistent with the level of uncertainty allowed in the final data. Ultimately the
33 decision maker determines what level of uncertainty is acceptable.

34 Instrument response, including both the background and check source response of the
35 instrument, should be tested and recorded at a frequency that ensures the data collected with
36 the equipment is reliable. For most portable radiation survey equipment, MARSSIM
37 recommends that a response check be performed at least twice daily when in use—typically
38 before beginning the day's measurements and again following the conclusion of measurements
39 on that same day. Additional checks can be performed if warranted by the instrument and the
40 conditions under which it is used. If the instrument response does not fall within the established
41 range, the instrument is removed from use until the reason for the deviation can be resolved
42 and acceptable response again demonstrated. If the instrument fails the post-survey source
43 check, all data collected during that time period with the instrument must be carefully reviewed

1 and possibly adjusted or discarded, depending on the cause of the failure. Ultimately, the
2 frequency of response checks must be balanced with the stability of the equipment being used
3 under field conditions and the quantity of data being collected. For example, if the instrument
4 experiences a sudden failure during the day's work due to physical harm, such as a punctured
5 probe, then the data collected up until that point is probably acceptable even though a post-use
6 performance check cannot be performed. If no obvious failure occurred but the instrument failed
7 the post-use response check, then the data collected with that instrument since the last
8 response check should be viewed with great skepticism and possibly re-collected or randomly
9 checked with a different instrument. Additional corrective action alternatives are presented in
10 **Appendix D**. If recalibration is necessary, acceptable response ranges must be reestablished
11 and documented.

12 Record requirements vary considerably and depend heavily on the needs of the user. Even
13 though Federal and State regulatory agencies all specify requirements, the following records
14 should be considered a minimum:

- 15 • laboratory quality control
 - 16 ○ records documenting the traceability of radiological standards
 - 17 ○ records documenting the traceability of electronic test equipment
- 18 • record-keeping of instrument calibration files
 - 19 ○ date the instrument was received in the calibration laboratory
 - 20 ○ initial condition of the instrument, including mechanical condition (e.g., loose or broken
21 parts, dents, punctures), electrical condition (e.g., switches, meter movement, batteries),
22 and radiological condition (i.e., presence or absence of contamination)
 - 23 ○ calibrator's records, including training records and signature on calibration records
 - 24 ○ calibration data, including model and serial number of instrument, date of calibration,
25 recommended recalibration date, identification of source(s) used, NIST certificate or
26 standard certificate from the industry-recognized organization (certificate must include
27 the standard expiration date), "as found" calibration results, and final calibration results—
28 "as returned" for use

29 In addition, records of instrument problems, failures, and maintenance can be included and are
30 useful in assessing performance and identifying possible needs for altered calibration
31 frequencies for some instruments. Calibration records should be maintained at the facility where
32 the instruments are used as permanent records and should be available either as hard copies or
33 in safe computer storage.

1 **6.6.5 Select Instrumentation Type—Radiation Survey Equipment**

2 This section briefly describes the typical types of instrumentation that may be used to conduct
3 radiological surveys. More detailed information relevant to each type of instrument and
4 measurement method is provided in **Appendix H**.

5 **6.6.5.1 Hand-Held Instruments**

6 Hand-held instruments typically are composed of a detection probe (utilizing a single detector)
7 and an electronic instrument to provide power to the detector and to interpret data from the
8 detector to provide a measurement display. They may be used to perform scanning surveys or
9 direct measurements. Hand-held measurements also allow the user the flexibility to constantly
10 vary the source-to-detector geometry for obtaining data from difficult-to-measure areas.

11 **6.6.5.2 Large Area Detectors**

12 Although hand-held instruments are very useful for making direct measurements and scanning
13 small and/or difficult-to-measure areas, large area detectors provide advantages when the
14 survey unit includes large, easily accessible areas. These detectors may consist of either a
15 single large detector or an array of detectors. Unlike most hand-held detectors, which can only
16 measure the concentration in a small area—typically about 100 cm²—some detectors can
17 measure the concentration in a much larger area. When used in combination with data logging
18 and positioning systems, large-area detectors can be used in place of direct measurements and
19 scanning, if the systems can meet the required MQOs.

20 **6.6.5.3 In situ Gamma Spectroscopy**

21 Some in situ gamma spectroscopy (ISGS) systems consist of a small hand-held unit that
22 incorporates the detector and counting electronics into a single package. Other ISGS systems
23 consist of a semiconductor detector, a cryostat, a multichannel analyzer electronics package
24 that provides amplification and analysis of the energy pulse heights, and a computer system for
25 data collection and analysis. ISGS systems typically are applied to perform direct
26 measurements, but they may be incorporated into innovative detection equipment setups to
27 perform scanning surveys.

28 **6.6.5.4 Laboratory Analysis**

29 Laboratory analysis consists of analyzing a portion or sample of the surface soil or building
30 surface. The laboratory will generally have recommendations or requirements concerning the
31 amount and types of samples needed for the analysis of radionuclides or radiations.
32 Communications should be established between the field team collecting the samples and the
33 laboratory analyzing the samples. More information on sampling is provided in **Section 7.5**.
34 Laboratory analyses can be developed for any radionuclide with any material, given sufficient
35 resources. Laboratory analyses typically require more time to complete than field analyses. The
36 laboratory may be located onsite or offsite. The quality of laboratory data typically is greater
37 than data collected in the field, because the laboratory is better able to control sources of
38 measurement method uncertainty. The planning team should consider the resources available
39 for laboratory analysis (e.g., time, money), the sample collection requirements or

1 recommendations, and the requirements for data quality (e.g., MDC, required measurement
2 method uncertainty) during discussions with the laboratory.

3 **6.6.6 Select a Measurement Method**

4 **Table 6.7** illustrates the potential applications for combinations of the instrument and
5 measurement techniques discussed in **Sections 6.6.1 and 6.6.5**, respectively. Sampling
6 followed by laboratory analysis is not included in these tables but is considered “GOOD” for all
7 applications. Please note the following qualifiers:

- 8 • GOOD: The measurement technique is well-suited for performing this application.
- 9 • FAIR: The measurement technique can adequately perform this application.
- 10 • POOR: The measurement technique is poorly suited for performing this application.
- 11 • NA: The measurement technique cannot perform this application.
- 12 • Few: A relatively small number, usually three or less.
- 13 • Many: A relatively large number, usually more than three.

14 **Table 6.8** illustrates that most measurement techniques can be applied to almost any sample
15 and type of radioactive material. The quantity of samples to be surveyed becomes a major
16 factor for the selection of measurement instruments and techniques described in this chapter.

17 Facilities that conduct routine surveys may benefit financially from investing in measurement
18 instruments and techniques that require less manual labor to conduct disposition surveys. Use
19 of such automated systems will also reduce the potential for ergonomic injuries and attendant
20 costs associated with routine, repetitive surveys performed using hand-held instruments.

21 Hand-held surveying remains the more economical choice for a small area, but as the area
22 increases, the cost of an automated system becomes an increasingly worthwhile investment to
23 reduce manual labor costs associated with surveying. Note that alpha radiation has no survey
24 design options that are described as “GOOD” in **Table 6.7**. The planning team should revisit
25 earlier DQO selections to see if a different approach is more acceptable.

26 Each type of measurement technique has associated advantages and disadvantages, some of
27 which are summarized in **Table 6.8**. All the measurement techniques described in this table
28 include source-to-detector geometry and sampling variability as common disadvantages.

29

30

1 **Table 6.7: Potential Applications for Instrumentation and Measurement Technique**
 2 **Combinations**

Radiation Type	Hand-Held Instruments	In Situ Gamma Spectroscopy
Direct Measurements		
Alpha	FAIR	NA
Beta	GOOD	NA
Photon	GOOD	GOOD
Neutron	GOOD	NA
Scanning Surveys		
Alpha	POOR	NA
Beta	GOOD	NA
Photon	GOOD	GOOD
Neutron	FAIR	NA

3 **6.7 Data Conversion**

4 This section describes methods for converting survey data to appropriate units for comparison
 5 to radiological criteria. As stated in **Chapter 4**, conditions applicable to satisfying
 6 decommissioning requirements include determining that any residual radioactive material will
 7 not result in individuals' being exposed to unacceptable levels of radiation or radioactive
 8 materials.

9 Radiation survey data are usually obtained in units that have no intrinsic meaning relative to
 10 DCGLs, such as the number of counts per unit time. For comparison of survey data to DCGLs,
 11 the survey data from field and laboratory measurements should be converted to DCGL units.
 12 Alternatively, the DCGL can be converted into the same units used to record survey results.

13 **6.7.1 Surface Activity**

14 When measuring surface activity, it is important to account for the physical surface area
 15 assessed by the detector to make probe area corrections and report data in the proper units
 16 (i.e., Bq/m², dpm/100 cm²). This is termed the physical probe area. A common misuse is to
 17 make probe area corrections using the effective probe area, which accounts for the amount of
 18 the physical probe area covered by a protective screen. **Figure 6.2** illustrates the difference
 19 between the physical and effective probe areas. The physical probe area is used because the
 20 reduced detector response due to the screen is accounted for during instrument calibration as
 21 long as the screen is in place during calibration.

1

2 **Table 6.8: Advantages and Disadvantages of Instrumentation and Measurement**
 3 **Technique Combinations**

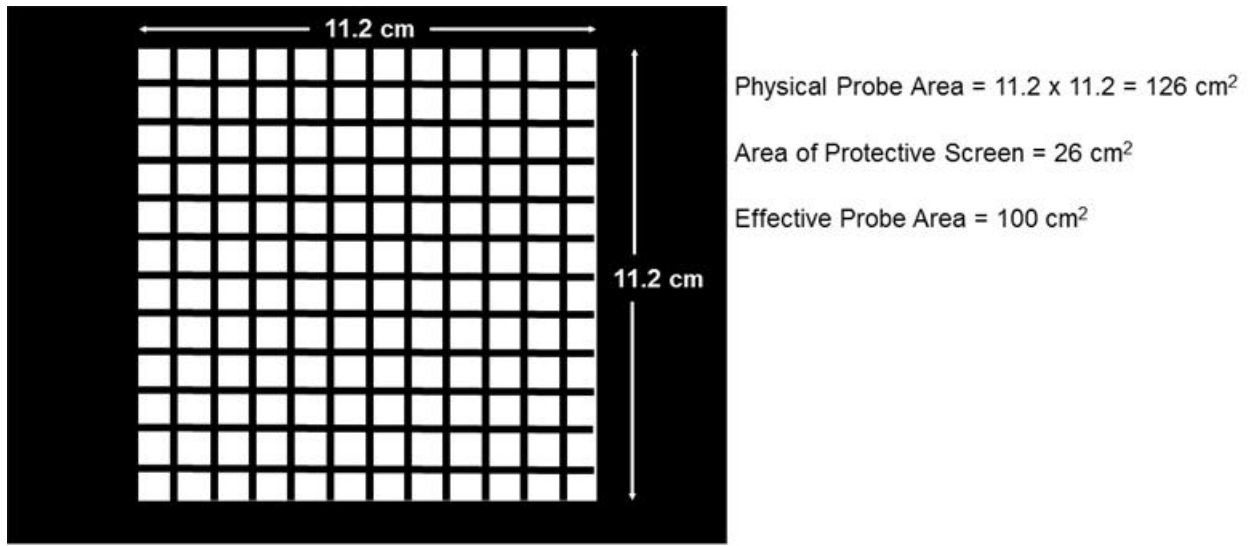
Instrument	Measurement Technique	Advantages	Disadvantages
Hand-Held Instruments	Direct	<ul style="list-style-type: none"> • Generally allows flexibility in media to be measured. • Detection equipment is usually portable. • Detectors are available to efficiently measure alpha, beta, gamma, x-ray, and neutron radiation. • Measurement equipment is relatively low cost. • May provide a good option for small areas. 	<ul style="list-style-type: none"> • Requires a relatively large amount of manual labor as a surveying technique; may make surveying large areas labor-intensive. • Detector windows may be fragile. • Most do not provide nuclide identification.
Hand-Held Instruments	Scanning	<ul style="list-style-type: none"> • Generally allows flexibility in media to be measured. • Detection equipment is usually portable. • Detectors are available to efficiently measure beta, gamma, x-ray, and neutron radiation. • Measurement equipment is relatively low cost. • May provide a good option for small areas. 	<ul style="list-style-type: none"> • Requires a relatively large amount of manual labor as a surveying technique; may make surveying large areas labor-intensive. • Detector windows may be fragile. • Most do not provide nuclide identification. • Incorporates more potential sources of uncertainty than most instrument and measurement technique combinations. • Potential ergonomic injuries and attendant costs associated with repetitive surveys.

Instrument	Measurement Technique	Advantages	Disadvantages
Hand-Held Instruments	Smear	<ul style="list-style-type: none"> • Only measurement technique for assessing removable radioactive material. • Removable radioactive material can be transferred and assessed in a low background counting area. 	<ul style="list-style-type: none"> • Instrument background may not be sufficiently low. • Detectors with a counting sensitive region larger than the smear surface area may require counting adjustments to account for inherent backgrounds associated with other media located under the detector sensitive region. • The results are not always reproducible and may not be considered quantitative.
ISGS	Direct	<ul style="list-style-type: none"> • Provides quantitative measurements with flexible calibration. • Generally requires a moderate amount of labor. • May be cost-effective for measuring large areas. • Good peak resolution with high purity germanium detectors. 	<ul style="list-style-type: none"> • Instrumentation may be expensive and difficult to set up and maintain. • May require liquid nitrogen supply (with ISGS semiconductor systems). • Size of detection equipment may discourage portability. • Poor peak resolution with NaI(Tl) detectors.
ISGS	Scanning	<ul style="list-style-type: none"> • Provides quantitative measurements with flexible calibration. • Generally requires a moderate amount of labor. • May be cost-effective for measuring large areas. 	<ul style="list-style-type: none"> • Instrumentation may be expensive and difficult to set up and maintain. • May require liquid nitrogen supply (with ISGS semiconductor systems). • Size of detection equipment may discourage portability.

Instrument	Measurement Technique	Advantages	Disadvantages
Laboratory Analysis	Sampling	<ul style="list-style-type: none"> • Generally provides the lowest MDCs and measurement method uncertainties, even for difficult-to-measure radionuclides. • Allows positive identification of radionuclides without gammas. 	<ul style="list-style-type: none"> • Most costly and time-consuming measurement technique. • May incur increased overhead costs while personnel are waiting for analytical results. • Great care must be taken to ensure samples are representative. • Detector windows may be fragile.
Laboratory Analysis	Smear	<ul style="list-style-type: none"> • Only measurement technique for assessing removable radioactive material. • Removable radioactive material can be transferred and assessed in a low background counting area. 	<ul style="list-style-type: none"> • Instrument background may not be sufficiently low. • Detectors with a counting sensitive region larger than the smear surface area may require counting adjustments to account for inherent backgrounds associated with other media located under the detector's sensitive region. • The results are not always reproducible and may not be considered quantitative.

Abbreviation: ISGS = in situ gamma spectrometer; MDC = minimum detectable concentration.

1
2



1
 2 **Figure 6.2: The Physical Probe Area of a Detector: Gas Flow Proportional Detector with**
 3 **Physical Probe Area of 126 cm^2**

4 The conversion of instrument display in counts to surface activity units of Bq/m^2 is obtained
 5 using **Equation 6-19**:

$$A_s = \frac{C_s/t_s}{\varepsilon_t \times W} \quad (6-19)$$

6 where C_s is the integrated counts recorded by the instrument, t_s is the time period over which
 7 the counts were recorded in seconds, ε_t is the total efficiency of the instrument in counts per
 8 disintegration, effectively the product of the instrument efficiency (ε_i) and the source efficiency
 9 (ε_s), and W is the physical probe area in square meters (m^2). To convert instrument counts to
 10 conventional surface activity units of decays per minute per 100 cm^2 , **Equation 6-19** can be
 11 modified as shown in **Equation 6-20**:

$$A_s = \frac{C_s/t_s}{\varepsilon_t \times (W/100)} \quad (6-20)$$

12 where t_s is recorded in minutes instead of seconds, and W is recorded in square centimeters
 13 instead of square meters.

14 Most instruments have background counts associated with the operation of the instrument. A
 15 correction for instrument background can be included in the data conversion calculation, as
 16 shown in **Equation 6-21**:

$$A_s = \frac{C_s/t_s - C_b/t_b}{\varepsilon_t \times W} \quad (6-21)$$

1 where C_b is the background counts recorded by the instrument, and t_b is the time period over
 2 which the background counts were recorded in seconds. Note that the instrument background is
 3 not the same as the measurements in the background reference area used to perform the
 4 statistical tests described in **Chapter 8. Equation 6-17** can be modified to provide conventional
 5 surface activity units of decays per minute per 100 cm², as shown in **Equation 6-22**:

$$A_s = \frac{C_s/t_s - C_b/t_b}{\varepsilon_t \times (W/100)} \quad (6-22)$$

6 where t_s and t_b are recorded in minutes instead of seconds, and W is recorded in square
 7 centimeters instead of square meters.

8 The presence of multiple radionuclides at a site requires additional considerations for
 9 demonstrating compliance with a dose- or risk-based requirement. As demonstrated in
 10 **Section 4.5.3**, a gross activity DCGL should be determined. **Example 9** illustrates the
 11 calculation of a weighted efficiency for a gross activity DCGL.

Example 9: Calculation of a Weighted Efficiency for a Gross Activity Derived Concentration Guideline Level

Consider a site contaminated with cesium-137 (¹³⁷Cs) and strontium/yttrium-90 (⁹⁰Sr/Y), with ¹³⁷Cs representing 60 percent of the total activity. The relative fractions are 0.6 for ¹³⁷Cs and 0.4 for ⁹⁰Sr/Y. If the derived concentration guideline level (DCGL) for ¹³⁷Cs is 8,300 becquerels per square meter (Bq/m²; 5,000 decays per minute [dpm]/100 square centimeters [cm²]) and the DCGL for ⁹⁰Sr/Y is 12,000 Bq/m² (7,200 dpm/100 cm²), the gross activity DCGL is calculated using **Equation 4-10**, as shown below:

$$\begin{aligned} \text{DCGL}_{\text{Gross Activity}} &= \frac{1}{\frac{f_{\text{Cs}}}{\text{DCGL}_{\text{Cs}}} + \frac{f_{\text{Sr/Y}}}{\text{DCGL}_{\text{Sr/Y}}}} = \frac{1}{\frac{0.6}{8,300 \text{ Bq/m}^2} + \frac{0.4}{12,000 \text{ Bq/m}^2}} \\ &= 9,500 \text{ Bq/m}^2 \text{ (5,700 dpm/100 cm}^2\text{)} \end{aligned}$$

Note that because the half-lives of ¹³⁷Cs and ⁹⁰Sr are approximately the same, the relative fractions of the two radionuclides will not change because both decay at the same rate. For other radionuclides, the relative fractions will change over time from the decay of one radionuclide relative to the other.

It is important to use an appropriately weighted total efficiency to convert from instrument counts to surface activity units using **Equations 6-19 through 6-22**. In this example, the individual efficiencies for ¹³⁷Cs and ⁹⁰Sr/Y should first be independently evaluated. The maximum energies for beta particles for ¹³⁷Cs and ⁹⁰Sr/Y are 0.51 MeV and 2.28 MeV, respectively. The corresponding instrument efficiencies for ¹³⁷Cs and ⁹⁰Sr/Y are determined to be 0.38 and 0.45, respectively. The surface efficiency of both nuclides is estimated to be 0.5.

The total efficiencies are calculated by multiplying the surface efficiency by the instrument efficiency, as shown below (see **Section 4.12.5.1** for further explanation):

$$\varepsilon_{t,Cs} = \varepsilon_{s,Cs} \times \varepsilon_{i,Cs} = (0.5)(0.38) = 0.19$$

$$\varepsilon_{t,Sr/Y} = \varepsilon_{s,Sr/Y} \times \varepsilon_{i,Sr/Y} = (0.5)(0.45) = 0.22$$

The overall efficiency is then determined by weighting each individual radionuclide efficiency by the relative fraction of each radionuclide (**Equation 4-21**):

$$\varepsilon_t = f_{Cs}\varepsilon_{t,Cs} + f_{Sr/Y}\varepsilon_{t,Sr/Y} = (0.6)(0.19) + (0.4)(0.22) = 0.20$$

The overall efficiency is 0.20 (20 percent).

1 **6.7.2 Soil Radionuclide Concentration and Exposure Rates**

2 Analytical procedures, such as alpha and gamma spectrometry, are typically used to determine
3 the radionuclide concentration in soil in units of Bq/kg. Net counts are converted to soil DCGL
4 units by dividing by the time, detector or counter efficiency, mass or volume of the sample, and
5 by the fractional recovery or yield of the chemistry procedure (if applicable). Refer to **Chapter 7**
6 for examples of analytical procedures.

7 Instruments, such as a pressurized ionization chamber (PIC) or micro-R meter are used to
8 measure exposure rate. Typically, exposure rates are read directly in millisieverts per hour
9 (mSv/h) (Standard International System of Units) or microroentgens (μ R) per hour. A gamma
10 scintillation detector (e.g., NaI(Tl)) provides data in cpm, and conversion to mSv/h is
11 accomplished by using site-specific calibration factors developed for the specific instrument
12 (**Section 6.6.4**).

13 In situ gamma spectrometry data may require special analysis routines before the spectral data
14 can be converted to soil concentration units or exposure rates. Commercially available
15 measurement systems may use proprietary methods to convert instrument counts to the
16 reported units. Although it is not always necessary to understand the conversion calculations,
17 any deviations from assumptions included in the conversion must be accounted for in the
18 estimate of total measurement uncertainty (**Section 6.4**). Consult the manufacturer to ensure
19 the total measurement uncertainty is determined correctly.

20 **6.8 Radon Measurements**

21 There are three radon isotopes in nature: ^{222}Rn (radon) in the ^{238}U decay chain, ^{220}Rn (thoron) in
22 the ^{232}Th decay chain, and ^{219}Rn (actinon) in the ^{235}U decay chain. ^{219}Rn is the least abundant of
23 these three isotopes, and because of its short half-life of 4 seconds, it has the least probability
24 of emanating into the atmosphere before decaying. ^{220}Rn , with a 55-second half-life, is
25 somewhat more mobile. ^{222}Rn , with a 3.8-day half-life, is capable of migrating through soil or
26 building material and reaching the atmosphere. Therefore, in most situations, ^{222}Rn should be
27 the predominant airborne radon isotope. In other instances, thorium-containing building material

1 or interior building structures where processed thorium ore is present can result in thoron's
2 becoming the predominant airborne radon isotope.

3 In some cases, radon may be detected within structures that do not contain residual radioactive
4 material, and conversely, some structures that contain residual radioactive material may not
5 yield detectable radon or thoron. Consult with your regulator for the applicability of radon or
6 thoron measurements as part of a site survey.

7 Because of the widespread nature of indoor air radon, many states have developed
8 requirements for certification/qualification of people who perform radon services. Therefore, as
9 part of the qualifications for the service provider, determine whether the measurement provider
10 or the laboratory analyzing the measurements is required to be certified by the state or locality
11 where the work is being performed. State radon contacts can be found at
12 [https://www.epa.gov/radon/find-information-about-local-radon-zones-and-state-contact-](https://www.epa.gov/radon/find-information-about-local-radon-zones-and-state-contact-information)
13 [information](https://www.epa.gov/radon/find-information-about-local-radon-zones-and-state-contact-information).

14 Many techniques have been developed over the years for measuring radon (Jenkins 1986) and
15 radon progeny in air. In addition, considerable attention is given by the U.S. Environmental
16 Protection Agency to the measurement of radon and radon progeny in homes (EPA 1992e).
17 Radon and radon progeny emit alpha and beta particles and gamma rays. Therefore, numerous
18 techniques can and have been developed for measuring these radionuclides based on detecting
19 alpha particles, beta particles, or gamma rays, independently or in some combination. This
20 section contains an overview of information dealing with the measurement of radon and radon
21 progeny. The information is focused on the measurement of ^{222}Rn ; however, the information
22 may be adapted for the measurement of ^{219}Rn and ^{220}Rn . There are commercial options for
23 measurements of ^{220}Rn , but options for ^{219}Rn are limited. More consideration should be given to
24 the two latter radon isotopes because of their short half-lives, which may prevent the shipment
25 of the sample for off-site laboratory analyses, depending on the sampling and measurement
26 methods.

27 Radon concentrations within a fixed structure can vary significantly from one section of the
28 building to another and can fluctuate over time. If a home has a basement, for instance, it is
29 usually expected that a higher radon concentration will be found there. Radon primarily enters
30 buildings that are at negative pressure with respect to the soil. A small increase in the relative
31 pressure between the soil and the inside of a structure can cause a significant increase in the
32 amount of radon entering the building from the soil. Many factors play a role in these variations,
33 but from a practical standpoint it is only necessary to recognize that fluctuations are expected
34 and that they should be accounted for. Long-term measurement periods (91 days or greater)
35 are required to determine a mean concentration inside a structure; however, a mean may not be
36 necessary to determine if a risk-reduction strategy is required. It may also not be necessary if
37 radon is being used as an indicator of nearby residual radioactive material.

38 Two analytical end points are of interest when performing radon measurements. The first and
39 most commonly used is radon concentration, which is stated in terms of activity per unit volume,
40 in Bq/m^3 or picocuries per liter (pCi/L). Although this terminology is consistent with most Federal
41 requirements, it only implies the potential dose equivalent associated with radon. The second

1 analytical end point is the potential alpha energy concentration (PAEC) (or equilibrium
2 equivalent concentration) of the radon progeny. Radon progeny usually attach very quickly to
3 charged aerosols in the air following creation. The fraction that remains unattached is usually
4 quite small (i.e., 5–10 percent). Because most aerosol particles carry an electrical charge and
5 are relatively massive ($\geq 0.1 \mu\text{m}$), they are capable of attaching to the surfaces of the lung.
6 Essentially all dose or risk from radon is associated with alpha decays from radon progeny
7 deposited in the respiratory system. If an investigator is interested in accurately determining the
8 potential dose or risk associated with radon in the air of a room, the radon progeny
9 concentration must be known. It should be noted, however, that various processes remove
10 radon progeny from a room. If the radon is removed or prevented from entering, there will be no
11 risk from decay products.

12 Radon progeny concentrations are usually reported in units of working levels, where one
13 working level is equal to the potential alpha energy associated with the radon progeny in secular
14 equilibrium with 100 pCi/L of radon. One working level is equivalent to 1.3×10^5 MeV/L of
15 potential alpha energy. Given a known breathing rate and lung attachment probability, the
16 expected mean lung dose from exposure to a known working level of radon progeny can be
17 calculated.

18 Radon progeny are not usually found in secular equilibrium with radon indoors because of the
19 plating out of the charged aerosols onto walls, furniture, etc. The ratio of ^{222}Rn progeny activity
20 to ^{222}Rn activity usually ranges from 0.2 to as high as 0.8 indoors (NCRP 1988). If only the ^{222}Rn
21 concentration is measured and it is not practical to measure the progeny concentrations, then
22 general practice is to assume a progeny to ^{222}Rn equilibrium ratio for indoor areas. The
23 appropriate regulatory agency should be consulted to determine the appropriate equilibrium
24 factor. This allows one to estimate the expected dose or risk associated with a given radon
25 concentration.

26 In general, the following generic guidelines should be followed when performing radon
27 measurements during site investigations:

- 28 • The radon measurement method used should be well understood, documented, and carried
29 out in compliance with certification requirements as applicable. Measurements in buildings
30 should conform to current radon standards of practice as required by the regulator.³
- 31 • Long-term measurements should be considered where short-term (screening) tests are
32 close to guidance levels.
- 33 • In nonresidential buildings, such as schools and commercial buildings, the impact of the
34 heating, ventilation, and air conditioning system on radon entry should be considered,
35 because radon levels may change significantly between occupied and non-occupied
36 periods.
- 37 • The impact of variable environmental conditions (e.g., humidity, temperature, dust loading,
38 and atmospheric pressure) on the measurement process should be accounted for when

³ Contact the American Association of Radon Scientists and Technologists for the current radon standards of practice.

1 necessary. Consideration should be given to effects on both the air collection process and
2 the counting system.

- 3 • The background response of the detection system should be accounted for.
- 4 • If measuring the potential alpha energy concentration directly is impractical to measure the
5 potential alpha energy concentration directly, then the progeny activities can be estimated
6 by assuming a specific equilibrium with radon. The concentrations of the radon progeny are
7 then estimated by applying an equilibrium factor to the measured radon concentration. The
8 appropriate regulatory agency should be consulted to determine the appropriate equilibrium
9 factor.

10 For a general overview, a list of common radiation detectors with their usual applications during
11 radon surveys is provided in **Table 6.9**. Descriptions and costs for specific equipment used for
12 the measurement of radon are contained in **Appendix H**.

13 The following provides a general overview of radon sampling and measurement concepts. The
14 intent of this section is to provide an overview of common methods and terminology.

15 **6.8.1 Direct Radon Measurements**

16 Direct radon measurements are performed by gathering radon into a chamber and measuring
17 the ionizations produced. A variety of methods have been developed, each making use of the
18 same fundamental mechanics but employing different measurement processes. The first step is
19 to get the radon into a chamber without collecting any radon progeny from the ambient air. A
20 filter is normally used to capture charged aerosols while allowing the radon gas to pass through.
21 Most passive monitors rely on diffusion of the ambient radon in the air into the chamber to
22 establish an equilibrium between the concentrations of radon in the air and in the chamber.
23 Active monitors use some type of air pump system for the air exchange method.

24 Once inside the chamber, the radon decays by alpha emission to form ^{218}Po , which usually
25 takes on a positive charge within thousandths of a second following formation. Some monitor
26 types collect these ionic molecules and subsequently measure the alpha particles emitted by
27 the radon progeny. Other monitor types, such as the electret ion chamber, measure the
28 ionization produced by the decay of radon and progeny in the air within the chamber by directly
29 collecting the ions produced inside the chamber. The electrets are influenced by the ambient
30 gamma radiation level; therefore, correction factors based on the gamma radiation level must be
31 established to adjust the radon results. Simple systems measure the cumulative radon during
32 the exposure period based on the total alpha decays that occur. More complicated systems
33 measure the individual pulse height distributions of the alpha and/or beta radiation emissions
34 and derive the radon plus progeny isotopic concentration in the air volume.

35 Care must be taken to accurately calibrate a system and to understand the effects of humidity,
36 temperature, dust loading, air currents, and atmospheric pressure on the system. These
37 conditions create a small adverse effect on some systems and a large influence on others.

38

1 **Table 6.9: Radiation Detectors with Applications to Radon Surveys**

Category	Measures	System	Description	Application	Time	Remarks
Integrating/ Averaging Methods	^{222}Rn	Activated charcoal adsorption	Activated charcoal is opened to the ambient air, then gamma counted on a gamma scintillator or in a liquid scintillation counter.	Measure radon concentration in indoor air.	2–7 days	LLD is 0.007–0.04 Bq/L (0.2–1.0 pCi/L). Must wait 3 hours after deployment ends to begin analysis. Not a true integrating device. Must be returned to the laboratory promptly.
	^{222}Rn ^{220}Rn Radon Flux	Electret ion chamber	This is a charged plastic vessel that can be opened for air to pass through. Voltage drop is then measured.	Measure radon concentration in air.	2–7 days for short term 91–365 days for long term	Must correct reading for gamma background concentration. Electret is sensitive to extremes of temperature and humidity. Reader is sensitive to temperature changes. LLD is 0.007–0.02 Bq/L (0.2–0.5 pCi/L).
		Alpha track detection	A small piece of special plastic or film inside a small container. Damage tracks from alpha particles are chemically etched and tracks counted.	Measure radon concentration in air.	91–365 days	LLD is 0.04 Bq/L-d (1 pCi/L-d). Typical deployment is a minimum of 90 days.

