MECHANICAL INTEGRITY TESTING (MIT)

EPA Region 6

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(Credits to George Robin, Steve Platt & Chuck Tinsley)

What we protect:

USDWs

(Underground Sources of Drinking Water)

Pronounced:

you wess dee dubyas

Mechanical Integrity (MI)

Part 1

Internal Mechanical Integrity

40 CFR §146.8(a)(1)

Part 2

External Mechanical Integrity

40 CFR §146.8(a)(2)

146.8 Mechanical integrity.

(a) An injection well has mechanical integrity if:

(Internal)

(1) There is no significant leak in the casing, tubing or packer;

(b) One of the following methods must be used to evaluate the absence of significant leaks under paragraph (a)(1) of this section:

(1) Following an initial pressure test, monitoring of the tubing-casing annulus pressure with sufficient frequency to be representative, as determined by the Director, while maintaining an annulus pressure different from atmospheric pressure measured at the surface;

(2) Pressure test with liquid or gas; or

(3) Records of monitoring showing the absence of significant changes in the relationship between injection pressure and injection flow rate for the following Class II enhanced recovery wells:

(i) Existing wells completed without a packer provided that a pressure test has been performed and the data is available and provided further that one pressure test shall be performed at a time when the well is shut down and if the running of such a test will not cause further loss of significant amounts of oil or gas; or

(ii) Existing wells constructed without a long string casing, but with surface casing which terminates at the base of fresh water provided that local geological and hydrological features allow such construction and provided further that the annular space shall be visually inspected. For these wells, the Director shall prescribe a monitoring program which will verify the absence of significant fluid movement from the injection zone into an USDW.

(External)

(a)(2) There is no significant fluid movement into an underground source of drinking water through vertical channels adjacent to the injection well bore.

c) One of the following methods must be used to determine the absence of significant fluid movement under paragraph (a)(2) of this section:

(1) The results of a temperature or noise log; or

(2) For Class II only, cementing records demonstrating the presence of adequate cement to prevent such migration; or

(3) For Class III wells where the nature of the casing precludes the use of the logging techniques prescribed at paragraph (c)(1) of this section, cementing records demonstrating the presence of adequate cement to prevent such migration;

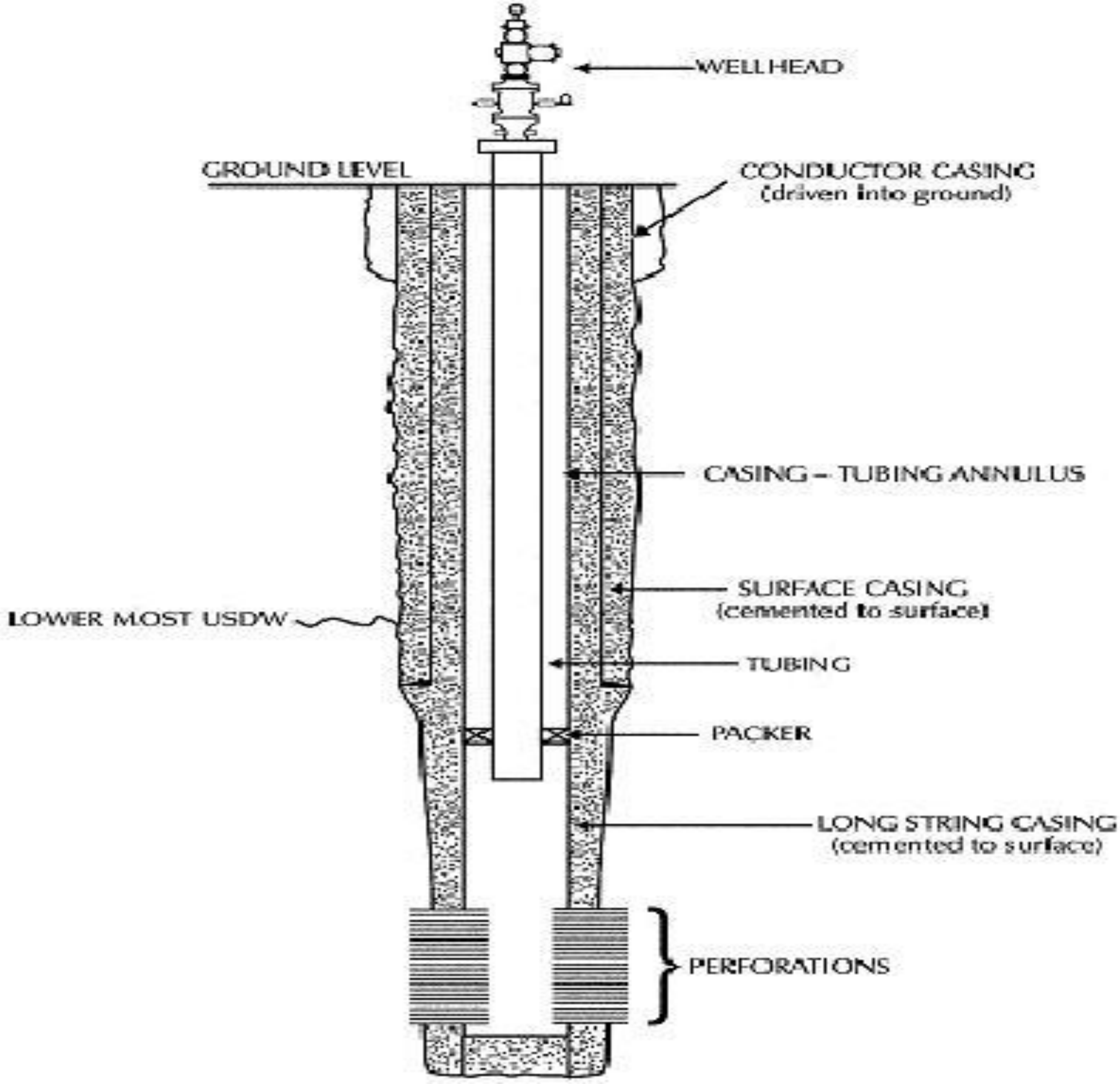
4) For Class III wells where the Director elects to rely on cementing records to demonstrate the absence of significant fluid movement, the monitoring program prescribed by §146.33(b) shall be designed to verify the absence of significant fluid movement.

(Alternative tests)

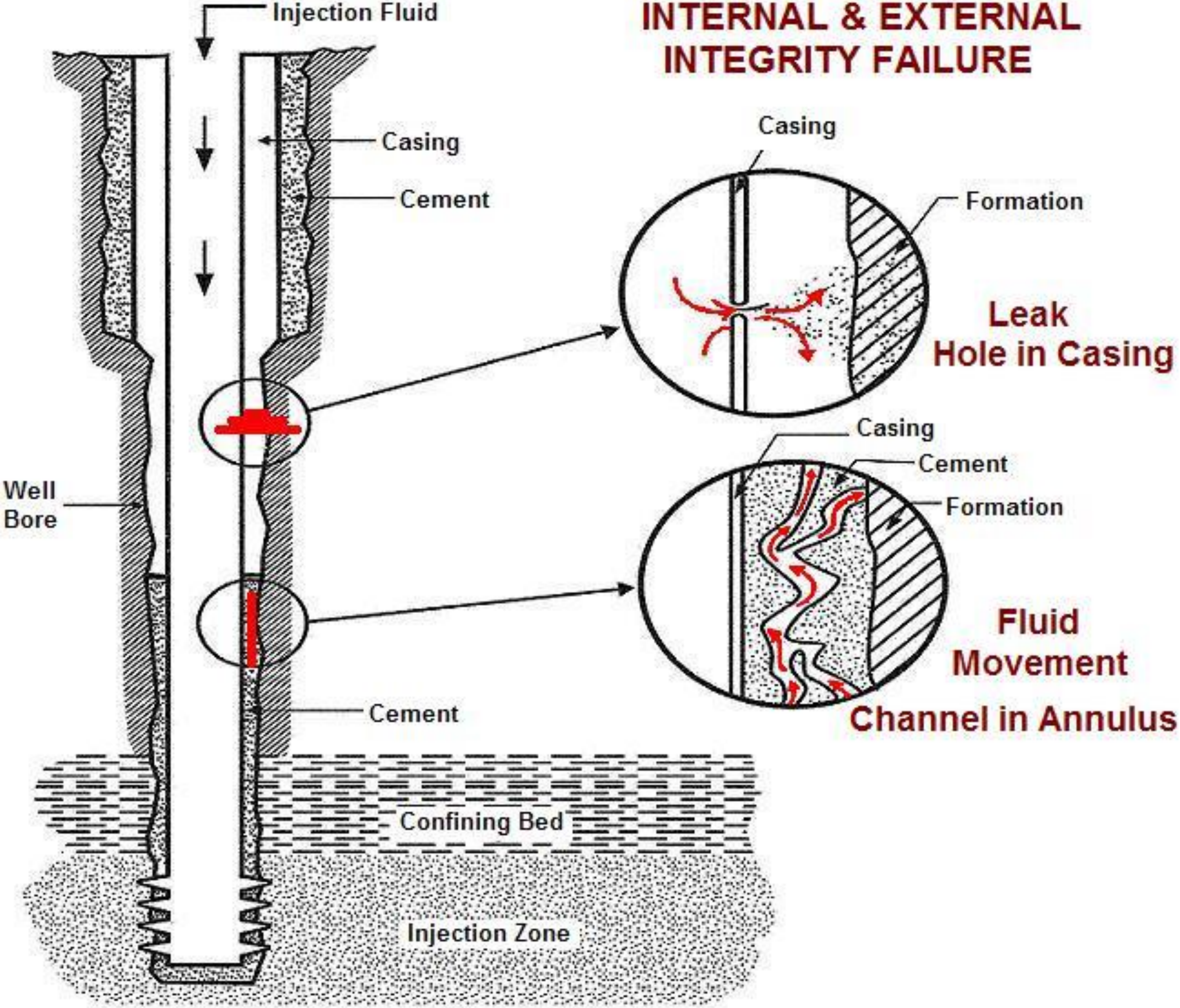
(d) The Director may allow the use of a test to demonstrate mechanical integrity other than those listed in paragraphs (b) and (c)(2) of this section with the written approval of the Administrator. To obtain approval, the Director shall submit a written request to the Administrator, which shall set forth the proposed test and all technical data supporting its use. The Administrator shall approve the request if it will reliably demonstrate the mechanical integrity of wells for which its use is proposed. Any alternate method approved by the Administrator shall be published in the FEDERAL REGISTER and may be used in all States unless its use is restricted at the time of approval by the Administrator.

(e) In conducting and evaluating the tests enumerated in this section or others to be allowed by the Director, the owner or operator and the Director shall apply methods and standards generally accepted in the industry. When the owner or operator reports the results of mechanical integrity tests to the Director, he shall include a description of the test(s) and the method(s) used. In making his/her evaluation, the Director shall review monitoring and other test data submitted since the previous evaluation.

(f) The Director may require additional or alternative tests if the results presented by the owner or operator under §146.8(e) are not satisfactory to the Director to demonstrate that there is no movement of fluid into or between USDWs resulting from the injection activity.


WELLHEAD
GROUND LEVEL
CONDUCTOR CASING
(driven into ground)
CASING – TUBING ANNULUS
SURFACE CASING
(cemented to surface)
LOWER MOST USDW
TUBING
PACKER
LONG STRING CASING
(cemented to surface)
PERFORATIONS

INTERNAL & EXTERNAL INTEGRITY FAILURE



What are our main MI concerns?

1 Any **leaks** in the system?

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2 Is injected fluid **entering and remaining** in the approved interval?

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1 Any **leaks** in the system?

2 Is injected fluid **entering and remaining** in the approved interval?

3 Is there **crossflow** of fluid into USDWs?

What are our main MI goals?

1 Any **leaks** in the system?

(Internal MI)

Goal:

Prevention of leakage through the "walls" of the well (casing, tubing, etc.)

Prevention of Leakage through the "walls" of the well (casing, tubing, etc.).

How leakage can be discovered:

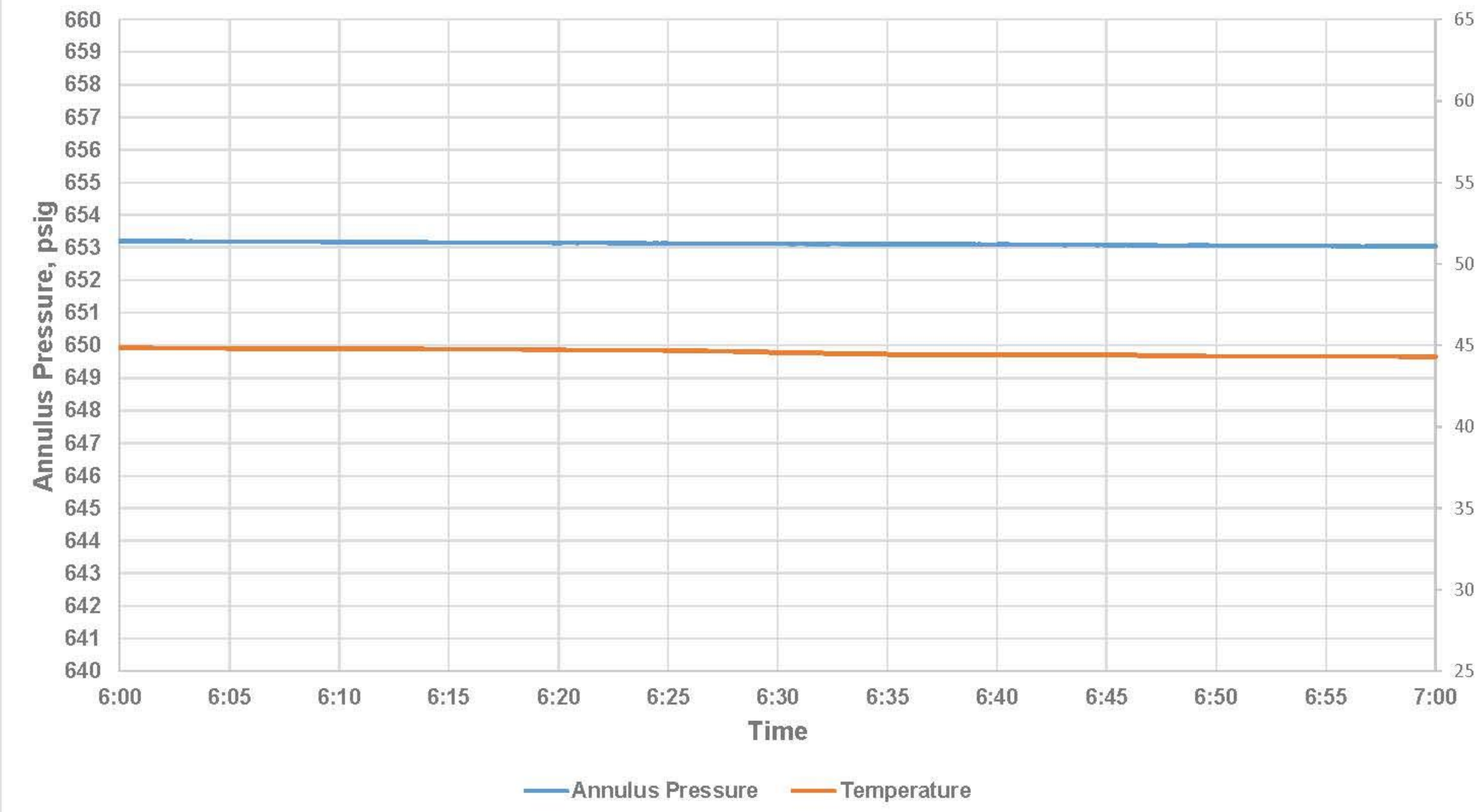
- pressure tests

INTERNAL MI ANNULUS PRESSURE TEST

- **Tests the tubing, casing and packer for leaks.**
- **Testing requirements vary by well Class and UIC program requirements. These vary by State or Tribe.**
- **Typically the casing/tubing annulus is pressured to the maximum allowable injection pressure to ensure the casing can withstand this pressure should the tubing or packer fail. Director variances can also be allowed.**
- **The test length is typically 30 minutes to 1 hour.**
- **Test failure is typically a pressure loss of > 5 – 10%**

January 23, 2018

(Beginning Pressure = 653.20 psi & Ending Pressure = 653.03 psi;
Beginning Temperature = 44.85°F & Ending Temperature = 44.30°F)



Revised 01-31-18

Prevention of Leakage through the "walls" of the well (casing, tubing, etc.).

How leakage can be discovered:

- pressure tests
- downhole logging (discussed later)

Prevention of Leakage through the "walls" of the well (casing, tubing, etc.).

How leakage can be discovered:

- **pressure tests**
- **downhole logging**
- **monitoring of injection activities.**
  - **Annulus pressure**
  - **Injection pressure/rate relationship**

What are our main MI Goals?

Prevention of Fluid Movement through Casing/Wellbore Annular Space

2 Is injected fluid **entering and remaining** in the approved interval?

(External MI)

What are our main MI Goals?

Prevention of Fluid Movement through Casing/Wellbore Annular Space

2 Is injected fluid **entering and remaining** in the approved interval?

(External MI)

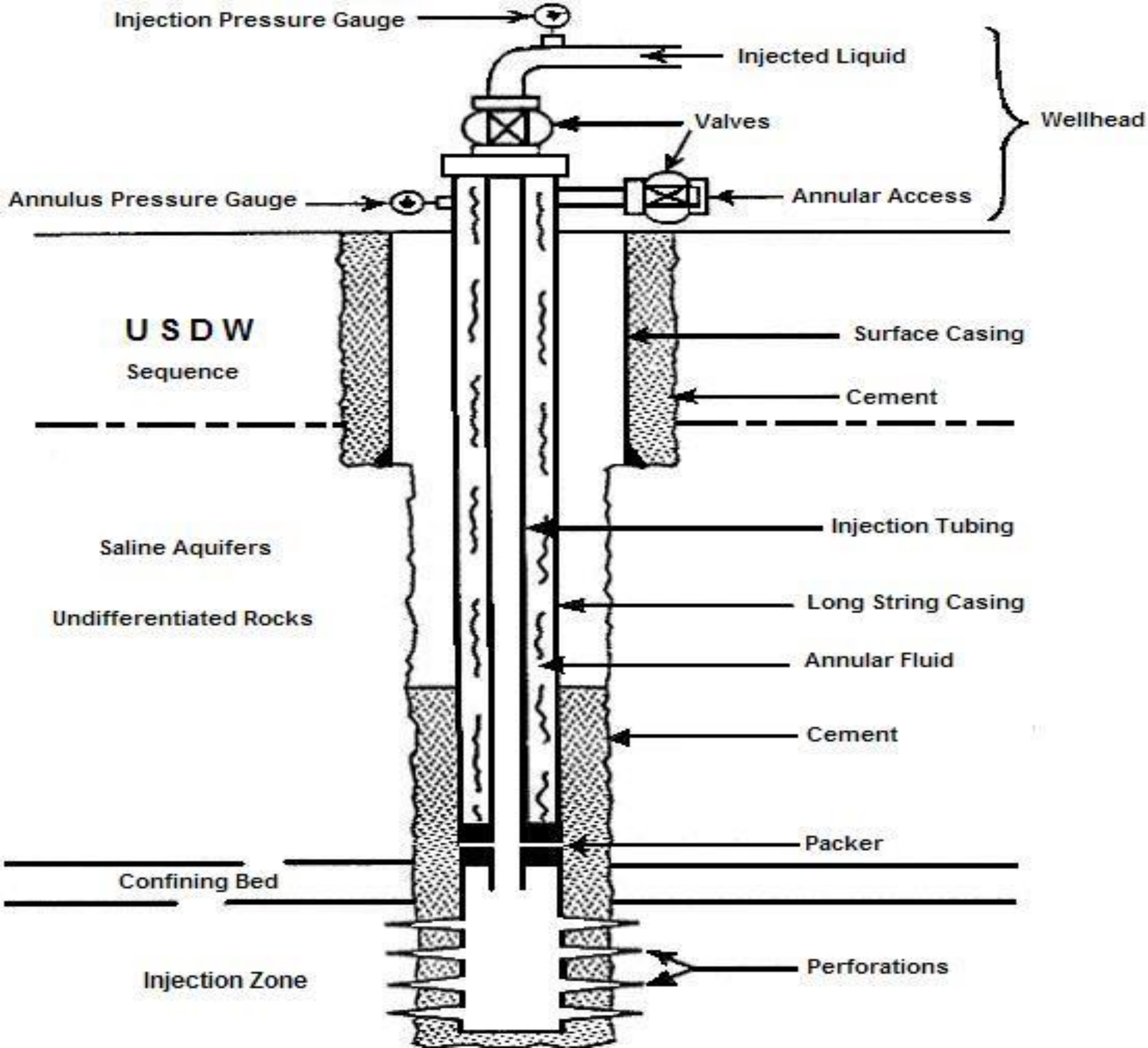
3 Is there **crossflow** of fluid into USDWs?

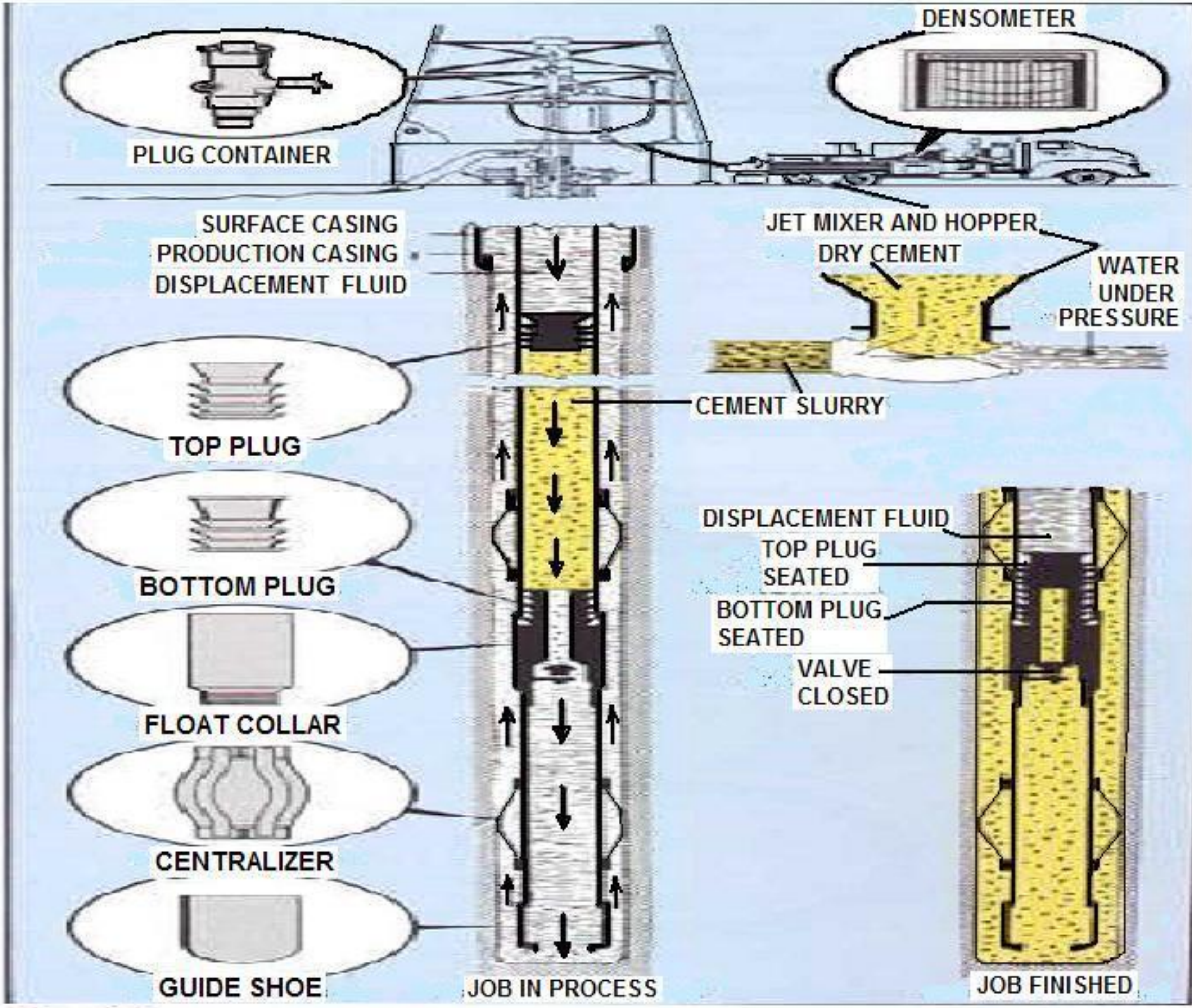
(External MI)

What are our main MI Goals?

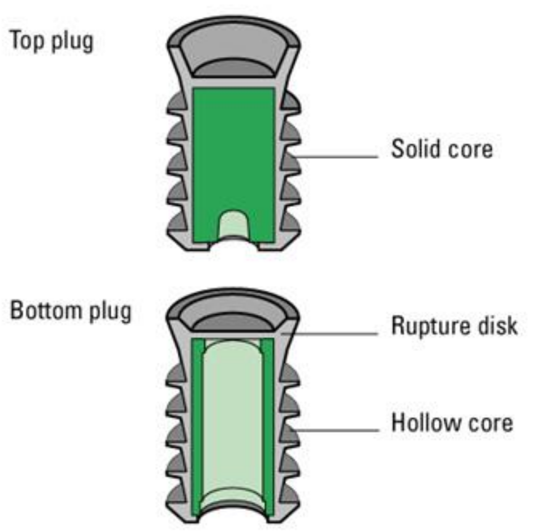
Prevention of Fluid Movement through Casing/Wellbore Annular Space

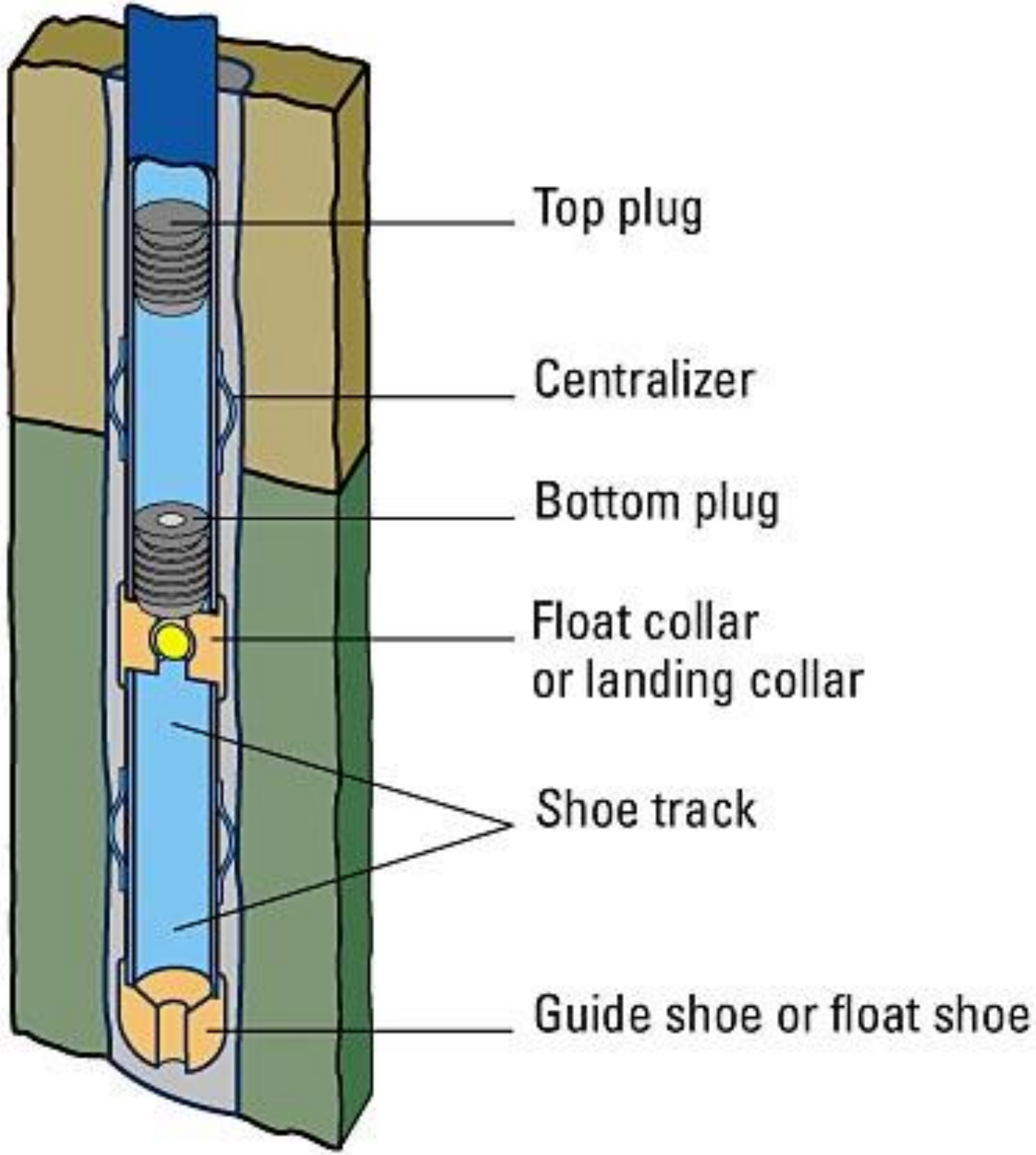
Proper cementing and construction


Injection Pressure Gauge
Injected Liquid
Valves
Wellhead
Annulus Pressure Gauge
Annular Access
U S D W
Sequence
Surface Casing
Cement
Injection Tubing
Saline Aquifers
Undifferentiated Rocks
Long String Casing
Annular Fluid
Cement
Packer
Confining Bed
Injection Zone
Perforations

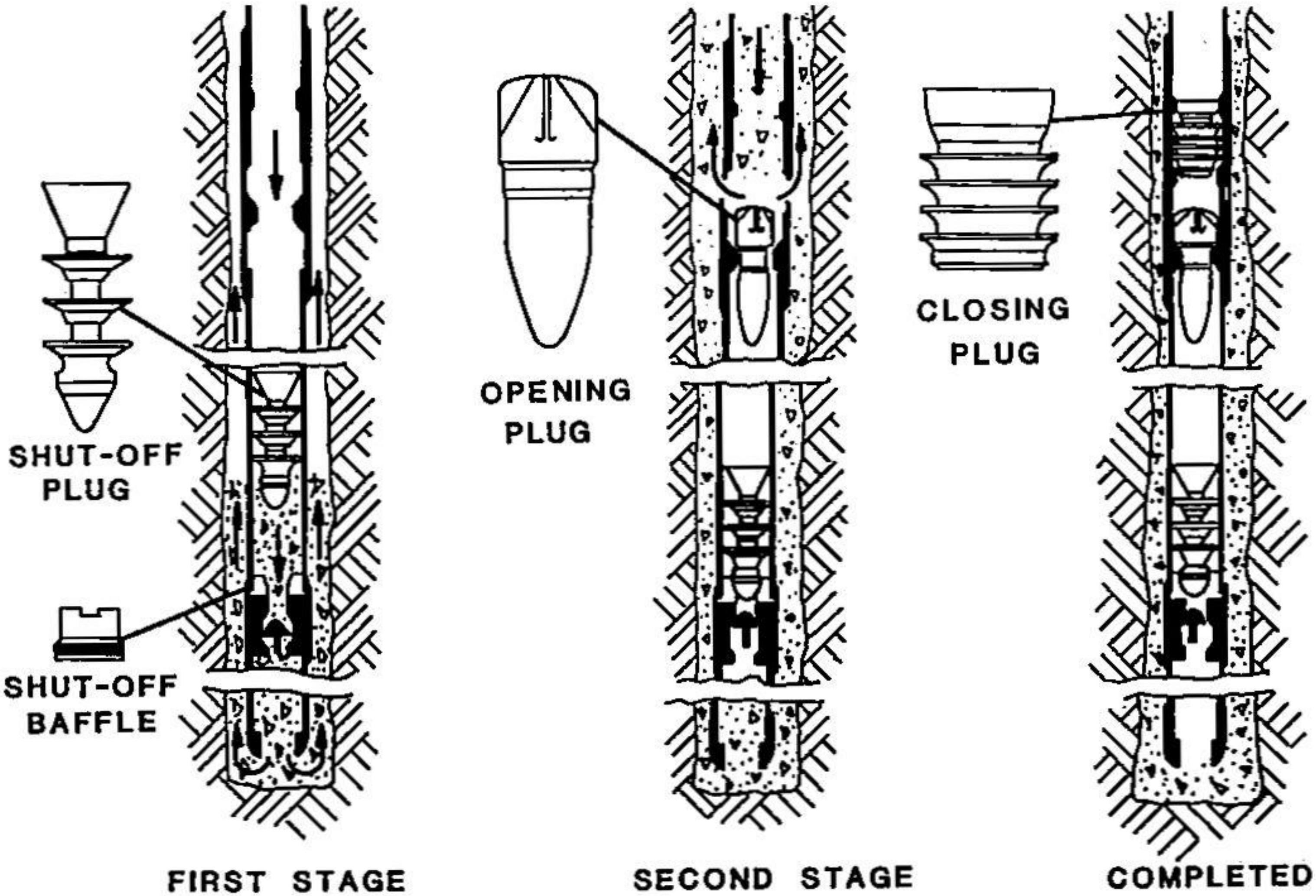

DENSOMETER
PLUG CONTAINER
SURFACE CASING
PRODUCTION CASING
DISPLACEMENT FLUID
JET MIXER AND HOPPER
DRY CEMENT
WATER UNDER PRESSURE
CEMENT SLURRY
TOP PLUG
BOTTOM PLUG
FLOAT COLLAR
CENTRALIZER
GUIDE SHOE
JOB IN PROCESS
DISPLACEMENT FLUID
TOP PLUG SEATED
BOTTOM PLUG SEATED
VALVE CLOSED
JOB FINISHED

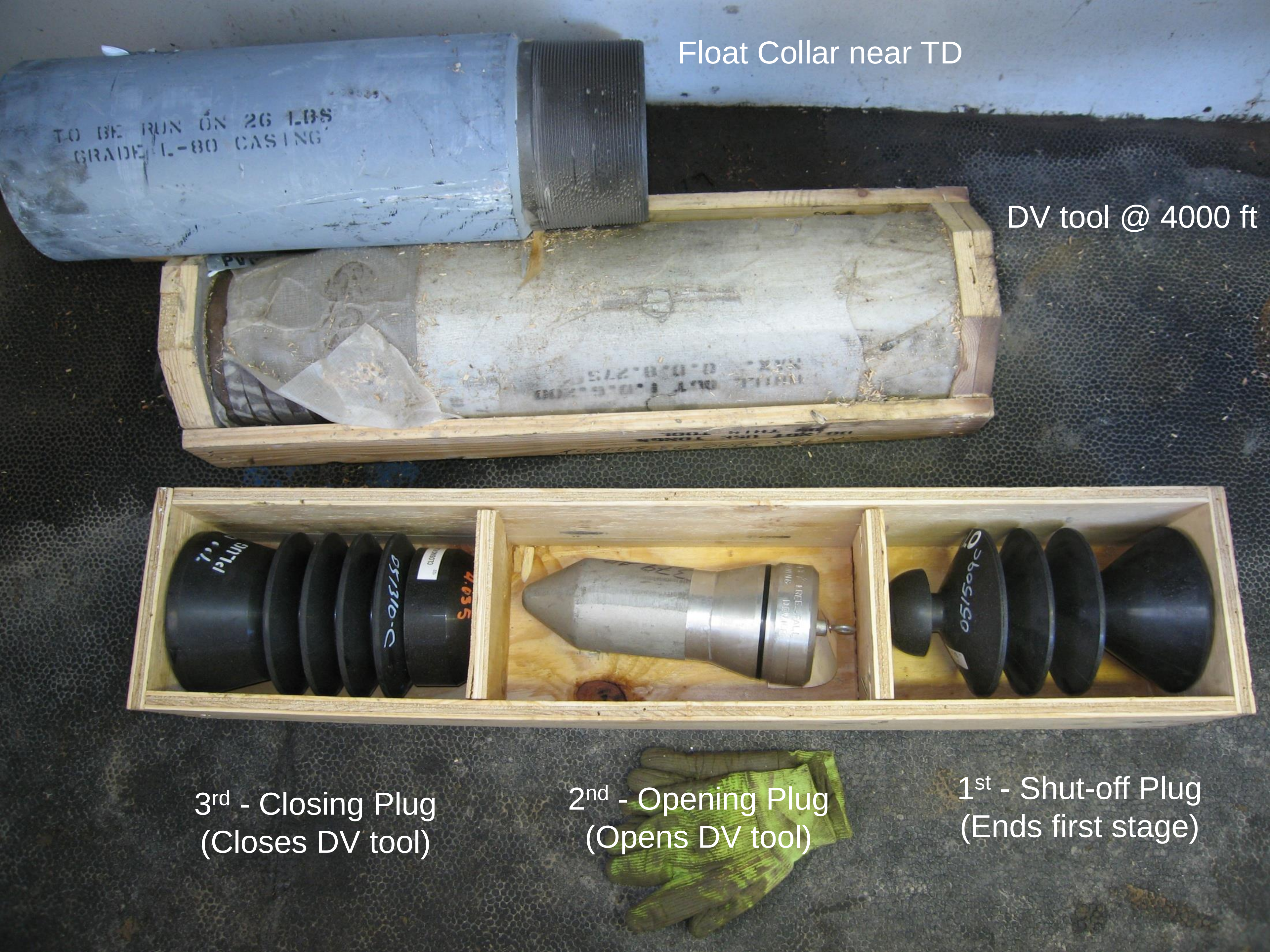
Casing Cementing Operations



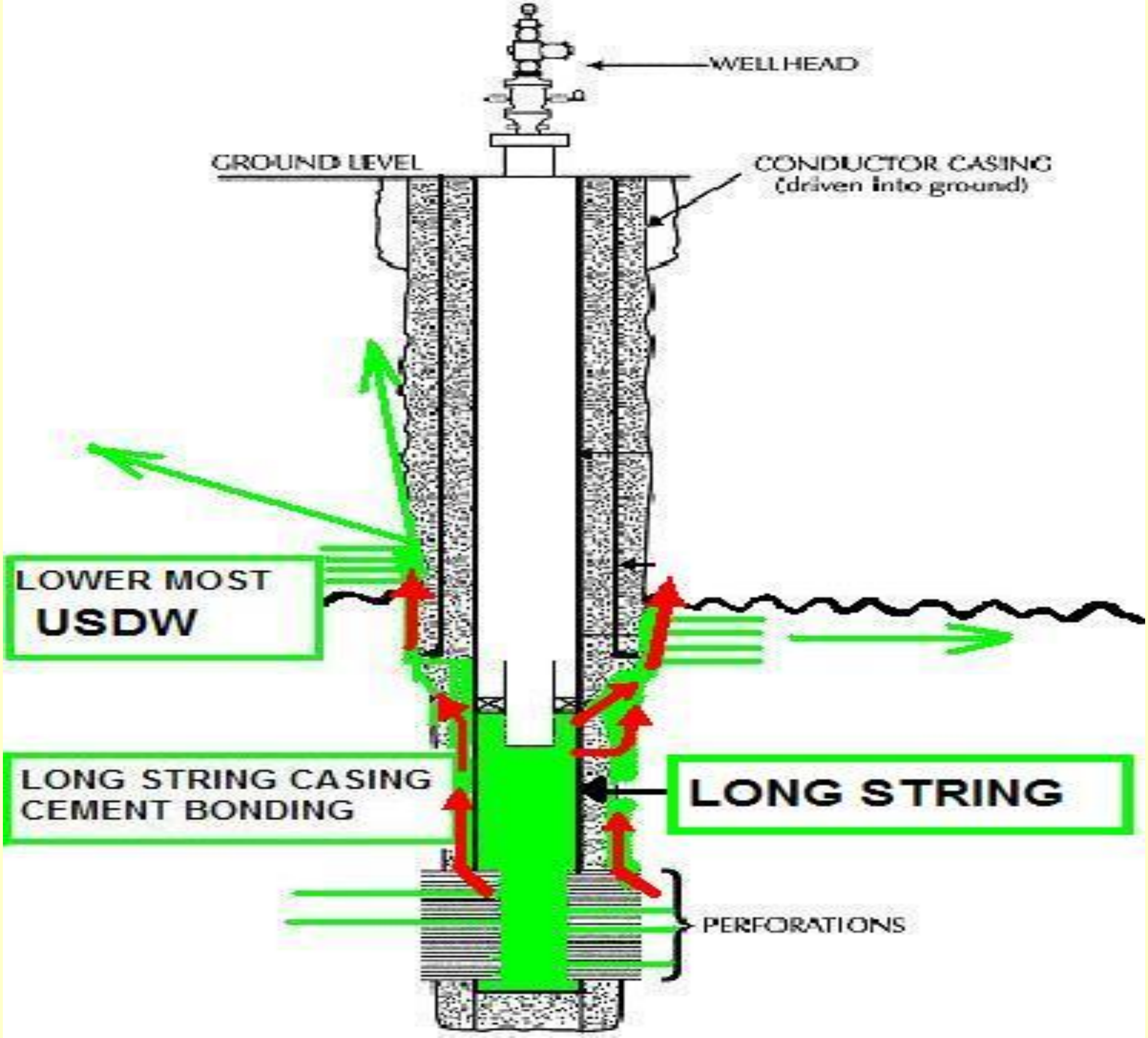


Two-stage Cementing Tools:
(Float Collar, DV tool, and Plugs)