Category	Measures	System	Description	Application	Time	Remarks
	²²² Rn Progeny ²²⁰ Rn Progeny	Filter/ detector unit	Air pump and filtration unit with TLD chips or nuclear track detectors.	Measure progeny concentration in air.	1 day – a few weeks	LLD is 0.0002 Working Level for a week-long measurement.
Continuous Monitors	²²² Rn ²²⁰ Rn	Ionization chambers, scintillation detectors, solid state detectors	Measure radon concentrations and log results on real-time basis. May provide spectral data, depending on device.	Measure radon concentration in air; “sniffer” to locate radon entry points in building.	Minutes to a few days	LLD is 150 Bq/m ³ (4 pCi/L) in 10 minutes.
Radon Progeny Measurements	²²² Rn Decay Products ²²⁰ Rn Decay Products	Continuous radon progeny monitors	Air pump and solid-state detector.	Measurement of PAEC. Can calculate equilibrium.	1 day– 1 week “grab samples” for some models	LLD is 20 nJ/m ³ (0.001 Working Level).
Short-Term Radon Flux Measurements	²²² Rn	Large-area activated charcoal collector	A canister containing activated charcoal is twisted into the surface and left for 24 hours.	Short-term radon flux measurements.	24 hours	The LLD is 0.007 Bq/m ² /s (0.2 pCi/m ² s).
		Electret Ion Chamber	Ion Chamber has filtered outlets to prevent saturation.	Short term radon flux measurements.	8 – 24 hours	Gamma correction for background required. LLD is 0.08 pCi/m ² s

1 Abbreviations: Bq = becquerels; L = liters; pCi = picocuries; d = day; LLD = lower limit of detection;
2 TLD = thermoluminescent dosimeter; m = meter; PAEC = potential alpha energy concentration; nJ = nanoJoules;
3 s = second.

4 *6.8.1.1 Integrating/Averaging Methods*

5 With integrating methods, measurements are made over a period of days, weeks, or months,
6 and the device is subsequently read by an appropriate device for the detector media used. The
7 most common detectors used are activated charcoal adsorbers (good for up to 1 week), EICs
8 (good for days to weeks), and alpha track plastics (good for weeks to months). Short-term
9 fluctuations are averaged out, thus making the measurement representative of average
10 concentration. Results in the form of an average value provide no way to determine the
11 fluctuations of the radon concentration over the measurement interval. Successive short-term
12 measurements can be used in place of single long-term measurements to gain better insight
13 into the seasonal dependence of the radon concentration. Continuous measurements can be
14 used to get better insight into the time dependence of the radon concentration, which can be of
15 particular importance in large buildings. Because charcoal allows continual adsorption and
16 desorption of radon, the method does not give a true integrated measurement over the
17 exposure time. Use of a diffusion barrier over the charcoal reduces the effects of drafts and high
18 humidity.

19 *6.8.1.2 Continuous Monitors*

20 Devices that measure direct radon concentrations over successive time increments are
21 generally called continuous radon monitors. These systems are more complex than integrating
22 devices, in that they measure the radon concentration and log the results to a data recording
23 device on a real-time basis. The monitor must take a reading at least once per hour to be
24 considered a continuous monitor. Continuous radon measurement devices normally allow the
25 noble gas radon to pass through a filter into a detection chamber where the radon decays and
26 the radon or the resulting progeny are measured. Common detectors used for real time
27 measurements are ion chambers, solid state surface barrier detectors, and ZnS(Ag) scintillation
28 detectors.

29 A principle of operation for monitors equipped with solid state detectors is an electrostatic
30 collection of alpha emitters with spectral analysis. The electric field within the sample cell drives
31 the positively charged ion to the detector where it attaches. The detector converts alpha
32 radiation directly to an electrical signal proportional in strength to the energy of alpha particle.
33 This makes it possible to tell which radionuclide produced the radiation; therefore, one can
34 distinguish ^{222}Rn from ^{220}Rn . If operated in air with a relatively high radon concentration, these
35 monitors need to be purged with filtered, fresh dry air with a normal radon concentration before
36 taking the next series of measurements. Continuous methods offer the advantage of providing
37 successive, short-term results over long periods of time. This allows the investigator not only to
38 determine the average radon concentration, but also to analyze the fluctuations in the values
39 over time. More complicated systems are available that measure the relative humidity and
40 temperature at the measurement location and log the values along with the radon

1 concentrations to the data logging device. This allows the investigator to make adjustments, if
2 necessary, to the resulting data before reporting the results.⁴

3 **6.8.2 Radon Progeny Measurements**

4 Radon progeny measurements are usually performed by collecting aerosols onto filter paper
5 and subsequently counting the filter for attached progeny. Some systems pump air through a
6 filter and then automatically count the filter for alpha or beta emissions. An equivalent but more
7 labor-intensive method is to collect a sample using an air sampling pump and then count the
8 filter in standalone alpha or beta counting systems. The measurement system may make use of
9 any number of different techniques, ranging from full alpha and beta spectrometric analysis of
10 the filters to simply counting the filter for total alpha and or beta emissions.

11 When performing total (gross) counting analyses, the assumption is usually made that the only
12 radioisotopes in the air are due to ²²²Rn and its progeny. This uncertainty, which is usually very
13 small, can be essentially eliminated when performing manual sampling and analysis by
14 performing a followup measurement of the filter after the radon progeny have decayed to a
15 negligible level. This value can then be used as a background value for the air. Of course, such
16 a simple approach is applicable only when ²²²Rn is the isotope of concern. For ²¹⁹Rn or ²²⁰Rn,
17 other methods would have to be used.

18 Time is a significant element in radon progeny measurements. Given any initial equilibrium
19 condition for the progeny isotopes, an investigator must be able to correlate the sampling and
20 measurement technique back to the true concentration values. When collecting radon progeny,
21 the buildup of total activity on the filter increases asymptotically until the activity on the filter
22 becomes constant (after approximately 3 hours of sampling). At this point, the decay rate of the
23 progeny atoms on the filter is equal to the collection rate of progeny atoms. This is an important
24 parameter to consider when designing a radon and progeny sampling procedure. Depending on
25 sensitivity requirements, collection times can be as short as 5 minutes (Maiello 2010). Although
26 it is possible to sample for other time periods, the equations developed for the three major ²²²Rn
27 progeny concentrations are valid for sampling times of 5 minutes only. Samples should be
28 shipped and analyzed as expeditiously as possible after sampling is concluded.

29 Note that the number of charged aerosol particles in the air can affect the results for radon
30 progeny measurements. If the number of particles is few, as is possible when humidity is low
31 and a room is very clean, then most of the progeny will not be attached and can plate out on
32 room surfaces before reaching the sample filter.

⁴ Depending on the device, these measurements would indicate unexpected disruptions when the device is used for radon testing. The theory is that opening windows or moving the device would cause a noticeable disruption in the measurement.

1 **6.8.3 Radon Flux Measurements**

2 Sometimes it is desirable to characterize the source of radon in terms of the rate at which radon
3 is emanating from a surface—that is, soil, uranium mill tailings, or concrete. One method used
4 for measuring radon flux is briefly described here.

5 The measurement of radon flux can be achieved by adsorption onto charcoal using a variety of
6 methods, such as a charcoal canister or a large-area collector (e.g., 25 cm polyvinyl chloride
7 [PVC] end cap). The collector is deployed by sealing the collection device onto the surface of
8 the material to be measured. After 24 hours of exposure, the activated charcoal is removed and
9 transferred to plastic containers. The amount of radon adsorbed on the activated charcoal is
10 determined by gamma spectroscopy. Because the area of the surface is well defined and the
11 deployment period is known, the radon flux (in units of Bq/m²-s or pCi/m²-s) can be calculated.

12 This method is reliable for measuring radon flux in normal environmental situations. However,
13 care should be taken if an extremely large source of radon is measured with this method. The
14 collection time should be chosen carefully to avoid saturating the canister with radon. If
15 saturation is approached, the charcoal loses its ability to absorb radon, and the collection rate
16 decreases. Even transporting and handling of a canister that is saturated with radon can be a
17 problem because of the dose rate from the gamma rays being emitted. One would rarely
18 encounter a source of radon that is so large that this would become a problem; however, the
19 potential for it should be recognized. Charcoal also can become saturated with water, which will
20 affect the absorption of radon. This can occur in areas with high humidity.

21 An alternative method for making passive radon flux measurements has been developed
22 recently using EICs. EIC technology has been widely used for indoor radon measurements. The
23 passive EIC procedure is similar to the procedures used with large-area activated charcoal
24 canisters. To provide the data for the background corrections, an additional EIC monitor is
25 located side-by-side on a radon-impermeable membrane. These data are used to calculate the
26 net radon flux. The Florida State Bureau of Radiation Protection has compared the results from
27 measurements of several phosphogypsum flux beds using the charcoal canisters and EICs and
28 has shown that the two methods give comparable results. The passive method seems to have
29 overcome some of the limitations encountered in the use of charcoal. The measurement periods
30 can be extended from hours to several days to obtain a better average, if needed. EIC flux
31 measurements are not affected by such environmental conditions as temperature, humidity, and
32 air flow. The measured detection capabilities are comparable to the charcoal method, but—
33 unlike charcoal—EICs do not become saturated by humidity. Intermediate readings can be
34 made if needed. In view of the low cost of the EIC reading and analysis equipment, the cost per
35 measurement can be as much as 50 percent lower than the charcoal method, with additional
36 savings in time. There are handling and storage requirements associated with these methods
37 and detectors. For more information, refer to the manufacturer and **Appendix H**.

38 **6.9 Special Equipment**

39 Various specialized systems have been developed that can be used during the performance of
40 RSSIs. These range from specially designed quick radiation scanning systems to commercial
41 global positioning systems (GPSs). The equipment may be designed to detect radiation directly,

1 detect and locate materials associated with the residual radioactive material (e.g., metal
2 containers), or locate the position where a particular measurement is performed. Because these
3 specialized systems are continuously being modified and developed for site-specific
4 applications, it is not possible to provide detailed descriptions of every system. The following
5 sections provide examples of specialized equipment that have been applied to radiation surveys
6 and site investigations.

7 **6.9.1 Local Microwave and Sonar Positioning Systems**

8 Local microwave or sonar beacons and receivers may provide useful location data in small
9 areas and tree-covered locales. With a number of fixed beacons in place, a roving unit can be
10 oriented and provide location data with similar accuracy and precision as the differential GPS
11 (DGPS). If the beacons are located at known points, the resulting positions can be determined
12 using simple calculations based on the known reference locations of the beacons.

13 The logistics of deploying the necessary number of beacons properly and the short range of the
14 signals are the major limitations of the system. In addition, multipathing of signals within wooded
15 areas or interior areas can cause jumps in the positioning data. These systems have
16 applicability both indoors and outdoors but require setting up a site-specific system that may
17 require adjustment for different locations (e.g., each room in a building).

18 **6.9.2 Laser Positioning Systems**

19 Laser positioning systems are becoming more popular for monitoring positions in three
20 dimensions. The newest systems use reflectorless electronic distance measurement to measure
21 the distance to an object without actually accessing the object. Laser systems use the principles
22 of phase shift and pulse (or time of flight) or a hybrid combination to measure distance. This
23 allows mapping of distant or inaccessible objects in hazardous areas. Using a reflector, or
24 retroprism, to identify the location of a surveyor or detector allows the system to track the
25 location of individual measurements. Laser systems are accurate to within a few millimeters at
26 distances up to 1,000 m. Laser systems require a clear line of sight between the object and the
27 laser. Systems with multiple lasers at different locations can be used to minimize issues with
28 line-of-sight interference.

29 **6.9.3 Mobile Systems with Integrated Positioning Systems**

30 In recent years, the advent of new technologies has introduced mobile sensor systems for
31 acquiring data that include fully integrated positioning systems. Portable and vehicle-based
32 versions of these systems record survey data while moving over surfaces to be surveyed and
33 simultaneously recording the location data from a roving DGPS receiver, local microwave/sonar
34 receiver, or special retroprism for a laser system. All measurement data are automatically stored
35 and processed with the measurement location for later posting (see **Section 8.2.2.2** for a
36 discussion of posting plots) or for mapping the results using a geographic information system.
37 These systems are designed with a variety of detectors for different applications. For example,
38 alpha or beta detectors have been mounted on a robot at a fixed distance over a smooth
39 surface. The robot moves at a predetermined speed over the surface to provide scanning
40 results and records individual direct measurements at predetermined intervals. This type of

1 system not only provides the necessary measurement data, but also reduces the uncertainty
2 associated with human factors. Other systems are equipped with several types of radiation
3 detectors, magnetometers, electromagnetic sensors, or various combinations of multiple
4 sensors. The limitations of each system should be evaluated on a site-specific basis to
5 determine if the positioning system, the detector, the transport system, or some combination
6 based on site-specific characteristics will represent the limits of the system.

7 **6.9.4 Radar, Magnetometer, and Electromagnetic Sensors**

8 The number of sensors and sensor systems applicable to the detection and location of buried
9 waste have increased in use and reliability in recent years. These systems are typically
10 applicable to scoping and characterization surveys where the identification of residual
11 radioactive materials in the subsurface is a primary concern. However, the results of these
12 surveys may be used during FSS planning to demonstrate that subsurface materials are not a
13 concern for a particular site or survey unit. Some of the major technologies are briefly described
14 in the following sections.

15 **6.9.4.1 Ground Penetrating Radar**

16 For most sites, ground-penetrating radar (GPR) is the only instrument capable of collecting
17 images of buried objects *in situ*, as compared to magnetometers (**Section 6.9.3.2**) and
18 electromagnetic sensors (**Section 6.9.3.3**), which detect the strength of signals as measured at
19 the ground surface. Additionally, GPR is unique in its ability to detect both metallic and
20 nonmetallic (e.g., plastic, glass) containers. GPR techniques are being studied to monitor the
21 performance and stability of soil covers at uranium mill tailings sites and other land disposal
22 sites with earthen covers (Necsoiu and Walter 2015).

23 Subsurface radar detection systems have been the focus of study for locating and identifying
24 buried or submerged objects that otherwise could not be detected. There are two major
25 categories of radar signals: (1) time domain and (2) frequency domain. Time-domain radar uses
26 short impulses of radar-frequency energy directed into the ground being investigated.
27 Reflections of this energy, based on changes in dielectric properties, are then received by the
28 radar. Frequency-domain radar, on the other hand, uses a continuous transmission, where the
29 frequency of the transmission can be varied either stepwise or continuously. The changes in the
30 frequency characteristics due to effects from the ground are recorded. Signal processing, in
31 both cases, converts this signal to represent the location of radar reflectors against the travel
32 time of the return signal. Greater travel time corresponds to a greater distance beneath the
33 surface.

34 Examples of existing GPR technologies currently being applied to subsurface investigations
35 include the following:

- 36 • narrow-band radar
- 37 • ultra-wideband radar
- 38 • synthetic aperture radar

- 1 • frequency modulated continuous radar
- 2 • polarized radar waves

3 The major limitation to GPR is the difficulty in interpreting the data, which is often provided in the
4 form of hazy, “waterfall-patterned” data images requiring an experienced professional to
5 interpret. Also, GPR can vary depending on the soil type—highly conductive clay soils often
6 absorb a large amount of the radar energy and may even reflect the energy. GPR can be
7 deployed using ground-based or airborne systems.

8 *6.9.4.2 Magnetometers*

9 Although soil affected by residual radioactive material and most radioactive waste possess no
10 ferromagnetic properties, the containers commonly used to hold radioactive waste (e.g., 55-
11 gallon drums) are made from steel. These containers possess significant magnetic
12 susceptibility, making the containers detectable using magnetometry.

13 Magnetometers sense the pervasive magnetic field of the Earth. This field, when encountering
14 an object with magnetic susceptibility, induces a secondary magnetic field in that object. This
15 secondary field creates an increase or decrease in Earth’s ambient magnetic field.
16 Magnetometers measure these changes in the expected strength of the ambient magnetic field.
17 Some magnetometers, called “vector magnetometers,” can sense both the direction and the
18 magnitude of these changes. However, for subsurface investigations only the magnitude of the
19 changes is used.

20 The ambient magnetic field on Earth averages 55,000 gamma in strength. The variations
21 caused by the secondary magnetic fields typically range from 10–1,000 gamma and average
22 around 100 gamma. Most magnetometers currently in use have a detection capability in the
23 0.1–0.01 gamma range and can detect these secondary fields.

24 An alternate magnetometer survey can be performed using two magnetometers in a
25 gradiometric configuration. This means that the first magnetometer is placed at the ground
26 surface, and the second is mounted approximately 0.5 m above the first. Data are recorded
27 from both sensors and compared. When the readings from both detectors are nearly the same,
28 it implies that there is no significant disturbance in the Earth’s ambient magnetic field or that
29 such disturbances are broad and far away from the gradiometer. When a secondary magnetic
30 field is induced in an object, it affects one sensor more strongly than the other, producing a
31 difference in the readings from the two magnetometers. This approach is similar to the use of a
32 guard detector in anti-coincidence mode in a low-background gas-flow proportional counter in a
33 laboratory (see **Appendix H** for a description of gas-flow proportional counters). The
34 gradiometric configuration filters out the Earth’s ambient magnetic field, large-scale variations,
35 and objects located far from the sensor to measure the effects of nearby objects, all without
36 additional data processing. Fifty-five-gallon drums buried 5–7 meters below the surface may be
37 detectable using a magnetometer. At many sites, multiple drums have been buried in trenches
38 or pits, and detection is straightforward. A single operator carrying a magnetometer with the
39 necessary electronics in a backpack can cover large areas in a relatively small amount of time.

1 The limitations on the system are related to the size of the objects and their depth below the
2 surface. Objects that are too small or buried too deep will not provide a secondary magnetic
3 field that can be detected at the ground surface.

4 *6.9.4.3 Electromagnetic Sensors*

5 Electromagnetic sensors emit an electromagnetic wave, in either a pulsed or continuous wave
6 mode, and then receive the result of that transmission. The result of the transmission is two
7 signals: quadrature and in-phase. As the wave passes through some material other than air, it is
8 slowed down by a resistive medium or sped up by a conductor through dielectric effects. This
9 produces the quadrature signal. If the electromagnetic wave encounters a highly conductive
10 object, it induces a magnetic field in the object. This induced electromagnetic field returns to the
11 sensor as a reflection of the original electromagnetic wave and forms the in-phase signal.

12 The in-phase signal is indicative of the presence, size, and conductivity of nearby objects
13 (e.g., 55-gallon drums), and the quadrature signal is a measure of the dielectric properties of the
14 nearby objects, such as soil. This means that electromagnetic sensors can detect all metallic
15 objects (including steel, brass, and aluminum), such as the metal in waste containers, and
16 sample the soil for changes in properties, such as those caused by leaks of contents.

17 Depths of interest are largely determined by the spacing between the coil used to transmit the
18 primary electromagnetic wave and the receiver used to receive that transmission. The rule of
19 thumb is that the depth of interest is on the order of the distance between the transmitter and
20 the receiver. A system designed with the transmitter and receiver placed tens of meters apart
21 can detect signals from tens of meters below the surface. A system with the transmitter and
22 receiver collocated can detect signals only from depths on the order of the size of the coil, which
23 is typically about 1 m. The limitations of electromagnetic sensors include a lack of clearly
24 defined signals and decreasing resolution of the signal as the distance below the surface
25 increases.

26 *6.9.5 Aerial Radiological Surveys*

27 Low-altitude aerial radiological surveys are designed to encompass large areas and may be
28 useful in—

- 29 • providing data to assist in the identification of residual radioactive materials and their
30 corresponding concentrations and spatial distributions
- 31 • characterizing the nature, extent and impact of the residual radioactive materials

32 The detection capability and data processing procedures provide total area coverage and a
33 detailed definition of the extent of gamma-producing isotopes for a specific area. The gamma
34 radiation spectral data are processed to provide a qualitative and quantitative analysis of the
35 radionuclides in the survey area. Flyover surveys establish a grid pattern (e.g., east–west) of
36 parallel lines approximately 60–150 m (200–500 feet) above the ground surface.

37 The survey consists of airborne measurements of natural and manmade gamma radiation from
38 the terrain surface. These measurements allow the determination of terrestrial spatial

- 1 distribution of isotopic concentrations and equivalent gamma exposure rates (e.g., ^{60}Co , $^{234\text{m}}\text{Pa}$,
- 2 and ^{137}Cs). The results are reported as isopleths or data points for the isotopes and are usually
- 3 superimposed on scale maps of the area.

DRAFT

7 SAMPLING AND PREPARATION FOR LABORATORY MEASUREMENTS

7.1 Introduction

The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) provides three methods for collecting radiation data while performing a survey: direct measurement, scanning, and sampling.¹ A direct measurement is a radioactivity measurement obtained by placing the detector near the surface or media being surveyed for a prescribed amount of time. An indication of the resulting concentration of radioactive material is read out directly. Scanning is an evaluation technique performed by moving a portable radiation detection instrument at a constant speed and distance relative to the surface to detect radiation. These measurement techniques are discussed in **Chapter 6**. The third method of obtaining radiation data involves collecting a portion of a larger quantity of media for sample analysis using instrumentation in the field or in a laboratory (NRC 2004).

Chapter 7 discusses issues involved in collecting and preparing samples for analysis. This information will assist in communications with the laboratory during survey planning.

Samples should be collected and analyzed by qualified individuals using the appropriate equipment and procedures. This manual assumes that the samples taken during the survey will be submitted to a qualified laboratory for analysis. The laboratory should have written procedures that document its analytical capabilities for the radionuclides of interest and a quality assurance/quality control (QA/QC) program that documents the compliance of the analytical process with established criteria. The method used to assay the radionuclides of concern should be recognized as a factor affecting analysis time.

Commonly used radiation detection and measuring equipment for radiological survey field applications is described in **Chapter 6** and **Appendix H**. Many of these equipment types may also be used for laboratory analyses, usually under more controlled conditions that provide for lower detection limits and measurement method uncertainties and greater abilities to identify and quantify between radionuclides. Laboratory methods often involve combinations of both chemical and physical preparation and instrument techniques to quantify the low levels expected in the samples. This chapter provides guidance to assist the MARSSIM user in selecting appropriate procedures for collecting and handling samples for laboratory analysis. More detailed information is available in documents listed in the reference section of this manual.

The development of data quality objectives (DQOs) and measurement quality objectives (MQOs) to define the data needs for a survey is described in **Section 7.2**. This includes making decisions regarding the need to collect samples, the appropriate sampling methods, and QC measurements implemented as part of the survey process. **Section 7.3** describes

¹ MARSSIM uses the word “should” as a recommendation, not as a requirement. Each recommendation in this manual is not intended to be taken literally and applied at every site. MARSSIM’s survey planning documentation will address how to apply the process on a site-specific basis.

1 communication with laboratory personnel during survey planning, before and during sample
2 collection, and during and after sample analysis. Collaborative communication with the
3 laboratory is an important aspect of the sampling and analysis process that helps ensure that
4 survey DQOs are met.

5 The selection of radiochemical laboratories based on their capability to meet technical,
6 reporting, and other contractual requirements is described in **Section 7.4**. **Section 7.5** covers
7 sample collection considerations to enhance the representativeness of the sample, and the
8 establishment of field sample preparation and preservation criteria is included in **Section 7.6**.

9 **Section 7.7** describes the selection of appropriate analytical methods to ensure that the
10 residual radionuclides—either as individual radionuclides or as a total amount of radioactivity as
11 identified in the DQOs and MQOs—can be detected at appropriate levels of sensitivity and that
12 requirements for measurement uncertainties are met. Sample tracking from field activities
13 through laboratory analysis and reporting is covered in **Section 7.8**. **Section 7.9** covers the
14 packaging and shipping of samples containing radioactive material to minimize radiation
15 exposure to the general public and meet applicable Federal and international requirements.

16 **7.2 Data Quality Objectives and Measurement Quality Objectives**

17 The survey design is developed and documented using the DQO process (see **Appendix D**).
18 The third step of the DQO process involves identifying the data needs for a survey. One
19 decision that can be made at this step is the selection of either a scan-only survey, direct
20 measurements in conjunction with scanning for performing a survey, or sampling and laboratory
21 analysis in conjunction with scanning as the appropriate data collection strategy for the survey.
22 This chapter addresses the sampling and laboratory analysis of samples.

23 Because DQOs apply to both sampling and analytical activities, what are needed from an
24 analytical perspective are performance objectives specifically for the analytical process of a
25 project. Chapter 3 of the Multi-Agency Radiological Laboratory Analytical Protocols (MARLAP;
26 NRC 2004) refers to these performance objectives as MQOs. An MQO is a quantitative or
27 qualitative statement of a performance objective or requirement for a performance characteristic
28 of a particular method. The MQOs can be viewed as the analytical portion of the overall project
29 DQOs. In a performance-based approach, the MQOs are used initially for the selection and
30 evaluation of analytical methods and protocols and are subsequently used for the ongoing and
31 final evaluation of the analytical data.

32 **7.2.1 Identifying Data Needs**

33 The decision maker and the survey planning team need to identify the data needs for the survey
34 being performed, including the following:

- 35 • type of samples to be collected or measurements to be performed (**Chapter 5**)
- 36 • radionuclide(s) of interest (**Section 4.3**)
- 37 • number of samples to be collected (**Sections 5.3.3–5.3.5**)
- 38 • type and frequency of field QC samples to be collected (**Section 4.9**)

- 1 • amount of material to be collected for each sample (**Section 4.7.3** and **Section 7.5**)
- 2 • sampling locations and frequencies (**Section 5.3.7**)
- 3 • standard operating procedures (SOPs) to be followed or developed
- 4 • measurement method uncertainty (**Section 6.4**)
- 5 • target detection capabilities for each radionuclide of interest (**Section 6.3**)
- 6 • cost of the methods being evaluated (cost per analysis as well as total cost) (**Appendix H**)
- 7 • necessary turnaround time
- 8 • sample preservation and shipping requirements (**Section 7.6**)
- 9 • specific background for each radionuclide of interest (**Section 4.5**)
- 10 • derived concentration guideline level (DCGL) for each radionuclide of interest (**Section 4.3**)
- 11 • measurement documentation requirements (**Section 5.3.11**)
- 12 • sample tracking requirements (**Section 7.8**)

13 Some of this information will be supplied by subsequent steps in the DQO process, and several
14 iterations of the process may be needed to identify all of the data needs. Consulting with a
15 radiochemist or health physicist may be necessary to properly evaluate the information before
16 deciding what combination of scan-only, direct measurements and scanning, or sampling
17 methods and scanning will be required to meet the DQOs. Surveys might require data from all
18 three collection methods (i.e., sample analysis, direct measurements, and scans) to
19 demonstrate compliance with the applicable regulations and DQOs for the project.

20 **7.2.2 Data Quality Indicators**

21 Precision, bias, representativeness, comparability, and completeness are some of the historical
22 data quality indicators (DQIs) recommended for quantifying the amount of error in survey data
23 (EPA 2002a). The first two of these DQIs represent different aspects of the measurement
24 method uncertainty (**Section 6.4**), with *precision* representing that portion of the measurement
25 method uncertainty due to random uncertainty and *bias* representing that portion of the
26 measurement method uncertainty due to systematic uncertainty. Together, these DQIs should
27 be considered when selecting a measurement technique (i.e., scanning, direct measurement, or
28 sampling) or an analytical technique (e.g., radionuclide-specific analytical procedure). In some
29 instances, the DQI requirements will help in the selection of an analytical technique. In other
30 cases, the analytical requirements will assist in the selection of appropriate levels for the DQIs.

31 **7.2.2.1 Precision**

32 Precision is a measure of agreement among replicate measurements of the same property
33 under prescribed similar conditions (ASQC 1995). Precision is determined quantitatively based
34 on the results of replicate measurements (equations are provided in EPA 1990). The number of

- 1 replicate analyses needed to determine a specified level of precision for a project is discussed
2 in **Section 4.9**. Several types of replicate analyses are available to determine the level of
3 precision, and these replicates are typically distinguished by the point in the sample collection
4 and analysis process where the sample is divided. Determining precision by replicating
5 measurements with results at or near the detection limit of the measurement system is not
6 recommended, because the measurement uncertainty is usually greater than the desired level
7 of precision.
- 8 • *Field replicates*² are two or more separate samples collected at the same point in time and
9 space (EPA 2002b). These samples, also known as collocated samples, are collected
10 adjacent to the routine field sample to determine local variability of the radionuclide
11 concentration. Typically, including for MARSSIM collection, field replicates are collected
12 about 0.5–3 feet away from the selected sample location. Analytical results from field
13 replicates can be used to assess site variation, but only in the immediate sampling area.
14 Field replicates should not be used to assess variability across a site and are not
15 recommended for assessing error (EPA 1995). Field replicates can be non-blind, single-
16 blind, or double-blind.
 - 17 • *Field splits* are two or more representative portions taken from a single, usually
18 homogenized, sample collected in the field (EPA 2002b). These portions are divided into
19 separate containers and treated as separate samples throughout the remaining sample
20 handling and analytical processes and are used to assess error associated with sample
21 heterogeneity, sample methodology, and analytical procedures. Field splits are used when
22 determining total error for critical samples with residual radioactive material concentrations
23 near the action level. A minimum of eight field split samples is recommended for valid
24 statistical analysis (EPA 1995). Counting multiple split samples of a homogenized field
25 sample will decrease the uncertainty of the sample, because the sample count times can be
26 combined to derive the overall count time for the sample. In some cases, homogenization
27 may not be possible (e.g., discrete [small] radioactive particles). Field split samples can be
28 non-blind, single-blind, or double-blind and are recommended for determining the level of
29 precision for a radiation survey or site investigation.
 - 30 • An *analytical laboratory replicate* is two or more representative aliquots (portions of a
31 homogeneous sample, removed for the purpose of analysis or other chemical treatment)
32 whose independent measurements are used to determine the precision of laboratory
33 preparation and analytical procedures (NRC 2004). It is used to determine method
34 precision, but because it is a non-blind sample (i.e., known to the analyst), it can be used by
35 the analyst only as an internal control tool and not as an unbiased estimate of analytical
36 precision (EPA 1990).
 - 37 • A *laboratory instrument replicate* is the repeated measurement of a sample that has been
38 prepared for counting (i.e., laboratory sample preparation and radiochemical procedures
39 have been completed). It is used to determine precision for the instrument (repeated
40 measurements of the same sample using same instrument) and the instrument calibration

² The term “field replicates” is used in some documents to refer to what this guidance calls field splits.

1 (repeated measurements of the same sample using different instruments, such as two
2 different germanium detectors with multichannel analyzers). A laboratory instrument
3 replicate is generally performed as part of the laboratory QC program and is a non-blind
4 sample. It is typically used as an internal control tool and not as an unbiased estimate of
5 analytical precision.

6 7.2.2.2 Bias

7 Bias is the systematic or persistent distortion of a measurement process that causes error in
8 one direction (ASQC 1995). Bias is determined quantitatively based on the analysis of samples
9 with a known concentration. There are several types of samples with known concentrations. QC
10 samples used to determine bias should be included as early in the analytical process as
11 possible.