Float Collar near TD
DV tool @ 4000 ft
3rd - Closing Plug
(Closes DV tool)
2nd - Opening Plug
(Opens DV tool)
1st - Shut-off Plug
(Ends first stage)
TO BE RUN ON 26 LBS
GRADE L-80 CASING
PLUG
051310-C
4.035


Centralizers
F250
FX4
OFF ROAD
BFGoodrich
All-Terrain T/A


WELLHEAD
GROUND LEVEL
CONDUCTOR CASING
(driven into ground)
LOWER MOST
USDW
LONG STRING CASING
CEMENT BONDING
LONG STRING
PERFORATIONS

Cement
Bond
Log

(CBL)

- **Cement needs to set properly before a cement integrity log is run. This can take from 10 to 50 hours for typical cement jobs.**

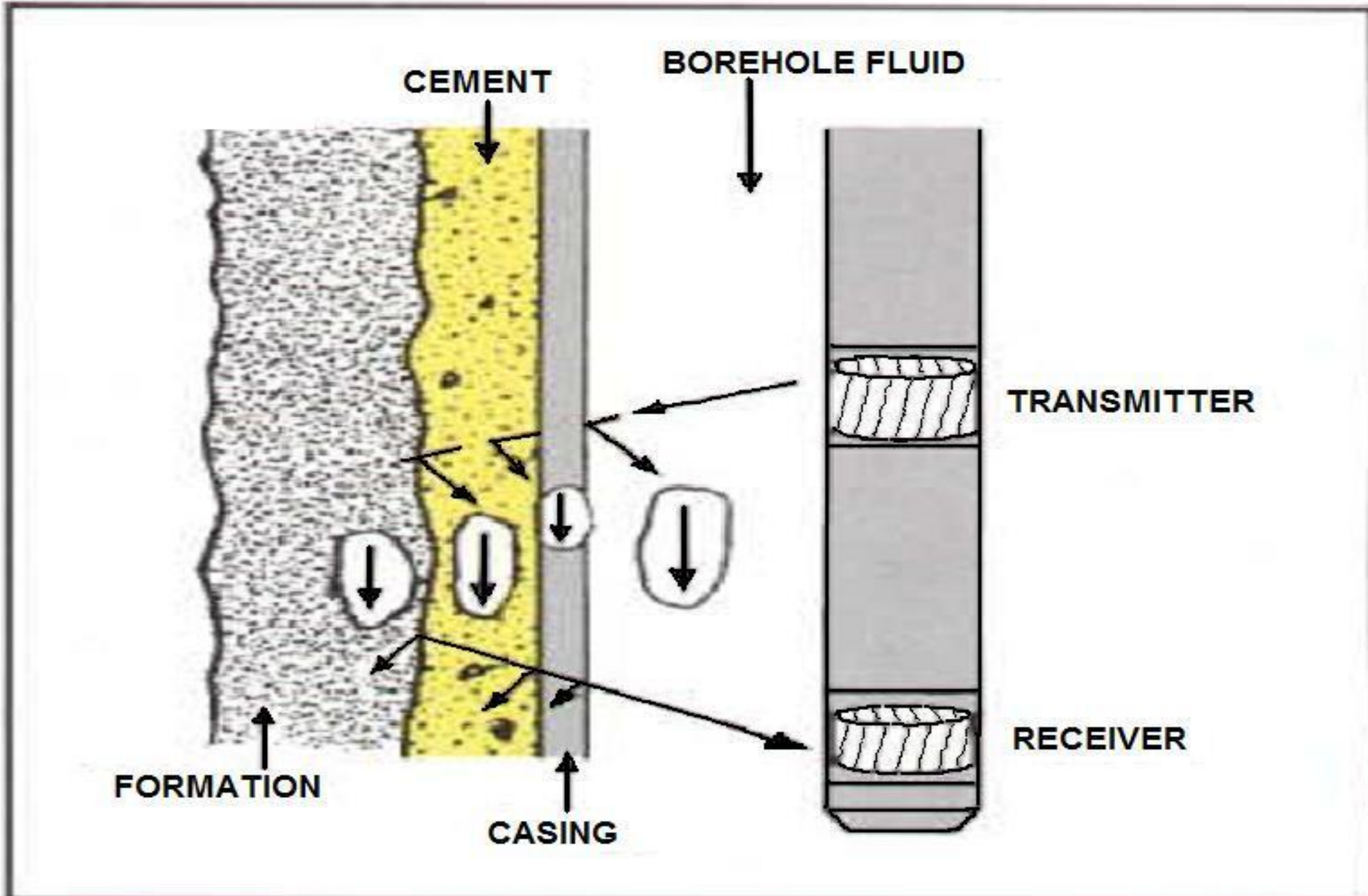
- **Full compressive strength is reached in 7 to 10 days. The setting time depends on the type of cement, temperature, pressure, and the use of setting accelerants.**

- **Excess pressure on the casing should be avoided during the curing period so that the cement bond to the pipe is not disturbed.**

- **Cement bond logs were run as early as 1958 with early sonic logs and the temperature log was used to find the cement top beginning in 1933.**

- **Cement integrity logs are run to determine the quality of the cement bond to the casing, to evaluate cement fill-up between the casing and the wellbore rock and to evaluate the cement bond to the wellbore rock.**

- **A poor cement bond may allow unwanted fluids to enter the wellbore or injected fluid to leave the injection interval.**



CEMENT LOGGING PRINCIPLES

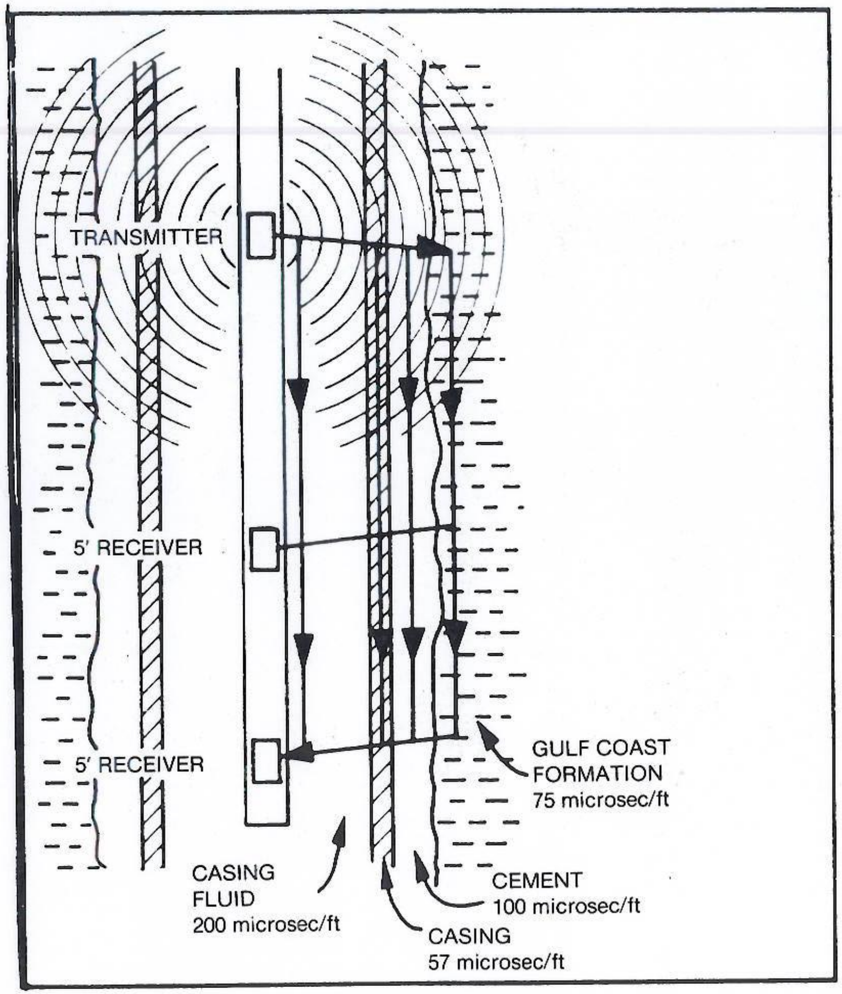


Figure 78. Typical transit times for various media inspection by the cement bond tool (Schlumberger, no date).

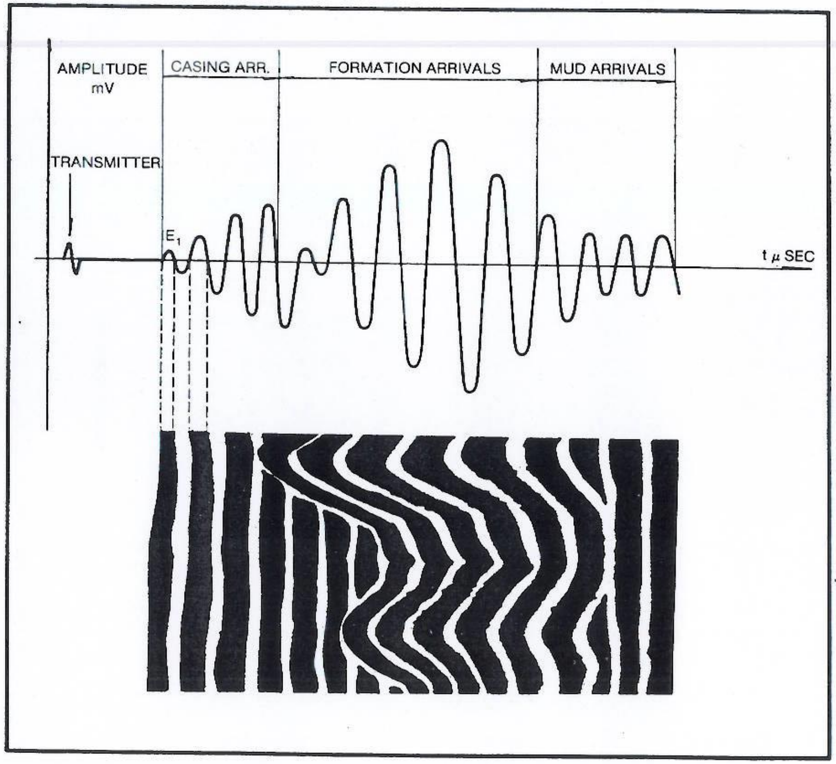
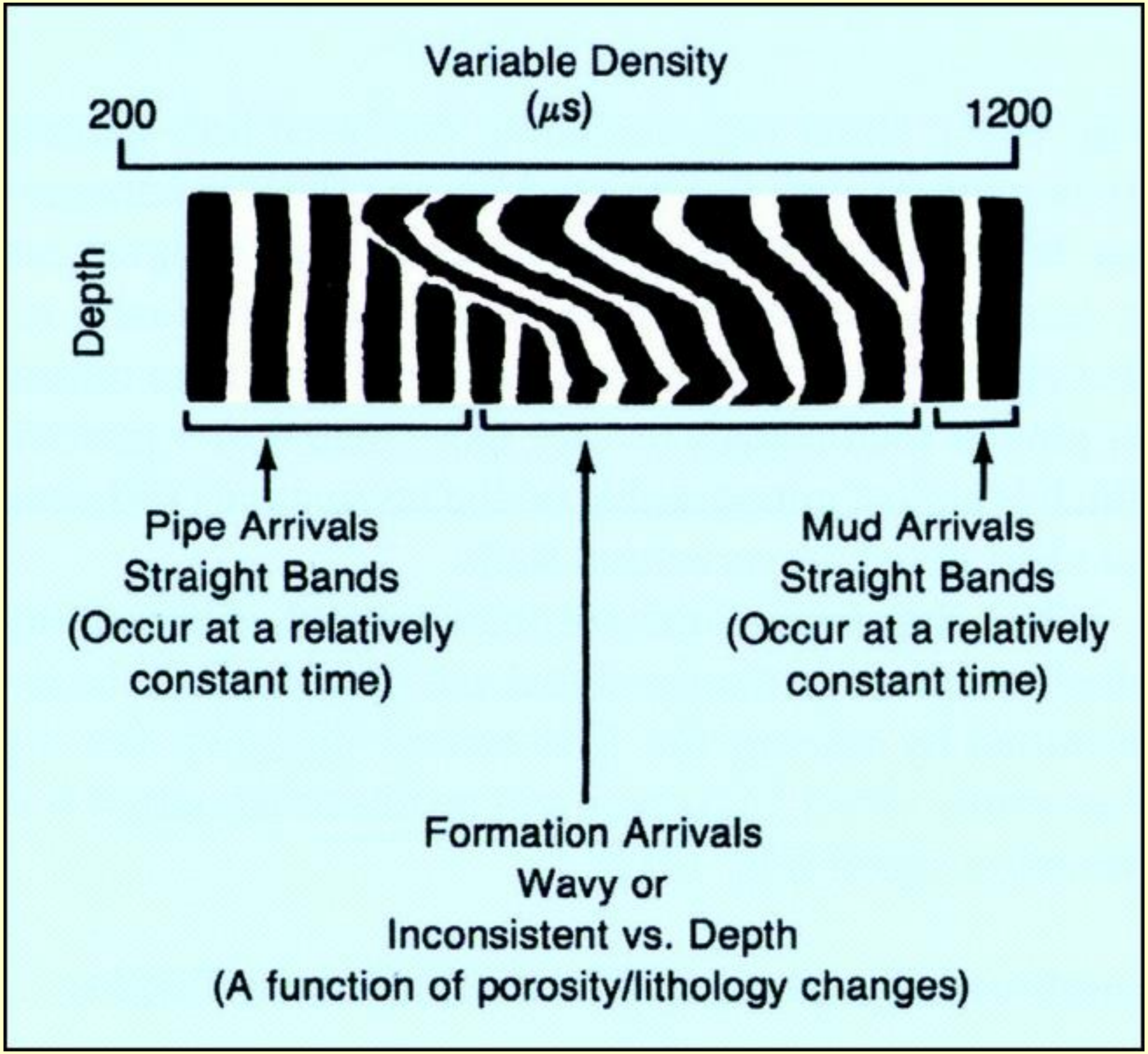
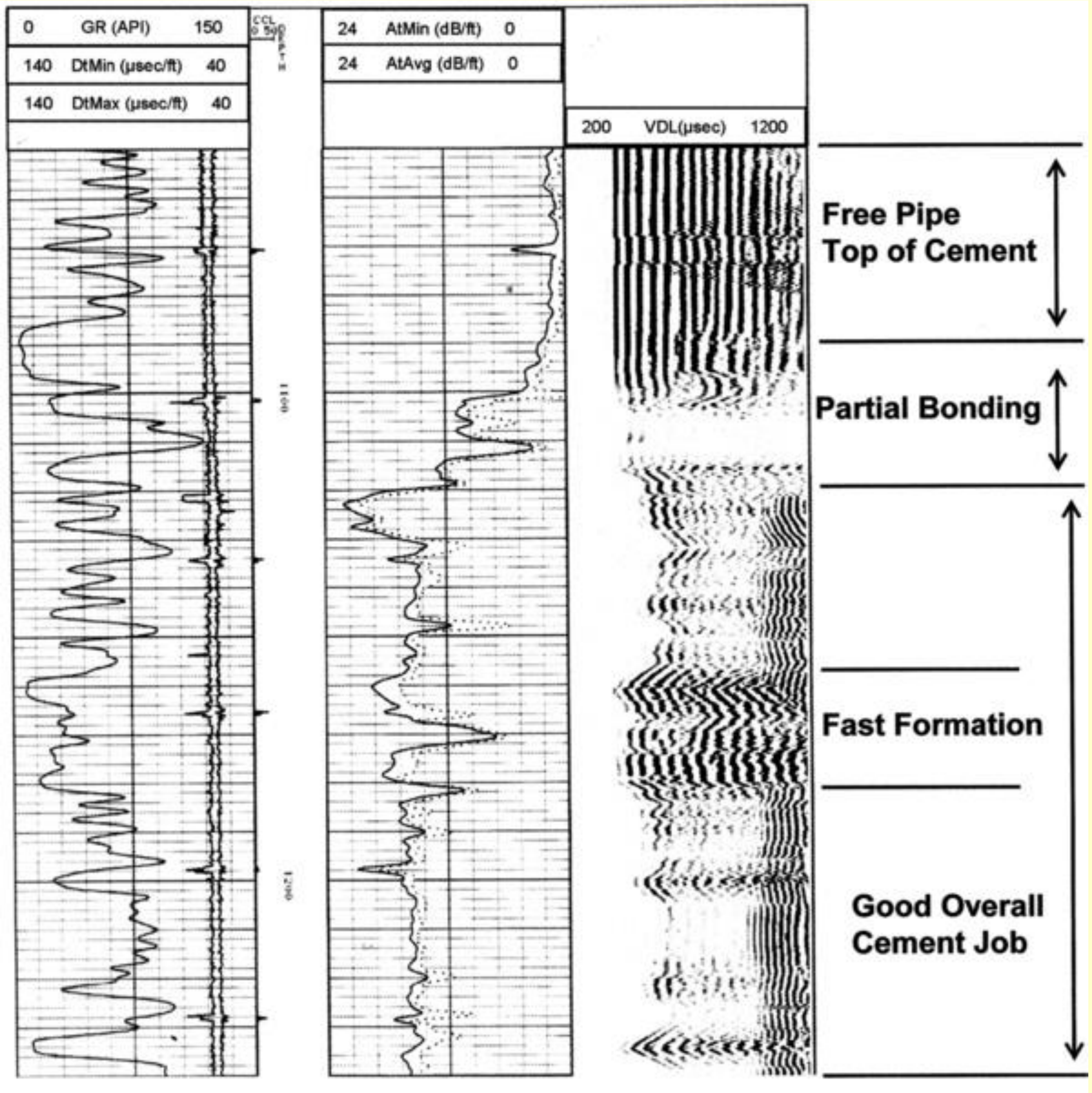


Figure 80. Principle of operation of the variable density log (Schlumberger, 1976).