- 12 • *Reference materials* are one or more materials or substances with property values that are
13 sufficiently homogeneous and well established to be used for the calibration of an
14 apparatus, the assessment of a measurement method, or for assigning values to materials
15 (ISO 2008). A certified reference material is one for which each certified property value is
16 accompanied by an uncertainty at a stated level of confidence. Radioactive reference
17 materials may be available for certain radionuclides (e.g., uranium) in soil, but reference
18 building materials may not be available. Because reference materials are prepared and
19 homogenized as part of the certification process, they are rarely available as double-blind
20 samples. When appropriate reference materials are available (i.e., proper matrix, proper
21 radionuclide, and proper concentration range), they are recommended for use in
22 determining the overall bias for a measurement system.
- 23 • *Performance evaluation (PE) samples* are used to evaluate the overall bias of the analytical
24 laboratory and detect any error in the analytical method used. These samples are usually
25 prepared by a third party, using a quantity of analyte(s) known to the preparer but unknown
26 to the laboratory, and always undergo certification analysis. The analyte(s) used to prepare
27 the PE sample is the same as the analyte(s) of interest. Laboratory procedural error is
28 evaluated by the percentage of analyte identified in the PE sample (EPA 1995). PE samples
29 are recommended for use in determining overall bias for a measurement system when
30 appropriate reference materials are not available. PE samples are equivalent to matrix
31 spikes prepared by a third party that undergo certification analysis and can be non-blind,
32 single-blind, or double-blind.
- 33 • *Matrix spike samples* are environmental samples that are spiked in the laboratory with a
34 known concentration of a target analyte(s) to verify percent recoveries. They are used
35 primarily to check sample matrix interferences but can also be used to monitor laboratory
36 performance. However, a data set of at least three or more results is necessary to
37 distinguish between laboratory performance and matrix interference (EPA 1995). Matrix
38 spike samples are often replicated to monitor method performance and evaluate error due to
39 laboratory bias and precision (when four or more pairs are analyzed). These replicates are
40 often collectively referred to as a matrix spike/matrix spike duplicate (MS/MSD).

41 Several additional terms are applied to samples prepared by adding a known amount of the
42 radionuclide of interest to the sample. The majority of these samples are designed to isolate

1 individual sources of bias within a measurement system by preparing pre- and post-operation
2 spikes. For example, the bias from the digestion phase of the measurement system can be
3 determined by comparing the result from a pre-digest spike to the result from a post-digest
4 spike.

5 Several types of samples are used to estimate bias caused by contamination during the sample
6 collection or analytical process:

- 7 • *Background samples* are collected from a non-impacted area with similar characteristics
8 (either onsite or offsite) where there is little or no chance of migration of the radionuclides of
9 concern (EPA 1995). Background samples are collected from the background reference
10 area (**Section 4.5**), to determine the natural composition and variability of the soil (especially
11 important in areas with high concentrations of naturally occurring radionuclides). They
12 provide a basis for comparison of radionuclide concentration levels with samples collected
13 from the survey unit when the statistical tests described in **Chapter 8** are performed.
- 14 • *Field blanks* are samples prepared in the field using certified clean sand, soil, or water and
15 then submitted to the laboratory for analysis (EPA 1995). A field blank is used to evaluate
16 contamination error associated with sampling methodology and laboratory procedures. It
17 also provides information about contaminants that may be introduced during sample
18 collection, storage, and transport. Field blanks are recommended for determining bias
19 resulting from contamination for a radiation survey or site investigation.
- 20 • *Method blanks* are analytical control samples used to demonstrate that reported analytical
21 results are not the result of laboratory contamination (ATSDR 2005). A method blank
22 contains distilled or deionized water and reagents and is carried through the entire analytical
23 procedure (laboratory sample preparation, digestion, and analysis).³

24 7.2.2.3 Representativeness

25 Representativeness is a measure of the degree to which data accurately and precisely
26 represent a characteristic of a population parameter at a sampling point (ASQC 1995).
27 Representativeness is a qualitative term that is reflected in the survey design through the
28 selection of a measurement technique (e.g., direct measurement or sampling) and the size of a
29 sample collected for analysis.

30 Sample collection and analysis is typically less representative of true radionuclide
31 concentrations at a specific measurement location than performing a direct measurement. This
32 is caused by the additional steps required in collecting and analyzing samples, such as sample
33 collection, field sample preparation, laboratory sample preparation, and radiochemical analysis.
34 However, direct measurement techniques with acceptable detection limits are not always
35 available. When sampling is required as part of a survey design, it is critical that the sample
36 collection procedures consider representativeness. The location of the sample is determined as
37 described in **Section 5.3.7**, but the size and content of the sample are usually determined as

³ The method blank is also referred to as a reagent blank. The method blank is generally used as an internal control tool by the laboratory because it is a non-blind sample.

1 the sample is collected. Sample size and content are discussed in **Section 4.7.3** and
2 **Section 7.5**. Sample collection procedures also need to consider the development of the
3 DCGLs when determining the representativeness of the samples.

4 *7.2.2.4 Comparability*

5 Comparability is a qualitative term that expresses the confidence that two data sets can
6 contribute to a common analysis and interpolation. Generally, comparability is provided by using
7 the same measurement system for all analyses of a specific radionuclide. In many cases,
8 equivalent procedures used within a measurement system are acceptable. For example, using a
9 liquid-liquid extraction purification step to determine the concentration of plutonium-238 (²³⁸Pu)
10 using alpha spectrometry may be equivalent to using an ion-exchange column purification step.
11 However, using a gross alpha measurement made with a gas proportional counting system
12 would not be considered equivalent. Comparability is usually not an issue except in cases
13 where historical data have been collected and are being compared to current analytical results
14 or when multiple laboratories are used to provide results as part of a single survey design and
15 the analytical methods have not been clearly communicated to the laboratories.

16 *7.2.2.5 Completeness*

17 Completeness is a measure of the amount of valid data obtained from the measurement
18 system, expressed as a percentage of the number of valid measurements that should have
19 been collected. Valid data is all data that are usable for an intended purpose, including data with
20 no validation qualifiers and data found to be estimated that are justifiable for use. For example,
21 data below the DCGL determined using the Wilcoxon Rank Sum test (DCGL_w) that are
22 estimated with high bias would be considered usable data. Completeness is of greater concern
23 for laboratory analyses than for direct measurements, because the consequence of having
24 incomplete data often requires the collection of additional samples. Direct measurements can
25 usually be repeated easily. The collection of additional samples generally requires a
26 remobilization of sample collection personnel, which can be expensive. Conditions at the site
27 may have changed, making it difficult or impossible to collect representative and comparable
28 samples without repeating the entire survey. On the other hand, if it is simply an analytical
29 problem and sufficient samples were originally collected, the analysis can be repeated using
30 archived sample material. Samples collected on a grid to locate areas of elevated activity are
31 also a concern for completeness. If one sample analysis result is not valid, the survey design
32 may not be able to detect areas of elevated activity near or at the missing sample location.

33 *7.2.2.6 Other Data Quality Indicators*

34 Several additional data quality indicators that influence the final status survey (FSS) design are
35 identified as DQOs and MQOs in **Section 2.3.1**. Many of these (e.g., selection and classification
36 of survey units, decision error rates, variability in the contaminant concentration, lower bound of
37 the gray region) are used to determine the number of measurements and are discussed in detail
38 in **Section 5.3**. The required detection capability (**Section 6.3**) and measurement method
39 uncertainties (**Section 6.4**) are directly related to the selection of a measurement method and a
40 radionuclide-specific analytical technique.

41 Cost, time, best available technology, or other constraints may create situations where the
42 required detection capabilities or measurement method uncertainties are deemed impracticable.

1 Under these circumstances, different values may be acceptable. Although laboratories will state
2 detection limits, these are usually based on ideal or optimistic situations and may not be
3 achievable under actual measurement conditions. Detection limits and measurement method
4 uncertainties are subject to variation from sample to sample, instrument to instrument, and
5 procedure to procedure, depending on sample size, geometry, background, instrument
6 efficiency, chemical recovery, abundance of the radiations being measured, counting time, self-
7 absorption in the prepared sample, and interferences from radionuclides or other materials
8 present in the sample.

9 **7.3 Communications with the Laboratory**

10 Laboratory analyses of samples are generally performed by personnel not directly involved in
11 the collection of the samples being analyzed. Samples are typically collected by one group
12 working in the field and analyzed by a second group located in a laboratory. This separation of
13 tasks can potentially lead to problems based on the lack of communication between the two
14 groups. For this reason, communications between the project manager, field personnel, and
15 laboratory personnel are vital to ensuring the success of a project. The MARLAP manual
16 (NRC 2004), Section 11.2.1 provides more information on communications with a laboratory.

17 **7.3.1 Communications During Survey Planning**

18 The radioanalytical laboratory is a valuable resource during survey planning. Information on
19 available analytical techniques, measurement method uncertainty, method detection capability,
20 required measurement uncertainties, analytical costs, and turnaround times can easily be
21 provided by the laboratory. All this information is used to make the decision to perform direct
22 measurements or collect samples for laboratory measurements. Additional information, such as
23 required sample size/volume, type of sample container, preservative requirements, and shipping
24 requirements—including the laboratory's availability for receipt of samples on weekends or
25 holidays—can be obtained and factored into the survey plan.

26 Involving the radioanalytical laboratory during survey planning also provides the laboratory with
27 site-specific information about the project. Information on the radionuclides of interest, possible
28 chemical and physical form of the residual radioactive material, and mechanism for release of
29 the residual radioactive material to the environment is used to modify or develop the analytical
30 method for site-specific conditions, if required. The laboratory should also be provided with the
31 site-specific action levels (i.e., DCGLs, investigation levels) early in the survey planning
32 process.

33 In some cases, it is not practical to select a radioanalytical laboratory early in the survey
34 process to participate in the survey planning activities. For example, Federal procurement
35 procedures require that a statement of work (SOW) identifying the tasks to be performed by the
36 laboratory be developed before selecting a laboratory. Unfortunately, the details of the tasks for
37 the laboratory to perform are developed during survey planning. This means that the information
38 provided by the laboratory and used during survey planning will be obtained from another
39 source, usually a radiochemist or health physicist trained in radiochemistry. The uncertainty
40 associated with this information and subsequent decisions made based on this information
41 increases. This may lead to increased costs caused by specifying an unnecessarily expensive
42 analytical method in the SOW, repeated sampling and analysis of samples that did not meet the

1 required detection capabilities, or measurement method uncertainties because the specified
2 analytical method was not sufficient. In addition, unnecessary or inappropriate analytical
3 methods may be selected by the laboratory because site-specific information concerning the
4 samples was not provided.

5 The laboratory should be consulted when planning the schedule for the survey to ensure that
6 the expected turnaround times can be met based on the projected laboratory workload.

7 **7.3.2 Communications Before and During Sample Collection**

8 In most situations, the sample collection and shipping containers are supplied by the laboratory;
9 therefore, the laboratory should be notified well in advance of the sampling trip so that these
10 items will be available to the sampling team during the survey.

11 The main purpose of communications with the laboratory during sample collection is to inform
12 the laboratory of modifications to the survey design specified in the planning documents
13 (e.g., Quality Assurance Project Plan [QAPP] and SOPs). The laboratory should have a copy of
14 the survey design in its possession before samples' being collected.

15 Modifications to the survey design are often minor deviations from the SOPs caused by site-
16 specific conditions and usually affect a small number of samples. For example, a rock
17 outcropping covered by a thin layer of soil may restrict the depth of the surface soil sample to
18 5 centimeters (cm; 2 inches [in.]) instead of the 10 cm (4 in.) specified in the SOP. If the mass of
19 the samples collected from this area of the site is one-half the expected sample mass, the
20 laboratory needs to be informed of this deviation from the SOP. Also, the laboratory should be
21 notified of the proper sample handling requirements (i.e., inform the laboratory of the proper
22 handling of gravel in the samples, as some residual radioactive material could be present in the
23 form of small gravel). Finally, the laboratory should be notified of the approximate activity
24 concentrations to be expected in samples to ensure that the laboratory is licensed and equipped
25 to handle samples with elevated activity concentrations.

26 In other situations, there may be an extensive modification to the number or types of samples
27 collected at the site that will affect the analytical methods, detection capabilities, required
28 measurement uncertainties, analytical costs, or even the assumptions used to develop the
29 DCGL. For example, a large portion of the site may have been converted to a parking lot. A
30 large pile of material that may represent the former surface soil will be sampled, as well as soil
31 collected from beneath the parking lot surface. The number of samples to be analyzed has
32 doubled compared to the original SOW.

33 If the expected timing of receipt of samples at the laboratory changes because of sample
34 collection schedule deviations, the laboratory should be notified. Most laboratories require prior
35 notification for samples to be received on weekends.

36 **7.3.3 Communications During Sample Analysis**

37 The laboratory should communicate with the project manager and field personnel during sample
38 analysis. The laboratory should provide a list of missing or damaged samples as soon as
39 practical after the samples are received. This allows the project manager to determine if
40 resampling is required to replace the missing or damaged samples. The project manager may

1 also request notification from the laboratory when samples are damaged or lost, or if any
2 security seals are missing or broken. Preliminary reports of analytical results may be useful to
3 help direct sampling activities and provide early indications of whether the survey objectives
4 defined by the DQOs and MQOs are being met. However, if preliminary results have not been
5 verified or validated, their usefulness is limited.

6 **7.3.4 Communications Following Sample Analysis**

7 Following sample analysis, the laboratory will provide documentation of the analytical results as
8 specified in the survey design, which should include the measurement result, measurement
9 uncertainty, minimum detectable activity, and quality control and chain-of-custody (COC)
10 documentation. Laboratory personnel should be available to assist with interpretation, data
11 verification, and data validation.

12 **7.4 Selecting a Radioanalytical Laboratory**

13 After the decision to perform sampling activities is made, the next step is to select the analytical
14 methods and determine the data needs for these methods. It is advisable to select a
15 radiochemical laboratory as early as possible in the survey planning process so it may be
16 consulted on the analytical methodology and the sampling activities. The laboratory provides
17 information on personnel, capabilities, and current workload that are necessary inputs to the
18 decision-making process. In addition, mobile laboratories can provide on-site analytical
19 capability. Obtaining laboratory or other services may involve a specific procurement process.
20 Federal procurement procedures may require additional considerations beyond the method
21 described here.

22 The procurement of laboratory services usually starts with the development of a request for
23 proposal (RFP) that includes an SOW describing the analytical services to be procured. Careful
24 preparation of the SOW is essential to the selection of a laboratory capable of performing the
25 required services in a technically competent and timely manner.

26 The technical proposals received in response to the procurement RFP must be reviewed by
27 personnel familiar with radioanalytical laboratory operations to select the most qualified offeror.
28 For complicated sites with a large number of laboratory analyses, it is recommended that a
29 portion of this evaluation take the form of a pre-award audit. The provision for this audit must be
30 in the RFP. The results of this audit provide a written record of the decision to use a specific
31 laboratory. Smaller sites or facilities may decide that a review of the laboratory's qualifications is
32 sufficient for the evaluation.

33 Six criteria should be reviewed during this evaluation:

- 34 • Does the laboratory possess the appropriate well-documented procedures, instrumentation,
35 and trained personnel to perform the necessary analyses? Necessary analyses are defined
36 by the data needs (radionuclide(s) of interest, required measurement uncertainties, and
37 target detection limits) identified by the DQO process.
- 38 • Is the laboratory experienced in performing similar analyses?

- 1 • Does the laboratory have satisfactory performance evaluation results from formal monitoring
2 or accreditation programs? The laboratory should be able to provide a summary of QA
3 audits and proof of participation in interlaboratory cross-check programs. Equipment
4 calibrations should be performed using National Institute of Standards and Technology
5 (NIST)-traceable reference radionuclide standards whenever possible.
- 6 • Is there an adequate capacity to perform all analyses within the desired timeframe? This
7 criterion considers whether the laboratory possesses a radioactive materials–handling
8 license or permit for the samples to be analyzed. Very large survey designs may indicate
9 that more than one analytical laboratory is necessary to meet the survey objectives. If
10 several laboratories are performing analyses as part of the survey, the analytical methods
11 used to perform the analyses should be similar to ensure comparability of results (see
12 **Appendix D**).
- 13 • Does the laboratory provide an internal QC review of all generated data that is independent
14 of the data generators?
- 15 • Are there adequate protocols for method performance documentation and sample security?

16 Providers of radioanalytical services should have an active and fully documented QA program in
17 place, typically via one or more documents, such as a Quality Management Plan, Quality
18 Assurance Manual, or QAPP. This program should comply with the objectives determined by
19 the DQO process in **Section 2.3**.

20 Requirements for the QA program (e.g. QAPP), COC requirements, and the numbers of
21 samples to be analyzed should be specified, communicated to the laboratory in writing, and
22 agreed upon. The Sampling and Analysis Plan (SAP), analytical procedures, and the
23 documentation and reporting requirements should also be specified, communicated to the
24 laboratory in writing, and agreed upon. The laboratory's accreditation, if required, should be
25 confirmed by contacting the organization that provided the certification. These topics are
26 discussed in detail in the following sections of this chapter. Additional guidance on obtaining
27 laboratory services can be found in Chapter 5 of the MARLAP manual (NRC 2004).

28 **7.5 Sampling**

29 This section provides guidance on developing appropriate sample collection procedures for
30 surveys designed to demonstrate compliance with a dose- or risk-based regulation. Sample
31 collection procedures are concerned mainly with ensuring that collected samples are
32 representative of the sample media, are large enough to provide sufficient material to achieve
33 the desired detection limit and required measurement uncertainties, and are consistent with
34 assumptions used to develop the conceptual site model and the DCGLs. Additional
35 considerations for sample collection activities are discussed in **Section 4.7.3**.

36 Commingled chemical and radioactive waste at a site can influence sample handling and
37 laboratory requirements. Also, the external exposure rates or radioactivity concentration of a
38 specific sample may limit the time that workers will be permitted to remain in intimate contact
39 with the samples or may dictate that smaller samples be taken and special holding areas be
40 provided for collected samples before shipment. These special handling considerations may
41 conflict with the size specifications for the analytical method, normal sampling procedures, or

1 equipment. There is a potential for biasing sampling programs by selecting samples that can be
2 safely handled or legally shipped to support laboratories, which could be a concern for scoping,
3 characterization, and Radiation Survey and Site Investigation (RSSI) samples.

4 **7.5.1 Surface Soil**

5 The purpose of surface soil sampling is to collect samples that accurately and precisely
6 represent the radionuclides and their concentrations at the location being sampled. To do this
7 and plan for sampling, a decision must be made as to the survey design. The selection of a
8 survey design is based on the Historical Site Assessment, results from preliminary surveys
9 (i.e., scoping characterization, remedial action support), and the objectives of the survey
10 developed using the DQO process. The selection between judgment, random, and systematic
11 survey designs is discussed in **Section 5.3**.

12 **7.5.1.1 Sample Volume**

13 The volume of soil collected should be specified in the sample collection procedure. In general,
14 large volumes of soil are more representative than small volumes of soil. In addition, large
15 samples provide sufficient material to ensure that required detection limits can be achieved and
16 that sample reanalysis can be done if there is a problem. However, large samples may cause
17 problems with shipping, storage, and disposal. All of these issues should be discussed with the
18 sample collection team and the analytical laboratory during development of sample collection
19 procedures. In general, surface soil samples range in size from 100 grams up to several
20 kilograms.

21 The sample collection procedure should also make clear if it is more important to meet the
22 volume requirement of the survey design or the surface area the sample represents. Constant
23 volume is related to comparability of the results, while surface area is more closely related to the
24 representativeness of the results. Maintaining a constant surface area and depth for samples
25 collected for a particular survey can eliminate problems associated with different depth profiles.
26 The actual surface area included as part of the sample may be important for estimating the
27 probability of locating areas of elevated concentration.

28 **7.5.1.2 Sample Content**

29 The material present in the field at the sample location may or may not provide a representative
30 sample. Vegetative cover, soil particle size distribution, inaccessibility, and lack of sample
31 material are examples of problems that may be identified during sample collection. All
32 deviations from the survey design as documented in the SOPs should be recorded as part of
33 the field sample documentation.

34 Sample content is generally defined by the assumptions used to develop the conceptual site
35 model and the DCGLs. A typical agricultural scenario assumes that the top few centimeters of
36 soil are available for resuspension in air; that the top 15 cm (6 in.) are homogenized by
37 agricultural activities (e.g., plowing); that roots can extend down several meters to obtain water
38 and nutrients, depending on the plant; and that external exposure is based on an assumed
39 thickness of contaminated soil (usually at the surface). Depending on the dominant exposure
40 pathways for each radionuclide, this can result in a complicated set of instructions for collecting
41 representative samples. This situation can be further complicated by the fact that the site is not

1 currently being used for agricultural purposes. For this situation, it is necessary to look at the
 2 analytical results from the preliminary surveys (i.e., scoping, characterization, remedial action
 3 support) to determine the expected depth of residual radioactive material.

4 In most situations the vegetative cover is not considered part of the surface soil sample and is
 5 removed in the field. It is important that the sample collection procedure clearly indicate what is
 6 and what is not considered part of the sample.

7 *7.5.1.3 Sampling Equipment*

8 The selection of proper sampling equipment is important to ensure that samples are collected in
 9 a reproducible manner and to minimize the potential for cross-contamination. Sampling
 10 equipment generally consists of a tool to collect the sample and a container to place the
 11 collected sample in. Sample tracking begins as soon as the sample is collected, so it may be
 12 necessary to consider security of collected samples required by the objectives of the survey.

13 Sampling tools are selected based on the type of soil, sample depth, number of samples
 14 required, and training of available personnel. The selection of a sampling tool may also be
 15 based on the expected use of the results. For example, if a soil sample is collected to verify the
 16 depth profile used to develop the calibration for in situ gamma spectrometry, it is important to
 17 preserve the soil core. **Table 7.1** lists several examples of tools used for collecting soil samples,
 18 situations where they are applicable, and some advantages and disadvantages involved in their
 19 use.

20 Samples collected below the surface are useful in establishing the extent of residual radioactive
 21 material in the vertical profile. Understanding the extent of residual radioactive material below
 22 the surface can be helpful in determining remediation alternatives and release criteria. Sample
 23 containers are generally not a major concern for collecting surface soil samples. Polyethylene
 24 bottles with screw caps and wide mouths are recommended and should be new or clean, dry,
 25 and checked for residual radioactive material before reuse. Polyethylene bags are acceptable,
 26 especially with heavy gauge plastic to avoid sample spillage from tears in the bags. These
 27 containers are fairly economical, provide easy access for adding and removing samples, and
 28 resist chemicals, breaking, and temperature extremes. Glass containers are also acceptable,
 29 but they are fragile and tend to break during shipment. Metal containers are sometimes used,
 30 but sealing the container can present a problem, and corrosion can be an issue if the samples
 31 are stored for a significant length of time.

32 **Table 7.1: Soil Sampling Equipment⁴**

Equipment	Application	Advantages	Disadvantages/ Considerations
Scoop, Trowel, or Post-Hole Digger	Soft surface soil	<ul style="list-style-type: none"> Inexpensive 	<ul style="list-style-type: none"> Trowels with painted surfaces should be avoided.

⁴ Reproduced and adapted from EPA 1995.

Equipment	Application	Advantages	Disadvantages/ Considerations
		<ul style="list-style-type: none"> • Easy to use and decontaminate 	
Bulb Planter	Soft Soil, 0–15 cm (0–6 in.)	<ul style="list-style-type: none"> • Easy to use • Uniform diameter and sample volume • Preserves soil core 	<ul style="list-style-type: none"> • Limited depth capability • Can be difficult to decontaminate
Soil Coring Device	Soft soil, 0–60 cm (0–24 in.)	<ul style="list-style-type: none"> • Relatively easy to use • Preserves soil core 	<ul style="list-style-type: none"> • Limited depth capability • Can be difficult to decontaminate
Thin-Wall Tube Sampler	Soft soil, 0–3 m (0–10 ft)	<ul style="list-style-type: none"> • Easy to use • Preserves soil core • Easy to decontaminate 	<ul style="list-style-type: none"> • Can be difficult to remove cores
Split Spoon Sampler	Soil, to bedrock	<ul style="list-style-type: none"> • Excellent depth range • Preserves soil core • Useful for hard soils 	<ul style="list-style-type: none"> • Often used in conjunction with drill rig for obtaining deep cores
Shelby Tube Sampler	Soft soil, to bedrock	<ul style="list-style-type: none"> • Excellent depth range • Preserves soil core • Tube may be used for shipping core to lab 	<ul style="list-style-type: none"> • May be used in conjunction with drill rig for obtaining deep cores
Bucket Auger	Soft soil, 7.5 cm–3 m (3 in.–10 ft)	<ul style="list-style-type: none"> • Easy to use • Good depth range • Uniform diameter and sample volume 	<ul style="list-style-type: none"> • May disrupt and mix soil horizons greater than 15 cm
Hand-Operated Power Auger	Soil, 15 cm–4.5 m (6 in.–5 ft)	<ul style="list-style-type: none"> • Good depth range • Generally used in conjunction with bucket auger 	<ul style="list-style-type: none"> • Destroys soil core • Requires two or more operators • Can be difficult to decontaminate

1 Abbreviations: cm = centimeters; in. = inches; m = meters; ft = feet.

1 **7.5.2 Building Surfaces**

2 Because building surfaces tend to be relatively smooth, and the radioactive material is assumed
3 to be on or near the surface, direct measurements are typically used to provide information on
4 residual radioactive material concentrations. Sometimes, however, it is necessary to collect
5 actual samples of the building material surface for analysis in a laboratory.

6 **7.5.2.1 Sample Volume**

7 The sample volume collected from building surfaces is usually a less significant DQO concern
8 than the area from which the sample was collected. This is because building surface DCGLs are
9 usually expressed in terms of activity per unit area. It is still necessary to consider the sample
10 volume to account for sample matrix effects that may reduce the chemical recovery, which in
11 turn affects the detection limit.

12 **7.5.2.2 Sample Content**

13 If residual radioactive material is covered by paint or some other treatment, the underlying
14 surface and the coating itself may contain residual radioactive material. If the residual
15 radioactive material is a pure alpha or low-energy beta emitter, measurements at the surface
16 will probably not be representative of the actual residual activity level. In this case, the surface
17 layer is removed from the known area, such as by using a commercial stripping agent or by
18 physically abrading the surface. The removed coating material is analyzed for activity content
19 and the level converted to appropriate units (i.e., becquerels/square meter [Bq/m²], decays per
20 minute [dpm]/100 cm²) for comparison with surface activity DCGLs. Direct measurements can
21 be performed on the underlying surface after removal of the coating.

22 Residual radioactive material may be incorporated into building materials, such as pieces of
23 concrete or other unusual matrices. Developing SOPs for collecting these types of samples may
24 involve consultation with the analytical laboratory to help ensure that the objectives of the
25 survey are achieved.

26 The thickness of the layer of building surface to be removed as a sample should be consistent
27 with the development of the conceptual site model and the DCGLs. For most sites, the surface
28 layer will only be the first few millimeters of the material being sampled.

29 **7.5.2.3 Sampling Equipment**

30 Tools used to provide samples of building surfaces depend on the material to be sampled.
31 Concrete may require chisels, hammers, drills, or other tools specifically designed to remove a
32 thin layer of the surface. Wood surfaces may require using a sander or a saw to collect a
33 sample. Paint may be chemically or physically stripped from the surface.

34 Sample containers for these samples are generally the same as those recommended for soil
35 samples. If chemicals are used to strip paint or other surface materials, the chemical resistance
36 of the container should be considered.

1 **7.5.3 Other Media**

2 Surface soil and building surfaces are the media addressed in MARSSIM during the FSS
3 design. Other media may be involved and may have been remediated. Data collection activities
4 during preliminary surveys (i.e., scoping, characterization, remedial action support) may involve
5 collecting samples of other media to support the FSS design. Examples of other media that may
6 be sampled include—

- 7 • subsurface soil
- 8 • ground water
- 9 • surface water
- 10 • sediments
- 11 • sewers and septic systems
- 12 • flora and fauna (plants and animals)
- 13 • airborne particulates
- 14 • air (gas)

15 **7.6 Field Sample Preparation and Preservation**

16 Proper sample preparation and preservation are essential parts of any radioactive material
17 sampling program. The sampling objectives should be specified before sampling activities
18 begin. Precise records of sample collection and handling are necessary to ensure that data
19 obtained from different locations or time frames are correctly compared.

20 The appropriateness of sample preparation techniques is a function of the analysis to be
21 performed (EPA 1992a, 1992b). Field sample preparation procedures are a function of the
22 specified analysis and the objectives of the survey. It is essential that these objectives be clearly
23 established and agreed on in the early stages of survey planning (see **Section 2.3**).

24 **7.6.1 Surface Soil**

25 Soil and sediment samples, in most protocols, require no field preparation and are not
26 preserved. In some protocols (e.g., if the sample will be analyzed for both volatile organics and
27 radionuclides), cooling of soil samples to 4 degrees Celsius is required during shipping and
28 storage of soil samples.

29 When replicate samples are prepared in the field, it is necessary to homogenize the sample
30 before separation into replicates. There are standard procedures for homogenizing soil in the
31 laboratory (ASTM 2010), but the equipment required for these procedures may not be available
32 in the field. Simple field techniques, such as cone and quarter, or using a riffle splitter to divide
33 the sample may be appropriate if the sample can be dried (ASTM 2003, EPA 1995). If the
34 sample contains significant amounts of residual water (e.g., forms clumps of soil) and there are
35 no facilities for drying the sample, it is recommended that the homogenization and separation

1 into replicates be performed in a laboratory. It is preferable to use non-blind replicates where the
2 same laboratory prepares and analyzes the replicates rather than use poorly homogenized or
3 heterogeneous samples to prepare replicate samples.

4 **7.6.2 Building Surfaces**

5 Field preparation and preservation of building and associated materials, including smear
6 samples, is not generally required. Homogenization of samples to prepare replicates is the
7 same for building surface material and soil.

8 **7.6.3 Other Media**

9 Other media may have significant requirements related to field sample preparation and
10 preservation. For example, water samples may need filtering and acidification. Storage at
11 reduced temperatures (i.e., cooling or freezing) to reduce biological activity may be necessary
12 for some samples. Adding chemical preservatives for specific radionuclides or media may also
13 be required. Guidance on sample preparation and preservation in matrices not discussed above
14 can be found in Chapter 10 of MARLAP.

15 **7.7 Analytical Procedures**

16 The selection of the appropriate radioanalytical methods is normally made before the
17 procurement of analytical services and is included in the SOW of the request for proposal. The
18 SOW may dictate the use of specific methods or be performance based. Unless there is a
19 regulatory requirement, such as conformance to the EPA drinking water methods (EPA 1980b),
20 the specification of performance-based methodology is encouraged. One reason for this is that
21 a laboratory will usually perform better using the methods it routinely employs, rather than other
22 methods with which it has less experience. The laboratory is also likely to have historical data
23 on performance for methods routinely used by that laboratory. However, the methods employed
24 in a laboratory should be derived from a reliable source.

25 This section briefly describes specific equipment and procedures to be used once the sample is
26 prepared for analysis. The results of these analyses (i.e., the concentrations of radioactive
27 material found in these samples) are the values used to determine the level of residual
28 radioactive material at a site. In a decommissioning effort, the DCGLs are expressed in terms of
29 the concentrations of certain radionuclides. It is of vital importance, therefore, that the analyses
30 be accurate, of adequate sensitivity, and have adequate minimum measurement uncertainties
31 for the radionuclides of concern. The selection of analytical procedures should be coordinated
32 with the laboratory and specified in the survey plan.

33 Analytical methods should be adequate to meet the data needs identified in the DQO process.
34 Consultation with the laboratory performing the analysis is recommended before selecting a
35 course of action. MARSSIM is not intended to limit the selection of analytical procedures; rather,
36 all applicable methods should be reviewed to provide results that meet the objectives of the
37 survey. The decision maker and survey planning team should decide whether routine methods
38 will be used at the site or if non-routine methods may be acceptable.

- 39 • Routine analytical methods are documented with information on minimum performance
40 characteristics, such as detection limit, minimum measurement uncertainty, precision and

1 accuracy, and useful range of radionuclide concentrations and sample sizes. Routine
2 methods may be issued by a recognized organization (e.g., Federal or State agency,
3 professional organization), published in a refereed journal, or developed by an individual
4 laboratory. The following are examples of sources for routine methods:

- 5 ○ Methods of Air Sampling and Analysis (Lodge 1988)
- 6 ○ Annual Book of ASTM Standards, Water and Environmental technology. Volume 11.05,
7 Environmental Assessment, Risk Management and Corrective Action (ASTM 2012)
- 8 ○ Standard Methods for the Examination of Water and Wastewater (APHA 2012)
- 9 ○ Environmental Measurements Laboratory Procedures Manual (DOE 1997)
- 10 ○ Inventory of Radiological Methodologies for Sites Contaminated With Radioactive
11 Materials (EPA 2006d)
- 12 ○ Radiochemistry Procedures Manual (EPA 1984)
- 13 ○ ANSI-AARST Radon Protocols/Standards
 - 14 ■ MAH-2014, Protocol for Conducting Measurements of Radon and Radon Decay
15 Products in Homes (AARST 2014a)
 - 16 ■ MAMF-2017, Protocol for Conducting Measurements of Radon and Radon Decay
17 Products in Multifamily Buildings (AARST 2017)
 - 18 ■ MALB-2014, Protocol for Conducting Measurements of Radon and Radon Decay
19 Products in Schools and Large Buildings (AARST 2014b)
 - 20 ■ MS-PC-2015, Performance Specifications for Instrumentation Systems Designed to
21 Measure Radon Gas in Air (AARST 2015)
 - 22 ■ MS-QA-2019, Radon Measurement Systems Quality Assurance (AARST 2019)
- 23 ● Non-routine methods address situations with unusual or problematic matrices; low detection
24 limits; or new parameters, procedures or techniques. Non-routine methods include
25 adjustments to routine methods, new techniques published in refereed literature, and
26 development of new methods.

27 References that provide information on radiochemical methodology and should be considered in
28 the methods review and selection process are available from such organizations as—

- 29 ● National Council on Radiation Protection and Measurements
- 30 ● American Society of Testing and Materials
- 31 ● American National Standards Institute
- 32 ● Radiological and Environmental Sciences Laboratory, Idaho Falls, Idaho (operated by the
33 U.S. Department of Energy)

- 1 • National Urban Security Technology Laboratory, New York City, NY (operated by the
2 U.S. Department of Homeland Security)

3 Equipment vendor literature, catalogs, and instrument manuals are often a source of useful
4 information on the characteristics of radiation detection equipment. **Table 7.2** provides a
5 summary of common laboratory methods with estimated detection limits.

6 Analytical procedures in the laboratory consist of several parts that are assembled to produce
7 an SOP for a specific project or sample type. These procedures may include all or only some of
8 the following elements:

- 9 • laboratory sample preparation
10 • sample dissolution
11 • sample purification
12 • preparation for counting
13 • counting
14 • data reduction

15 **7.7.1 Photon-Emitting Radionuclides**

16 There is minimal special sample preparation required for counting samples using a germanium
17 detector or a sodium iodide (NaI) detector beyond placing the sample in a known geometry for
18 which the detector has been calibrated. The procedures to be followed to process a raw soil
19 sample to obtain a representative subsample for analysis depend, to some extent, upon the size
20 of the sample, the amount of processing already undertaken in the field, and—most important—
21 the radionuclide of interest (NRC 2004). The samples can be measured as they arrive at the
22 laboratory, or the sample can be dried, ground to a uniform particle size, and mixed to provide a
23 more homogeneous sample if required by the SOPs. Guidance on the preparation of samples,
24 including soil samples, can be found in Chapter 12 of MARLAP (NRC 2004).

25 The samples are typically counted using a germanium detector with a multichannel analyzer or
26 a NaI detector with a multichannel analyzer. Germanium detectors have better resolution and
27 can identify peaks (and the associated radionuclides) at lower concentrations. NaI detectors
28 often have a higher efficiency and are significantly less expensive than germanium detectors.
29 Low-energy photons (i.e., x-rays and gamma rays below 50 kilo-electron volts) can be
30 measured using specially designed detectors with an entrance window made from a very light
31 metal, typically beryllium. Descriptions of germanium and NaI detectors are provided in
32 **Appendix H.**

33 Data reduction is usually the critical step in measuring photon-emitting radionuclides. Often
34 several hundred individual gamma ray energies are detected within a single sample. Computer
35 software is usually used to identify energy peaks and associate these peaks with their
36 respective radionuclides. The software is also used to correct for the efficiency of the detector
37 and the geometry of the sample and to provide results in terms of concentrations with the

Table 7.2: Typical Measurement Sensitivities for Laboratory Radiometric Procedures

Sample Type	Radionuclides or Radiation Measured	Procedure	Approximate Detection Capability
Smears (Filter Paper)	Gross alpha	Gas-flow proportional counter; 5 min count Alpha scintillation detector with scaler; 5 min count	0.08 Bq (5 dpm) 0.33 Bq (20 dpm)
	Gross beta	Gas-flow proportional counter; 5 min count End window GM with scaler; 5 min count (unshielded detector)	0.17 Bq (10 dpm) 1.33 Bq (80 dpm)
	Low energy beta (³ H, ¹⁴ C, ⁶³ Ni)	Liquid scintillation spectrometer; 5 min count	0.50 Bq (30 dpm)
Soil Sediment	¹³⁷ Cs, ⁶⁰ Co, ²²⁶ Ra (²¹⁴ Bi) ^a , ²³² Th (²²⁸ Ac), ²³⁵ U	Germanium detector (25% relative efficiency) with multichannel analyzer; pulse height analyzer; 500 g sample; 15 min analysis	0.04–0.1 Bq/g (1–3 pCi/g)
	²³⁴ , ²³⁵ , ²³⁸ U; ²³⁸ , ²³⁹ , ²⁴⁰ Pu; ²²⁷ , ²²⁸ , ²³⁰ , ²³² Th; other alpha emitters	Alpha spectroscopy with multichannel analyzer—pyrosulfate fusion and solvent extraction; surface barrier detector; pulse height analyzer; 1 g sample; 16 h count	0.004–0.02 Bq/g (0.10.5 pCi/g)
Water	Gross alpha	Gas-flow proportional counter; 100 ml sample, 200 min count	0.04 Bq/L (1 pCi/L)
	Gross beta	Gas-flow proportional counter; 100 ml sample, 200 min count	0.04 Bq/L (1 pCi/L)
	¹³⁷ Cs, ⁶⁰ Co, ²²⁶ Ra (²¹⁴ Bi), ²³² Th (²²⁸ Ac), ²³⁵ U	Germanium detector (25% relative efficiency) with multichannel analyzer; pulse height analyzer; 3.5 L sample, 16 h count	0.4 Bq/L (10 pCi/L)
	²³⁴ , ²³⁵ , ²³⁸ U; ²³⁸ , ²³⁹ , ²⁴⁰ Pu; ²²⁷ , ²²⁸ , ²³⁰ , ²³² Th; other alpha emitters	Alpha spectroscopy with multichannel analyzer—solvent extraction; surface barrier detector; pulse height analyzer; 100 ml sample, 30 min count	0.004–0.02 Bq/L (0.1–0.5 pCi/L)
	³ H	Liquid scintillation spectrometry; 5 ml sample, 30 min count	10 Bq/L (300 pCi/L)

Abbreviations: min = minute; Bq = becquerel; dpm = disintegrations per minute; GM = Geiger-Mueller; g = grams; h = hour; pCi = picocuries; ml = milliliters; L = liters

^a Indicates that a member of the decay series is measured to determine activity level of the parent radionuclide of primary interest.

1 associated uncertainty. It is important that the software be either a well-documented commercial
2 package or thoroughly evaluated and documented before use.

3 **7.7.2 Beta-Emitting Radionuclides**

4 Laboratory sample preparation is an important step in the analysis of surface soil and other solid
5 samples for beta-emitting radionuclides. The laboratory will typically have a sample preparation
6 procedure that involves drying the sample and grinding the soil so that all particles are smaller
7 than a specified size to provide a homogeneous sample. A small portion of the homogenized
8 sample is usually all that is required for the individual analysis.

9 Once the sample has been prepared, a small portion is dissolved, fused, or leached to provide a
10 clear solution containing the radionuclide of interest. The only way to ensure that the sample is
11 solubilized is to completely dissolve the sample. However, this can be an expensive and time-
12 consuming step in the analysis. In some cases, leaching with strong acids can consistently
13 provide greater than 80 percent recovery of the radionuclide of interest (NCRP 1976) and may
14 be acceptable for certain applications. After dissolution, the sample is purified using a variety of
15 chemical reactions to remove bulk chemical and radionuclide impurities. The objective is to
16 provide a chemically and radiologically pure sample for measurement. Examples of purification
17 techniques include precipitation, liquid-liquid extraction, ion-exchange chromatography,
18 distillation, and electrodeposition. Gross beta measurements may also be performed on material
19 that has not been purified.

20 After the sample is purified, it is prepared for counting. Beta-emitting radionuclides are usually
21 prepared for a specific type of counter in a specified geometry. Some samples can be
22 precipitated and collected on a filter in a circular geometry to provide a homogeneous sample.
23 Other samples can be converted to the appropriate chemical form and diluted to a specified
24 volume in preparation for counting.

25 Measurements of some samples may be performed using a gas-flow proportional counter.
26 Because total beta activity is measured, it is important that the purification step be performed to
27 remove any interfering radionuclides. Other samples can be added to a liquid scintillation
28 cocktail and counted using a liquid scintillation spectrometer. Liquid scintillation spectrometers
29 can be used for low-energy beta-emitting radionuclides, such as ^3H and ^{63}Ni . Proper
30 applications can decrease lower limits of detection for all nuclides; however, typical applications
31 in many labs limit the minimum detectable activity to those that are higher than standard gas
32 proportional counting. Gas-flow proportional counters have a very low background. **Appendix H**
33 provides a description of both the gas-flow proportional counter and the liquid scintillation
34 spectrometer.

35 **7.7.3 Alpha-Emitting Radionuclides**

36 Laboratory sample preparation for alpha-emitting radionuclides is similar to that for beta-emitting
37 radionuclides. Sample dissolution and purification tasks are also similar to those performed for
38 beta-emitting radionuclides.

39 Because of the limited penetrating power of alpha particles, the preparation for counting is often
40 a critical step. Gross alpha measurements can be made using small sample sizes with a gas-
41 flow proportional counter, but self-absorption of the alpha particles results in a relatively high
42 detection limit for this technique. Liquid scintillation spectrometers can also be used to measure
43 alpha-emitting radionuclides, but the resolution limits the usefulness of this technique. Most
44 alpha-emitting radionuclides are measured in a vacuum (to limit absorption by air) using alpha

1 spectroscopy. This method requires that the sample be prepared as a virtually weightless mount
2 in a specific geometry. Electrodeposition is the traditional method for preparing samples for
3 counting. This technique provides the highest resolution, but it requires a significant amount of
4 training and expertise on the part of the analyst to produce a high-quality sample. Precipitation
5 of the radionuclide of interest on the surface of a substrate is often used to prepare samples for
6 alpha spectroscopy. While this technique generally produces a spectrum with lower resolution,
7 the preparation time is relatively short compared to electrodeposition, and personnel can be
8 trained to prepare acceptable samples relatively quickly.

9 Alpha-emitting radionuclides are typically measured using alpha spectroscopy. The data
10 reduction requirements for alpha spectroscopy are greater than those for beta-emitting
11 radionuclides and similar to those for photon-emitting radionuclides. Alpha spectroscopy
12 produces a spectrum of alpha particles detected at different energies, but because the sample
13 is purified before counting, all of the alpha particles come from radionuclides of a single
14 element. This simplifies the process of associating each peak with a specific radionuclide, but
15 the lower resolution associated with alpha spectroscopy increases the difficulty of identifying the
16 peaks. Although commercial software packages are available for interpreting alpha
17 spectroscopy results, an experienced operator is required to ensure that the software is working
18 properly.

19 **7.8 Sample Tracking**

20 Sample tracking refers to the identification of samples, their location, and the individuals
21 responsible for their custody and transfer of the custody. This process covers the entire process
22 from collection of the samples and remains intact through the analysis and final holding or
23 disposal. It begins with the taking of a sample where its identification and designation of the
24 sample are critical to being able to relate the analytical result to a site location.

25 Tracking samples from collection to receipt at the analytical laboratory is normally done through
26 a COC process and documented on a COC or tracking record. The purpose of the COC record
27 is to ensure the security and legal defensibility of the sample throughout the process. When
28 samples are received by the laboratory, internal tracking and COC procedures should be in
29 place. These procedures should be documented through SOPs that ensure integrity of the
30 samples. Documentation of changes in the custody of a sample is important. This is especially
31 true for samples that may be used as evidence to establish compliance with release criteria. In
32 such cases, there should be sufficient evidence to demonstrate that the integrity of the sample
33 is not compromised from the time it is collected to the time it is analyzed. During this time, the
34 sample should either be under the positive control of a responsible individual or secured and
35 protected from any activity that could change the true value of the results or the nature of the
36 sample. When this degree of sample handling or custody is necessary, written procedures
37 should be developed for field operations and for interfacing between the field operations and the
38 analytical laboratory. This ensures that a clear transfer of the custodial responsibility is well-
39 documented and that no questions exist as to who is responsible for the sample at any time.

40 **7.8.1 Field Tracking Considerations**

41 Suggestions for field sample tracking are given below:

- 42 • Field personnel are responsible for maintaining field logbooks with adequate information to
43 relate the sample identifier (sample number) to its location and for recording other
44 information necessary to adequately interpret results of sample analytical data. Logbooks

- 1 may use electronic records, provided information is stored in manner that is tamper-proof
2 and retrievable if electronic media fail.
- 3 • The sample collector is responsible for the care and custody of the samples until they are
4 properly transferred or dispatched. This means that samples are in their possession, under
5 constant observation, or secured. Samples may be secured in a sealed container, locked
6 vehicle, locked room, etc.
 - 7 • Sample labels should be completed for each sample using waterproof ink or in a tamper-
8 proof and recoverable electronic medium.
 - 9 • The survey manager or designee determines whether or not proper custody procedures
10 were followed during the field work and decides if additional sampling is indicated.
 - 11 • If photographs are included as part of the sampling documentation, the name of the
12 photographer, date, time, site location, and site description should be entered sequentially in
13 a logbook as the photos are taken. After the photographs are printed, the prints should be
14 serially numbered. Alternatively, the information can be filed in a tamper-proof electronic
15 form or database.

16 **7.8.2 Transfer of Custody**

17 Suggestions for transferring sample custody are given below:

- 18 • All samples leaving the site should be accompanied by a COC record. This record should be
19 standardized and document sample custody transfer from the sampler, often through
20 another person, to the laboratory. The sample collector is responsible for initiating the
21 tracking record. The record should include a list, containing sample designation (number), of
22 the samples in the shipping container and the analysis requested for each sample.
- 23 • Shipping containers should be sealed and include a tamper-indicating seal that will indicate
24 if the container seal has been disturbed. The method of shipment, courier name, or other
25 pertinent information should be listed in the COC record.
- 26 • The original COC record should accompany the samples. A copy of the record should be
27 retained by the individual or organization relinquishing the samples. If a sample is to be split
28 and distributed to more than one analytical laboratory, multiple forms will be needed to
29 accompany sample sets.
- 30 • Discuss the custody objectives with the shipper to ensure that the objectives are met. For
31 example, if the samples are sent by mail and the originator of the sample requires a record
32 that the shipment was delivered, the package should be registered with return receipt
33 requested. If, on the other hand, the objective is to simply provide a written record of the
34 shipment, a certificate of mailing may be a less expensive and appropriate alternative.
- 35 • The individual receiving the samples should sign, date, and note the time of receipt on the
36 record. The condition of the container and the tamper-indicating seal should be documented
37 on the COC. Any problems with the individual samples, such as a broken container, should
38 be noted on the record.
- 39 • COC procedures may utilize tamper-proof electronic media, as appropriate.

1 **7.8.3 Radiochemical Holding Times**

2 In some circumstances, sample holding times are particularly important. For example, liquid
3 samples are usually analyzed as quickly as possible. This would also be true for short half-lived
4 radionuclides. Minimizing the holding times in these situations can reduce the measurement
5 uncertainties and lower the minimum detectable concentrations.

6 For this reason, the SOW should contain the requirements for radiological holding and sample
7 turnaround times. It is important that the laboratory review the specifications for radionuclides
8 that have short half-lives (less than 30 days), because the method proposed by the laboratory
9 may depend on the required radiological holding time. For very short-lived radionuclides, it is
10 crucial to analyze the samples within the first two half-lives to meet the MQOs conveniently.
11 Additionally, samples requiring parent decay or progeny ingrowth should be held for sufficient
12 time before counting. Limits for minimum ingrowth and maximum or minimum decay times
13 should be established for all analytical methods where they are pertinent. For ingrowth, the
14 limits should reflect the minimum time required to ensure that the radionuclides of interest have
15 accumulated sufficiently to not adversely affect the detection limit or uncertainty (e.g., holding
16 samples for ^{226}Ra analysis to permit ingrowth of ^{222}Rn). Alternatively, requirements for holding
17 times may be set to ensure that interfering radionuclides have a chance to decay sufficiently
18 Conversely, the time for radioactive decay of the radionuclides of interest should be limited such
19 that the decay factor does not elevate the minimum detectible concentration or adversely affect
20 the measurement uncertainty (NRC 2004).

21 **7.8.4 Laboratory Tracking**

22 When the samples are received by the laboratory, they are prepared for radiochemical
23 analyses, which includes dividing the sample into aliquots. The tracking and COC
24 documentation within the laboratory become somewhat complicated because several portions
25 of the original sample may exist in the laboratory at a given time. The term "tracking" refers to
26 an accountability process that meets generally acceptable laboratory practices as described by
27 accrediting bodies but is less stringent than a formal COC process. Similar to the COC process,
28 tracking also develops a record of all individuals responsible for the custody and transfer of
29 samples. The use of a computer-based laboratory information management system can greatly
30 assist in tracking samples and fractions through the analytical system.

31 The minimal laboratory tracking process consists of the following:

- 32 • transfer of custody on receipt of the samples (original COC form is retained by the laboratory
33 and submitted with the data package for the samples)
- 34 • documentation of sample storage (location and amount)
- 35 • documentation of removal and return of sample aliquots (amount, date and time, person
36 removing or returning, and reason for removal)
- 37 • transfer of the samples and residues to the receiving authority (usually the site from which
38 they were taken)
- 39 • tamper-proof electronic systems acceptable for laboratory tracking

40 The procedure for accomplishing the above varies from laboratory to laboratory, but the exact
41 details of performing the operations of sample tracking should be contained in an SOP.

1 7.9 Packaging and Transporting Samples

2 All samples being shipped for radiochemical analysis should be properly packaged and labeled
3 before transport offsite or within the site. The primary concern is the possibility of spills, leaks, or
4 breakage of the sample containers. In addition to resulting in the loss of samples and cross-
5 contamination, the possible release of hazardous material poses a threat to the safety of
6 persons handling and transporting the package.

7 Suggestions for packaging and shipping radioactive environmental samples are listed below:

- 8 • Review NRC requirements (10 CFR Part 71) and U.S. Department of Transportation (DOT)
9 requirements (49 CFR Parts 171–177) for packaging and shipping radioactive
10 environmental samples.
- 11 • Visually inspect each sample container for indication of leaks or defects in the sample
12 container.
 - 13 ○ Liquid samples should be shipped in plastic containers, if possible, and the caps on the
14 containers should be secured with tape. One exception to the use of plastic bottles is
15 samples collected for ^3H analyses, which may require glass containers.
 - 16 ○ Heavy plastic bags with sealable tops can be used to contain solid samples (e.g., soil,
17 sediment, air filters). The zipper lock should be secured with tape. Heavy plastic lawn
18 bags can be used to contain vegetation samples. The tops should be closed with a “tie”
19 that is covered by tape to prevent it from loosening and slipping off.
- 20 • Wipe individual sample containers with a damp cloth or paper towel to remove any exterior
21 contamination. The outer surfaces of containers holding samples collected in an area
22 containing residual radioactive material should be surveyed with one or more hand-held
23 instruments appropriate for the suspected type of radioactive material.
- 24 • If glass sample containers are used, place sample containers inside individual plastic bags
25 and seal to contain the sample in case of breakage.
- 26 • Use packing material (e.g., paper, Styrofoam™, bubble wrap) to immobilize and isolate each
27 sample container and buffer hard knocks on the outer container during shipping. This is
28 especially important in cold weather, when plastic containers may become brittle and water
29 samples may freeze.
- 30 • When liquid samples are shipped, include a sufficient quantity of an absorbent material
31 (e.g., vermiculite) to absorb all liquid packed in the shipping container in case of breakage.
32 This absorbent material also may suffice as the packing material.
- 33 • Include the original signed and dated COC form, identifying each sample in the package. It
34 is good practice to place the COC form in a plastic bag to prevent it from becoming wet or
35 contaminated in case of a spill during shipment. If possible, avoid having multiple packages
36 of samples covered by a single COC form.
- 37 • Seal closed the package and apply COC tape in such a manner that it must be torn (broken)
38 to open the package. The tape should carry the signature of the sender, and the date and
39 time, so that it cannot be removed and replaced undetected.

- 1 • Ice chests constructed of metal or hard plastic make excellent shipping containers for
2 radioactive environmental samples.
- 3 • Regulations may require specific labeling and markings on the external surface of each
4 shipping container and may also require handling instructions and precautions be attached
5 to the shipping container. Some information should be included on the package even if not
6 required by the regulations, such as the sender's and receiver's (consignee and consignor)
7 names, addresses, and telephone numbers. When required by shipping regulation, proper
8 handling instructions and precautions should be clearly marked on shipping containers.
- 9 • Shipments with dry ice or other hazardous packaging material are subject to requirements
10 pertaining to the packaging, apart from the radioactive or hazardous contents.

11 If samples are sent offsite for analysis, the shipper is responsible for complying with all
12 applicable Federal, State, and local regulations. Applicable Federal regulations are briefly
13 addressed below. Any State or local regulation will very likely reflect a Federal regulation.

14 **7.9.1 U.S. Nuclear Regulatory Commission Regulations**

15 NRC regulations for packaging, preparation, and shipment of licensed material are contained in
16 10 CFR Part 71: "Packaging and Transportation of Radioactive Materials."

- 17 • Samples containing low levels of radioactive material are exempted as set forth in §§ 71.10.
- 18 • Low Specific Activity material (LSA) is defined in §§ 71.4: "Definitions." Samples classified
19 as LSA need only meet the requirements of the DOT, discussed below, and the
20 requirements of §§ 71.88: "Air transport of plutonium." Most environmental samples either
21 will fall into this category or will be exempt of any DOT regulations.

22 **7.9.2 U.S. Department of Transportation Regulations**

23 The DOT provides regulations governing the transport of hazardous materials under the
24 Hazardous Materials Transportation Act of 1975 (88 Stat. 2156, Public Law 93-633). Applicable
25 requirements of the regulations are found in 49 CFR Parts 171–177. Shippers of samples
26 containing radioactive material should be aware of the current rules in the following areas:

- 27 • Accident reporting: 49 CFR 171
- 28 • Marking and labeling packages for shipment: 49 CFR 172
- 29 • Packaging: 49 CFR 173
- 30 • Placarding a package: 49 CFR 172
- 31 • Registration of shipper/carrier: 49 CFR 107
- 32 • Shipper required training: 49 CFR 172
- 33 • Shipping papers and emergency information: 49 CFR 172
- 34 • Transport by air: 49 CFR 175
- 35 • Transport by rail: 49 CFR 174

- 1 • Transport by vessel: 49 CFR 176
- 2 • Transport on public highway: 49 CFR 177

3 **7.9.3 U.S. Postal Service Regulations**

4 Any package containing radioactive materials may not be mailed if it is required to bear the
5 DOT's Radioactive White-1 (49 CFR 172.436), Radioactive Yellow-II (49 CFR 172.438), or
6 Radioactive Yellow-III (49 CFR 172.440) label, or if it contains quantities of radioactive material
7 in excess of those authorized in Publication 6, Radioactive Material, of the U.S. Postal Service.

8 **7.9.4 International Atomic Energy Agency Regulations**

9 In the event that samples or other radioactive materials, such as calibration sources, are
10 shipped outside the boundaries of the United States, the shipment of those materials must
11 comply with the International Atomic Energy Agency *Regulations for the Safe Transport of*
12 *Radioactive Material* (IAEA 2005). The areas addressed in the Regulations include—

- 13 • activity limits and material restrictions
- 14 • requirements and controls for transport
- 15 • radioactive material package and packaging requirements
- 16 • test procedures
- 17 • administrative controls and requirements

8 INTERPRETATION OF SURVEY RESULTS

8.1 Introduction

This chapter discusses the interpretation of survey results, primarily those of the final status survey (FSS). Interpreting a survey's results is most straightforward when measurement data are entirely higher or lower than the wide-area derived concentration guideline level (DCGL_w). In such cases, the decision that a survey unit meets or exceeds the release criteria requires little in terms of data analysis. However, formal statistical tests provide a valuable tool when a survey unit's measurements are neither clearly above nor exclusively below the DCGL_w. Nevertheless, the survey design always makes use of the statistical tests to help ensure that the number of sampling points and the measurement detectability and uncertainty are adequate, but not excessive, for the decision to be made. Although most statistical analysis is completed using statistical software packages, this chapter provides an explanation to facilitate the reader's understanding of the mechanics behind the calculations of these statistical tests.

Section 8.2 discusses the assessment of data quality. The remainder of **Chapter 8** deals with application of the statistical tests used in the decision-making process and the evaluation of the test results. In addition, an example checklist is provided to assist the user in obtaining the necessary information for interpreting the results of an FSS. **Section 8.3** discusses the application of the Sign test to survey data involving radionuclides that are not in the background. **Section 8.4** discusses the application of the Wilcoxon Rank Sum (WRS) test to survey data involving radionuclides that are in the background and, for Scenario B, the application of the quantile test when the null hypothesis is not rejected. Comparisons of scan-only results to an upper confidence limit are discussed in **Section 8.5**. **Section 8.6** discusses the results, including the elevated measurement comparison (EMC), and interpretation of the statistical tests. **Section 8.7** discusses the documentation requirements.

8.2 Data Quality Assessment

Data Quality Assessment (DQA) is a scientific and statistical evaluation that determines whether the data are of the right type, quality, and quantity to support their intended use. An overview of the DQA process is presented in **Section 2.3** and **Appendix D**. The DQA process has five steps:

- Review the Data Quality Objectives (DQOs), Measurement Quality Objectives (MQOs) and Survey Design (**Section 8.2.1**)
- Conduct a Preliminary Data Review (**Section 8.2.2**)
- Select the Statistical Test (**Section 8.2.3**)
- Verify the Assumptions of the Statistical Test (**Section 8.2.4**)
- Draw Conclusions from the Data (**Section 8.2.5**)

1 The effort applied to DQA should be consistent with the graded approach used to develop the
2 survey design. More information on DQA can be found in *Data Quality Assessment: A User's*
3 *Guide* (EPA QA/G-9R, EPA 2006a) and *Data Quality Assessment: Statistical Tools for*
4 *Practitioners* (EPA QA/G-9S, EPA 2006b).

5 Data should be verified and validated as described in the Quality Assurance Project Plan
6 (QAPP). Guidance on data verification and validation can be found in **Appendix D** and Multi-
7 Agency Radiation Laboratory Analytical Protocols (MARLAP) (NRC 2004) Chapter 8. Guidance
8 on developing a QAPP is available in EPA QA/G-5 (EPA 2002a) and MARLAP Chapter 4.

9 **8.2.1 Review the Data Quality Objectives, Measurement Quality Objectives, and Survey** 10 **Design**

11 The first step in the DQA evaluation is a review of the DQO outputs to ensure that they are still
12 applicable. The review of the DQOs and survey design should also include the MQOs
13 (e.g., measurement uncertainty, detectability). For example, if the data suggest the survey unit
14 was misclassified as Class 3 instead of Class 1 (i.e., because measurement results above the
15 DCGL_w were obtained), then the original DQOs should be redeveloped for the correct
16 classification; or, for example, if the data show the measurement uncertainty exceeds the
17 estimate used to design the survey, the DQOs and MQOs should be revisited.

18 The survey design and data collection documentation should be reviewed for consistency with
19 the DQOs. For example, the review should check that the calculated *N* number of samples was
20 taken in the correct locations and that the samples were analyzed using measurement systems
21 with required detection capability and uncertainty. Example checklists for different types of
22 surveys are given in **Chapter 5**.

23 Determining that the survey design provides adequate power is important to decision making,
24 particularly in cases where the average levels of residual radioactive material are near the
25 DCGL_w. This can be done both prospectively during survey design to test the efficacy of a
26 proposed design and retrospectively during interpretation of survey results to determine that the
27 objectives of the design are met. The procedure for generating power curves for specific tests is
28 discussed in **Appendix M**. Note that the accuracy of a prospective power curve depends on
29 having good estimates of the data variability, σ , and the number of measurements. After the
30 data are analyzed, a sample estimate of the data variability, namely the sample standard
31 deviation (*s*) and the actual number of valid measurements will be known. While the Type I (α)
32 decision error rate will always be achieved, the consequence of inadequate power is an
33 increased Type II (β or false negative) decision error rate.

- 34 • For Scenario A, this means that a survey unit that actually meets the release criteria has a
35 higher probability of being incorrectly deemed *not to meet* the release criteria.
- 36 • For Scenario B, this means that a survey unit that does not meet the release criteria has a
37 higher probability of being incorrectly deemed to *meet* the release criteria.

38 Regulators are primarily concerned with errors that result from determining that a survey unit
39 meets the release criteria when it does not. This incorrect decision is a Type I error under
40 Scenario A and a Type II error under Scenario B. Site owners are also concerned with errors

1 that result from determining that a survey unit does not meet the release criteria when it does.
2 This incorrect decision is a Type II error under Scenario A and a Type I error under Scenario B.

3 **8.2.2 Conduct a Preliminary Data Review**

4 To learn about the structure and quality of the data—identifying patterns, relationships, or
5 potential anomalies—it is recommended that the quality assurance (QA) and quality control
6 (QC) reports be reviewed and that basic statistical quantities be calculated and graphs of the
7 data, or populations estimators, be prepared so that objective evidence is provided to support
8 conclusions about the data set.