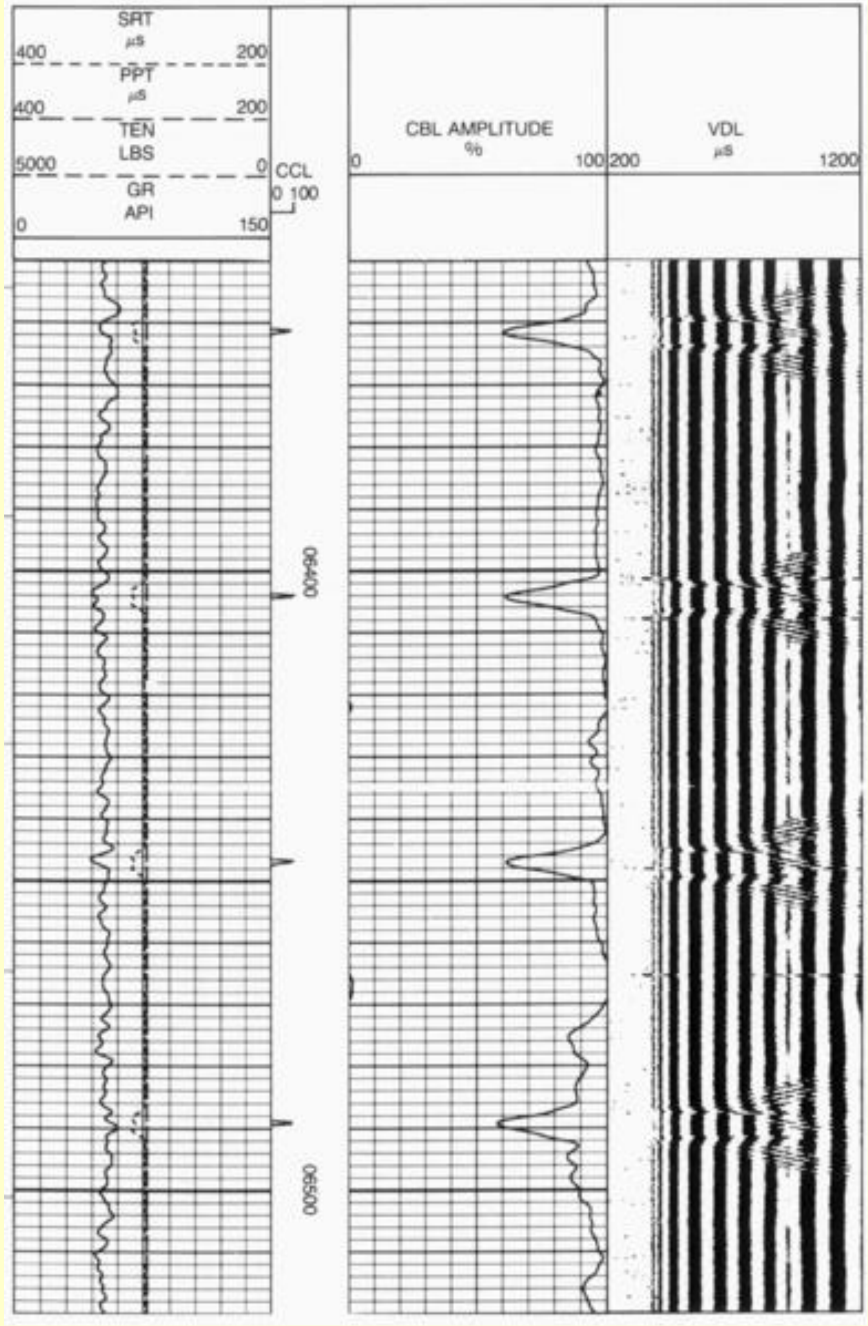


Identification of important features on a variable-density log (VDL) (courtesy of Baker Atlas).

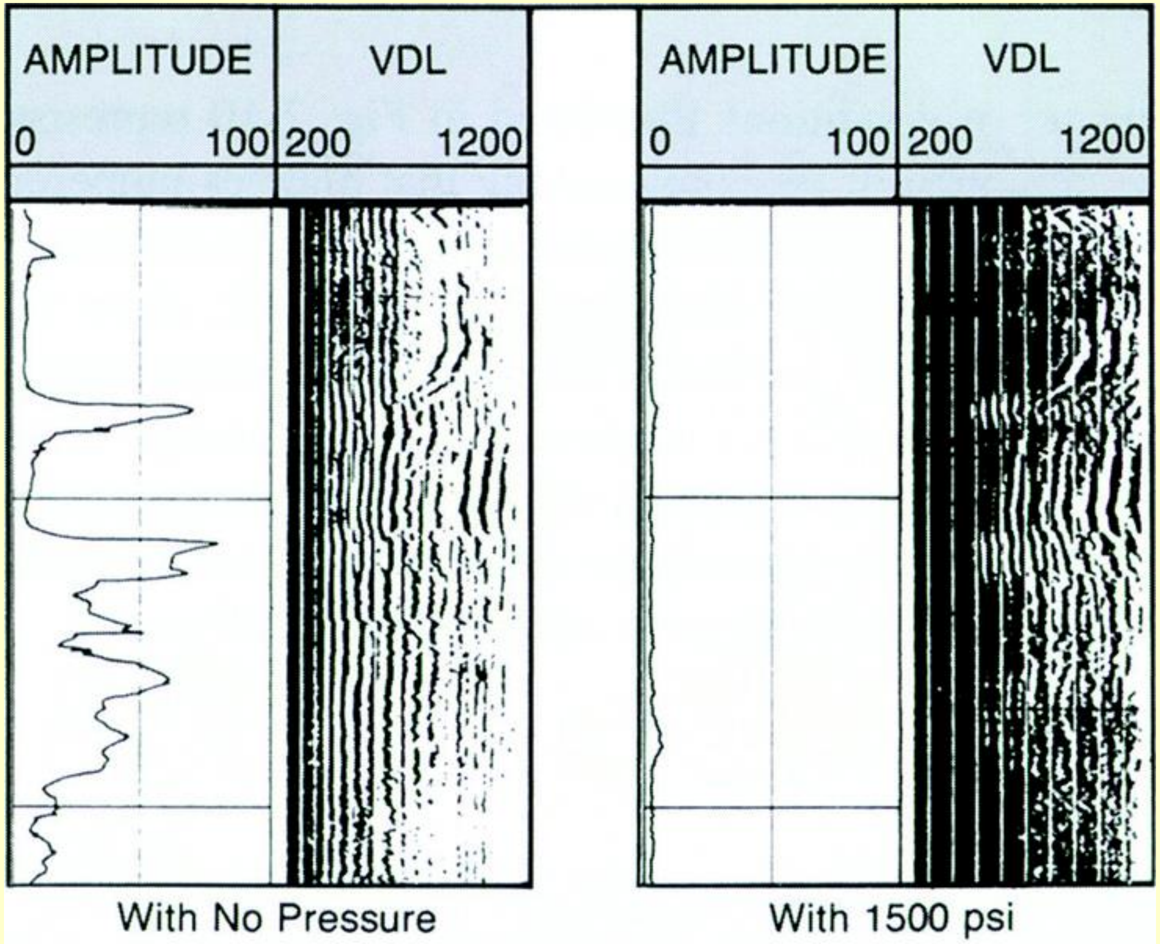


Typical cement-bond log presentation (courtesy of Baker Atlas).

In cases of poor bonding, casing-collar signals may also be identified as "w" patterns (anomalies)



Field example showing microannulus effect on amplitude and VDL log displays (courtesy of Baker Atlas).



Pressuring the casing improves the acoustic coupling to the formation and the casing signal will decrease and the formation signal will become more obvious

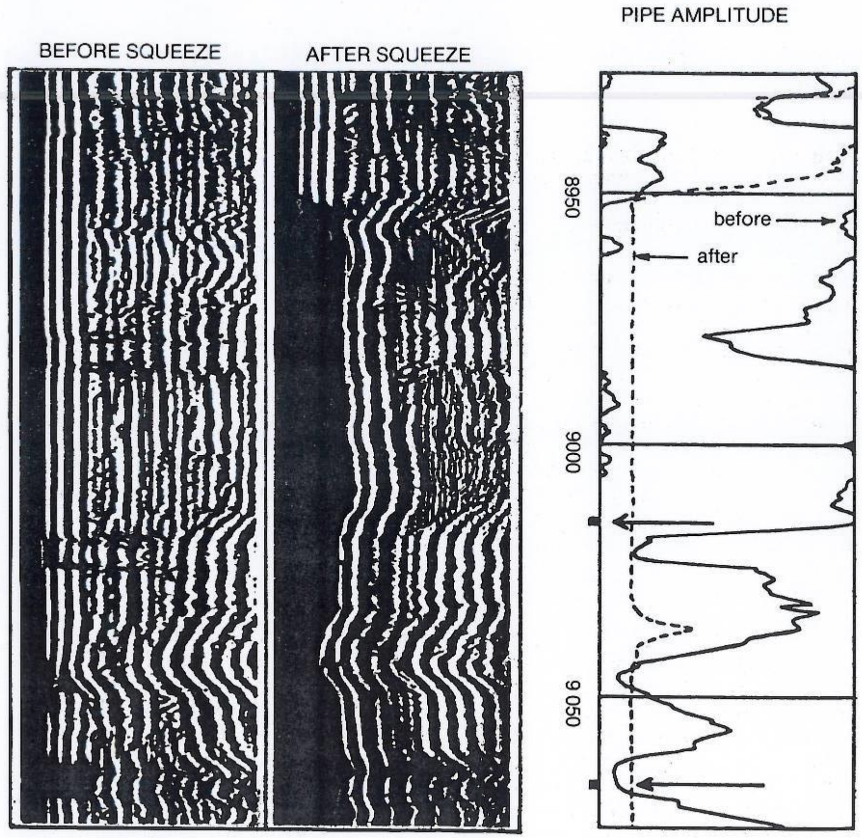
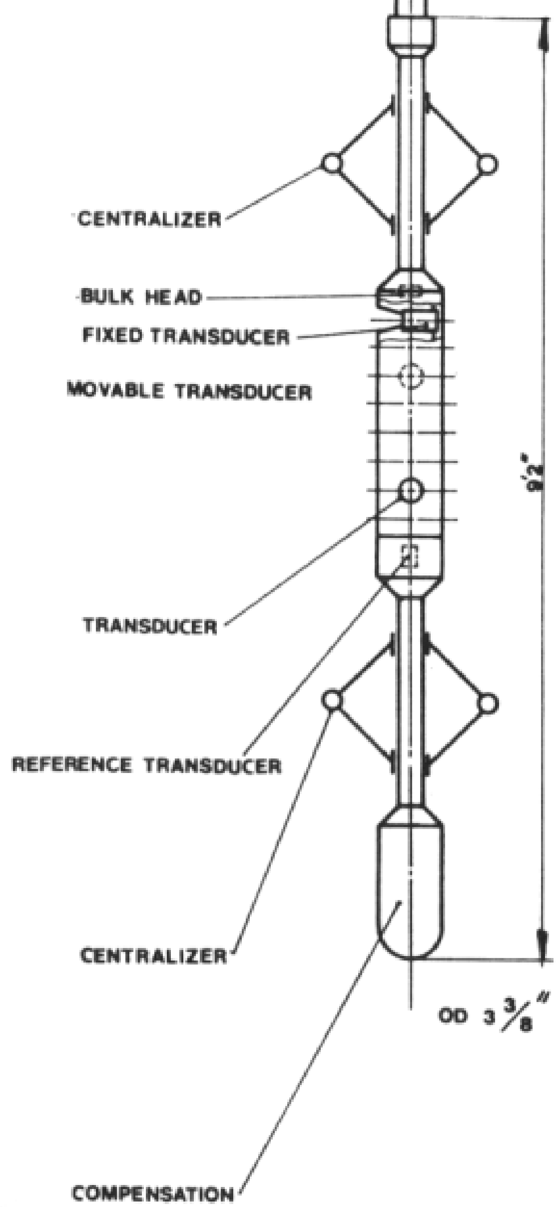


Figure 90. Elimination of a channel by cement squeezing (Walker, 1968).

CEMENT EVALUATION TOOL

(CET)



Cement Evaluation Tool

(Courtesy of Schlumberger)

CET
PURPOSE

- SAME AS **CEMENT BOND LOG (CBL)** ONLY MORE ADVANCED PRINCIPLE
- INVESTIGATES CEMENT **RADIALLY**
- MEASURES CASING **DIAMETER**, CASING **ROUNDNESS**, AND TOOL **ECCENTERING**

CET
PRINCIPLE OF OPERATION

- ULTRA SONIC ENERGY MAKES CASING **RESONATE**
- **RATE OF DAMPENING** IS MEASURED
- RADIAL INVESTIGATION IS ACHIEVED WITH **9 TRANSDUCERS**

CET
FACTORS AFFECTING MEASUREMENT

- TYPE OF **FLUID** IN WELL
- **THICKNESS** OF CASING WALL
- AMOUNT OF **CEMENT BONDED** TO CASING
- **COMPRESSIVE STRENGTH** OF CEMENT

CET
EQUIPMENT

- 8 TRANSDUCERS IN **HELICAL PATTERN**

- 1 TRANSDUCER (MEASURES **FLUID SOUND VELOCITY**)

- **TOOL SIZE** = 3-3/8 inches to 4 inches

CET
PROCEDURE

- REMOVE **TUBING**

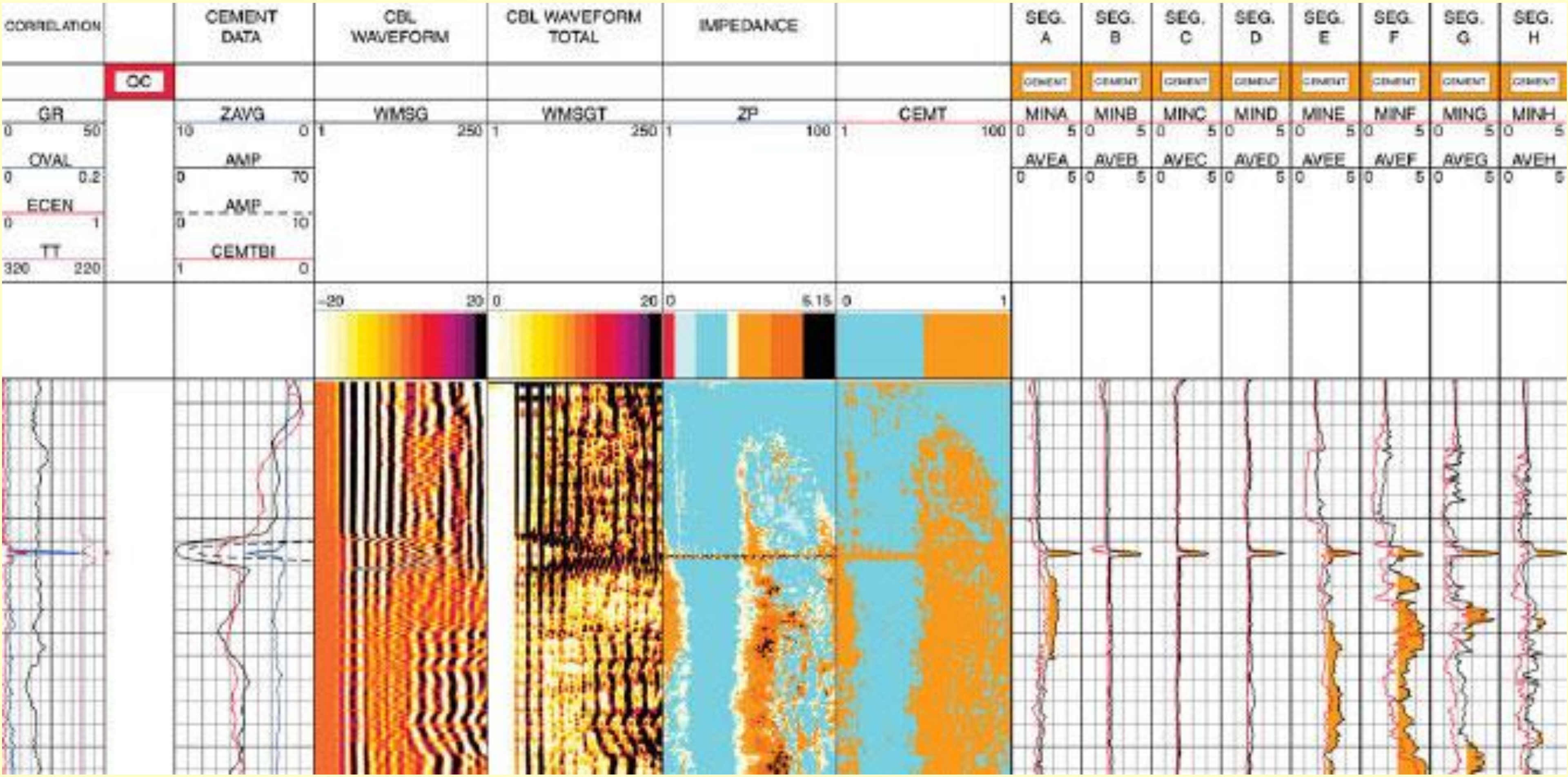
- ENSURE TOOL IS **CENTRALIZED**

- LOG ONLY IN **LIQUID FILLED** CASING

- RUN WITH CASING **COLLAR LOCATOR** AND **GAMMA RAY**

CET
ADVANTAGES

- **RADIAL** CEMENT EVALUATION
- CEMENT **CHANNEL IDENTIFICATION**
- IMMUNE TO **MICROANNULUS**
- NOT AFFECTED BY **“FAST FORMATIONS”**
- “EASIER” TO **INTERPRET**



CORRELATION
CEMENT DATA
CBL WAVEFORM
CBL WAVEFORM TOTAL
IMPEDANCE
SEG. A
SEG. B
SEG. C
SEG. D
SEG. E
SEG. F
SEG. G
SEG. H
QC
GR
ZAVG
WMSG
WMSGT
ZP
CEMT
MINA
MINB
MINC
MIND
MINE
MINF
MING
MINH
OVAL
AMP
AVEA
AVEB
AVEC
AVED
AVEE
AVEF
AVEG
AVEH
ECEN
AMP
TT
CEMTBI

A GOOD

MANUAL

TO HAVE

ON

HAND

EPA/600/R-94/124
July 1994

Temperature, Radioactive Tracer, and Noise Logging for Injection Well Integrity

by

R. M. McKinley
Exxon Production Research

Cooperative Agreement No. CR-818926

Project Officer

Jerry T. Thornhill
Extramural Activities and Assistance Division
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ADA, OKLAHOMA 74820

RADIOACTIVE TRACER

SURVEYS

(RATS)

RADIOACTIVE TRACER SURVEY PURPOSE

- FLOW PROFILING (volumetric)
- DETERMINE FLUID MIGRATION
  - BOTTOMHOLE CEMENT CHANNELS (Time Drive)
  - CASING, TUBING, PACKER LEAKS (Internal MI)(Slug Chase)

RATS
OPERATION PRINCIPLES

- **USE RADIOACTIVE IODINE (1/2 life = 8 days)**
- **EJECT TRACER @ surface or downhole**
- **FOLLOW TRACER as it travels**
- **USE GAMMA RAY TOOL as detector**
- **DETECT MIGRATION OF TRACER through tubing and/or casing**

RATS EQUIPMENT

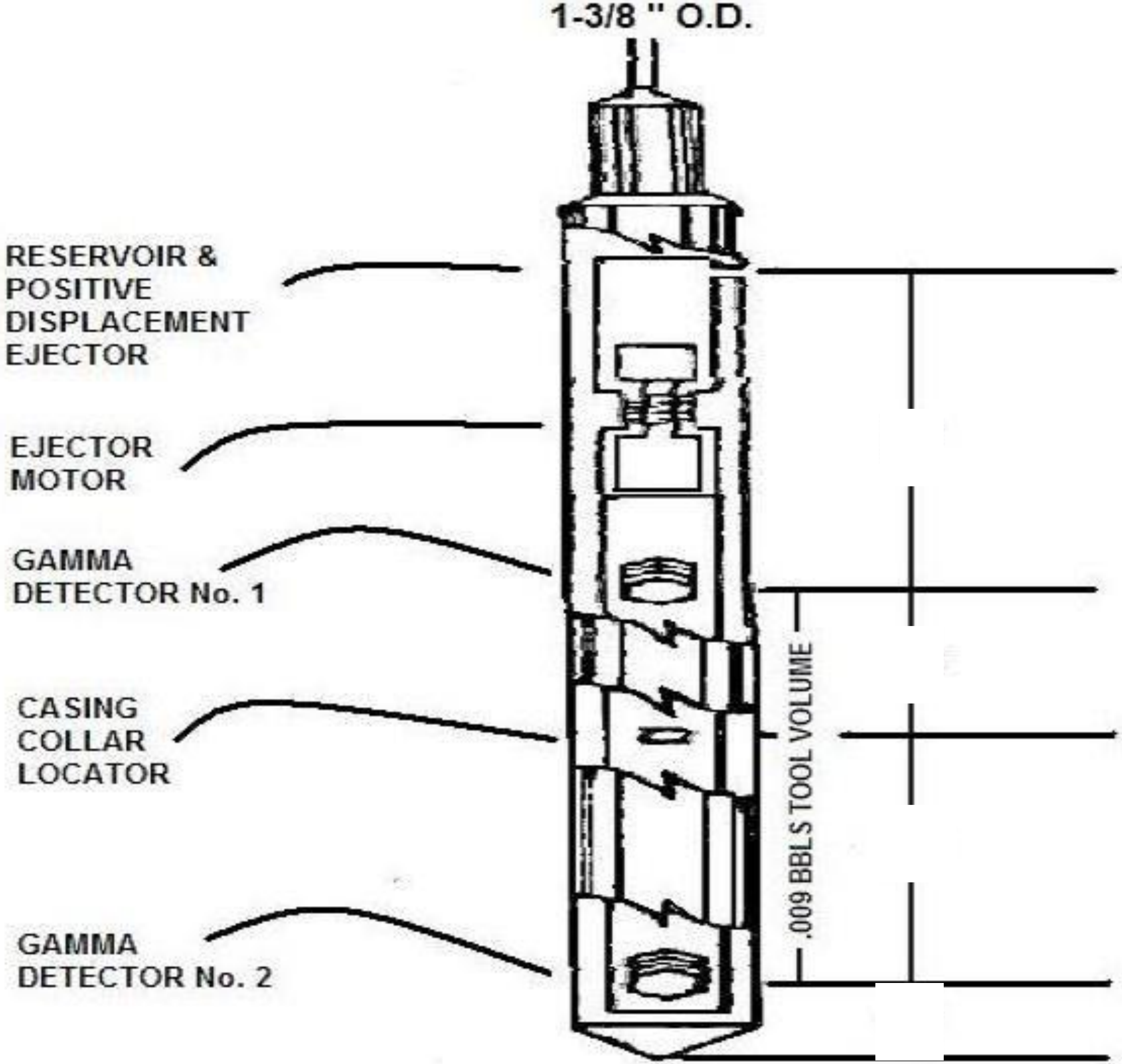
- Radioactive material EJECTOR
  Surface or downhole
- 2 or more Gamma Ray DETECTORS
- Ejector/Detector CONFIGURATION varies depending on objective
- Tool DIAMETER as small as 1-1/2 inches