9 **8.2.2.1 Data Evaluation and Conversion**

10 Radiological survey data are usually obtained in units that have no intrinsic meaning relative to
11 DCGLs, such as the number of counts per unit time. For comparison of survey data to DCGLs,
12 the survey data from field and laboratory measurements are converted to DCGL units. Further
13 information on instrument calibration and data conversion is given in **Section 6.7**.

14 Basic statistical quantities that should be calculated for the sample data set are the—

- 15 • sample mean
- 16 • sample standard deviation
- 17 • sample median¹

18 Other statistical quantities that may be calculated are—

- 19 • the standard error for the mean
- 20 • the highest measurement
- 21 • the lowest measurement

22 The sample mean, \bar{x} , can be calculated using **Equation 8-1**:

$$\bar{x} = \frac{1}{N} \sum_{i=1}^N x_i \quad (8-1)$$

¹ The term “sample” here is a statistical term and should not be confused with laboratory samples. For the calculation of basic statistical quantities above, data may consist of scan data, direct measurement data, or laboratory sample data. See also the glossary definition of sample.

- 1 where N is the number of samples, and x_i are the results of the individual samples. The sample
 2 standard deviation, s , can be calculated using **Equation 8-2**:

$$s = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{x})^2} \quad (8-2)$$

- 3 The median is the middle value of the data set when the number of data points is odd and is the
 4 average of the two middle values when the number of data points is even. Thus, 50 percent of
 5 the data points are above the median, and 50 percent are below the median. **Example 1**
 6 illustrates how to calculate the sample standard deviation.

Example 1: Calculate the Sample Standard Deviation

Suppose the following 20 concentration values are from a survey unit:

90.7, 83.5, 86.4, 88.5, 84.4, 74.2, 84.1, 87.6, 78.2, 77.6,
 86.4, 76.3, 86.5, 77.4, 90.3, 90.1, 79.1, 92.4, 75.5, 80.5.

First, the sample mean of the data should be calculated:

$$\begin{aligned} \bar{x} &= \frac{1}{N} \sum_{i=1}^N x_i \\ &= \frac{1}{N} (90.7 + 83.5 + 86.4 + \dots + 92.4 + 75.5 + 80.5) \\ &= 83.5 \end{aligned}$$

The sample mean is 83.5. The sample standard deviation should also be calculated:

$$\begin{aligned} s &= \sqrt{\frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{x})^2} \\ &= \sqrt{\frac{1}{20-1} [(90.7 - 83.5)^2 + (83.5 - 83.5)^2 + \dots + (75.5 - 83.5)^2 + (80.5 - 83.5)^2]} \\ &= 5.7 \end{aligned}$$

The sample standard deviation is 5.7.

- 7 For Scenario A, the mean concentration of the survey unit should always be compared to the
 8 $DCGL_W$. A mean survey unit concentration less than the $DCGL_W$ is a necessary, but not
 9 sufficient, requirement for the release of the survey unit if the radionuclide is not present in the
 10 background. Where remediation is inadequate, this comparison may readily reveal that a survey

1 unit contains excess residual radioactive material—even before applying statistical tests. For
 2 example, if the sample mean of the data exceeds the $DCGL_W$ and the radionuclide of interest
 3 does not appear in background, then the survey unit clearly does not meet the release criteria.
 4 On the other hand, if every measurement in the survey unit is below the $DCGL_W$, the survey unit
 5 clearly meets the release criteria.²

6 The value of the sample standard deviation is especially important. If the standard deviation is
 7 too large compared to that assumed during the survey design, this may indicate that an
 8 insufficient number of samples were collected to achieve the desired power of the statistical
 9 test. Again, inadequate power can lead to unnecessary remediation for Scenario A (of particular
 10 interest to the regulated) or inadequate remediation for Scenario B (of particular interest to the
 11 regulator).

12 Large differences between the mean and the median would be an indication of skewness in the
 13 data. This would also be evident in a histogram of the data. **Example 2** illustrates a comparison
 14 of the sample mean and median.

Example 2: Comparison of the Sample Mean and the Median

Using the data from the earlier example, take the 20 concentration values from the survey unit:

90.7, 83.5, 86.4, 88.5, 84.4, 74.2, 84.1, 87.6, 78.2, 77.6,
 86.4, 76.3, 86.5, 77.4, 90.3, 90.1, 79.1, 92.4, 75.5, 80.5.

Sort and rank the data from lowest to highest:

1	2	3	4	5	6	7	8	9	10
74.2	75.5	76.3	77.4	77.6	78.2	79.1	80.5	83.5	84.1
11	12	13	14	15	16	17	18	19	20
84.4	86.4	86.4	86.5	87.6	88.5	90.1	90.3	90.7	92.4

For the example data above, the median is 84.25 (i.e., $(84.1 + 84.4)/2$). The difference between the median and the mean (i.e., $84.25 - 83.5 = 0.75$) is a small fraction of the sample standard deviation (i.e., 5.7). Thus, in this instance, the mean and median would not be considered significantly different.

15 Examining the minimum, maximum, and range of the data may provide additional useful
 16 information. The maximum is the value of the largest observed sample, the minimum is the

² It can be verified that if every measurement is below the $DCGL_W$, the conclusion from the statistical tests will always be that the survey unit does not exceed the release criteria.

1 value of the smallest observed sample, and the range is the difference between the maximum
2 and minimum. When there are 30 or fewer data points, values of the range much larger than
3 about 4 to 5 standard deviations would be unusual. For larger data sets, the range might be
4 wider. **Example 3** illustrates how to determine the sample range.

Example 3: Determination of the Sample Range

The minimum in the previous example is 74.2 and the maximum is 92.4, so the range is 18.2 (92.4 - 74.2 = 18.2). Dividing the range by the standard deviation indicates how many standard deviations wide the sample data represent:

$$\frac{18.2}{5.7} = 3.2$$

This is only 3.2 standard deviations. Thus, the range is not unusually large.

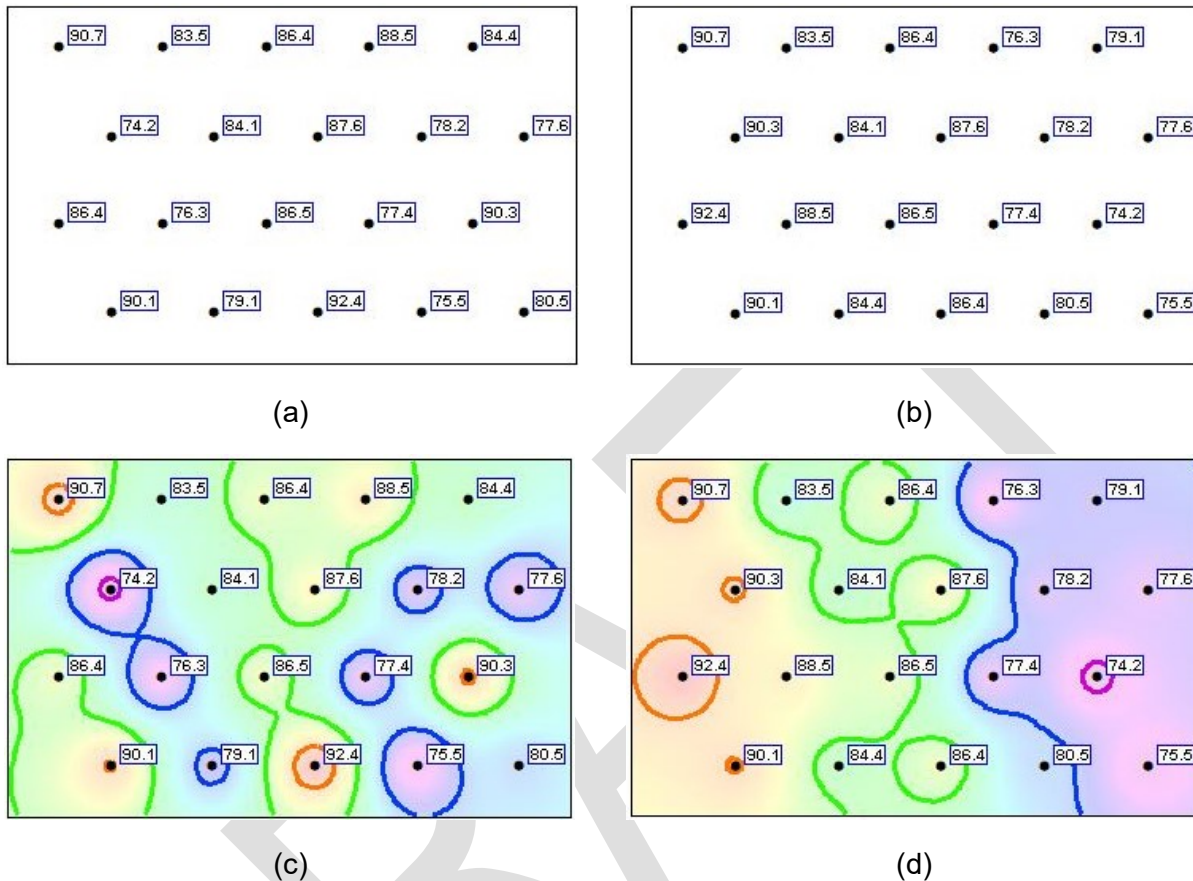
5 8.2.2.2 Graphical Data Review

6 At a minimum, a graphical data review should consist of a posting plot and a histogram.
7 Quantile plots are also useful diagnostic tools, particularly in the two-sample case, to compare
8 the survey unit and reference area in cases where the radionuclide is present in the background
9 or measurements are not radionuclide specific. Quantile plots are discussed in **Appendix L,**
10 **Section L.2.**

11 A posting plot is simply a map of the survey unit with the data values entered at the
12 measurement locations. This potentially reveals heterogeneities in the data, especially possible
13 areas of elevated residual radioactive material. Even in a reference area, a posting plot can
14 reveal spatial trends in background data that might affect the results of the statistical tests used
15 when the radionuclide is present in the background or measurements are not radionuclide
16 specific.

17 If the data given in the examples above were obtained using a triangular grid in a rectangular
18 survey unit, the posting plot might resemble the display in **Figure 8.1. Figures 8.1a and 8.1c**
19 show no unusual patterns in the data, whereas **Figures 8.1b and 8.1d** show the exact same
20 values (and therefore the same mean) but with a different distribution of residual radioactive
21 material. **Figures 8.1b and 8.1d** also reveal an obvious trend toward smaller values as one
22 moves from left to right across the survey unit, which can be discerned only if spatial information
23 is available and analyzed. The graphical display of data in a posting plot is beneficial to better
24 understanding the distribution of residual radioactive material at a site.

25 If the posting plot reveals systematic spatial trends in the survey unit, the cause of the trends
26 would need to be investigated. In some cases, such trends could be due to residual radioactive
27 material, but they may also be due to inhomogeneities in the survey unit background. Other
28 diagnostic tools for examining spatial data trends may be found in EPA Guidance Document
29 QA/G-9S (EPA 2006b). The use of geostatistical tools to evaluate spatial data trends may also
30 be useful in some cases (EPA 1989b).



1 **Figure 8.1: Examples of Posting Plots**

2 Geographic information system (GIS) tools can also be used to help with creation of conceptual
 3 models (e.g., provide spatial context and a better understanding of site features that may control
 4 or enhance radionuclide transport in the environment). Figures created with GIS tools can also
 5 assist with identifying relatively homogeneous areas of residual radioactivity for delineation of
 6 survey units. Examples of features that can be captured on a figure using GIS tools include the
 7 following:

- 8 • study area and property boundary
- 9 • buildings where residual radioactivity may be present
- 10 • roads
- 11 • surface water features (streams, ponds, runoff basins, ditches, culverts)

- 1 • underground features (underground storage tanks, piping)
- 2 • topography, surface geology, and outcrop locations
- 3 • hydrostratigraphic surfaces and isopach maps
- 4 • water table and potentiometric surfaces
- 5 • sampling locations
- 6 • monitoring well locations
- 7 • contaminant distributions

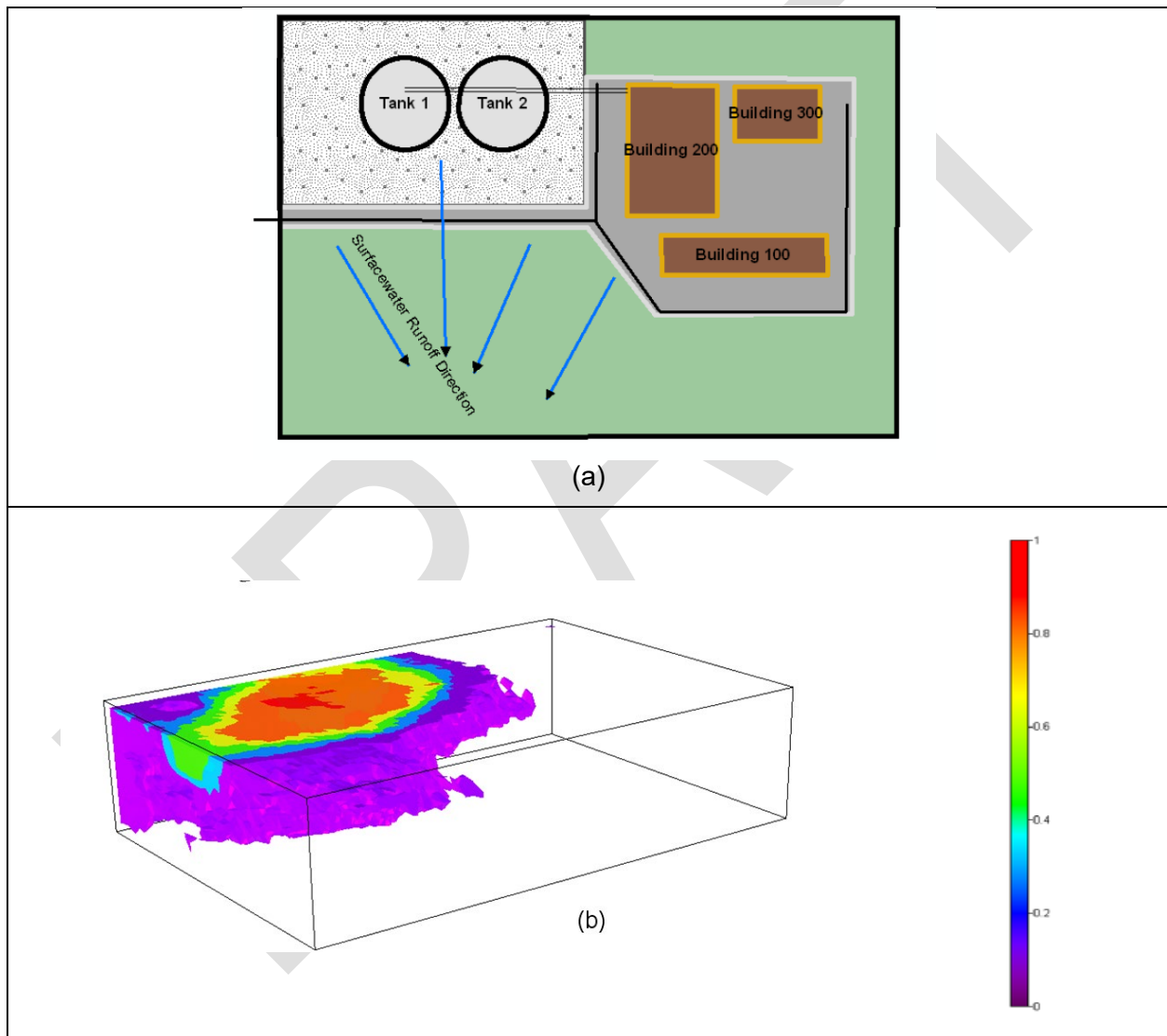
8 For example, **Figure 8.2a** shows a map that includes the location of two hypothetical tanks.
9 Leaks are known to have occurred near the tanks. GIS information on the location of important
10 features and topography of surficial (or subsurface) structures can be used to identify areas
11 where residual radioactivity may be present and more likely to have been transported
12 (e.g., surface water runoff direction). GIS information and geostatistical tools can be helpful in
13 designing survey plans and identifying areas most likely to be above risk-based thresholds. For
14 example, the geostatistical tools available in such codes as Visual Sample Plan and Spatial
15 Analysis and Decision Assistance (SADA) can be used to analyze data and extrapolate data in
16 areas where no data are available. **Figure 8.2** illustrates the use of SADA (Version 5) in
17 creating a three-dimensional visualization of the volume of soil most likely to be affected based
18 on sampling results and use of geostatistical tools available in the code. **Figure 8.2b** illustrates
19 how geostatistical tools can help interpolate and extrapolate data to determine the probability of
20 exceeding a threshold following characterization.

21 A frequency plot (or a histogram) is a useful tool for examining the general shape of a data
22 distribution. This plot is a bar chart of the number of data points within a certain range of values.
23 A frequency plot of the example data from **Figure 8.1** is shown in **Figure 8.3**. A simple method
24 for generating a rough frequency plot is the stem-and-leaf display discussed in **Appendix L,**
25 **Section L.1**. The frequency plot may reveal any obvious departures from symmetry, such as
26 skewness or bimodality (two peaks), in the data distributions for the survey unit or reference
27 area. The presence of two peaks in the survey unit frequency plot may indicate the existence of
28 isolated areas of residual radioactive material, which may need to be further investigated as part
29 of the EMC tests.

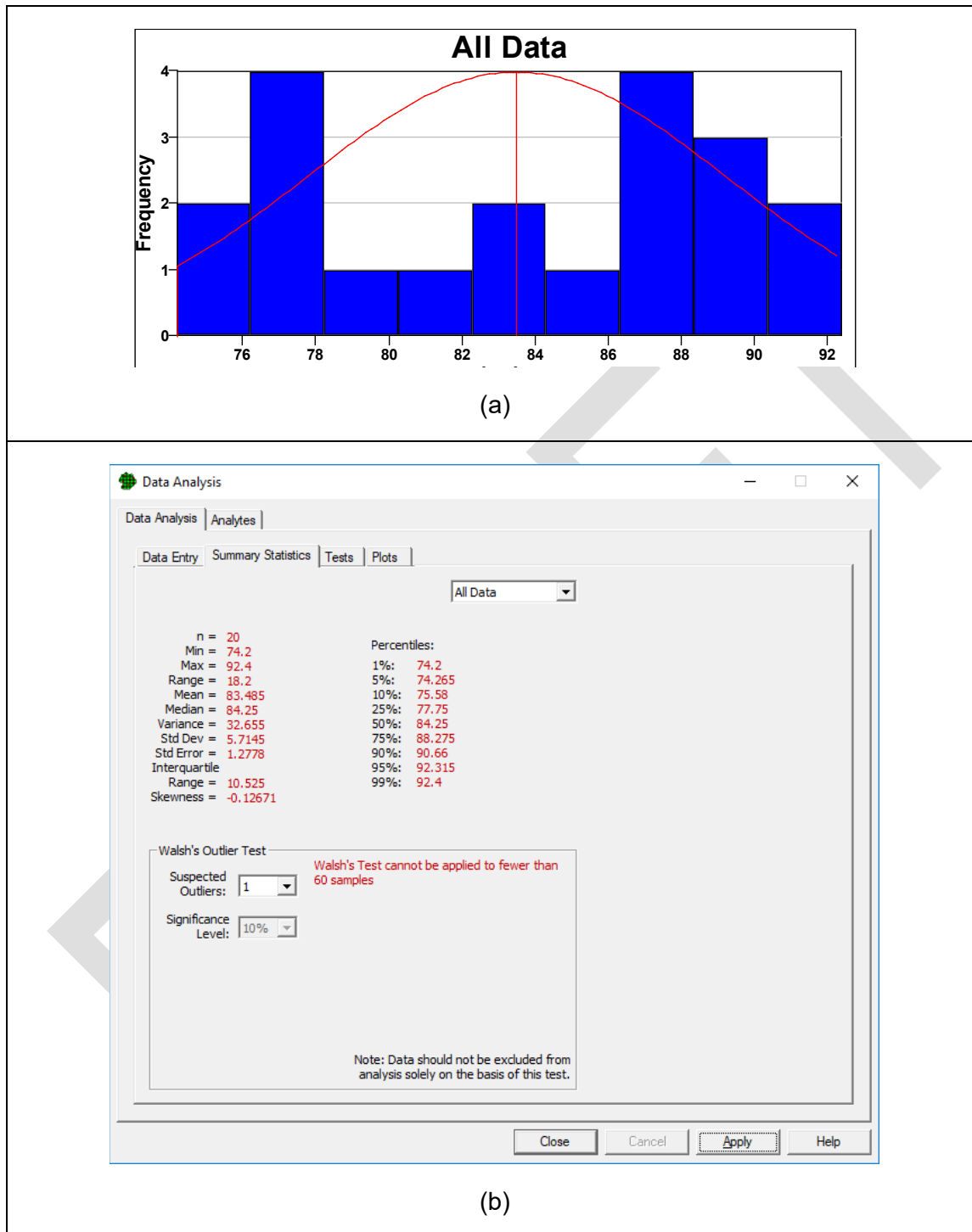
30 The presence of two peaks in the background reference area or survey unit frequency plot may
31 also indicate a mixture of background concentration distributions due to different soil types,
32 construction materials, etc., or it could indicate the presence of residual radioactivity in the
33 background reference area.³ The greater variability in the data due to the presence of such a
34 mixture will reduce the power of the statistical tests to detect an adequately remediated survey
35 unit that meets the release criteria for Scenario A or to detect a survey unit that does not meet

³ In some cases, it may be necessary to perform additional investigation to determine if background reference areas were properly classified as non-impacted.

1 the release criteria for Scenario B. These situations should be avoided whenever possible by
2 carefully matching the background reference areas to the survey units and choosing more
3 homogeneous survey units, as discussed in more detail in **Appendix D**. If relatively
4 homogenous survey units cannot be identified, consistent with the underlying assumptions in
5 the $DCGL_W$ derivation, then other approaches may need to be taken to evaluate the
6 acceptability of the survey units for release (e.g., increased focus on evaluation of the risk of
7 elevated areas). Consult with your regulator for highly heterogeneous survey units.



8 **Figure 8.2: Sample GIS Visualization, Modified from Figures 3.4 and 7.8 in NUREG/CR-**
9 **7021 (NRC 2012).**



1 Figure 8.3: Example of a Frequency Plot (a) and Other Statistical Information Output from
 2 Visual Sample Plan v. 7 (b)

1 Caution should be exercised when developing frequency plots (commonly referred to as
2 histograms). The shape of a histogram can depend on the choice of the bin widths and ranges.
3 If bins are too wide, features of the underlying distribution within the bin width may be missed. If
4 bins are too narrow, the bin-to-bin variability can be mistaken as a feature of the underlying
5 distribution. Additional caution should be exercised when interpreting histograms for small data
6 sets where smaller features, such as a second smaller peak, may not be observed.

7 Skewness or other asymmetry can impact the accuracy of the statistical tests. When the
8 underlying data distribution is highly skewed, it is often because there are a few elevated areas.
9 Because the Elevated Measurement Comparison derived concentration guideline level
10 ($DCGL_{EMC}$) is specifically used to evaluate the acceptability of elevated areas (i.e., the ability of
11 a site with elevated areas of residual radioactivity material above the $DCGL_W$ to meet release
12 criteria), the limitations associated with use of statistical tests based on the median or mean for
13 nonhomogeneous residual radioactivity are mitigated. In cases where highly heterogeneous
14 residual radioactive material is present, care should be taken to ensure that the lateral extent of
15 the elevated area is delineated and a $DCGL_{EMC}$ is calculated consistent with the actual size of
16 the elevated area. When a number of elevated areas are present, techniques can be used to
17 evaluate the cumulative risk of the elevated areas dependent on the distribution of the elevated
18 areas in the survey unit.

19 *8.2.2.3 Draw Conclusions from the Preliminary Data Review*

20 In some instances, a preliminary review of the data may be sufficient to draw conclusions without
21 performing the statistical tests described in **Section 8.2.3**. For example, under Scenario A, the
22 sample mean of the survey unit data can be compared to the reference area sample mean and
23 the $DCGL_W$ to get a preliminary indication of the survey unit status. If the difference of the survey
24 unit sample mean and the reference area sample mean is greater than $DCGL_W$, then the survey
25 unit cannot be released. Alternatively, significantly higher concentrations in the reference area
26 compared to the survey unit may be an indicator that the reference area is not appropriate for the
27 survey unit and warrants further investigation

28 **Tables 8.3–8.5** describe examples of other circumstances leading to specific conclusions based
29 on a simple examination of the data without the need to perform certain statistical tests.

30 *8.2.3 Select the Statistical Test*

31 An overview of the statistical considerations important for FSSs appears in **Section 2.5** and
32 **Appendix D**. The parameter of interest is the mean concentration in the survey unit. The
33 nonparametric tests recommended in this manual, in their most general form, are tests of the
34 median. For data that are from a skewed distribution, the mean could be significantly larger than
35 the median. Therefore, the mean should be compared to the $DCGL_W$ to ensure that the mean is
36 less than the $DCGL_W$, as indicated in **Section 8.2.2.3**. If the data are highly skewed because of
37 the presence of elevated areas, the EMC test helps ensure that the site is acceptable for release.

1 If one assumes that the data are from a symmetric distribution where the median and the mean
2 are effectively equal, these statistical evaluations are also tests of the mean. If the assumption
3 of symmetry is violated, then nonparametric tests of the median approximately test the mean.
4 Computer simulations (Hardin and Gilbert, 1993) have shown that the approximation is a good
5 one—that is, the correct decision will be made about whether the mean concentration exceeds
6 the $DCGL_W$, even when the data come from a skewed distribution. In this regard, Hardin and
7 Gilbert found the nonparametric tests to be correct more often than the commonly used
8 Student's t test. The robust performance of the Sign and WRS tests over a wide range of
9 conditions is the reason that they are recommended in this manual.

10 When a given set of assumptions is true, a parametric test designed for exactly that set of
11 conditions will have the highest power. For example, if the data are from a normal distribution,
12 the Student's t test will have higher power than the nonparametric tests. It should be noted that
13 for large enough sample sizes (e.g., large number of measurements), the Student's t test is not
14 a great deal more powerful than the nonparametric tests. On the other hand, when the
15 assumption of normality is violated, the nonparametric tests can be much more powerful than
16 the t test. Therefore, any statistical test may be used, provided that the data are consistent with
17 the assumptions underlying their use. When these assumptions are violated, the prudent
18 approach is to use the nonparametric tests, which generally involve fewer assumptions than
19 their parametric equivalents.

20 The Sign test, described in **Section 5.3.4**, is typically used when the radionuclide is not present
21 in background and radionuclide-specific measurements are made. The Sign test may also be
22 used if the radionuclide is present in the background at such a small fraction of the $DCGL_W$
23 value as to be considered insignificant. In this case, background concentrations of the
24 radionuclide are included with the residual radioactive material (i.e., the entire amount is
25 attributed to facility operations). Thus, the total concentration of the radionuclide is compared to
26 the release criteria. This option should be used only if one expects that ignoring the background
27 concentration will not affect the outcome of the statistical tests. The advantage of ignoring a
28 small background contribution is that no reference area is needed. This can simplify the FSS
29 considerably. Some alternative statistical tests to the Sign test are described in Chapter 14 of
30 NUREG-1505, *A Nonparametric Statistical Methodology for the Design and Analysis of Final*
31 *Status Decommissioning Surveys* (NRC 1998a) and in **Chapter 2**.

32 The Sign test (**Section 8.3.1**) evaluates whether the median of the data is above or below the
33 $DCGL_W$. If the data distribution is symmetric, the median is equal to the mean. In cases where
34 the data are severely skewed, the mean may be above the $DCGL_W$, while the median is below
35 the $DCGL_W$. In such cases, the survey unit does not meet the release criteria regardless of the
36 result of the statistical tests. On the other hand, if the largest measurement is below the $DCGL_W$,
37 the Sign test will always show that the survey unit meets the release criteria.

38 For FSSs, the WRS test discussed in **Section 5.3.3** can be used when the radionuclide of
39 concern appears in background or if measurements used are not radionuclide-specific. The
40 WRS test (**Section 8.4.1**) assumes the reference area and survey unit data distributions are
41 similar except for a possible shift in the medians. When the data are severely skewed, the value
42 for the mean difference may be above the $DCGL_W$, while the median difference is below the
43 $DCGL_W$. In such cases, the survey unit does not meet the release criteria regardless of the

1 result of the statistical test. On the other hand, if the difference between the largest survey unit
 2 measurement and the smallest reference area measurement is less than the $DCGL_W$, the WRS
 3 test will always show that the survey unit meets the release criteria.

4 The use of paired observations for survey units with different backgrounds and some alternative
 5 statistical tests to the WRS test are described in Chapters 12 and 14, respectively, of NUREG-
 6 1505, *A Nonparametric Statistical Methodology for the Design and Analysis of Final Status*
 7 *Decommissioning Surveys* (NRC 1998a). If Scenario B was selected during the DQO process,
 8 the quantile test is performed to test for skewness when the WRS test does not reject the null
 9 hypothesis.

10 If individual scan-only survey results are recorded, a nonparametric confidence interval can be
 11 used to evaluate the results of the FSS. Similarly, a confidence interval can be used to evaluate
 12 a series of in situ measurements with overlapping fields of view. A one-tailed version of
 13 Chebyshev's inequality or software (e.g., EPA's ProUCL software) can be used to evaluate the
 14 probability of exceeding the upper bound of the grey region (UBGR) using an upper confidence
 15 limit (UCL). The use of a UCL applies to both Scenario A (where the UBGR equals the $DCGL_W$)
 16 and Scenario B (where the UBGR equals the discrimination limit [DL]). **Table 8.1** provides a
 17 summary of the statistical tests and evaluation methods discussed in this chapter.

18 **Table 8.1: Summary of Statistical Tests and Evaluation Methods**

Statistical Test or Evaluation Method	Applicability
Sign Test (see Section 8.3 and Table 8.3)	<ul style="list-style-type: none"> • Radionuclide not in background <i>and</i> nuclide-specific measurements • Scenario A or B
WRS Test (see Section 8.4 and Table 8.4)	<ul style="list-style-type: none"> • Radionuclide in background <i>or</i> non-nuclide specific measurements • Scenario A or B
Quantile Test (see Section 8.4)	<ul style="list-style-type: none"> • Test for non-uniform distribution of radioactive material • Combined with WRS Test • Scenario B only
Comparison to UCL (see Section 8.5 and Table 8.5)	<ul style="list-style-type: none"> • Scan-only surveys or in situ surveys • Scenario A or B

19 Abbreviations: WRS test = Wilcoxon Rank Sum test; UCL = upper confidence limit.

20 **8.2.4 Verify the Assumptions of the Statistical Tests**

21 An evaluation to determine that the data are consistent with the underlying assumptions made
 22 for the statistical procedures helps to validate the use of a test. One may also determine that
 23 certain departures from these assumptions are acceptable when given the actual data and other
 24 information about the study.

1 For surveys consisting of a combination of scanning with samples or direct measurements, the
2 nonparametric tests described in this chapter assume that the data from the reference area or
3 survey unit consist of independent samples from each distribution. Spatial dependencies that
4 potentially affect the assumptions can be assessed using posting plots (**Section 8.2.2.2**). More
5 sophisticated tools for determining the extent of spatial dependencies are also available
6 (e.g., EPA QA/G-9S, EPA 2006b). These methods tend to be complex and are best used with
7 guidance from a professional statistician.

8 Asymmetry in the data can be diagnosed with a stem-and-leaf display, a histogram, or a
9 quantile plot.

10 One of the primary advantages of the nonparametric tests is that they involve fewer
11 assumptions about the data than their parametric counterparts. If parametric tests are used,
12 (e.g., Student's t test), then any additional assumptions made in using them should be verified
13 (e.g., testing for normality). These issues are discussed in detail in EPA QA/G-9S (EPA 2006b).

14 One of the more important assumptions made in the survey designs described in
15 **Sections 5.3.3 and 5.3.4** is that the sample sizes determined for the tests are sufficient to
16 achieve the DQOs set for the Type I and Type II error rates. Verification of the power of the
17 tests ($1 - \beta$) correctly determines a site that does not meet the release criterion is not released
18 under Scenario B, regardless of what the test determined, which may be of particular interest to
19 the regulator and is, therefore, required for surveys conducted under Scenario B. For Scenario
20 A, verification of the power of the tests to correctly release a site that meets the release criteria,
21 regardless of what the test determined, may be of particular interest to the site owner/operator.
22 Methods for assessing the power are discussed in **Appendix M**.

23 For these reasons, it is better to plan the surveys cautiously, including—

- 24 • overestimating the potential data variability
- 25 • taking more than the minimum number of measurements
- 26 • overestimating minimum detectable concentrations (MDCs) and measurement method
27 uncertainties

28 If one is unable to show that the DQOs and MQOs were met with reasonable assurance, a
29 resurvey may be needed. Examples of assumptions and possible methods for their assessment
30 are summarized in **Table 8.2**.

31 For scan-only surveys where data are compared to a UCL, Chebyshev's inequality should be
32 used with caution when there are very few points in the data set. **Section 6.7** provides
33 information on converting the instrument reading to the appropriate units for reporting the UCL.
34 This is because the population mean and standard deviation in the Chebyshev formula are
35 being estimated by the sample mean and sample standard deviation. In a small data set from a
36 highly skewed distribution, the sample mean and sample standard deviation may be
37 underestimated if the high concentration but low probability portion of the distribution is not
38 captured in the sample data set.

1 **Table 8.2: Methods for Checking the Assumptions of Statistical Tests**

Assumption	Diagnostic
Spatial Independence	Posting Plot
Symmetry	Histogram, Quantile Plot
Data Variance	Sample Standard Deviation
Adequate Power	Retrospective Power Chart

2 **8.2.5 Draw Conclusions from the Data**

3 The types of measurements that can be made in a survey unit are direct measurements,
4 laboratory samples, and scans.

5 Specific details for conducting the statistical tests are given in **Section 8.3** (Sign test),
6 **Section 8.4** (WRS test and quantile test), and **Section 8.5** (upper confidence limit test). When
7 the data clearly show that a survey unit meets or exceeds the release criteria, the result is often
8 obvious without performing the formal statistical analysis. The data still need to meet the
9 assumptions for the statistical tests, (e.g., ensuring adequate power in Scenario B.) **Tables 8.3–**
10 **8.5** display various survey results and their conclusions.

11 **Table 8.3: Summary of Statistical Tests for Radionuclide Not in Background and**
12 **Radionuclide-Specific Measurement**

Survey Result	Conclusion
Scenario A	
All measurements are less than DCGL _w .	Survey unit meets release criteria.
Sample mean is greater than DCGL _w .	Survey unit does not meet release criteria.
Any measurement is greater than DCGL _w , and the sample mean is less than DCGL _w .	Conduct Sign test and EMC.
Scenario B	
Sample mean is less than the AL.	Survey unit meets release criteria.
All measurements are greater than AL.	Survey unit does not meet release criteria.
Any measurement is greater than the AL, and the sample mean is greater than AL.	Conduct Sign test and EMC.

13 Abbreviations: DCGL_w = wide-area derived concentration guideline level; EMC = elevated measurement comparison;
14 AL = action level.
15

1 **Table 8.4: Summary of Statistical Tests for Radionuclide in Background or Radionuclide**
 2 **Non-Specific (Gross) Measurements**

Survey Result	Conclusion
Scenario A	
Difference between largest survey unit measurement and smallest reference area measurement is less than the DCGL _w .	Survey unit meets release criteria.
Difference between survey unit sample mean and reference area sample mean is greater than the DCGL _w .	Survey unit does not meet release criteria.
Difference between any survey unit measurement and any reference area measurement is greater than DCGL _w , and the difference between survey unit sample mean and reference area sample mean is less than the DCGL _w .	Conduct WRS test and EMC.
Scenario B	
Difference between survey unit sample mean and reference area sample mean is less than the AL.	Conduct quantile test.
Difference between smallest survey unit measurement and largest reference area measurement is greater than the AL.	Survey unit does not meet release criteria.
Difference between any survey unit measurement and any reference area measurement is less than the AL, and the difference between survey unit sample mean and reference area sample mean is greater than AL.	Conduct WRS test, quantile test, and EMC.

3 Abbreviations: DCGL_w = wide-area derived concentration guideline level; WRS test = Wilcoxon Rank Sum test;
 4 EMC = elevated measurement comparison; AL = action level.
 5

6 If applicable release criteria for elevated measurements exist, then both the measurements at
 7 discrete locations and the scans are also subject to the EMC. The result of comparing individual
 8 measurements to DCGL_{EMC} is not conclusive as to whether the survey unit meets or exceeds
 9 the release criteria, but it is a flag or trigger for further investigation. The investigation may
 10 involve taking further measurements to determine that the area and level of the elevated
 11 residual radioactive material are such that the resulting dose or risk meets the release criteria.⁴
 12 The investigation should also provide adequate assurance, using the DQO process, that there

⁴ Rather than, or in addition to, taking further measurements, the investigation may involve assessing the adequacy of the exposure pathway model used to obtain the DCGLs and the consistency of the results obtained with the Historical Site Assessment and the scoping, characterization, and remedial action support surveys.

1 **Table 8.5: Summary of Results for Scan-Only Surveys**

Survey Result ^a	Conclusion
Scenario A	
UCL is less than DCGL _w .	Survey unit meets average release criteria; conduct the EMC.
UCL is greater than DCGL _w .	Survey unit does not meet release criteria.
Scenario B	
UCL is less than DL.	Survey unit meets average release criteria; conduct the EMC.
UCL is greater than DL.	Survey unit does not meet release criteria.

2 Abbreviations: UCL = upper confidence limit; DCGL_w = wide-area derived concentration guideline level; EMC =
3 elevated measurement comparison; DL = discrimination limit.

4 ^a See **Section 8.5** for additional details on calculating the UCL.

5 are no undiscovered areas of elevated residual radioactive material in the survey unit that might otherwise result in a
6 dose or risk exceeding the release criteria when considered in conjunction with the dose or risk posed by the
7 remainder of the survey unit. In some cases, this may lead to reclassifying all or part of a survey
8 unit unless the results of the investigation indicate that reclassification is not necessary. The
9 investigation level appropriate for each class of survey unit and type of measurement is shown
10 in **Table 5.4** and is described in **Section 5.3.8. Example 4** provides background information
11 that will be used in **Examples 5–8**.

Example 4: Illustrative Examples Background Information

This example provides the background for **Examples 5–8**.

To illustrate the data interpretation process, consider an example facility with 14 survey units consisting of interior concrete surfaces, one interior survey unit with drywall surfaces, and two outdoor surface soil survey units. The radionuclide of concern is cobalt-60 (⁶⁰Co). The interior surfaces were measured with a gas-flow proportional counter (see **Appendix H**) with an active surface area of 100 square centimeters (cm²) to determine gross beta activity. Because these measurements are not radionuclide-specific, appropriate reference areas were chosen for comparison. The exterior surface soil was measured with a germanium spectrometer to provide radionuclide-specific results. A reference area is not needed because ⁶⁰Co does not have a significant background in soil.

The exterior surface soil Class 3 survey unit incorporates areas that are not expected to contain residual radioactive material. The exterior surface soil Class 2 survey unit is similar to the Class 3 survey unit but is expected to contain concentrations of residual radioactive material below the wide-area derived concentration guideline level (DCGL_w). The Class 1

interior concrete survey units are expected to contain small areas of elevated activity that may or may not exceed the DCGL_w. The Class 2 interior drywall survey unit is similar to the Class 1 interior concrete survey unit, but the drywall is expected to have a lower background, less measurement variability, and a more uniform distribution of radioactive material. The Class 2 survey unit is not expected to contain areas of residual radioactive material above the DCGL_w. The survey design parameters and DQOs developed for these survey units under Scenario A are summarized in **Table 8.6**.

Table 8.7 provides survey design parameters and DQOs developed for two survey units under Scenario B where the lower bound of the gray region is zero or indistinguishable from background for a radionuclide that is in the natural background.

1 **Table 8.6: Final Status Survey Parameters for Example Survey Units for Scenario A**

Survey Unit	Type	DQO		LBGR	DCGL _w ^a	Estimated Standard Deviation, σ^b		Test/Section
		α	β			Survey	Reference	
Exterior Surface Soil	Class 2	0.025	0.025	128 Bq/kg	140 Bq/kg	4.0 Bq/kg	N/A	Sign/ Example 5
Exterior Surface Soil	Class 3	0.025	0.01	128 Bq/kg	140 Bq/kg	4.0 Bq/kg	N/A	Sign/ Example 6
Interior Concrete	Class 1	0.05	0.05	3,000 dpm/ 100 cm ²	5,000 dpm/ 100 cm ²	625 dpm/ 100 cm ²	220 dpm/ 100 cm ²	WRS/ Appendix A
Interior Drywall	Class 2	0.025	0.05	3,000 dpm/ 100 cm ²	5,000 dpm/ 100 cm ²	200 dpm/ 100 cm ²	200 dpm/ 100 cm ²	WRS/ Example 7

- 2 Abbreviations: DQO = data quality objective; LBGR = lower bound of the gray region; DCGL_w = derived concentration
 3 guideline level using the Wilcoxon Rank Sum test; σ = standard deviation; α = Type I decision error; β = Type II
 4 decision error; Bq = becquerel; kg = kilogram; dpm = disintegrations per minute; cm = centimeter.
 5 ^a DCGL_w is given in units of becquerels per kilogram or disintegrations per minute per 100 square centimeters.
 6 ^b Estimated standard deviation from scoping, characterization, and Remedial Action Support surveys

7 **8.3 Radionuclide Not Present in Background**

8 The statistical test discussed in this section is used to compare each survey unit directly with the
 9 applicable release criteria. A reference area is not included because the measurement
 10 technique is radionuclide-specific and the radionuclide of concern is not present in background
 11 (see **Section 8.2.3**). In this case, the concentrations of residual radioactive material are
 12 compared directly with the DCGL_w. The method in this section should be used only if the
 13 radionuclide is not present in background or is present at such a small fraction of the DCGL_w
 14 value as to be considered insignificant. In addition, the Sign test is applicable only if
 15 radionuclide-specific measurements are made to determine the concentrations. Otherwise, the
 16 method in **Section 8.4** is recommended.

1 **Table 8.7: Final Status Survey Parameters for Example Survey Units for Scenario B**

Survey Unit	Type	DQO		AL	DL ^a	Estimated Standard Deviation, σ^b		Test/Section
		α	β			Survey	Reference	
Exterior Surface Soil	Class 1	0.05	0.05	0 Bq/kg	12 Bq/kg	6 Bq/kg	6 Bq/kg	WRS
Exterior Surface Soil ^c	Class 3	0.05	0.01	0 Bq/kg	12 Bq/kg	6 Bq/kg	6 Bq/kg	WRS

2 Abbreviations: DQO = data quality objective; DL = discrimination limit; σ = standard deviation; α = Type I decision
 3 error; β = Type II decision error; Bq = becquerel; kg = kilogram; WRS = Wilcoxon Rank Sum.

4 ^a AL is zero.

5 ^b Estimated standard deviation from scoping, characterization, and Remedial Action Support surveys.

6 ^c This survey unit is not worked out in further examples.

7 Reference area samples are not needed when there is sufficient information to indicate that
 8 there is essentially no background concentration for the radionuclide being considered. With
 9 only a single set of survey unit samples, the statistical test used here is the Sign test. See
 10 **Section 5.3.4** for further information appropriate to following the example and discussion
 11 presented here.

12 **8.3.1 Sign Test**

13 The Sign test is designed to detect failure of the survey unit to meet release criteria if the
 14 radioactive material is distributed across that survey unit. Although the parameter of interest is
 15 usually the mean concentration of residual radioactive material in the survey unit, the median is
 16 used in the Sign test as an estimate of the mean. This test does not assume that the data follow
 17 any particular distribution, such as normal or lognormal.

18 In Scenario A, the hypothesis tested by the Sign test is as follows:

19 Null Hypothesis

20 H_0 : The median concentration of residual radioactive material in the survey unit is
 21 greater than or equal to the DCGL_w.

22 Versus

23 Alternative Hypothesis

24 H_1 : The median concentration of residual radioactive material in the survey unit is
 25 less than the DCGL_w; also defined as H_a .

26 The null hypothesis is assumed to be true unless the statistical test indicates that it should be
 27 rejected in favor of the alternative. For Scenario A, the null hypothesis states that the probability

1 of a measurement less than the $DCGL_W$ is less than one-half, i.e., the 50th percentile (or
2 median) is greater than the $DCGL_W$.

3 Because the Sign test uses the median instead of the mean, the null hypothesis in Scenario A
4 may be rejected if the median concentration is less than the $DCGL_W$, even if the mean
5 concentration is greater than or equal to the $DCGL_W$. If the mean concentration is greater than
6 or equal to the $DCGL_W$, the survey unit does not meet the release criteria (see **Table 8.3**)
7 Furthermore, in addition to the Sign test, the $DCGL_{EMC}$ (see **Section 5.3.5**) is compared to each
8 measurement to ensure none exceeds the $DCGL_{EMC}$. If a measurement exceeds the $DCGL_{EMC}$,
9 then additional investigation is recommended, at least locally, to determine the actual areal
10 extent of the elevated concentration.

11 In Scenario B, the hypothesis tested by the Sign test is as follows:

12 Null Hypothesis

13 H_0 : The median concentration of residual radioactive material in the survey unit is
14 less than or equal to the AL.

15 Versus

16 Alternative Hypothesis

17 H_1 : The median concentration of residual radioactive material in the survey unit is
18 greater than the AL.

19 Again, the null hypothesis is assumed to be true unless the statistical test indicates that it should
20 be rejected in favor of the alternative. For Scenario B, the null hypothesis states that the
21 probability of a measurement greater than the AL is less than one-half (i.e., the 50th percentile
22 [or median] is less than the AL).

23 When using the Sign test for both Scenario A and B, it is necessary to show that there are a
24 sufficient number of measurements or samples with concentrations below the $DCGL_W$ or AL,
25 respectively. Under Scenario A, when there are too many measurements or samples with
26 concentrations above the $DCGL_W$, we fail to reject the null hypothesis that the survey unit does
27 not meet the release criteria. Under Scenario B, when there are too many measurements or
28 samples with concentrations above the lower bound of the gray region (LBGR), we reject the
29 null hypothesis that the survey unit does meet the release criteria.

30 When the values of α and β are selected in the DQO process, an important difference between
31 Scenario A and Scenario B should be considered. For a fixed value of N , a lower value for α is
32 more protective in Scenario A, but is less protective in Scenario B. In both scenarios, a lower
33 value for α requires a higher degree of evidence before the null hypothesis is rejected. In
34 Scenario A, the null hypothesis is that the survey unit exceeds the release criteria, and a lower
35 value for α makes it more difficult to reject this hypothesis. In Scenario B, the null hypothesis is
36 that the survey unit meets the release criteria, and a lower value of α makes it more difficult to
37 reject this hypothesis.

38 Note that some individual survey unit measurements may exceed the $DCGL_W$ even when the
39 survey unit as a whole meets the release criteria. In fact, a survey unit sample mean that is

1 close to the $DCGL_W$ might have almost half of its individual measurements greater than the
2 $DCGL_W$. Such a survey unit may still not exceed the release criteria. The risk associated with
3 any areas above the DCGL is evaluated by developing a $DCGL_{EMC}$ based on dose or risk
4 modeling. The $DCGL_{EMC}$ is higher than the $DCGL_W$ and consider the size of the elevated area.
5 As long as the concentration in the elevated areas are less than the $DCGL_{EMC}$, the site can be
6 released. See **Section 8.6.1** for additional details.

7 The assumption is that the survey unit measurements are independent random samples from a
8 symmetric distribution. If the distribution of measurements is symmetric, the median and the
9 mean are the same. If the distribution of measurements is highly skewed, then the efficacy of
10 the statistical tests is reduced because of the underlying homogeneity assumptions inherent in
11 the decision criteria (i.e., DCGL calculations).

12 The hypothesis specifies release criteria in terms of a $DCGL_W$. The test should have sufficient
13 power ($1 - \beta$, as specified in the DQOs) to detect concentrations of residual radioactive material
14 at the LBGR, which is less than the $DCGL_W$. If σ is the standard deviation of the measurements
15 in the survey unit, then the relative shift (the width of the gray region, which is calculated by
16 $DCGL_W - LBGR$, divided by the standard deviation $[\Delta/\sigma]$) reflects the difference between the
17 average concentration of radioactive material and the DCGL relative to measurement variability.
18 The procedure for determining Δ/σ is given in **Section 5.3.3.2**.

19 As stated above, the null hypothesis for Scenario B is that the median concentration of residual
20 radioactive material in the survey unit is less than the LBGR (or AL). To use the Sign test with
21 Scenario B, the concentration of radioactive material in background should be zero or
22 insignificant compared to the LBGR (or AL). In some cases, the LBGR (or AL) may be set equal
23 to zero (e.g., release criteria require that concentrations be indistinguishable from background
24 and the radionuclide is not present in background). In this case, results should be scattered
25 about zero; therefore, if there are too many results with concentrations greater than zero, the
26 null hypothesis should be rejected. Results less than zero are both possible and likely when the
27 concentrations are truly equal to zero and measurements are subject to some random
28 component of measurement method uncertainty.

29 In this case, the number of positive and negative results are expected to be the same, and the
30 average of all the results is expected to be zero. When analyzing samples where the
31 concentration is very small, the data analysis should be reviewed carefully, because even
32 relatively small systematic errors can result in relatively large differences in the number of
33 positive and negative results.

34 Some laboratories report results below the lower limit of detection as "< LLD" or below the
35 minimum detectable activity as "< MDA". Under Scenario A, the use for the Sign test of such
36 results is usually not problematic, because the DL is required to be less than the $DCGL_W$, and
37 any values less than the DL will also be less than the $DCGL_W$. However, under Scenario B, in
38 which the DL is greater than the AL, it is difficult to determine if the concentrations reported as

1 “< LLD” or “< MDA” are greater than or less than the AL. For this reason, the Sign test should be
2 used only for Scenario B when actual concentrations, no matter how small, are reported.

3 **8.3.2 Applying the Sign Test**

4 The Sign test is applied as outlined in the following five steps, and further illustrated by
5 Examples 5 and 6. Separate instructions are given for Scenarios A and B.

6 Scenario A

- 7 1. List the survey unit measurements: $x_i, i = 1, 2, 3, \dots, N$.
- 8 2. Subtract each measurement, x_i , from the $DCGL_W$ to obtain the differences: $D_i =$
9 $DCGL_W - x_i, i = 1, 2, 3, \dots, N$.
- 10 3. Discard each difference that is exactly zero and reduce the sample size, N , by the
11 number of such measurements exactly equal to the $DCGL_W$.
- 12 4. Count the number of positive differences. The result is the test statistic $S+$. (Note that
13 a positive difference corresponds to a measurement below the $DCGL_W$ and
14 contributes evidence that the survey unit meets the release criteria).
- 15 5. Large values of $S+$ indicate that the null hypothesis is false. The value of $S+$ is
16 compared to the critical values in **Table I.4**. If $S+$ is greater than the critical value, k ,
17 in that table, the null hypothesis is rejected.

18 Scenario B

- 19 1. List the survey unit measurements: $x_i, i = 1, 2, 3, \dots, N$.
- 20 2. Subtract the AL from each measurement, x_i , to obtain the differences: $D_i = x_i - AL,$
21 $i = 1, 2, 3, \dots, N$.
- 22 3. Discard each difference that is exactly zero and reduce the sample size, N , by the
23 number of such measurements exactly equal to the AL.
- 24 4. Count the number of positive differences. The result is the test statistic $S+$. (Note that
25 a positive difference corresponds to a measurement above the AL and contributes
26 evidence that the survey unit does not meet the release criteria.)
- 27 5. Large values of $S+$ indicate that the null hypothesis is false. The value of $S+$ is
28 compared to the critical values in Table I.4. If $S+$ is greater than the critical value, k ,
29 in that table, the null hypothesis is rejected.

30 Passing a survey unit without making a single calculation may seem an unconventional
31 approach. However, the key is in the survey design, which is intended to ensure enough
32 measurements are made to satisfy the DQOs. As in the previous example, after the data are
33 collected, the conclusions and power of the test can be checked by constructing a retrospective
34 power curve as outlined in **Appendix M**.

1 In addition to checking the power of the statistical test, it is also important to ensure that the
 2 uncertainty of the measurements met the MQOs for required measurement uncertainty. One
 3 final consideration remains regarding the survey unit classification: “Was any definite amount of
 4 residual radioactive material found in the survey unit?” This will depend on the MDC of the
 5 measurement method. Generally, the MDC is at least three or four times the estimated
 6 measurement standard deviation. For example, in **Table 8.9**, the largest observation,
 7 9.3 becquerels/kilogram (Bq/kg; 0.25 picocuries/gram [pCi/g]), is less than three times the
 8 estimated measurement standard deviation of 3.8 Bq/kg (0.10 pCi/g). Thus, it is unlikely that
 9 any of the measurements could be considered indicative of positive residual radioactive
 10 material. This means that the Class 3 survey unit classification was appropriate. **Examples 5**
 11 **and 6** illustrate how to use the Sign test on Class 2 and 3 exterior soil units.

Example 5: Sign Test for a Class 2 Exterior Soil Survey Unit

Refer back to **Example 4** for background information. For the Class 2 Exterior Soil survey unit, the Sign test is appropriate, because the radionuclide of concern does not appear in background and radionuclide-specific measurements were made. Scenario A is selected.

Table 8.6 shows that the DQOs for this survey unit include $\alpha = 0.025$ and $\beta = 0.025$. The DCGL_W is 140 becquerels/kilogram (Bq/kg; 3.8 picocuries/gram [pCi/g]), and the LBGR was selected to be 128 Bq/kg (3.5 pCi/g). The estimated standard deviation of the measurements is $\sigma = 4.0$ Bq/kg (0.11 pCi/g). The relative shift was calculated to be 3.0, as shown below:

$$\Delta/\sigma = \frac{\text{DCGL}_W - \text{LBGR}}{\sigma} = \frac{140 \text{ Bq/kg} - 128 \text{ Bq/kg}}{4.0 \text{ Bq/kg}} = 3.0$$

Table 5.3 indicates the number of measurements estimated for the Sign Test, N , is 20 ($\alpha = 0.025$, $\beta = 0.025$, and $\Delta/\sigma = 3$). (**Table I.2** in **Appendix I** also lists the number of measurements estimated for the Sign test.) This survey unit is Class 2, so the 20 measurements needed were made on a random-start triangular grid. When laying out the grid, 22 measurement locations were identified.

The 22 measurements taken on the exterior lawn Class 2 survey unit are shown in the first column of **Table 8.8**. The mean of these data is 129 Bq/kg (3.5 pCi/g), and the standard deviation is 11 Bq/kg (0.30 pCi/g). Since the number of measurements is even, the median of the data is the average of the two middle values $(126+128)/2 = 127$ Bq/kg (3.4 pCi/g). A quantile plot of the data is shown in **Appendix L, Figure L.3**.

Five measurements exceed the DCGL_W value of 140 Bq/kg: 142, 143, 145, 148, and 148. However, none exceed the mean of the data plus three standard deviations: $129+(3 \times 11) = 162$ Bq/kg (4.3 pCi/g). Thus, these values appear to reflect the overall variability of the concentration measurements rather than to indicate an area of elevated activity—*provided* that these measurements were scattered through the survey unit. However, if a posting plot demonstrates that the locations of these measurements are

grouped together, then that portion of the survey unit containing these locations merits further investigation.

The middle column of **Table 8.8** contains the differences, $DCGL_W - \text{Data}$, and the last column contains the signs of the differences. The bottom row shows the number of measurements with positive differences, which is the test statistic $S+$. In this case, $S+ = 17$.

The value of $S+$ is compared to the appropriate critical value in **Table I.4**. In this case, for $N = 22$ and $\alpha = 0.025$, the critical value is 16. Because $S+ = 17$ exceeds this value, the null hypothesis that the survey unit exceeds the release criteria is rejected.

1 **Table 8.8: Example Sign Analysis: Class 2 Exterior Soil Survey Unit**

Data (Bq/kg)	$DCGL_W - \text{Data}$ (Bq/kg)	Sign
121	19	+
143	-3	-
145	-5	-
112	28	+
125	15	+
132	8	+
122	18	+
114	26	+
123	17	+
148	-8	-
115	25	+
113	27	+
126	14	+
134	6	+
148	-8	-
130	10	+
119	21	+
136	4	+
128	12	+
125	15	+
142	-2	-
129	11	+
Number of positive differences $S+ = 17$		

2

Example 6: Sign Test for a Class 3 Exterior Soil Survey Unit

Refer back to **Example 4** for background information. For the Class 3 exterior soil survey unit, the Sign test is again appropriate, because the radionuclide of concern does not appear in background and radionuclide-specific measurements were made. Scenario A is selected.

Table 8.6 shows that the DQOs for this survey unit include $\alpha = 0.025$ and $\beta = 0.01$. The $DCGL_W$ is 140 becquerels/kilogram (Bq/kg; 3.8 picocuries/gram [pCi/g]), and the LBGR was selected to be 128 Bq/kg (3.5 pCi/g). The estimated standard deviation of the measurements is $\sigma = 4.0$ Bq/kg (0.11 pCi/g). The relative shift was calculated to be 3.0, as shown below:

$$\Delta/\sigma = \frac{DCGL_W - LBGR}{\sigma} = \frac{140 \text{ Bq/kg} - 128 \text{ Bq/kg}}{4.0 \text{ Bq/kg}} = 3.0$$

Table 5.3 indicates that the sample size estimated for the Sign test, N , is 23 ($\alpha = 0.025$, $\beta = 0.01$, and $\Delta/\sigma = 3$). This survey unit is Class 3, so the measurements were made at random locations within the survey unit. The 23 measurements taken on the exterior lawn are shown in the first column of **Table 8.9**. The mean of these data is 2.1 Bq/kg (0.057 pCi/g), and the standard deviation is 3.3 Bq/kg (0.089 pCi/g). None of the data exceed $2.1 \text{ Bq/kg} + (3 \times 3.3) \text{ Bq/kg} = 12.0 \text{ Bq/kg}$ (0.32 pCi/g). Because N is odd, the median is the middle (12th-highest) value, namely 2.6 Bq/kg (0.070 pCi/g).

An initial review of the data reveals that every data point is below the $DCGL_W$, so the survey unit meets the release criteria specified in **Table 8.3**. For purely illustrative purposes, the Sign test analysis is performed. The middle column of **Table 8.9** contains the quantity $DCGL_W - \text{Data}$. Because every data point is below the $DCGL_W$, the sign of $DCGL_W - \text{Data}$ is always positive. The number of positive differences is equal to the number of measurements, N , and so the Sign test statistic S^+ is 23. The null hypothesis will always be rejected at the maximum value of S^+ (which in this case is 23) and the survey unit passes. Thus, the application of the Sign test in such cases requires no calculations and one need not consult a table for a critical value. If the survey is properly designed, the critical value must always be less than N .

Notice that some of these measurements are negative (-0.37 in cell A6). This might occur if an analysis background (e.g., the Compton continuum under a spectrum peak) is subtracted to obtain the net concentration value. The data analysis is both easier and more accurate when numerical values are reported as *obtained* rather than reporting the results as “less than” or not detected.

- 1 If one determines that residual radioactive material is definitely present, this would indicate that
- 2 the survey unit was initially misclassified. Ordinarily, MARSSIM recommends a resurvey using a
- 3 Class 1 or Class 2 design. In some cases, the original survey may have met the requirements

1 for the Class 1 or 2 design. Section 8.6.3 includes additional discussion on the misclassification
 2 of survey units.

3 For example, if one determines that the survey unit is a Class 2, a resurvey might be avoided if
 4 the survey unit does not exceed the maximum size recommended for such a classification. In
 5 this case, the only difference in survey design would be whether the measurements were
 6 obtained on a random or on a triangular grid. Provided that the initial survey's scanning
 7 methodology has sufficient detection capability to detect areas at the $DCGL_W$, versus the higher
 8 $DCGL_{EMC}$, the scan would be able to compensate for differences in the survey grid sample
 9 locations, and those differences alone would not affect the outcome of the statistical analysis.
 10 Therefore, if the above conditions were met, a resurvey might not be necessary.

11 **Table 8.9: Sign Test Example Data for Class 3 Exterior Survey Unit**

Sample Number	A	B	C
	Data (Bq/kg)	$DCGL_W$ -Data (Bq/kg)	Sign
1	3.0	137.0	+
2	3.0	137.0	+
3	1.9	138.1	+
4	0.37	139.6	+
5	-0.37	140.4	+
6	6.3	133.7	+
7	-3.7	143.7	+
8	2.6	137.4	+
9	3.0	137.0	+
10	-4.1	144.1	+
11	3.0	137.0	+
12	3.7	136.3	+
13	2.6	137.4	+
14	4.4	135.6	+
15	-3.3	143.3	+
16	2.1	137.9	+
17	6.3	133.7	+
18	4.4	135.6	+
19	-0.37	140.4	+
20	4.1	135.9	+
21	-1.1	141.1	+
22	1.1	138.9	+
23	9.3	130.7	+
	Number of positive differences $S^+ =$		23

1 **8.4 Radionuclide Present in Background**

2 The statistical tests discussed in this section will be used to compare each survey unit with an
3 appropriately chosen, site-specific reference area. Each reference area should be selected on
4 the basis of its similarity to the survey unit, as discussed in **Section 4.6.3**.

5 **8.4.1 Wilcoxon Rank Sum Test and Quantile Test**

6 In Scenario A, the comparison of measurements from the reference area and survey unit is
7 made using the WRS test. In Scenario B, in addition to the WRS test, the quantile test should be
8 used to further evaluate survey units when the WRS test fails to reject the null hypothesis. The
9 recommended tests should be conducted for each survey unit. In addition, the EMC is
10 performed against each measurement to ensure that it does not exceed a specified
11 investigation level (e.g., $DCGL_{EMC}$ for Class 1 survey units). If any measurement in the
12 remediated survey unit exceeds the specified investigation level, then additional investigation is
13 recommended, at least locally, regardless of the outcome of the WRS test.

14 The WRS test is most effective when residual radioactive material is uniformly present
15 throughout a survey unit. For Scenario A, the test is designed to detect whether this residual
16 radioactive material exceeds the $DCGL_W$. For Scenario B, it is designed to detect whether this
17 residual radioactive material exceeds the AL.

18 The advantage of the nonparametric WRS test is that it does not assume that the data are
19 normally or lognormally distributed. The WRS test also allows “less than” measurements to be
20 present in the reference area and the survey units. The WRS test can generally be used with up
21 to 40 percent “less than” measurements in either the reference area or the survey unit.
22 However, the use of “less than” values in data reporting is not recommended, as discussed in
23 **Sections 2.3.5 and 8.3**. When possible, report the actual result of a measurement together with
24 its uncertainty.