RATS PROCEDURE

- **LOAD TRACER at surface**
- **RUN tool in tubing or casing**
- **RUN BASE LOG with well on injection**
- **EJECT tracer at or near surface if running in casing**
- **EJECT tracer above the packer if in tubing**
- **FOLLOW tracer to injection zone, while checking for leaks**
- **LOG ABOVE PERFORATIONS/SCREEN for channels outside casing**
- **Can check FLOW PROFILE with Spinner**
- **Run with CASING COLLAR LOCATOR**

FACTORS AFFECTING GAMMA-RAY MEASUREMENT

- **RADIOACTIVE (HOT) formations**
- **INJECTION RATE**
- **Ejector/Detector CONFIGURATION**
- **PIPE SCALE**



SCHEMATIC OF RADIOACTIVE TRACER FOR INJECTION LOGGING

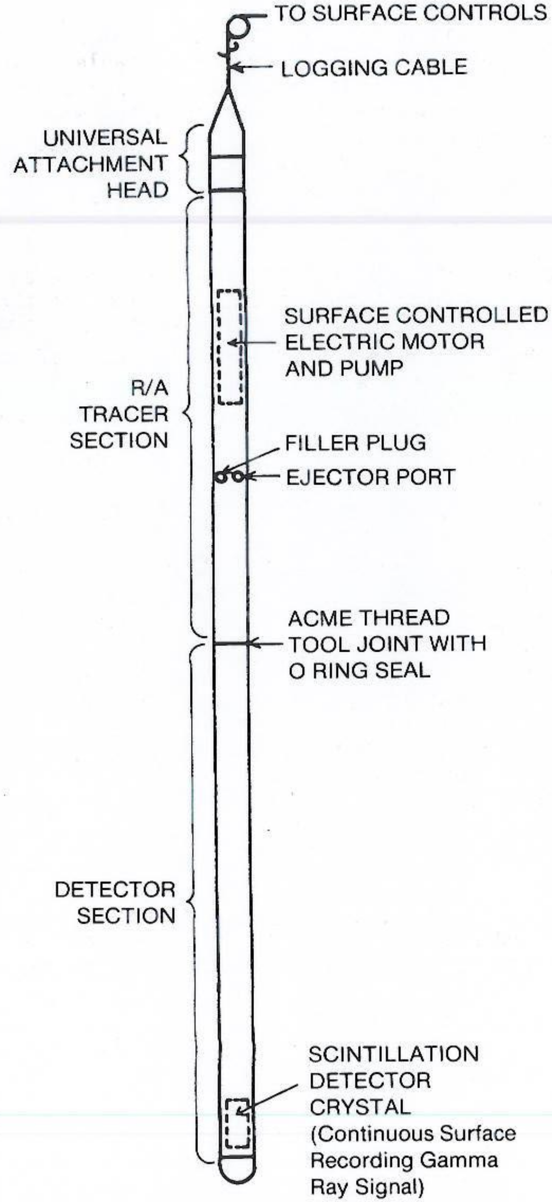


Figure 73. Radioactive tracer tool (Ford, 1962).

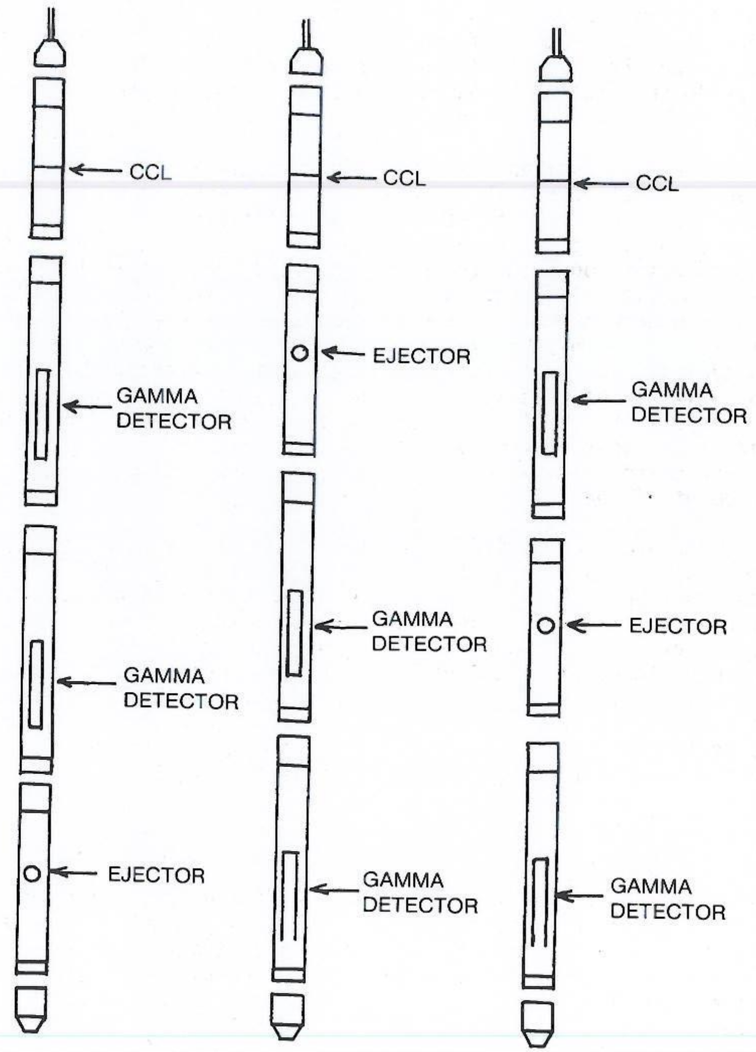
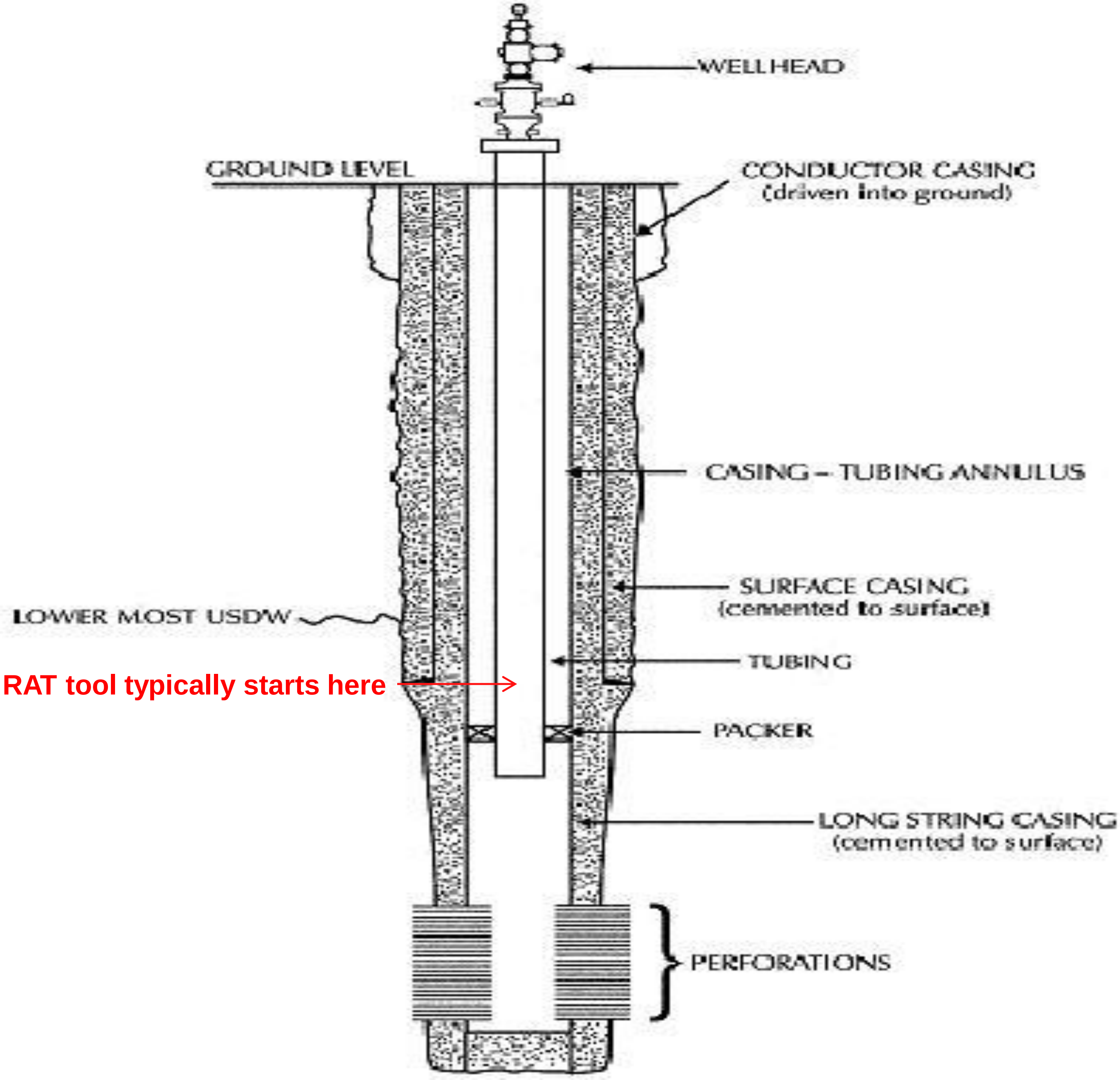


Figure 74. Three possible configurations of a radioactive tracer tool (courtesy Schlumberger) (Dewan, 1982).

Slug

Chase


WELLHEAD
GROUND LEVEL
CONDUCTOR CASING
(driven into ground)
CASING – TUBING ANNULUS
SURFACE CASING
(cemented to surface)
LOWER MOST USDW
TUBING
RAT tool typically starts here
PACKER
LONG STRING CASING
(cemented to surface)
PERFORATIONS

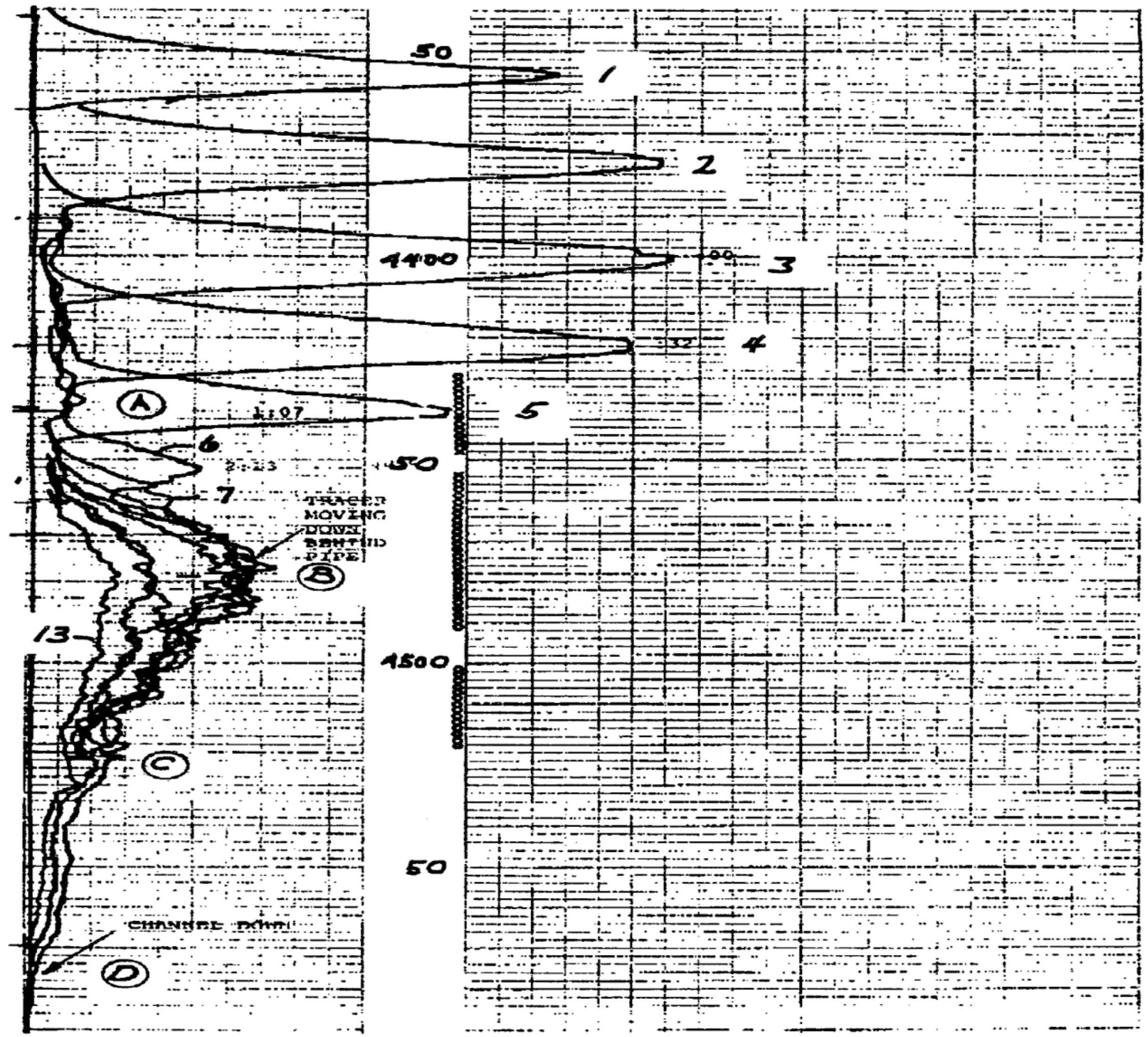


Figure 41. Slug-tracking survey from well on injection at 950 BPD

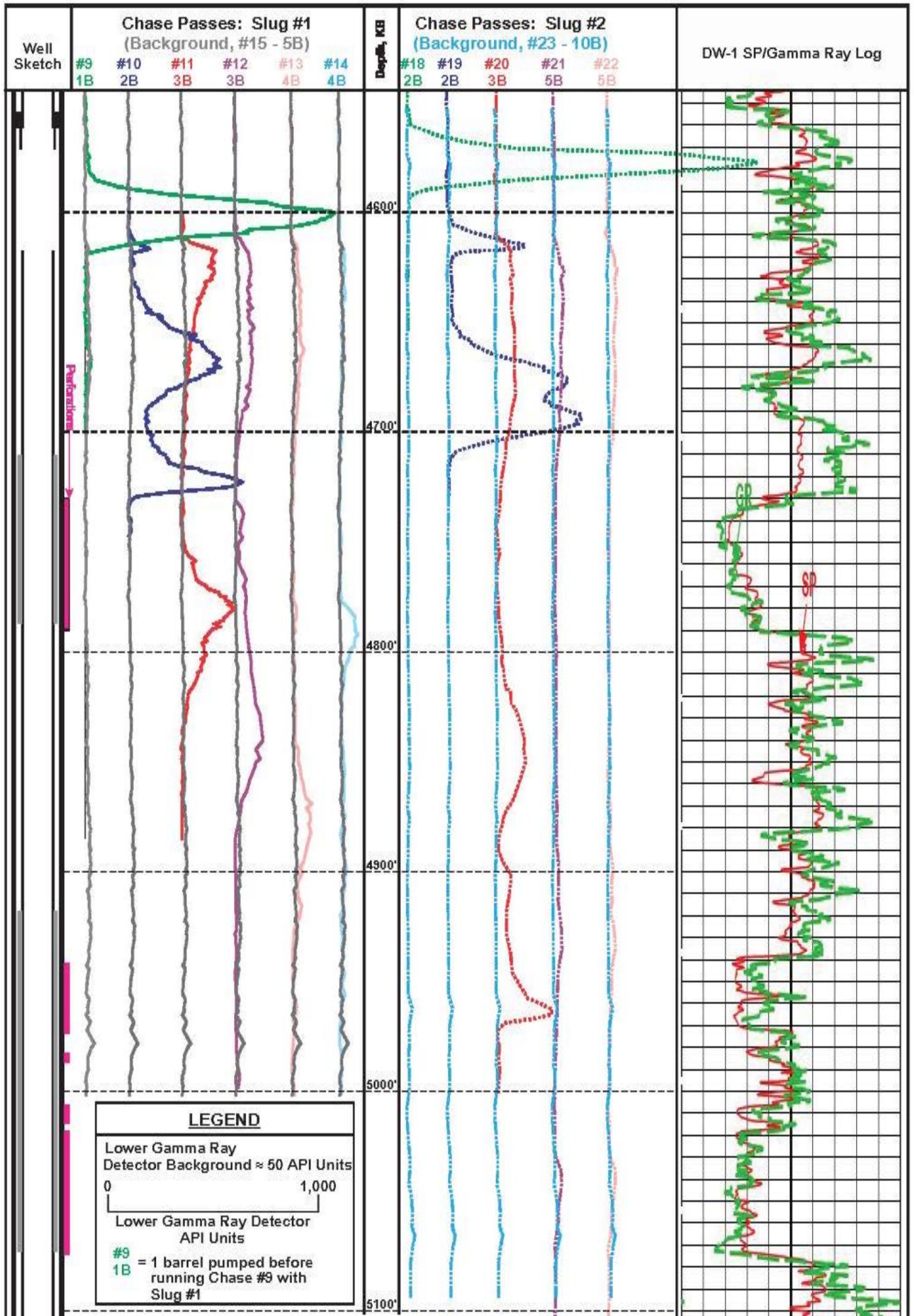
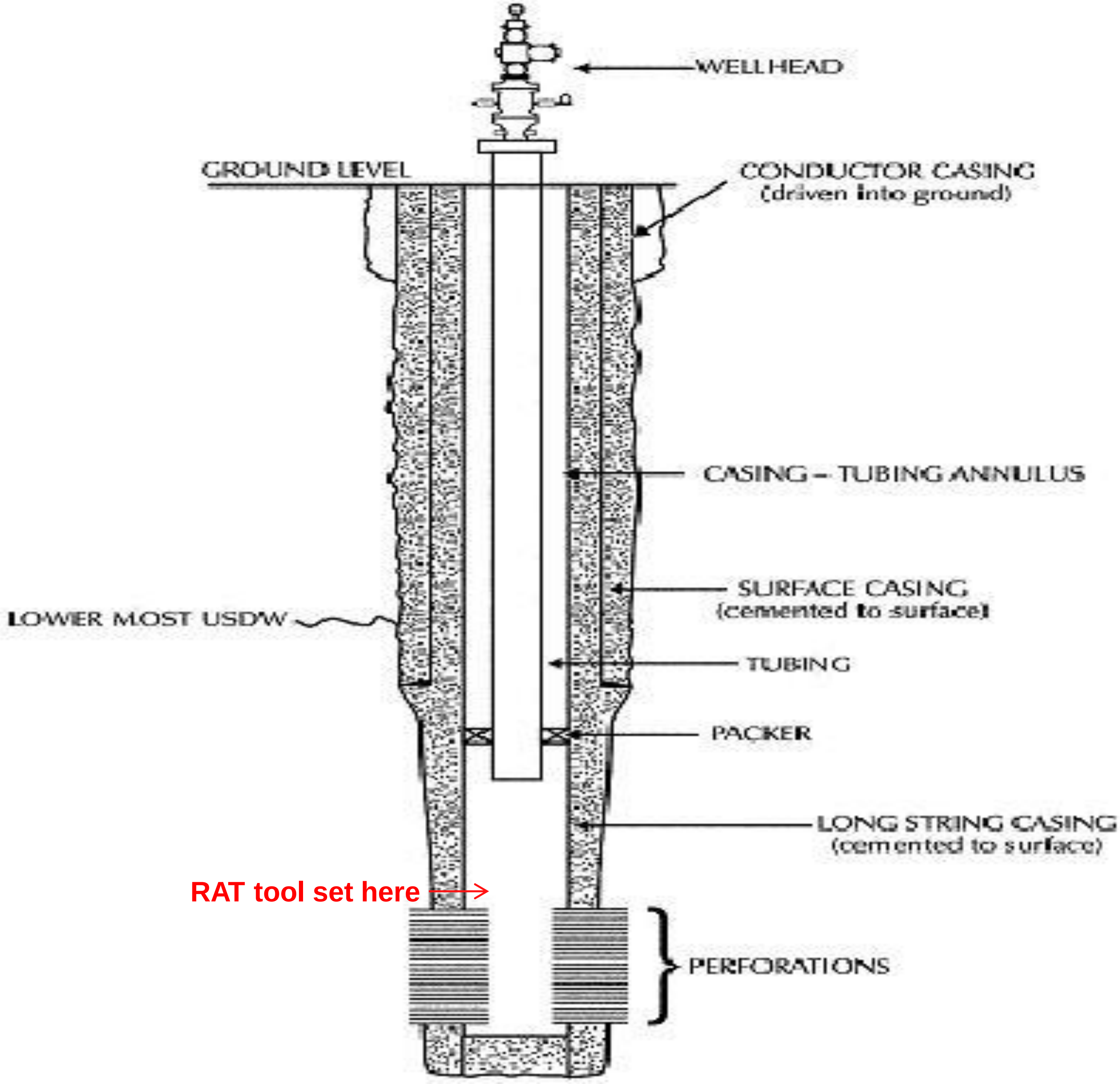

Well Sketch
Chase Passes: Slug #1
(Background, #15 - 5B)
#9 1B
#10 2B
#11 3B
#12 3B
#13 4B
#14 4B
Depth, KB
Chase Passes: Slug #2
(Background, #23 - 10B)
#18 2B
#19 2B
#20 3B
#21 5B
#22 5B
DW-1 SP/Gamma Ray Log
Perforations
4600'
4700'
4800'
4900'
5000'
5100'
GR
SP
LEGEND
Lower Gamma Ray Detector Background ≈ 50 API Units
0
1,000
Lower Gamma Ray Detector API Units
#9 1B = 1 barrel pumped before running Chase #9 with Slug #1

FIGURE 3.1.3.2

TIME

DRIVES

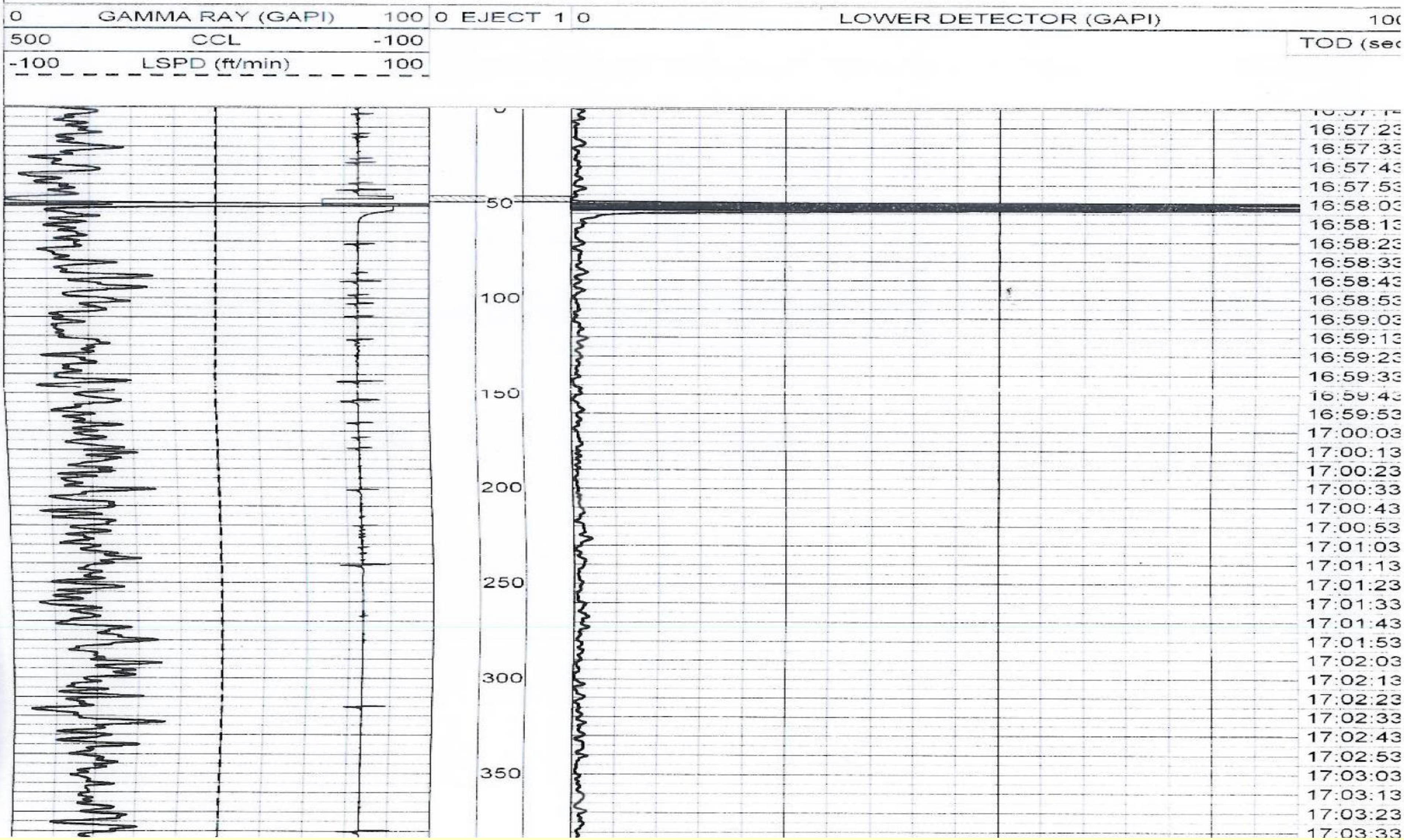

WELLHEAD
GROUND LEVEL
CONDUCTOR CASING
(driven into ground)
CASING – TUBING ANNULUS
SURFACE CASING
(cemented to surface)
LOWER MOST USDW
TUBING
PACKER
LONG STRING CASING
(cemented to surface)
RAT tool set here
PERFORATIONS

Gulf Coast Well Analysis

TIME DRIVE # 2 EJECTED AT 7395' AT 16:58

UPPER DETECTOR AT 7392' LOWER DETECTOR AT 7400'
INJECTION RATE 200 GPM AT 180 PSI

Database File:	[redacted]
Dataset Pathname:	pass20
Presentation Format:	tracer
Dataset Creation:	Fri Jul 13 16:57:14 2012 by Log PIP Casedhole Loggi
Charted by:	Time scaled 72"/hour

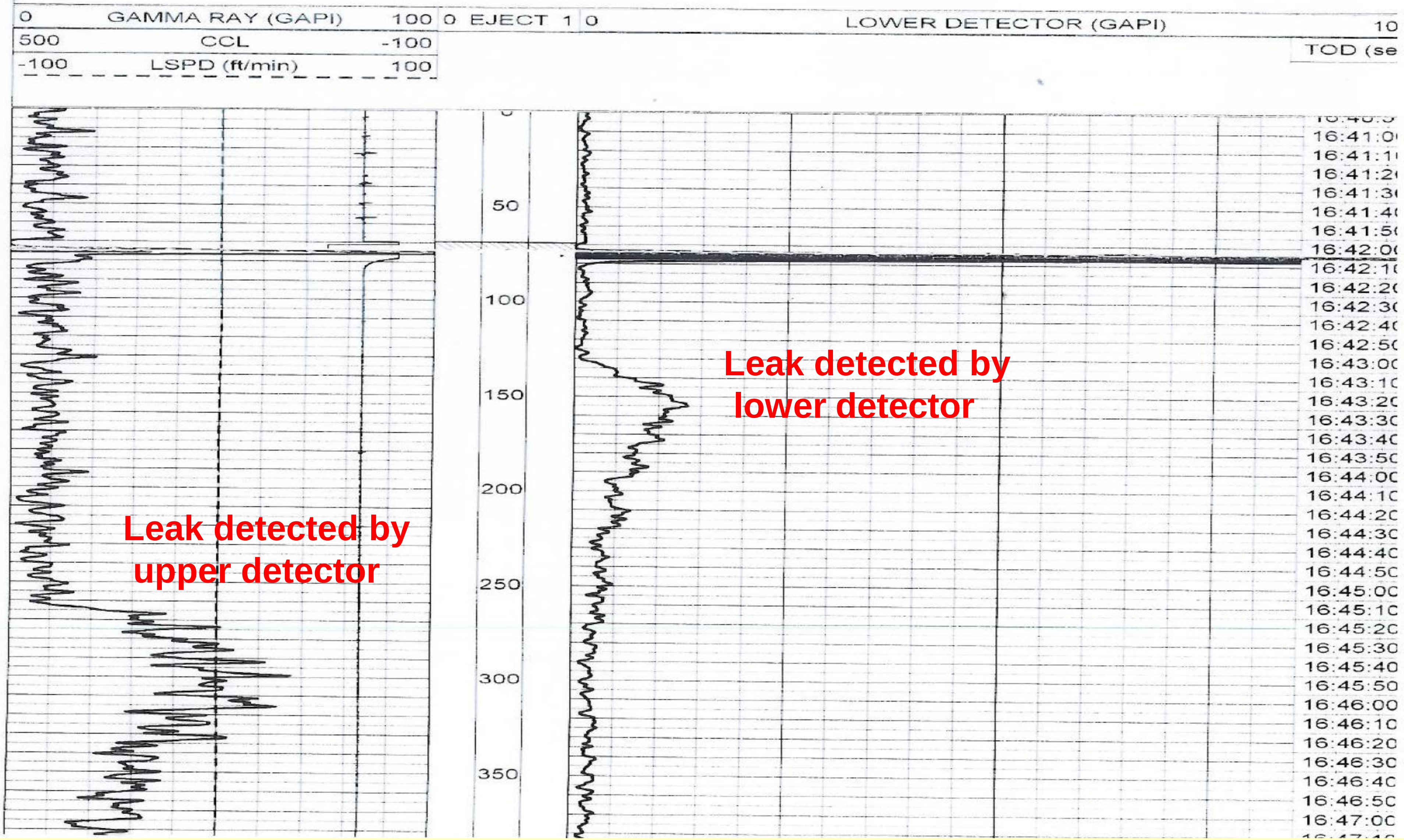


Gulf Coast Well Analysis

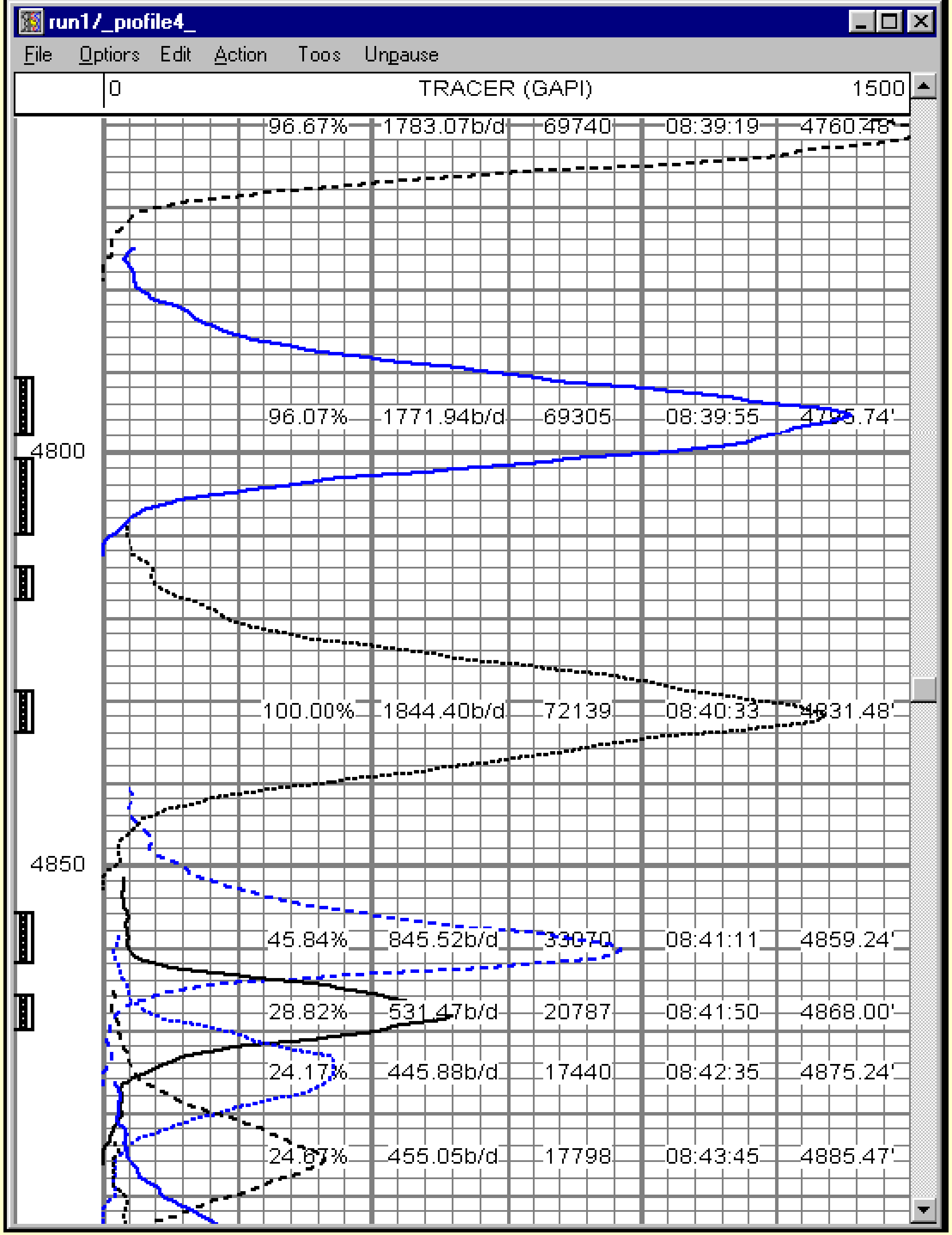
TIME DRIVE # 1 EJECTED AT 7435' AT 16:42

UPPER DETECTOR AT 7432' LOWER DETECTOR AT 7440'
INJECTION RATE 200 GPM AT 100 PSI

Database File:	[redacted]
Dataset Pathname:	pass18
Presentation Format:	tracer
Dataset Creation:	Fri Jul 13 16:40:50 2012 by Log PIP Casedhole Loggi
Charted by:	Time scaled 72"/hour



Flow Profiles

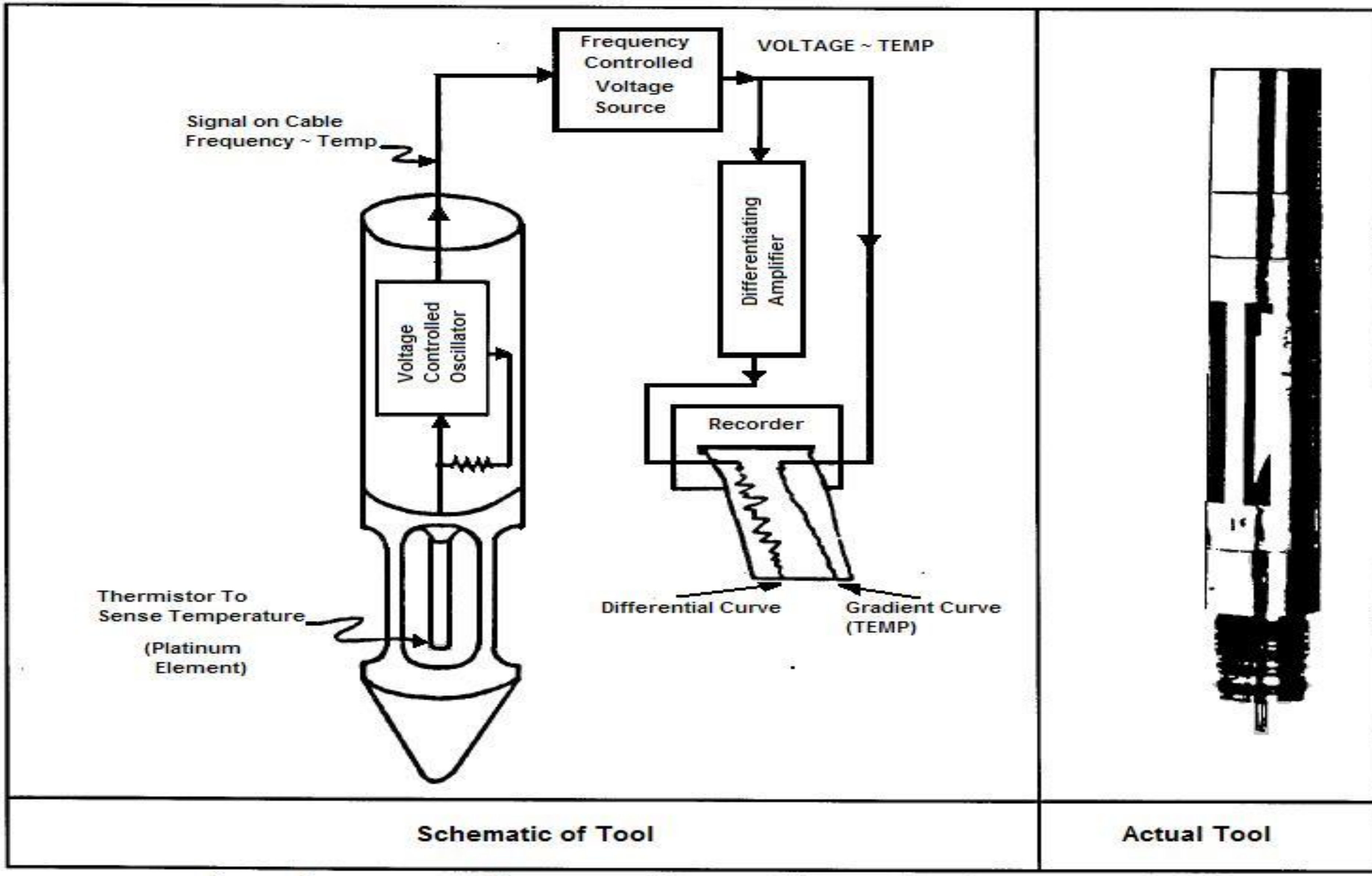


TEMPERATURE SURVEYS

(External MI)

TEMPERATURE SURVEYS

- Oldest of the Production Surveying Instruments (mid 1930s)
  - Mercury/piston
  - Vapor pressure/bourdon type element (Bottomhole temperature measurements)
  - Thermistor – platinum element – resolves temperature changes of 0.05 deg F
    - » **Analog Logging Units**
    - » **Digital Logging Units**



A surface recording, continuous thermometer

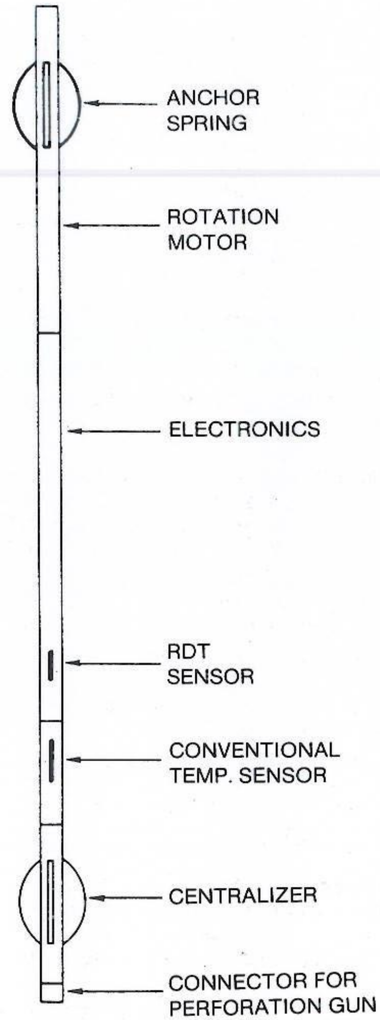


Figure 16. Schematic of RDT logging tool (Cooke, 1978).