25 The quantile test is a statistical test for non-uniformity in the distribution of the residual
26 radioactive material. The quantile test was developed to detect differences between the survey
27 unit and the reference area that consist of a shift to higher values in only a fraction of the survey
28 unit. The quantile test is performed only when Scenario B is used and only if the null hypothesis
29 is not rejected for the WRS test. Using the quantile test in tandem with the WRS test results in
30 higher power to identify survey units that do not meet the release criteria than either test by itself.

31 Using the quantile test in tandem with the WRS test also results in higher probability of Type I
32 errors when the true concentration is equal to the AL. The probability of making a Type I error
33 on at least one of the two tests is approximately $\alpha = \alpha_Q + \alpha_W$ where α_Q and α_W are the values
34 of alpha selected for the quantile and WRS tests, respectively. For this reason, when the
35 quantile test is performed in tandem with the WRS test α_Q and α_W should both be set equal to
36 $\alpha/2$ so that when the true concentration is equal to the AL, the probability of a Type I error of
37 the two tests in tandem is approximately α .

1 In Scenario A, the hypothesis tested by the WRS test is as follows:

2 Null Hypothesis

3 H_0 : The median concentration of residual radioactive material in the survey unit
4 exceeds that in the reference area by more than the $DCGL_w$.

5 Versus

6 Alternative Hypothesis

7 H_1 : The median concentration of residual radioactive material in the survey unit
8 exceeds that in the reference area by less than the $DCGL_w$.

9 In Scenario B, the hypothesis tested by the WRS test is as follows:

10 Null Hypothesis

11 H_0 : The median concentration of residual radioactive material in the survey unit
12 exceeds that in the reference area by less than the AL.

13 Versus

14 Alternative Hypothesis

15 H_1 : The median concentration of residual radioactive material in the survey unit exceeds
16 that in the reference area by more than the AL.

17 Scenario B is used when the goal of remediation is that residual radioactive material in the survey
18 unit be indistinguishable from background activity levels in the reference area (e.g., $AL = 0$) or
19 when the AL is below some discrimination level.

20 When the values of α and β are selected in the DQO process, an important difference between
21 Scenario A and Scenario B should be considered. For a fixed value of N , a lower value for α is
22 more protective in Scenario A, and a lower value for α is less protective in Scenario B. In both
23 scenarios, a lower value for α requires a higher degree of evidence before the null hypothesis is
24 rejected. In Scenario A, the null hypothesis is that the survey unit exceeds the release criteria,
25 and a lower value for α makes it more difficult to reject this hypothesis. In Scenario B, the null
26 hypothesis is that the survey unit meets the release criteria, and a lower value of α makes it
27 more difficult to reject this hypothesis. An illustration of this effect is shown in **Example 8**
28 presented in **Section 8.4.3**.

29 In both scenarios, the null hypothesis is assumed to be true unless the statistical test indicates
30 that it should be rejected in favor of the alternative. One assumes that any difference between
31 the reference area and survey unit concentration distributions is due to a shift in the survey unit
32 concentrations to higher values (i.e., due to the presence of residual radioactive material in
33 addition to background). Note that some or all of the survey unit measurements may be larger
34 than some reference area measurements while still meeting the release criteria. Indeed, some
35 survey unit measurements may exceed some reference area measurements by more than the
36 $DCGL_w$. The result of the hypothesis test determines whether the survey unit as a whole is
37 deemed to meet the release criteria. The EMC is used to screen individual measurements.

1 Two assumptions underlie this test: (1) Samples from the reference area and survey unit are
 2 independent, identically distributed random samples, and (2) each measurement is independent
 3 of every other measurement, regardless of the set of samples from which it came.

4 **8.4.2 Applying the Wilcoxon Rank Sum Test**

5 The WRS test is applied as outlined in the following six steps and further illustrated by the examples
 6 in **Section 8.4.3** and **Appendix A**. Separate instructions are provided for Scenarios A and B.

7 Scenario A

- 8 1. Obtain the adjusted reference area measurements, z_i , by adding the DCGL_W to each
 9 reference area measurement, x_i . $z_i = x_i + \text{DCGL}_W$. The m adjusted reference
 10 sample measurements, z_i , from the reference area and the n sample measurements,
 11 y , from the survey unit are pooled and ranked in order of increasing size from 1 to N ,
 12 where $N = m + n$.
- 13 2. If several measurements are tied (i.e., have the same value), all are assigned the
 14 average rank of that group of tied measurements.
- 15 3. If there are t "less than" values, all are given the average of the ranks from 1 to t .
 16 Therefore, they are all assigned the rank $t(t + 1)/(2t) = (t + 1)/2$, which is the
 17 average of the first t integers. If there is more than one detection limit, all observations
 18 below the largest detection limit should be treated as "less than" values.⁵
- 19 4. Sum the ranks of the adjusted measurements from the reference area, W_r . Note that
 20 because the sum of the first N integers is $N(N + 1)/2$, one can equivalently sum the
 21 ranks of the measurements from the survey unit, W_s , and compute $W_r =$
 22 $N(N + 1)/2 - W_s$.
- 23 5. Compare W_r with the critical value given in **Table I.5** for the appropriate values of n ,
 24 m , and α . If W_r is greater than the tabulated value, reject the hypothesis that the
 25 survey unit exceeds the release criteria.

26 Scenario B

- 27 1. Obtain the adjusted survey unit measurements, z_i , by subtracting the AL from each
 28 survey unit measurement, y_i . $z_i = y_i - \text{AL}$.

⁵ If more than 40 percent of the data from either the reference area or survey unit are "less than," the WRS test *cannot* be used. Such a large proportion of non-detects suggest that the DQO process be revisited for this survey to determine if the survey unit was properly classified or the appropriate measurement method was used. As stated previously, the use of "less than" values in data reporting is not recommended. Wherever possible, the actual result of a measurement, together with its uncertainty, should be reported.

- 1 2. The m adjusted sample measurements, z_i , from the survey unit and the n reference
2 measurements, x_i , from the reference area are pooled and ranked in order of
3 increasing size from 1 to N , where $N = m + n$. (Note: When using **Table I.5** for
4 Scenario B, the roles of m and n are reversed.)
- 5 3. If several measurements are tied (i.e., have the same value), all are assigned the
6 average rank of that group of tied measurements.
- 7 4. If there are t “less than” values, they are all given the average of the ranks from 1 to
8 t . Therefore, all are assigned the rank $t(t + 1)/(2t) = (t + 1)/2$, which is the
9 average of the first t integers. If there is more than one detection limit, all
10 observations below the largest detection limit should be treated as “less than” values.
- 11 5. Sum the ranks of the adjusted measurements from the survey unit, W_s . Note that
12 because the sum of the first N integers is $N(N + 1)/2$, one can equivalently sum the
13 ranks of the measurements from the reference area, W_r , and compute $W_s =$
14 $N(N + 1)/2 - W_r$.
- 15 6. Compare W_s with the critical value given in **Table I.5** for the appropriate values of n ,
16 m , and α . (Because the quantile test is used in addition to the WRS test, $\alpha/2$ should
17 be used rather than α .) If W_s is greater than the tabulated value, reject the null
18 hypothesis that the survey unit does not exceed the release criteria.

19 **Example 7** illustrates the WRS test in practice for a Class 2 interior drywall survey unit.

Example 7: Wilcoxon Rank Sum Test Example: Class 2 Interior Drywall Survey Unit

Refer to **Example 4** for background information. In this example, the gas-flow proportional counter measures gross beta activity (see **Appendix H**), and the measurements are not radionuclide-specific. The Wilcoxon Rank Sum (WRS) test is appropriate for the Class 2 interior drywall survey unit because background contributes to gross beta activity even though the radionuclide of interest does not appear in background. Scenario A is selected because the derived concentration guideline level using the WRS test ($DCGL_W$) is higher than the discrimination limit. As a result, the quantile test will not be needed for this example.

Table 8.6 shows that the data quality objectives (DQOs) for this survey unit include $\alpha = 0.025$ and $\beta = 0.05$. The $DCGL_W$ is 8,300 becquerels/square meter (Bq/m^2 ; 5,000 decays per minute [dpm]/100 square centimeters [cm^2]) and the lower bound of the gray region (LBGR) was selected to be 5,000 Bq/m^2 (3,000 dpm/100 cm^2). The estimated standard deviation, σ , of the measurements is about 830 Bq/m^2 (500 dpm/100 cm^2). The relative shift was calculated to be 4.0, as shown below:

$$\Delta/\sigma = \frac{DCGL_W - LBGR}{\sigma} = \frac{8,300 \text{ Bq/m}^2 - 5,000 \text{ Bq/m}^2}{830 \text{ Bq/m}^2} = 4.0$$

In **Table 5.2**, one finds that the number of measurements estimated for the WRS test is 11 in each survey unit and 11 in each reference area ($\alpha = 0.025$, $\beta = 0.05$, and $\Delta/\sigma = 4$). (**Table I.3** in **Appendix I** also lists the number of measurements estimated for the WRS test.)

Table 8.10 lists the data obtained from the gas-flow proportional counter in units of counts per minute (cpm). A reading of 160 cpm with this instrument corresponds to the DCGL_W of 8,300 Bq/m² (5,000 dpm/100 cm²). Column A lists the measurement results as they were obtained. The sample mean and sample standard deviation of the reference area measurements are 44 and 4.4 cpm, respectively. The sample mean and sample standard deviation of the survey unit measurements are 98 and 5.3 cpm, respectively. In column B, the code "R" denotes a reference area measurement, and "S" denotes a survey unit measurement. Column C contains the Adjusted Data. The Adjusted Data are obtained by adding the DCGL_W to the reference area measurements (see **Section 8.4.2**, Step 1). The ranks of the adjusted data appear in Column D. They range from 1 to 22, because there is a total of 11+11 measurements (see **Section 8.4.2**, Step 2).

Note that two cases of measurements tied with the same value, at 104 and 205. Each tied measurement is always assigned the average of the ranks. Therefore, both measurements at 104 are assigned rank $(9 + 10)/2 = 9.5$ (see **Section 8.4.2**, Step 3). Also note that the sum of *all* of the ranks is still $22(22 + 1)/2 = 253$. Checking this value with the formula in Step 5 of **Section 8.4.2** is recommended to guard against errors in the rankings.

Column E contains only the ranks belonging to the reference area measurements. The total is 187. This is compared with the entry for the critical value of 156 in **Table I.5** for $\alpha = 0.025$, with $n = 11$ and $m = 11$. Because the sum of the reference area ranks is greater than the critical value, the null hypothesis (i.e., that the mean survey unit concentration exceeds the DCGL_W) is rejected.

If some of the values of the survey unit had been higher and had ranked above some of the reference unit samples, then the sum of the reference values would have been lower (because the survey values are not counted and would have displaced downward reference values). This then moves the sum closer to the critical value. If enough survey sample ranks had displaced reference rankings, then the sum would have been below the critical value and the null hypothesis would be accepted.

1 **Table 8.10: WRS Test for Class 2 Interior Drywall Survey Unit in Example 7**

Sample Number	A	B	C	D	E
	Data (cpm)	Unit or Area	Adjusted Data	Ranks	Reference Area Ranks
1	49	R	209	22	22
2	35	R	195	12	12
3	45	R	205	17.5	17.5
4	45	R	205	17.5	17.5

Sample Number	A	B	C	D	E
	Data (cpm)	Unit or Area	Adjusted Data	Ranks	Reference Area Ranks
5	41	R	201	14	14
6	44	R	204	16	16
7	48	R	208	21	21
8	37	R	197	13	13
9	46	R	206	19	19
10	42	R	202	15	15
11	47	R	207	20	20
12	104	S	104	9.5	0
13	94	S	94	4	0
14	98	S	98	6	0
15	99	S	99	7	0
16	90	S	90	1	0
17	104	S	104	9.5	0
18	95	S	95	5	0
19	105	S	105	11	0
20	93	S	93	3	0
21	101	S	101	8	0
22	92	S	92	2	0
	Sum =			253	187

1 Abbreviation: cpm = counts per minute.

2 **8.4.3 Applying the Quantile Test—Used Only in Scenario B**

3 The quantile test was developed to detect differences between the survey unit and the
4 reference area that consist of a shift to higher values in only a fraction of the survey units. It
5 should be noted that, in general, this shift is not necessarily the same as the shift used for the
6 WRS test. The quantile test is better at detecting situations in which only a portion of the survey
7 unit contains excess residual radioactive material. The WRS test is better at detecting situations
8 in which any excess residual radioactive material is uniform across the entire survey unit. The
9 quantile test is used only in Scenario B. The quantile test is performed after the WRS test, if the
10 null hypothesis for the WRS test has not been rejected. Using the quantile test in tandem with
11 the WRS test in Scenario B results in higher power to detect survey units that have not been
12 adequately remediated than either test has by itself.

13 The quantile test is outlined in the six steps below:

- 14 1. Calculate α_Q . ($\alpha_Q = \alpha/2$).
- 15 2. Obtain the adjusted survey unit measurements, z_i , by subtracting the AL from each survey
16 unit measurement, y_i : $z_i = y_i - AL$. If the $DCGL_W$ is equal to zero, then this step is not
17 necessary.
- 18 3. The n adjusted survey unit measurements, z_i , and the m reference area measurements, x_i ,
19 are pooled and ranked in order of increasing size from 1 to N , where $N = m + n$.

- 1 4. If several measurements are tied (i.e., have the same value), all are assigned the mean rank
2 of that group of tied measurements.
- 3 5. Look up the values for r and k in **Tables I.7–I.10** to be based on the number of measurements
4 in the survey unit (n), the number of measurements in the reference area (m), and α_Q . The
5 operational decision described in the next step is made using the values for r and k .
- 6 6. If k or more of the r largest measurements in the combined ranked data set are from the
7 survey unit, the null hypothesis is rejected.
- 8 **Examples 8–10** illustrate how certain tests can be used under a variety of testing scenarios.

Example 8: Class 2 Interior Survey Example Under Scenario B Using Wilcoxon Rank Sum and Quantile Tests

Refer to **Example 4** for background information. The data for an example Wilcoxon Rank Sum (WRS) test using Scenario B are shown in Column A of **Table 8.11**. In Column B, the label “R” is inserted to denote a reference area measurement, and the label “S” to denote a survey unit measurement. Column C contains the adjusted data obtained by subtracting the lower bound of the gray region (LBGR) of 142 counts per minute (cpm) from just the survey unit measurements (the reference area measurements are not adjusted). The ranks of the adjusted data in Column C are listed in Column D. The ranks range from 1 to 24, because there are $12 + 12 = 24$ measurements. The sum of all the ranks is $N(N + 1)/2 = (24 \times 25)/2 = 300$. Column E contains only the ranks belonging to the adjusted survey unit measurements. The sum of the ranks of the adjusted survey unit data is 194.5. From **Table I.5**, for $\alpha = 0.025$ and $n = m = 12$, the critical value is 184. Because the sum of the adjusted survey unit ranks, 194.5, is greater than the critical value, 184, the null hypothesis that the survey unit concentrations do not exceed the LBGR is rejected (i.e., the site is determined to be dirty). In Scenario B, the true concentration of radioactive material in the survey unit is judged to be in excess of 142 cpm above the background.

For the quantile test, **Table I.8** provides the critical value, k , of the largest r measurements for different values of n , the number of measurements from the survey unit, and m , the number of measurements from the reference area. The same rankings in Column D of **Table 8.11** for the WRS test can be used for the quantile test. If k or more of the r largest measurements in the combined ranked data set are from the survey unit, the null hypothesis is rejected. For a survey unit that has failed the WRS test, as was the case in this example, it is not usually necessary to also perform the quantile test. However, the quantile test is presented for illustrative purposes.

In **Table 8.11**, Columns F and G show the sorted ranks of the adjusted data and the location associated with each rank (i.e., “R” for reference area and “S” for survey unit). In **Table I.8**, the closest entry to $n = m = 12$ is for $n = m = 10$. The values of $r = 7$, $k = 6$ and $\alpha = 0.029$ are found. Thus, the null hypothesis is rejected if six of the seven largest adjusted measurements

come from the survey unit. From **Table 8.11**, we find that only five of the seven largest adjusted measurements come from the survey unit, so the null hypothesis is not rejected based on the quantile test. The values of n and m that were used are close to, but not equal to, the actual values so the α value will be different from that listed in the table. It is prudent to check a few other entries in **Table I.8** that are near the actual sample size. Additionally, Chapter 7 in NUREG-1505 (NRC 1998a) provides equations to calculate exact and approximate values of the alpha error for the quantile test as a function of n , m , k , and r .

1 **Table 8.11: WRS and Quantile Test Under Scenario B for Class 2 Interior Drywall Survey**
 2 **Unit in Example 8**

Sample Number	A	B	C	D	E	F	G
	Data (cpm)	Area	Adjusted Data	Ranks	Survey Unit Ranks	Sorted Ranks	Location Associated with Sorted Ranks ^a
1	47	R	47	18	—	1	R
2	28	R	28	1	—	2	R
3	36	R	36	6	—	3	R
4	37	R	37	7	—	4.5	R
5	39	R	39	9.5	—	4.5	S
6	45	R	45	13	—	6	R
7	43	R	43	11	—	7	R
8	34	R	34	3	—	8	S
9	32	R	32	2	—	9.5	R
10	35	R	35	4.5	—	9.5	R
11	39	R	39	9.5	—	11	R
12	51	R	51	21	—	13	R
13	209	S	67	24	24	13	S
14	197	S	55	23	23	13	S
15	188	S	46	16	16	16	S
16	191	S	49	19	19	16	S
17	193	S	51	21	21	16	S
18	187	S	45	13	13	18	R
19	188	S	46	16	16	19	S
20	180	S	38	8	8	21	R
21	193	S	51	21	21	21	S
22	188	S	46	16	16	21	S
23	187	S	45	13	13	23	S
24	177	S	35	4.5	4.5	24	S
			Sum =	300	194.5	—	—

3 ^a Measurements from the reference area and the survey unit are denoted by R and S, respectively. The adjusted data
 4 and data columns are identical when AL= 0.

5

Example 9: Example Using NUREG-1505 Kruskal-Wallis Test to Determine Whether Appropriate to Consider Variability from Background under Scenario B

NUREG-1505 (NRC 1998a) provides guidance on methods used to demonstrate indistinguishability from background when Scenario B is deemed appropriate to use (e.g., when the DCGL is close to background considering variability). A difficulty arises in the ability to release a site when variations in mean background among the potential reference areas become comparable in magnitude to the width of the gray region. Because any difference in radioactivity between the reference area and survey unit is assumed to be due to residual radioactivity, and it is not possible to determine if the difference is actually due to differences in background concentrations between the two areas, tests are available to determine the significance of background variability and how this variability can be considered in the statistical tests used to help determine if the site is clean.

The parametric F-test (assumes a normal distribution) and nonparametric Kruskal-Wallis test (does not make an assumption regarding the underlying distribution) can be used to determine if variability between the means of potential reference areas is statistically significant. See data in **Table 8.12** used to determine ranks of reference area measurements used to perform the Kruskal-Wallis test. NUREG-1505 Equation 13-3 is used to calculate a Kruskal-Wallis statistic:

$$K = \frac{12}{N(N+1)} \left(\sum_{i=1}^k \frac{R_i^2}{n_i} \right) - 3(N+1)$$

where N is the total number of measurements in all the reference areas $i=1$ to k reference areas; n_i is the number of measurements in a given reference area; and R_i is the sum of the ranks of the measurements in a given reference area.

The test statistic of 14.0 is compared to the critical values provided in NUREG-1505 Table 13.1. In the example, the Kruskal Wallis statistic of 14.0 is above the critical threshold for $4 - 1 = 3$ reference areas that range from 11.3 for an α value of 0.01 to 4.6 for an α value of 0.2. Therefore, the null hypothesis that the variability in the reference area means is zero can be rejected with high confidence (i.e., the null hypothesis is rejected even for very small α or false positive error rates). Although the Kruskal-Wallis test (or F-test) is used to determine if it is appropriate to consider reference area variability in applying Scenario B, NUREG-1505 also indicates that background variability could be given the benefit of the doubt, in which case the Kruskal-Wallis test (or F-test) need not be conducted.

If it is determined that the variability between reference means should be considered, NUREG-1505 Equation 13-13 can be used to calculate the variance, $\hat{\omega}^2$, which can be used to determine the lower bound of the gray region (LBGR, or action level [AL]) for Scenario B. NUREG-1505 provides an example where the mean square between reference areas, s_b^2 ,

and mean square within reference areas, s_w^2 , calculated manually using Equation 13-13 or output from ANOVA testing can be used to compute $\hat{\omega}^2 = (s_b^2 - s_w^2)/n_0$, where n_0 is equal to the number of measurements per reference area when the number of measurements in each reference area is the same (or see Equation 13-13 in NUREG-1505 when the number of measurements in the reference areas are not the same). Using the ANOVA output in

Table 8.13,

$$\hat{\omega}^2 = \frac{s_b^2 - s_w^2}{n_0} = \frac{6.52 - 0.97}{10} = 0.55$$

As part of the data quality objective process, an agreed-upon value for the LBGR as a multiple of $\hat{\omega}$ can be selected (e.g., NUREG-1505 states that $3 \hat{\omega}$ is a reasonable default [or in the example $\sqrt{55} \times 3 = 0.74 \times 3 = 2.22$ for the LBGR]). Note that the difference in means between reference areas 2 and 4 in Table 13.2 is 1.82, which is similar to the LBGR calculated based on $3 \hat{\omega}$. NUREG-1505, Table 13.5 also provides information on the power of the F-test, which is used to approximate the power of the Kruskal-Wallis test, to help determine the number of reference areas and the number of measurements that should be taken in each reference area to perform the Kruskal-Wallis test and to estimate $\hat{\omega}$. In all cases, the regulatory authority should be consulted to determine the acceptability of using Scenario B, as well as determining appropriate values for the test parameters.

1 **Table 8.12: Calculation of $\hat{\omega}^2$ for Example 9**

Sample Number	Measurements				Measurement Ranks				Measurements Squared			
	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4
1	0.27	1.04	2.45	3.77	6	13	27	39	0.07	1.08	6.00	14.21
2	1.87	0.39	0.34	2.63	20	9	8	31	3.50	0.15	0.12	6.92
3	0.97	2.07	3.06	4.05	10	23	37	40	0.94	4.28	9.36	16.40
4	1.01	0.57	2.83	1.72	11	2	35	19	1.02	0.32	8.01	2.96
5	2.08	1.97	1.09	1.50	24	21	14	17	4.33	3.88	1.19	2.25
6	1.62	0.22	0.26	2.47	18	3	5	29	2.62	0.05	0.07	6.10
7	0.30	1.39	2.80	1.42	7	15	34	16	0.09	1.93	7.84	2.02
8	1.98	0.05	2.77	2.47	22	4	33	28	3.92	0.00	7.67	6.10
9	2.18	0.75	2.42	2.76	25	1	26	32	4.75	0.56	5.86	7.62
10	1.02	2.50	2.86	3.35	12	30	36	38	1.04	6.25	8.18	11.22
Sum	13.30	7.87	20.88	26.14	—	—	—	—	22.28	18.50	54.30	75.80
Average	1.33	0.79	2.09	2.61	—	—	—	—	—	—	—	—
Average Squared	1.77	0.62	4.36	6.83	—	—	—	—	—	—	—	—

2 **Table 8.13: Analysis of Variance for Example 9 Data**

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Statistic
Between Groups	19.56	3	6.52	6.69
Within Groups	35.08	36	0.97	—

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Statistic
Total	54.65	39	—	—

1

Example 10: Class 1 Interior Concrete Survey Unit

As in the previous example, the gas-flow proportional counter measures gross beta activity (see **Appendix H**) and the measurements are not radionuclide-specific. The nonparametric statistical test for when the radionuclide is present in background is appropriate for the Class 1 interior concrete survey unit because gross beta activity contributes to the overall background, even though the specific radionuclide of interest does not appear in background.

Appendix A provides a detailed description of the calculations for the Class 1 interior concrete survey unit.

2 8.4.4 Multiple Radionuclides

3 The use of the unity rule when there is more than one radionuclide to be considered is
4 discussed in **Section 4.4**. An example application of the use of the unity rule appears in
5 **Examples 11 and 12**.

Example 11: Application of WRS Test to Multiple Radionuclides

Consider a site with both cobalt-60 (^{60}Co) and cesium-137 (^{137}Cs) contamination. ^{137}Cs appears in background from fallout at a typical concentration of about 37 becquerels/kilogram (Bq/kg; 1 picocurie/gram [pCi/g]). Assume that the DCGL_w for ^{60}Co is 74 Bq/kg (2 pCi/g) and for ^{137}Cs is 52 Bq/kg (1.4 pCi/g). In disturbed areas, the background concentration of ^{137}Cs can vary considerably. An estimated spatial standard deviation of 19 Bq/kg (0.5 pCi/g) for ^{137}Cs will be assumed. During remediation, it was found that the concentrations of the two radionuclides were not well correlated in the survey unit. ^{60}Co concentrations were more variable than the ^{137}Cs concentrations, and 26 Bq/kg (0.7 pCi/g) is estimated for its standard deviation. Measurement errors for both ^{60}Co and ^{137}Cs using gamma spectrometry will be small compared to this. For the comparison to the release criteria, the weighted sum of the concentrations of these radionuclides is computed from—

$$T = \frac{{}^{60}\text{Co concentration}}{{}^{60}\text{Co DCGL}} + \frac{{}^{137}\text{Cs concentration}}{{}^{137}\text{Cs DCGL}}$$

$$= \frac{{}^{60}\text{Co concentration}}{74 \text{ Bq/kg}} + \frac{{}^{137}\text{Cs concentration}}{52 \text{ Bq/kg}}$$

The variance of the weighted sum, assuming that the ^{60}Co and ^{137}Cs concentrations are spatially unrelated, is—

$$\begin{aligned}\sigma^2(T) &= \left[\frac{\sigma(\text{ }^{60}\text{Co concentration})}{\text{ }^{60}\text{Co DCGL}} \right]^2 + \left[\frac{\sigma(\text{ }^{137}\text{Cs concentration})}{\text{ }^{137}\text{Cs DCGL}} \right]^2 \\ &= \left[\frac{26 \text{ Bq/kg}}{74 \text{ Bq/kg}} \right]^2 + \left[\frac{19 \text{ Bq/kg}}{52 \text{ Bq/kg}} \right]^2 = 0.26\end{aligned}$$

Thus, $\sigma = 0.5$. The wide-area derived concentration guideline level (DCGL_W) for the weighted sum is 1. The null hypothesis for Scenario A is that the survey unit exceeds the release criterion. During the data quality objective process, the lower bound of the gray region (LBGR) was set at 0.5 for the weighted sum, so that $\Delta = \text{DCGL}_W - \text{LBGR} = 1.0 - 0.5 = 0.5$, and $\Delta/\sigma = 0.5/0.5 = 1.0$. The acceptable error rates chosen were $\alpha = \beta = 0.05$. To achieve this, 32 samples each are required in the survey unit and the reference area.

The weighted sums are computed for each measurement location in both the reference area and the survey unit. The WRS test is then performed on the weighted sum. The calculations for this example are shown in **Table 8.14**. The DCGL_W for the unity rule (i.e., 1.0) is added to the weighted sum for each location in the reference area. The ranks of the combined survey unit and adjusted reference area weighted sums are then computed. The sum of the ranks of the adjusted reference area weighted sums is then compared to the critical value for $n = m = 32$, $\alpha = 0.05$, which is 1,162 (see formula following **Table I.5**). In **Table 8.14**, the sum of the ranks of the adjusted reference area weighted sums is 1,281. This exceeds the critical value, so the null hypothesis is rejected. In Scenario A, this means the survey unit meets the release criteria. The difference between the mean of the weighted sums in the survey unit and the reference area is $1.86 - 1.16 = 0.7$. Thus, the estimated dose or risk due to residual radioactive material in the survey unit is approximately equal to 70 percent of the release criterion.

1

Example 12: Use of ProUCL for the WRS Test for Multiple Radionuclides

As **Table 8.14** does for **Example 11**, **Table 8.15** provides sample results for a survey unit with residual radioactive material that includes cobalt-60 (^{60}Co) and cesium-137 (^{137}Cs). Because ^{137}Cs from fallout is found in the background, samples were also collected and analyzed from a reference area. The wide-area derived concentration guideline levels (DCGL_W) for ^{137}Cs and ^{60}Co are 1.4 and 2.0 Bq/kg, respectively. The unity rule is used to determine if the survey unit meets the release criteria. Scenario A was selected. To perform the WRS test, ProUCL, Version 5.0 was used. ProUCL is a freeware statistical software program, provided by the U.S. Environmental Protection Agency.

The data can be entered by hand or copied and pasted from another software program. Descriptions can be provided for the column headers by right-clicking the column header and selecting "Header Name." For this example, the columns were named "Reference" and

“Survey Unit.” **Figure 8.4** shows the initial program inputs of the weighted sums of the reference area and survey unit with their column headings.

To perform the WRS test, the two-sample Wilcoxon-Mann-Whitney test was selected. The Wilcoxon-Mann-Whitney test is a nonparametric of the same hypothesis as the WRS test. The two tests use a different test statistic and critical value, but both tests will provide the same conclusion. The test can be selected by first choosing “Two Sample” from the “Hypothesis Testing” menu, and then selecting “Wilcoxon-Mann-Whitney.”

Variables are selected by clicking on the variable name in the list of variables, and then clicking the corresponding “>>” button. The Reference Area results are selected as the “Background/Ambient” variable, and the Survey Unit results are selected as the “Area of Concern/Site” variable, as shown in **Figure 8.5**.

Clicking the “Options” in the dialog window shown in **Figure 8.5**, generates another dialog window. This window allows the user to specify the “Confidence Coefficient.” The confidence coefficient is equal to $(1 - \alpha)$. For this example, the “Confidence Coefficient” of 95 percent is selected, corresponding to $\alpha = 0.05$. The dialog window also allows the user to specify the form of the hypothesis. For this example, Form 2 is selected, and the value of 1 is entered for the “Substantial Difference.” When using Form 2, the unadjusted reference area results should be used instead of the adjusted reference area results.

Clicking the “OK” button shown in **Figure 8.6** saves the changes and closes the dialog window. Clicking the “OK” button shown in **Figure 8.5** closes that dialog window and generates the output sheet shown in **Figure 8.7**. As shown near the bottom of **Figure 8.7**, the null hypothesis is rejected, and the survey unit is demonstrated to pass the statistical test. The elevated measurement comparison would still need to be performed before deciding that the survey unit has met the release criteria.