TEMPERATURE SURVEY PURPOSE

- LOCATE **CEMENT TOPS** AFTER PRIMARY CEMENTING (HEAT FROM EXOTHERMIC REACTION)

- **FLUID MIGRATION** DETERMINATION
  - CASING SHOE BEHIND PIPE
  - TUBING, CASING, PACKER LEAKS
  - INTERFORMATIONAL FLUID FLOW

- **FLOW** (VOLUMETRIC) **PROFILING** (RARE)

- **IDENTIFICATION OF** INTERVALS PRODUCING **GAS** (COOLING EFFECT FROM EXPANSION)

TEMPERATURE SURVEY OPERATION PRINCIPLE

- DOWNHOLE TEMPERATURE GOVERNED BY **GEOTHERMAL GRADIENT**

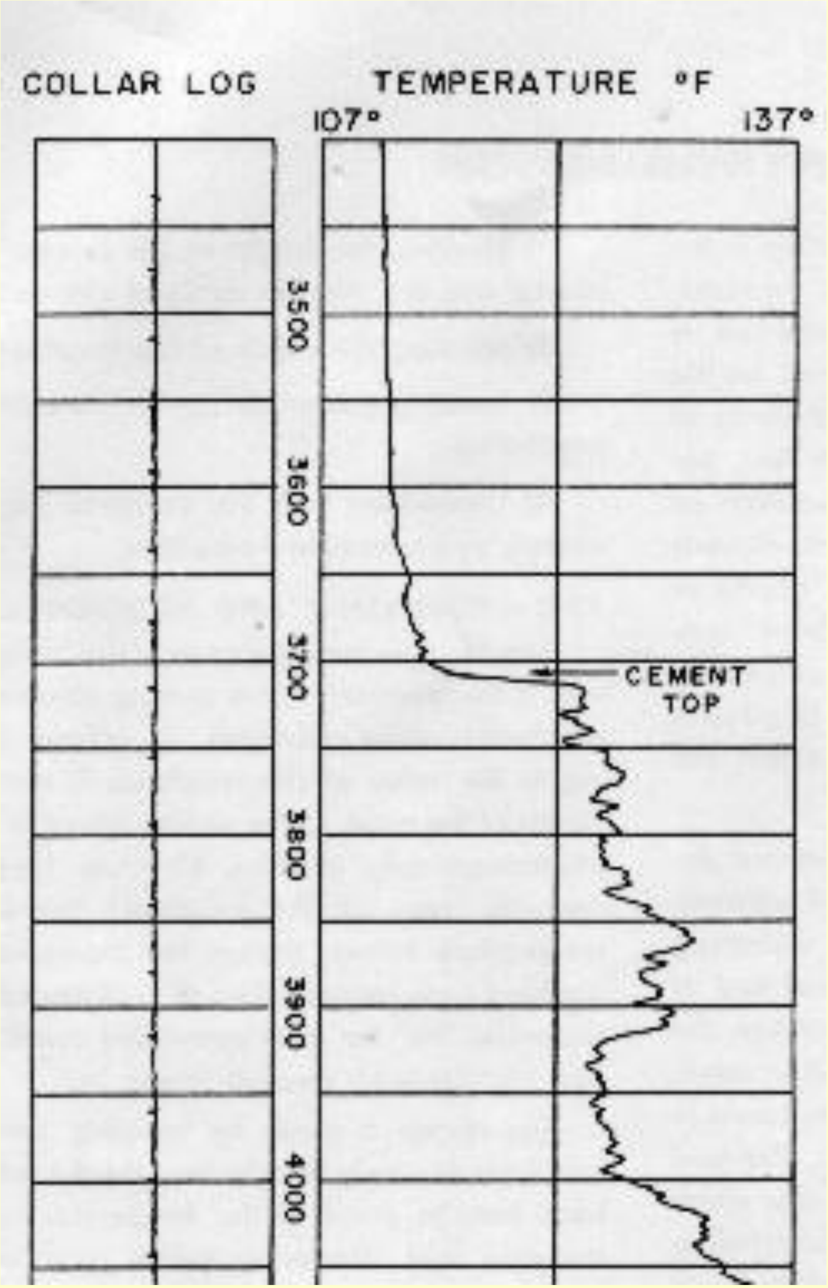
- INJECTION OF FLUID WITH LARGE **TEMPERATURE DIFFERENCE** (FROM GRADIENT)

- **ZONES** (OR LEAKS) TAKING INJECTED FLUIDS WILL **RETURN** TO GEOTHERMAL GRADIENT AT A **SLOWER RATE**

- Since cement gives off heat as it cures, the temperature log was used to provide evidence that the well was actually cemented to a level that met expectations. An example is shown at right.

- The top of cement is located where the temperature returns to geothermal gradient.

- The log must be run during the cement curing period as the temperature anomaly will fade with time.



TEMP SURVEY – A BASIC PROCEDURE

- LET WELL **STAND IDLE** AT LEAST 24 HOURS
- RUN **“BASE LOG”** – GEOTHERMAL GRADIENT
- ENSURE INJECTION FLUID **TEMPERATURE IS SIGNIFICANTLY DIFFERENT** FROM BOTTOM-HOLE TEMPERATURE
- START **INJECTION WHILE LOGGING** HOLE (OPTIONAL)
- **SHUT-IN** AFTER PREDETERMINED VOLUME IS INJECTED
- LOG HOLE **AFTER 0, 12, AND 24 HOURS** SHUT-IN

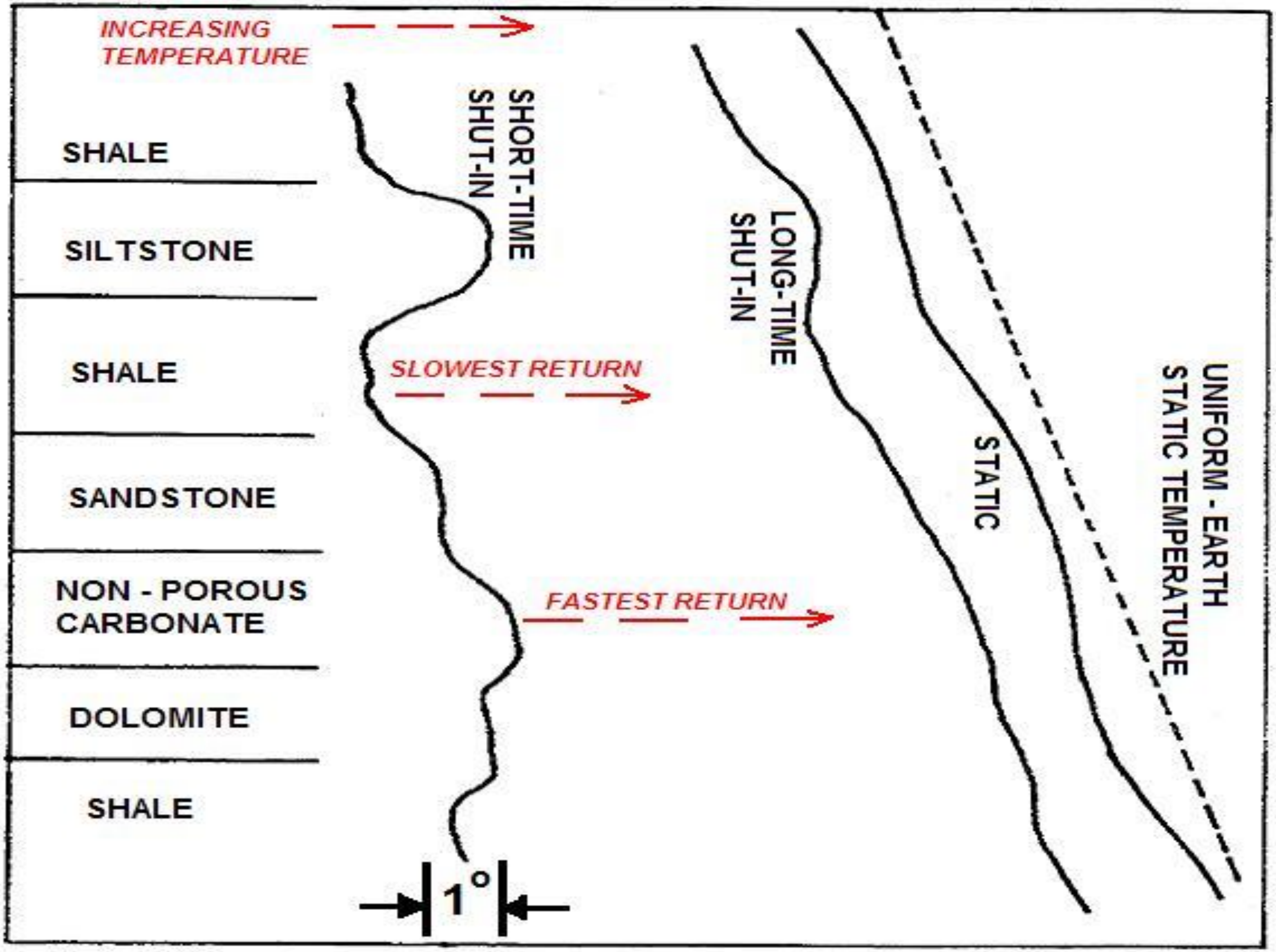


Figure 8 ***Hypothetical Influence of lithology on wellbore temperature warming with time to static conditions***

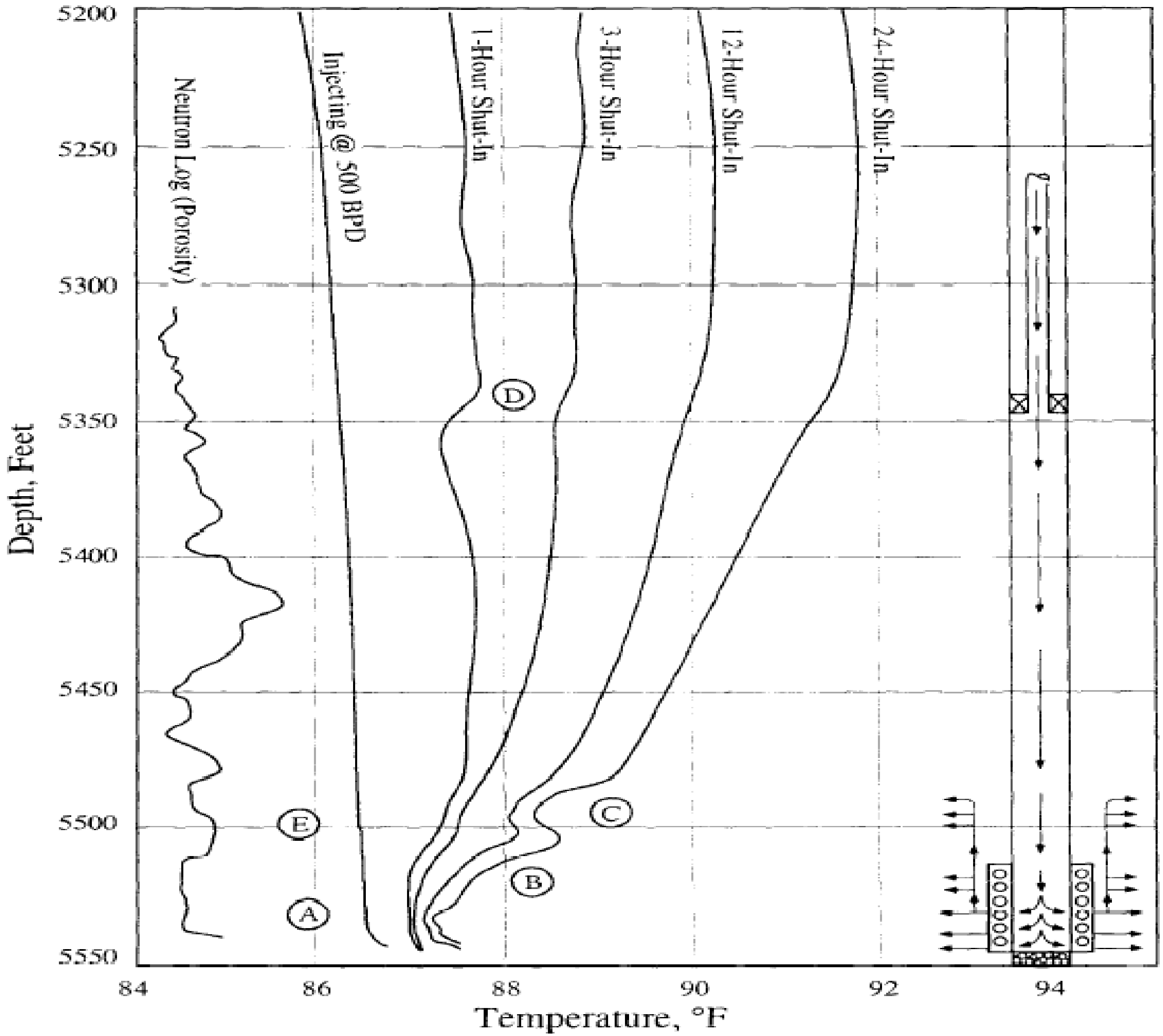


Figure 20. **Injecting and shut-in temperature surveys from well on continuous injection at about 500 BPD for almost one year.**

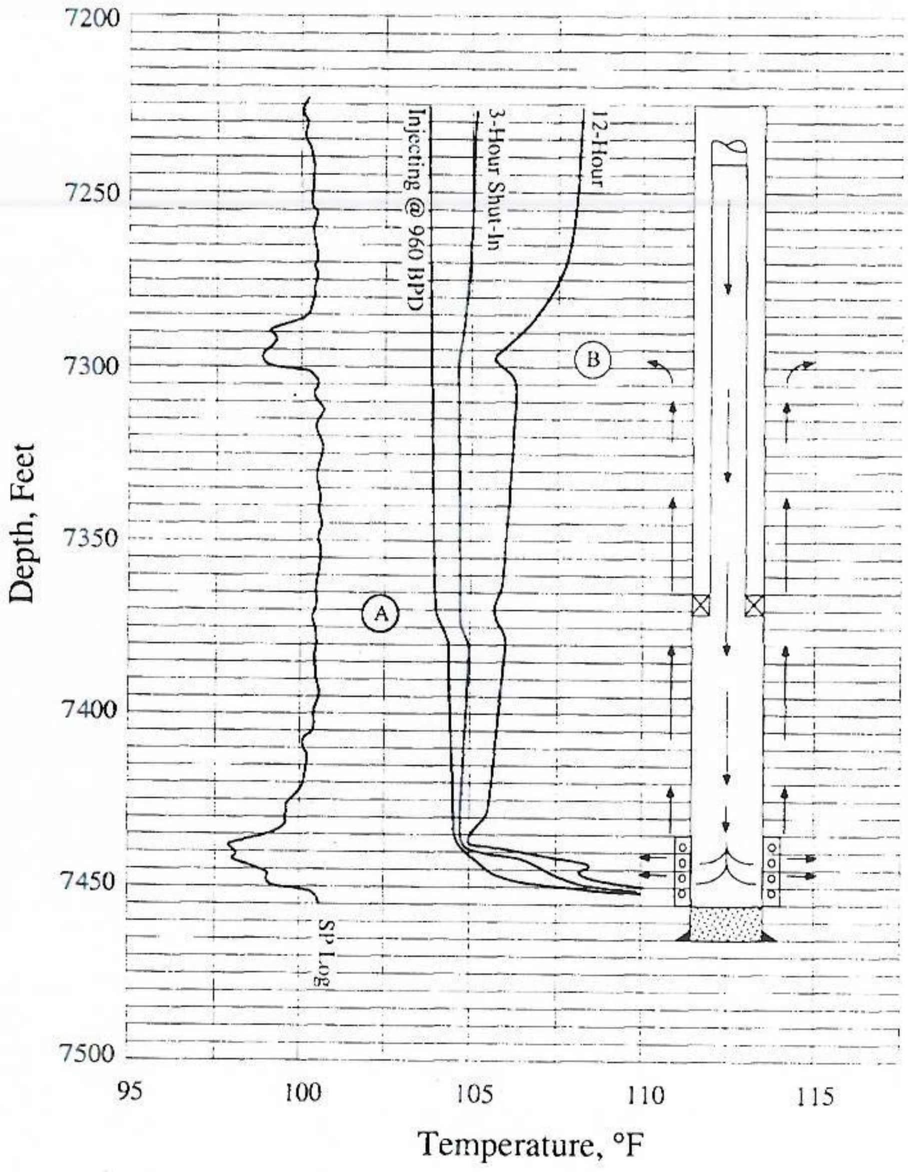


Figure 22. Temperature surveys from a well on injection at 960 BPD with flow behind pipe even on shut-in status.