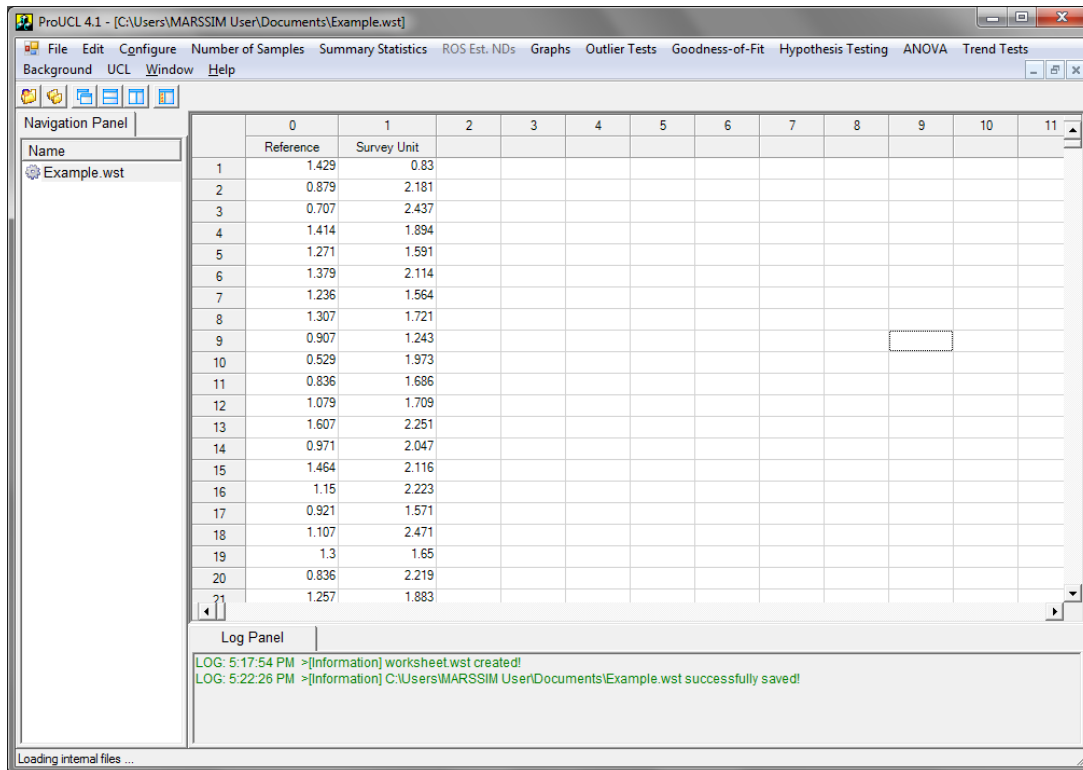
1 **Table 8.14: Example 11 WRS Test for Two Radionuclides**

Sample Number	Reference Area		Survey Unit		Weighted Sum			Ranks	
	¹³⁷ Cs	⁶⁰ Co	¹³⁷ Cs	⁶⁰ Co	Ref	Survey	Adj Ref	Survey	Adj Ref
1	2.00	0	1.12	0.06	1.43	0.83	2.43	1	56
2	1.23	0	1.66	1.99	0.88	2.18	1.88	43	21
3	0.99	0	3.02	0.56	0.71	2.44	1.71	57	14
4	1.98	0	2.47	0.26	1.41	1.89	2.41	23	55
5	1.78	0	2.08	0.21	1.27	1.59	2.27	9	50
6	1.93	0	2.96	0.00	1.38	2.11	2.38	37	54
7	1.73	0	2.05	0.20	1.23	1.56	2.23	7	46
8	1.83	0	2.41	0.00	1.30	1.72	2.30	16	52
9	1.27	0	1.74	0.00	0.91	1.24	1.91	2	24
10	0.74	0	2.65	0.16	0.53	1.97	1.53	27	6
11	1.17	0	1.92	0.63	0.83	1.68	1.83	13	18
12	1.51	0	1.91	0.69	1.08	1.71	2.08	15	32
13	2.25	0	3.06	0.13	1.61	2.25	2.61	47	63
14	1.36	0	2.18	0.98	0.97	2.05	1.97	30	28
15	2.05	0	2.08	1.26	1.46	2.12	2.46	39	58
16	1.61	0	2.30	1.16	1.15	2.22	2.15	45	41
17	1.29	0	2.20	0.00	0.92	1.57	1.92	8	25
18	1.55	0	3.11	0.50	1.11	2.47	2.11	59	35
19	1.82	0	2.31	0.00	1.30	1.65	2.30	11	51
20	1.17	0	2.82	0.41	0.84	2.22	1.84	44	19
21	1.76	0	1.81	1.18	1.26	1.88	2.26	22	48
22	2.21	0	2.71	0.17	1.58	2.02	2.58	29	62
23	2.35	0	1.89	0.00	1.68	1.35	2.68	3	64
24	1.51	0	2.12	0.34	1.08	1.68	2.08	12	33
25	0.66	0	2.59	0.14	0.47	1.92	1.47	26	5
26	1.56	0	1.75	0.71	1.12	1.60	2.12	10	38
27	1.93	0	2.35	0.85	1.38	2.10	2.38	34	53
28	2.15	0	2.28	0.87	1.54	2.06	2.54	31	61
29	2.07	0	2.56	0.56	1.48	2.11	2.48	36	60
30	1.77	0	2.50	0.00	1.27	1.78	2.27	17	49
31	1.19	0	1.79	0.30	0.85	1.43	1.85	4	20
32	1.57	0	2.55	0.70	1.12	2.17	2.12	42	40
Avg	1.62	0	2.28	0.47	1.16	1.86	2.16	sum =	sum =
Std Dev	0.43	0	0.46	0.48	0.31	0.36	0.31	799	1281

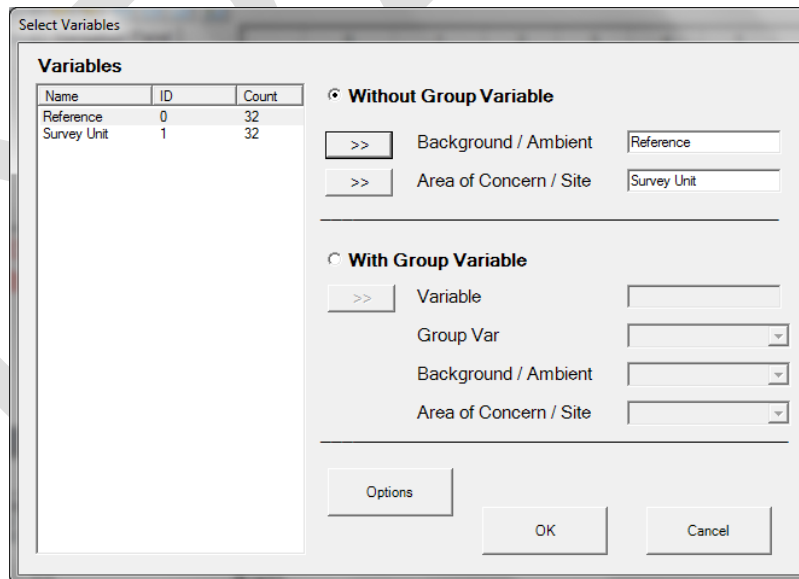
1 **Table 8.15: Example 12 WRS Test for Two Radionuclides**

Sample Number	Reference Area Results (Bq/kg)		Survey Unit (Bq/kg)		Reference Area (x_i)	Survey Unit (y_i)	Adjusted Reference Area (z_i)
	¹³⁷ Cs	⁶⁰ Co	¹³⁷ Cs	⁶⁰ Co			
1	2.00	0.00	1.12	0.06	1.429	0.830	2.429
2	1.23	0.00	1.66	1.99	0.879	2.181	1.879
3	0.99	0.00	3.02	0.56	0.707	2.437	1.707
4	1.98	0.00	2.47	0.26	1.414	1.894	2.414
5	1.78	0.00	2.08	0.21	1.271	1.591	2.271
6	1.93	0.00	2.96	0.00	1.379	2.114	2.379
7	1.73	0.00	2.05	0.20	1.236	1.564	2.236
8	1.83	0.00	2.41	0.00	1.307	1.721	2.307
9	1.27	0.00	1.74	0.00	0.907	1.243	1.907
10	0.74	0.00	2.65	0.16	0.529	1.973	1.529
11	1.17	0.00	1.92	0.63	0.836	1.686	1.836
12	1.51	0.00	1.91	0.69	1.079	1.709	2.079
13	2.25	0.00	3.06	0.13	1.607	2.251	2.607
14	1.36	0.00	2.18	0.98	0.971	2.047	1.971
15	2.05	0.00	2.08	1.26	1.464	2.116	2.464
16	1.61	0.00	2.30	1.16	1.150	2.223	2.150
17	1.29	0.00	2.20	0.00	0.921	1.571	1.921
18	1.55	0.00	3.11	0.50	1.107	2.471	2.107
19	1.82	0.00	2.31	0.00	1.300	1.650	2.300
20	1.17	0.00	2.82	0.41	0.836	2.219	1.836
21	1.76	0.00	1.81	1.18	1.257	1.883	2.257
22	2.21	0.00	2.71	0.17	1.579	2.021	2.579
23	2.35	0.00	1.89	0.00	1.679	1.350	2.679
24	1.51	0.00	2.12	0.34	1.079	1.684	2.079
25	0.66	0.00	2.59	0.14	0.471	1.920	1.471
26	1.56	0.00	1.75	0.71	1.114	1.605	2.114
27	1.93	0.00	2.35	0.85	1.379	2.104	2.379
28	2.15	0.00	2.28	0.87	1.536	2.064	2.536
29	2.07	0.00	2.56	0.56	1.479	2.109	2.479
30	1.77	0.00	2.50	0.00	1.264	1.786	2.264
31	1.19	0.00	1.79	0.30	0.850	1.429	1.850
32	1.57	0.00	2.55	0.70	1.121	2.171	2.121

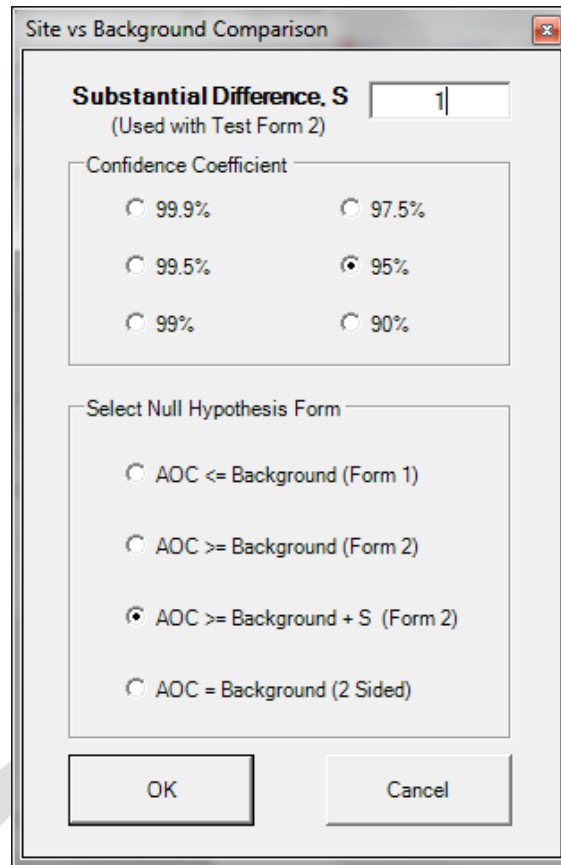
2



1
 2 **Figure 8.4: ProUCL Worksheet for Example 12**



3
 4 **Figure 8.5: ProUCL Select Variables Window for Hypothesis Testing for Example 12**



1

2 **Figure 8.6: ProUCL Hypothesis Testing Options Window for Example 12**

Wilcoxon-Mann-Whitney Site vs Background Comparison Test for Full Data Sets without NDs		
User Selected Options		
From File	C:\Users\MARSSIM User\Documents\Example.wst	
Full Precision	OFF	
Confidence Coefficient	95%	
Substantial Difference	1	
Selected Null Hypothesis	Site or AOC Mean/Median >= Background Mean/Median Plus Substantial Difference, S (Form 2)	
Alternative Hypothesis	Site or AOC Mean/Median Less Than Background Mean/Median Plus Substantial Difference, S	
Area of Concern Data: Survey Unit		
Background Data: Reference		
Raw Statistics		
	Site	Background
Number of Valid Observations	32	32
Number of Distinct Observations	32	29
Minimum	0.83	0.471
Maximum	2.471	1.679
Mean	1.863	1.161
Median	1.907	1.193
SD	0.361	0.308
SE of Mean	0.0638	0.0544
Wilcoxon-Mann-Whitney (WMW) Test		
H0: Mean/Median of Site or AOC >= Mean/Median of Background + 1		
Site Rank Sum W-Stat	799.5	
WMW Test U-Stat	-3.223	
WMW Critical Value (0.050)	-1.645	
P-Value	0.0006354	
Conclusion with Alpha = 0.05		
Reject H0. Conclude Site < Background + 1.00		
P-Value < alpha (0.05)		

1

2 **Figure 8.7: ProUCL Output for Example 12**

3 **8.5 Scan-Only Surveys**

4 The use of the UCL can apply to both Scenario A and B for scan-only surveys where individual
 5 results are recorded. When release decisions are made about the estimated mean of a sampled
 6 population, the assessment of the survey results is accomplished by comparing a UCL for the
 7 mean to the DCGL_w or DL for Scenarios A and B, respectively.

8 If individual scan-only survey results are recorded, a nonparametric confidence interval can be
 9 used to evaluate the results of the release survey. Similarly, a confidence interval can be used
 10 to evaluate a series of direct measurements with overlapping fields of view. A one-tailed version
 11 of Chebyshev’s inequality or software (e.g., EPA’s ProUCL software) can be used to evaluate
 12 the probability of exceeding the UBGR (i.e., using a UCL). The use of a UCL applies to both
 13 Scenario A (where the UBGR equals the DCGL_w) and Scenario B (where the UBGR equals the
 14 DL).

1 Chebyshev's inequality calculates the probability that the absolute value of the difference of the
2 true but unknown mean of the population and a random number from the data set is at least a
3 specified value. That is, given a specified positive number (n), a mean (μ), and a random
4 number from the data set (r), then the probability that $[\mu - r]$ is greater than or equal to n is
5 equal to α . In addition, a one-tailed version of the inequality can be used to calculate a UCL for
6 a data set that is independent of the data distribution (i.e., there is no requirement to verify the
7 data are from a normal, lognormal, or any other specified kind of distribution) by letting the
8 inequality equal the UCL. The UCL can be calculated using **Equation 8-3**:

$$\text{UCL} = \mu + \sqrt{\frac{\sigma^2}{n\alpha} - \frac{\sigma^2}{n}} \quad (8-3)$$

9 The comparison to the UCL is described in the following steps:

- 10 1. Calculate the mean (μ) and standard deviation (σ) of the number of results (n) in the
11 data set.
- 12 2. For Scenario A, retrieve the Type I error rate (α) used to design the survey. For
13 Scenario B, substitute the Type II error rate (β) used to design the survey for α in
14 **Equation 8-3**.
- 15 3. Using Chebyshev's inequality, calculate the maximum UCL using **Equation 8-3**.

16 If the maximum UCL is less than the UBGR, the survey demonstrates compliance with the
17 disposition criterion (i.e., reject the null hypothesis for Scenario A or fail to reject the null
18 hypothesis for Scenario B).

19 Chebyshev's inequality must be used with caution when there are very few points in the data
20 set. This is because the population mean and standard deviation in the Chebyshev formula are
21 being estimated by the sample mean and sample standard deviation. In a small data set from a
22 highly skewed distribution, the sample mean and sample standard deviation may be
23 underestimated if the high concentration but low probability portion of the distribution is not
24 captured in the sample data set.

25 **8.6 Evaluate the Results: The Decision**

26 When the data and the results of the tests have been obtained, the specific steps required to
27 achieve survey unit release depend on the procedures instituted by the governing regulatory
28 agencies and site-specific ALARA⁶ considerations. The following suggested considerations are

⁶ "as low as reasonably achievable"

1 for the interpretation of the test results with respect to the release limit established for the site or
2 survey unit. Note that the tests need not be performed in any particular order.

3 **8.6.1 Elevated Measurement Comparison**

4 If applicable release criteria for elevated measurements exist, then the EMC consists of
5 comparing each measurement from the survey unit with the investigation levels discussed in
6 **Section 5.3.8**. The EMC is performed both for measurements obtained on the systematic
7 sampling grid and for locations flagged by scanning measurements. Any measurement from the
8 survey unit that is equal to or greater than an investigation level indicates an area of relatively
9 high concentrations that should be investigated, regardless of the outcome of the nonparametric
10 statistical tests.

11 Under Scenario A, the statistical tests may reject the null hypothesis when only a very few high
12 measurements are obtained in the survey unit, regardless of how high the measurements are.
13 In a similar manner, under Scenario B, the statistical tests might not reject the null hypothesis
14 when only a few high measurements are obtained in the survey unit. The use of the quantile test
15 and the EMC against the investigation levels may be viewed as assurance that unusually large
16 measurements will receive proper attention regardless of the outcome of those tests and that
17 any area having the potential for significant dose or risk contributions will be identified. The EMC
18 is intended to flag potential failures in the remediation process. This should not be considered
19 the primary means to identify whether a survey unit meets the release criteria.

20 Note that the $DCGL_{EMC}$ is an a priori limit, established both by the $DCGL_W$ and by the survey
21 design (i.e., grid spacing and scanning MDC). The true extent of an area of elevated activity can
22 be determined only after performing the survey and taking additional measurements. Upon the
23 completion of further investigation, the a posteriori limit can be established. The area of elevated
24 activity is generally bordered by concentration measurements below the $DCGL_W$. An individual
25 elevated measurement on a systematic grid could conceivably represent an area four times as
26 large as the systematic grid area used to define the $DCGL_{EMC}$. This is the area bounded by the
27 nearest neighbors of the elevated measurement location. The results of the investigation should
28 show that the appropriate $DCGL_{EMC}$ is not exceeded. If measurements above the stated
29 scanning MDC are found by sampling or by direct measurements at locations that were not
30 flagged during the scanning survey, then this may indicate the scanning method does not meet
31 the DQOs.

32 The preceding discussion primarily concerns Class 1 survey units. Measurements exceeding
33 the $DCGL_W$ in Class 2 or Class 3 areas may indicate survey unit misclassification. Scanning
34 coverage for Class 2 and Class 3 survey units is less stringent than for Class 1. If the
35 investigation levels of **Section 5.3.8** are exceeded, an investigation should (1) ensure that the
36 area of elevated activity discovered meets the release criteria, and (2) provide reasonable
37 assurance that other undiscovered areas of elevated activity do not exist. If further investigation
38 determines that the survey unit was misclassified with regard to potential for residual radioactive
39 material, then a resurvey using the method appropriate for the new survey unit classification is
40 appropriate.

1 **8.6.2 Interpretation of Statistical Test Results**

2 The result of the statistical test is the decision to reject or not to reject the null hypothesis.
 3 Provided that the results of investigations triggered by the EMC were resolved, a rejection of the
 4 null hypothesis leads to the decision that the survey unit meets the release criteria in
 5 Scenario A. In Scenario B, failure to reject the null hypothesis in both the WRS and quantile
 6 tests leads to the decision that the survey unit meets the release criteria, provided that EMC
 7 results are acceptable. However, estimating the mean concentration of residual radioactive
 8 material in the survey unit may also be necessary so that dose or risk calculations can be made.
 9 This estimate is designated by δ . The mean concentration is generally the best estimator for δ .
 10 However, only the unbiased measurements from the statistically designed survey should be
 11 used in the calculation of δ .

12 If residual radioactive material is found in an isolated area of elevated activity—in addition to
 13 residual radioactive material distributed relatively uniformly across the survey unit—the unity
 14 rule (**Section 4.4**) can be used to ensure that the total dose is within the release criteria, as
 15 shown in **Equation 8-4**:

$$\frac{\delta}{DCGL_W} + \frac{(\text{mean concentration in elevated area} - \delta)}{DCGL_{EMC}} \leq 1 \quad (8-4)$$

16 If there is more than one elevated area, a separate term could be included in **Equation 8-4** for
 17 each area. The use of the unity rule for more than one elevated area may imply that a person is
 18 centered on each area of elevated radioactive material and exposed simultaneously. This is an
 19 impossible situation and represents a very cautious exposure scenario. If there are multiple
 20 elevated areas, then alternative approaches may be considered:

- 21 1. The MARSSIM user could determine the elevated area (primary area) that contributes the
 22 most to the total dose or risk. As shown by Abelquist (2008), the doses from elevated areas
 23 other than the primary area can be very small and might be negligible.
- 24 2. The dose or risk due to the actual residual radioactive material distribution could be
 25 calculated if an appropriate exposure pathway model is available.

26 Other approaches for handling elevated concentrations of radioactive material may be utilized
 27 and should be coordinated with the regulator.

28 The MARSSIM user should consult with the responsible regulatory agency for guidance on an
 29 acceptable approach to address the dose or risk from elevated areas of residual radioactive
 30 material. Note that these approaches generally apply only to Class 1 survey units, because
 31 areas of elevated activity above the $DCGL_W$ should not exist in Class 2 or Class 3 survey units.

32 A retrospective power analysis for the test will often be useful, especially when the null
 33 hypothesis is not rejected (see **Appendix M**). When the null hypothesis is not rejected, it may
 34 be because it is true, or it may be because the test did not have sufficient power to detect that it

1 is not true. The power of the test will be primarily affected by changes in the actual number of
2 measurements obtained and their standard deviation. An effective survey design will slightly
3 overestimate both the number of measurements and the standard deviation to ensure adequate
4 power. This ensures that a survey unit is not subjected to additional remediation simply because
5 the FSS is not sensitive enough to detect that residual radioactive material is below the DCGL_w.
6 When the null hypothesis is rejected in Scenario A, the power of the test becomes a somewhat
7 moot question. Nonetheless, even in this case, a retrospective power curve can be a useful
8 diagnostic tool and an aid to designing future surveys and for other survey units at the site.
9 When the null hypothesis is accepted in Scenario B, the power of the test is of particular
10 importance. If an insufficient number of samples are collected, the null hypothesis that the
11 survey unit meets the release criteria may be accepted simply because of the lack of sufficient
12 power to detect residual radioactive material in the survey unit above the release criteria. If the
13 retrospective power analysis reveals a lack of sufficient power, it may be necessary to revisit the
14 DQO process with the updated estimate of σ .

15 **8.6.3 If the Survey Unit Fails**

16 The systematic planning process included in MARSSIM should include planning for possible
17 survey unit failure. Early discussions with appropriate regulatory personnel about what actions
18 can and should be taken if the survey unit fails may prevent long delays later in the project.
19 However, if the survey unit fails in a way that is not anticipated, agreed upon actions may not be
20 applicable, and discussions will need to take place to address the unanticipated results.

21 The information provided in MARSSIM is fairly explicit concerning the steps that should be
22 taken to show that a survey unit meets the release criteria. Less has been said about the
23 procedures that should be used if the survey unit fails at any point. This is primarily because
24 there are many different ways that a survey unit may fail the FSS. The mean concentration of
25 residual radioactive material may not pass the nonparametric statistical tests. Further
26 investigation following the elevated measurement comparison may show a large enough area
27 with a concentration too high to meet the release criteria. Investigation levels may have caused
28 locations to be flagged during scanning that indicate unexpected levels of residual radioactive
29 material for the survey unit classification. Site-specific information is needed to fully evaluate all
30 of the possible reasons for failures, their causes, and their remedies.

31 When a survey unit fails to demonstrate compliance with the release criteria, the first step is to
32 review and confirm the data that led to the decision. Once this is done, the DQO process
33 (**Appendix D**) can be used to identify and evaluate potential solutions to the problem. The
34 concentration of residual radioactive material in the survey unit should be determined to help
35 define the problem. Once the problem has been stated, the decision concerning the survey unit
36 should be developed into a decision rule. Next, determine the additional data, if any, that are
37 needed to document that the survey unit demonstrates compliance with the release criteria.
38 Alternatives to resolving the decision statement should be developed for each survey unit that
39 fails the tests. These alternatives are evaluated against the DQOs, and a survey design that
40 meets the objectives of the project is selected. **Example 13** discusses a Class 2 survey unit with
41 measurements exceeding the DCGL_w.

Example 13: Class 2 Survey Unit with Measurements Exceeding the DCGL_w

A Class 2 survey unit passes the nonparametric statistical tests but has several measurements on the sampling grid that exceed the derived concentration guideline level determined using the Wilcoxon Rank Sum test (DCGL_w). This is unexpected in a Class 2 area, so these measurements are flagged for further investigation. Additional sampling confirms several areas where the concentration exceeds the DCGL_w. This indicates that the survey unit was misclassified. However, the scanning technique that was used was sufficient to detect concentrations of residual radioactive material at the derived concentration guideline level determined using the elevated measurement comparison (DCGL_{EMC}) calculated for the sample grid. No areas exceeding the DCGL_{EMC} were found. Thus, the only difference between the performed final status survey (FSS) and the required FSS for a Class 1 area is that the scanning may not have covered 100 percent of the survey unit area. In this case, one might simply increase the scan coverage to 100 percent. Reasons the survey unit was misclassified should be noted. If no areas exceeding the DCGL_{EMC} are found, the survey unit essentially demonstrates compliance with the release criteria as a Class 1 survey unit.

If a Class 2 survey unit has been misclassified as a Class 1 survey unit, the size of the survey unit should be considered to determine if the survey unit should be divided into two or more smaller survey units, based on the recommended survey sizes in **Table 4.1** and the concentration of radioactive material in different areas of the survey unit. If the scanning technique was not sufficiently sensitive, it may be possible to reclassify as Class 1 only that portion of the survey unit containing the higher measurements. This portion would be resampled at the higher measurement density required for a Class 1 survey unit, with the rest of the survey unit remaining as Class 2.

- 1 **Example 14** discusses a Class 1 survey unit with elevated areas.

Example 14: Class 1 Survey Unit with Elevated Areas

Consider a Class 1 Survey unit that passes the nonparametric statistical tests and contains some areas that were flagged for investigation during scanning. Further investigation, sampling, and analysis indicate one area is truly elevated. This area has a concentration that exceeds the derived concentration guideline level determined using the Wilcoxon Rank Sum test by a factor greater than the area factor calculated for its actual size. This area is then remediated. Remediation control sampling shows that the residual radioactive material was removed, and no other areas were affected by residual radioactive material. In this case, one may simply document the original final status survey (FSS), the fact that remediation was performed, the results of the remedial action support survey, and the additional remediation data. In some cases, additional FSS data may not be needed to meet the release criteria.

1 **Example 15** discusses a Class 1 survey unit that fails the statistical test.

Example 15: Class 1 Survey Unit Fails the Statistical Test

Consider a Class 1 area that fails the nonparametric statistical tests. Confirmatory data indicate that the mean concentration in the survey unit exceeds the derived concentration guideline level determined using the Wilcoxon Rank Sum test over a majority of its area. This indicates remediation of the entire survey unit is necessary, followed by another final status survey (FSS). Reasons for performing an FSS in a survey unit with significant amounts of residual radioactive material should be noted.

2 **Examples 13–15** are meant to illustrate the actions that may be necessary to secure the
3 release of a survey unit that has failed to meet the release criteria. The DQO process should be
4 revisited to plan how to attain the original objective, which is to safely release the survey unit by
5 showing that it meets the release criteria. Whatever data are necessary to meet this objective
6 will be in addition to the FSS data already in hand.

7 **8.6.4 Removable Radioactive Material**

8 Some regulatory agencies may require that smear samples be taken at indoor grid locations as
9 an indication of removable surface activity. In addition, the percentage of removable activity
10 assumed in the dose modeling can have a large impact on estimated doses. As such, it might
11 be necessary to confirm this assumption regarding the amount of removable contamination.
12 However, measurements of smears are very difficult to interpret quantitatively. In general, the
13 results of smear samples should be used for determining compliance with requirements that
14 specifically require a smear measurement. In addition, they may be used as a diagnostic tool to
15 determine whether further investigation is necessary.

16 **8.7 Documentation**

17 Documentation of the FSS should provide a complete and unambiguous record of the
18 radiological status of the survey unit relative to the established DCGLs. In addition, sufficient
19 data and information should be provided to enable an independent evaluation of the results of
20 the survey—including repeating, when possible, measurements at some future time. The
21 documentation should comply with all applicable regulatory requirements. Additional information
22 on documentation is provided in **Chapter 3**, **Chapter 5**, and **Appendix D**.

23 Much of the information in the final status report will be available from other decommissioning
24 documents. However, to the extent practicable, this report should be a stand-alone document
25 with minimum information incorporated by reference. This document should describe the
26 instrumentation or analytical methods applied, how the data were converted to DCGL units, the
27 process of comparing the results to the DCGLs, and the process of determining that the DQOs
28 were met.

29 The results of actions taken as a consequence of individual measurements or sample
30 concentrations in excess of the investigation levels should be reported with any additional data,

- 1 remediation, or resurveys performed to demonstrate that issues concerning potential areas of
 2 elevated activity were resolved. The results of the data evaluation using statistical methods to
 3 determine whether release criteria were satisfied should be described. If criteria were not met,
 4 or if results indicate a need for additional data, appropriate further actions should be determined
 5 by the site management in consultation with the responsible regulatory agency. **Example 16**
 6 provides an example of a data interpretation checklist.

Example 16: Example Data Interpretation Checklist

Convert Data to Standard Units

- _____ Structure activity should be in becquerels/square meter (Bq/m²) (decays per minute [dpm]/100 square centimeters [cm²]).
- _____ Solid media (soil, building surfaces, etc.) activity should be in in Bq/kilogram (kg) (picocuries/gram [pCi/g]).

Evaluate Elevated Measurements

- _____ Identify elevated data.
- _____ Compare data with derived elevated area criteria.
- _____ Determine need to remediate and/or reinvestigate elevated condition.
- _____ Compare data with survey unit classification criteria.
- _____ Determine need to investigate and/or reclassify.

Assess Survey Data

- _____ Review data quality objectives (DQOs), measurement quality objectives (MQOs), and survey design.
- _____ Verify that data of adequate quantity and quality were obtained.
- _____ Perform preliminary assessments (graphical methods) for unusual or suspicious trends or results—investigate further as appropriate.

Perform Statistical Tests

- _____ Select appropriate tests for the radionuclide.
- _____ Conduct tests.
- _____ Compare test results against hypotheses.
- _____ Confirm power level of tests.

Compare Results to Guidelines

- _____ Determine mean or median concentrations.
- _____ Confirm that residual activity satisfies guidelines.

Compare Results with DQOs and Measurement Quality Objectives (MQOs)

_____ Determine whether all DQOs and MQOs are satisfied.

_____ Explain/describe deviations from design-basis DQOs/MQOs.

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National Environmental Policy Act of 1970, 42 U.S.C. § 4321 et seq.

Nuclear Non-Proliferation Act of 1978, as amended, 22 U.S.C. § 3201 et seq.

Nuclear Waste Policy Act (NWPA) of 1982, as amended, 42 U.S.C. § 10101

Omnibus Diplomatic Security and Antiterrorism Act of 1986, 22 U.S.C. 4852

Price-Anderson Amendments Act of 1988, Public Law 100-408, 102 Stat. 1066

Public Health Service Act, as amended, 42 U.S.C § 241 et seq.

Reorganization Plan No. 3 of 1970, 35 Fed. Reg. 15623 (October 6, 1970)

Resource Conservation and Recovery Act (RCRA) of 1976, 42 U.S.C. §§ 6901-6992k

Safe Drinking Water Act (SDWA) of 1974, as amended, 42 U.S.C. § 300f et seq.

Solar, Wind, Waste, and Geothermal Power Production Incentives Act of 1990, Pub. L. 101-575,
104 Stat. 2834

Toxic Substances Control Act (TSCA) of 1976, 15 U.S.C. §§ 2601-2692

Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978, as amended, 42 U.S.C. § 2022

Waste Isolation Pilot Plant Land Withdrawal Act of 1992, Public Law No: 102-579

West Valley Demonstration Project Act of 1980, Pub. L. No. 96-368, Stat. 2443