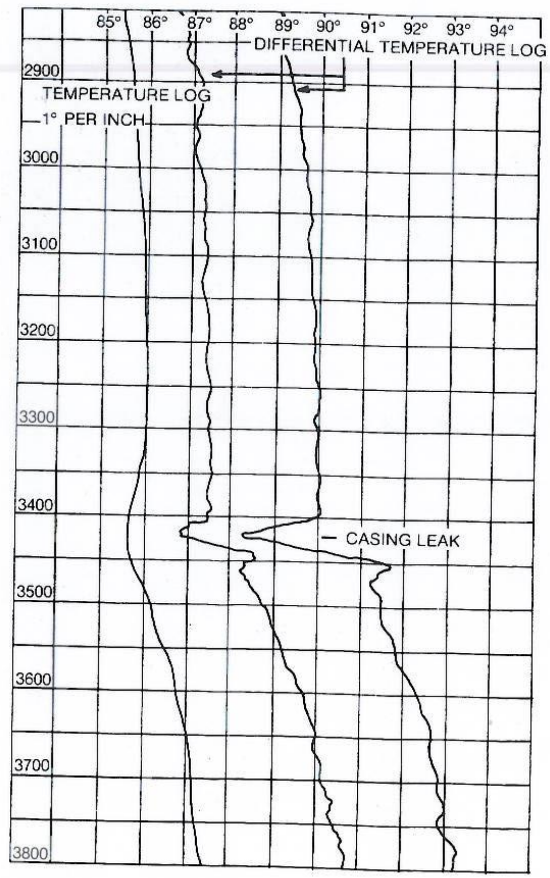
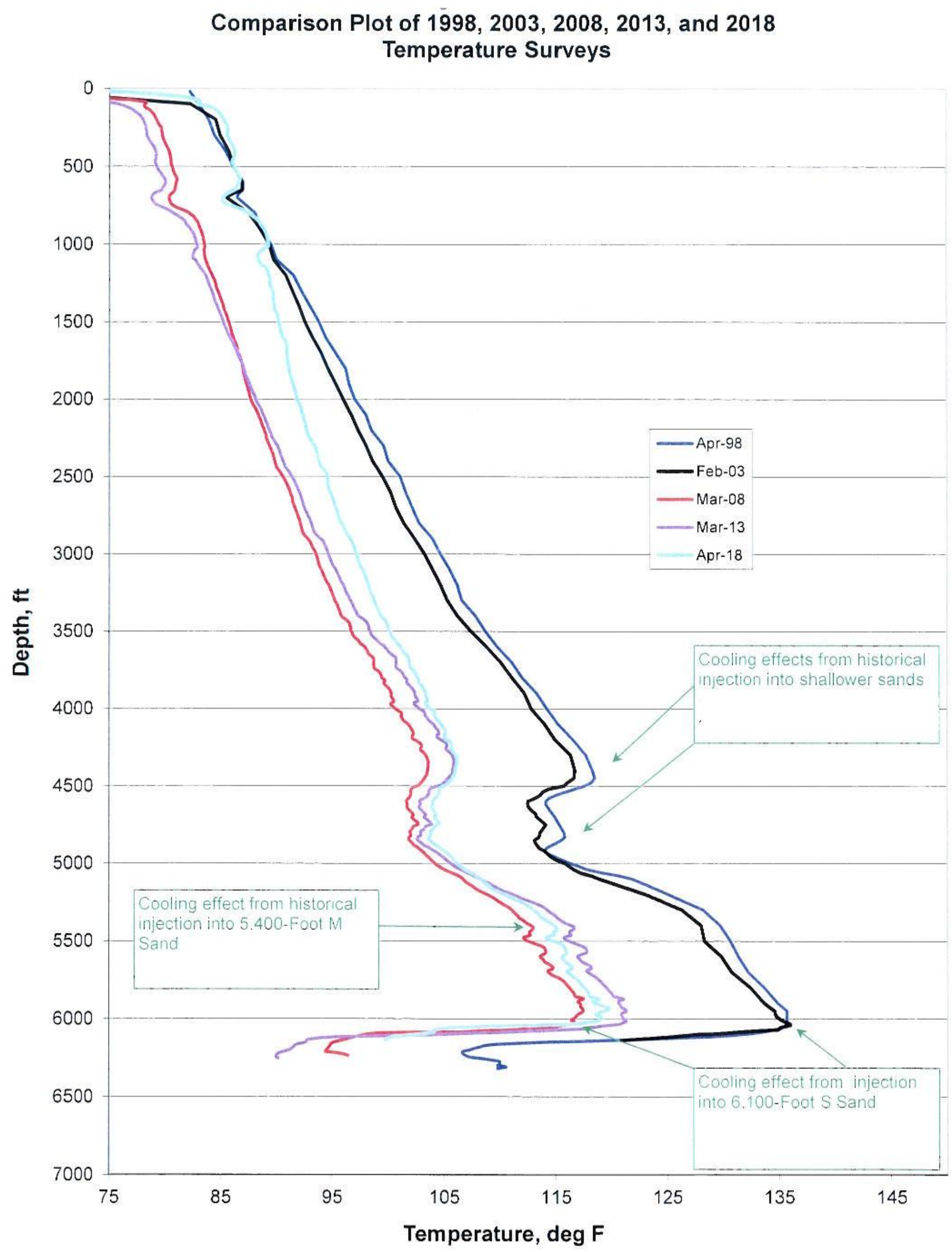


Figure 22. Temperature logs used in locating a casing leak (Peacock, 1965).


Comparison Plot of 1998, 2003, 2008, 2013, and 2018
Temperature Surveys
Depth, ft
Temperature, deg F
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
75
85
95
105
115
125
135
145
Apr-98
Feb-03
Mar-08
Mar-13
Apr-18
Cooling effects from historical injection into shallower sands
Cooling effect from historical injection into 5,400-Foot M Sand
Cooling effect from injection into 6,100-Foot S Sand

NOISE LOG

(External MI)

NOISE LOG PURPOSE

- TO "HEAR" FLUID FLOW OCCURRING INSIDE OR OUTSIDE WELL TUBULARS

  - ✓ BEHIND CASING CHANNELS (water flow pressure drop OR gas thru liquid)

  - ✓ TUBING AND/OR CASING LEAKS

NOISE LOG
OPERATION PRINCIPLES

- **FLUID TURBULENCE (FLOW) - - - NOISE**
- **NOISE OCCURS OVER A RANGE OF FREQUENCIES - - TYPICAL TO THE KIND OF FLOW CREATED**
  - **GAS flow upward thru liquid**
    - **» Flows in “bubbles” which “ring”**

NOISE LOG
OPERATION PRINCIPLES

- **FLUID TURBULENCE (FLOW) - - - NOISE**
- **NOISE OCCURS OVER A RANGE OF FREQUENCIES - - TYPICAL TO THE KIND OF FLOW CREATED**
  - **FLUID turbulence when forced across constriction – pressure drop**

NOISE LOG
OPERATION PRINCIPLES

- **FLUID TURBULENCE (FLOW) - - - NOISE**
- **NOISE OCCURS OVER A RANGE OF FREQUENCIES - - TYPICAL TO THE KIND OF FLOW CREATED**
  - **200 Hz (cycles per second)**
  - **600 Hz**
  - **1000 Hz**
  - **2000 Hz**

NOISE LOG EQUIPMENT

- **TRANSDUCER (converts sound to electrical signal - to be amplified)**

- **FREQUENCY SEPARATING FILTERS**

- **SPEAKER (esp. headphones for operator)**

- **TYPICAL SIZE = 1¾ inch X 3½ feet (as small as 1 inch O.D.)**

NOISE LOG CHARACTERISTICS

ESSENTIAL TO INTERPRETATION

- **LOUDNESS - measured levels above ambient... amplitude... on all 4 frequencies**

  - severity of the problem

- **CHARACTER – variation in level on a particular cut from station to station is related to the path of flow**

  - how flow is taking place

- **PITCH – frequency content of sound at a peak in noise level**

  - type of flow (single phase or gas thru liquid)

NOISE LOG
OPERATION GUIDELINES

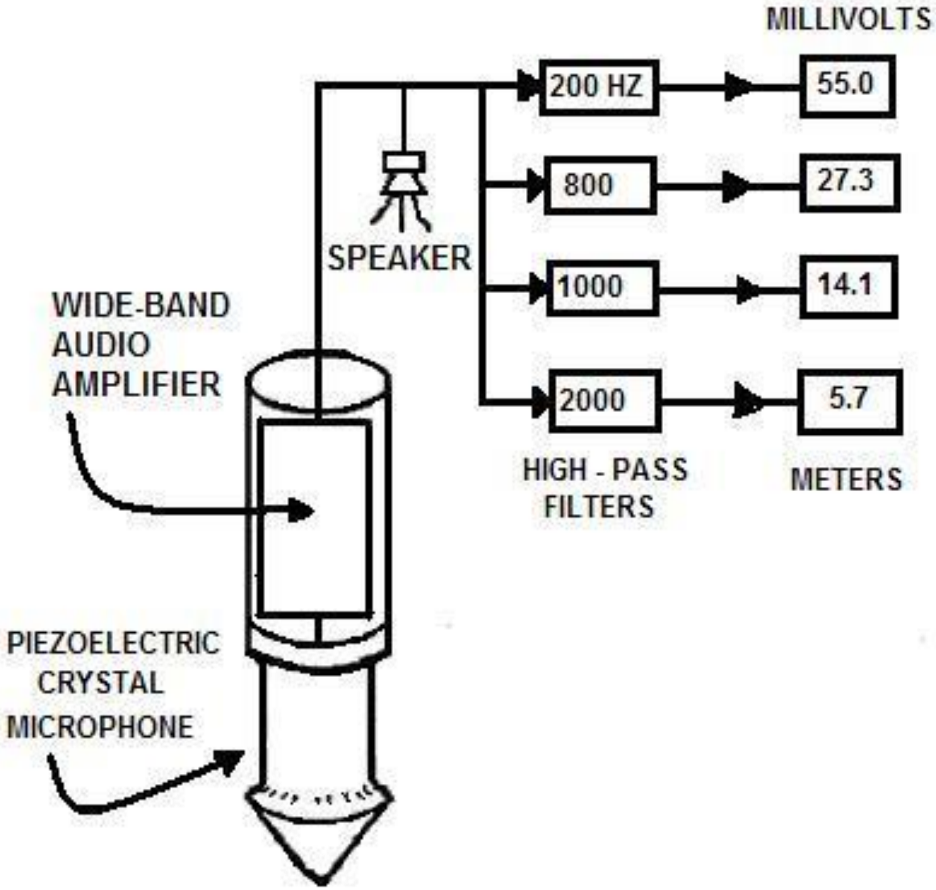
- **Logging Sonde takes readings at different depths while STATIONARY.**
- **Log can be utilized in virtually any DOWNHOLE CONDITION (liquid or gas filled).**
- **APPLY CRITERIA**

NOISE LOG
OPERATION CRITERIA

- Operator consults CONSTRUCTION DETAILS
- WELL SHUT-IN (for behind-pipe flow)
- Record Noise Levels at the 4 FREQUENCIES (200Hz, 600Hz, 1000Hz, 2000Hz)
- MINIMUM READINGS taken opposite the Confining Layer, Base of USDWs and Well Construction changes
- SPACING: readings every 50 to 200 feet (low noise areas); 10 feet or less (zones of interest)
- READING TIMES of 3 or more minutes each

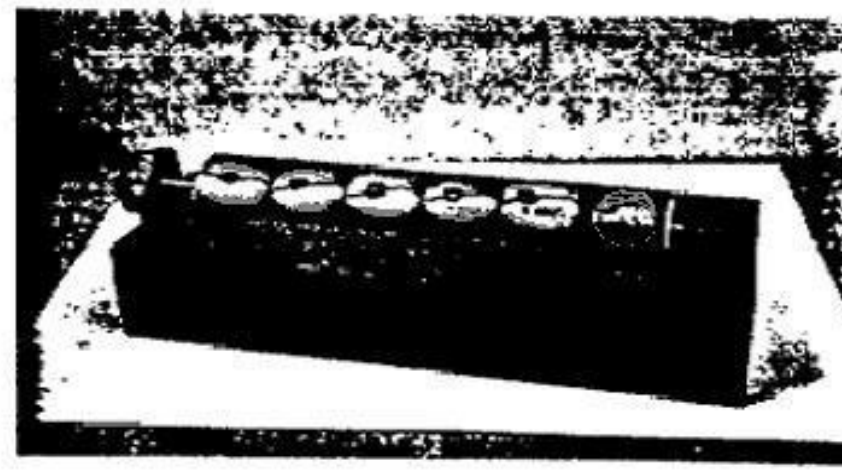
EXAMPLE NOISE LOG PROCEDURE

- PULL TUBING ONLY if necessary
- RUN BASE LOG – well shut-in
- START INJECTION (if necessary to initiate flow)
- RUN NOISE LOG – at same base log stops
- ENSURE TOOL IS STATIONARY at stops
- At ZONES OF INTEREST, perform readings at 10 ft. intervals plus/minus for locating source



TOOL SCHEMATIC

SIX PIEZOELECTRIC CRYSTALS



CRYSTALS ASSEMBLED FOR ENCAPSULATION

Noise (sound) logging sonde with piezoelectric detection elements shown separately

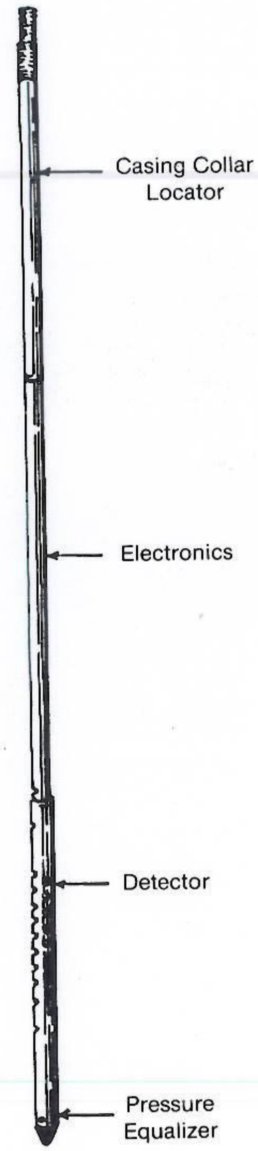
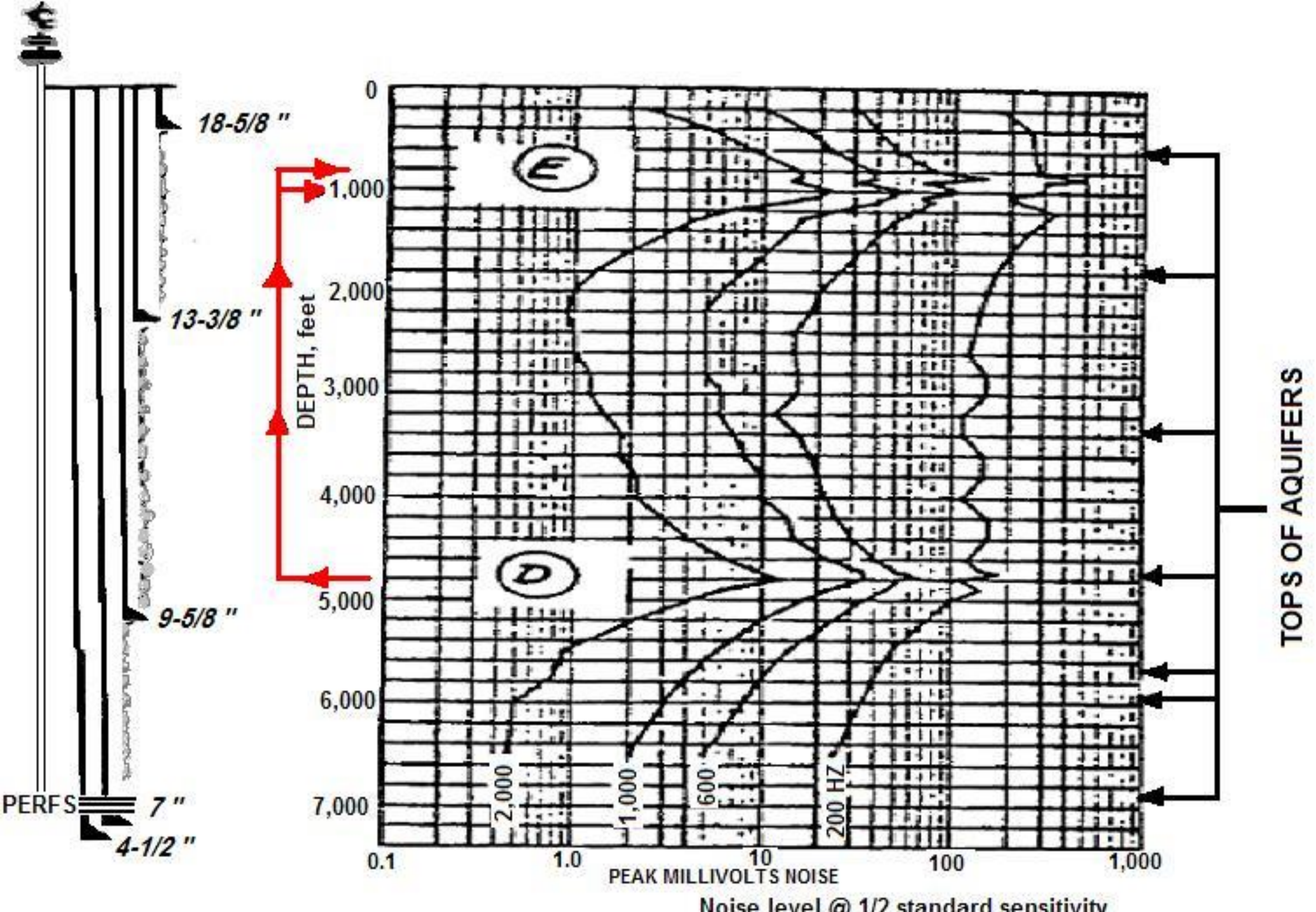


Figure 24. Typical noise logging tool (Robinson, 1976b).



Noise log from shut-in well with water flow behind pipe @ 5,000 BPD estimated rate

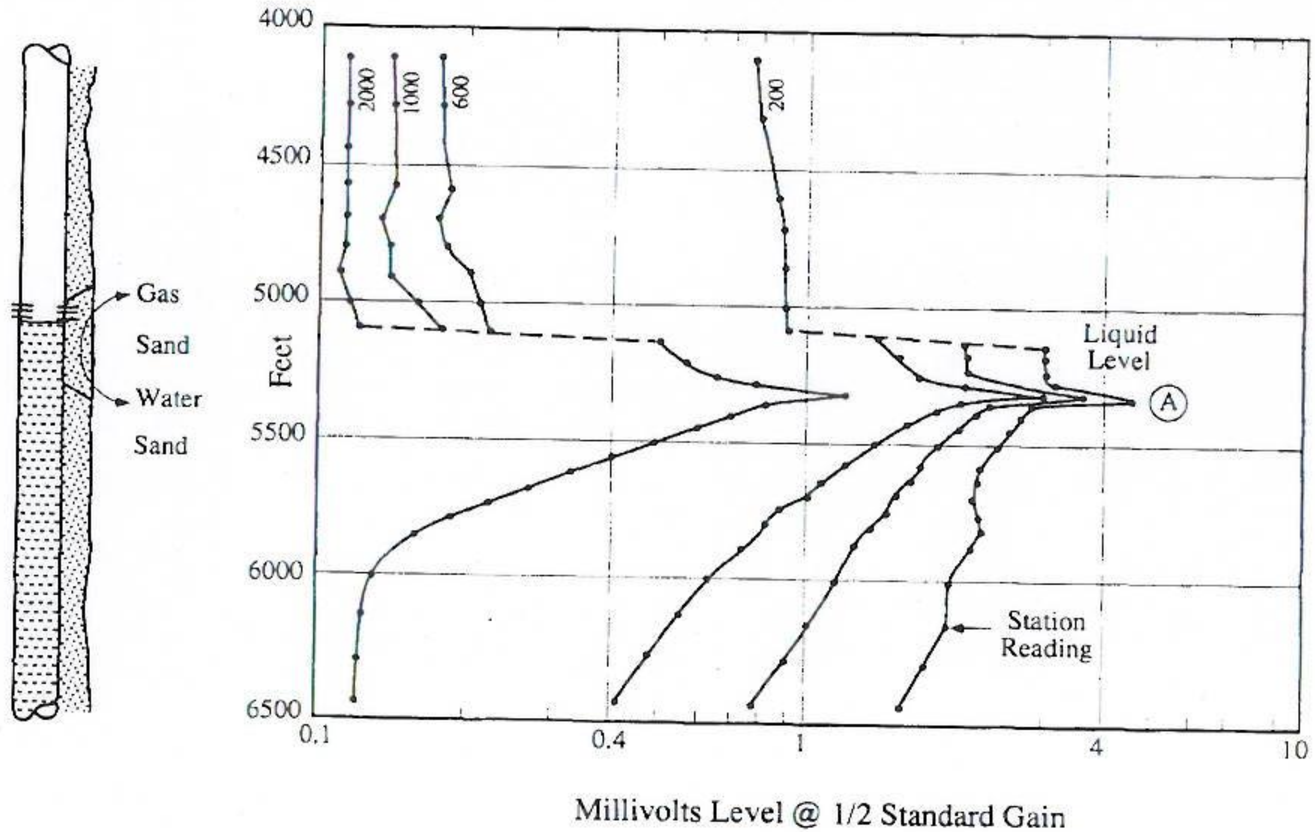


Figure 79. Noise log format with a 20-BPD water flow behind pipe into a gas zone depleted by 250 PSI.

OXYGEN ACTIVATION

TRACER SURVEYS

(OA Logs)

(External MI)

OA LOG
PURPOSE

- **Determine presence of**
  FLUID FLOW BEHIND CASING

- **Measure**
  - **Flow DIRECTION**
  - **Linear Flow VELOCITY**
  - **Volume Flow RATE ESTIMATE**
  - **RADIAL DISTANCE From Tool**

OA LOG
PRINCIPLE OF OPERATION

- Similar to Radioactive Tracer Survey (RATS)
- Tracer is CREATED within the flowing water behind the casing
  - Water behind pipe is bombarded with ENERGETIC NEUTRONS
  - Radioactive Nitrogen Isotope with half-life of 7 seconds formed when neutrons react with oxygen in water
- EMMITED GAMMA RAYS detected by two detectors at different distances

OA LOG LIMITATIONS

- **DEPTH OF INVESTIGATION**
  (approximately 12 inches)

- **FLUID COMPOSITION**
  (must contain Oxygen)

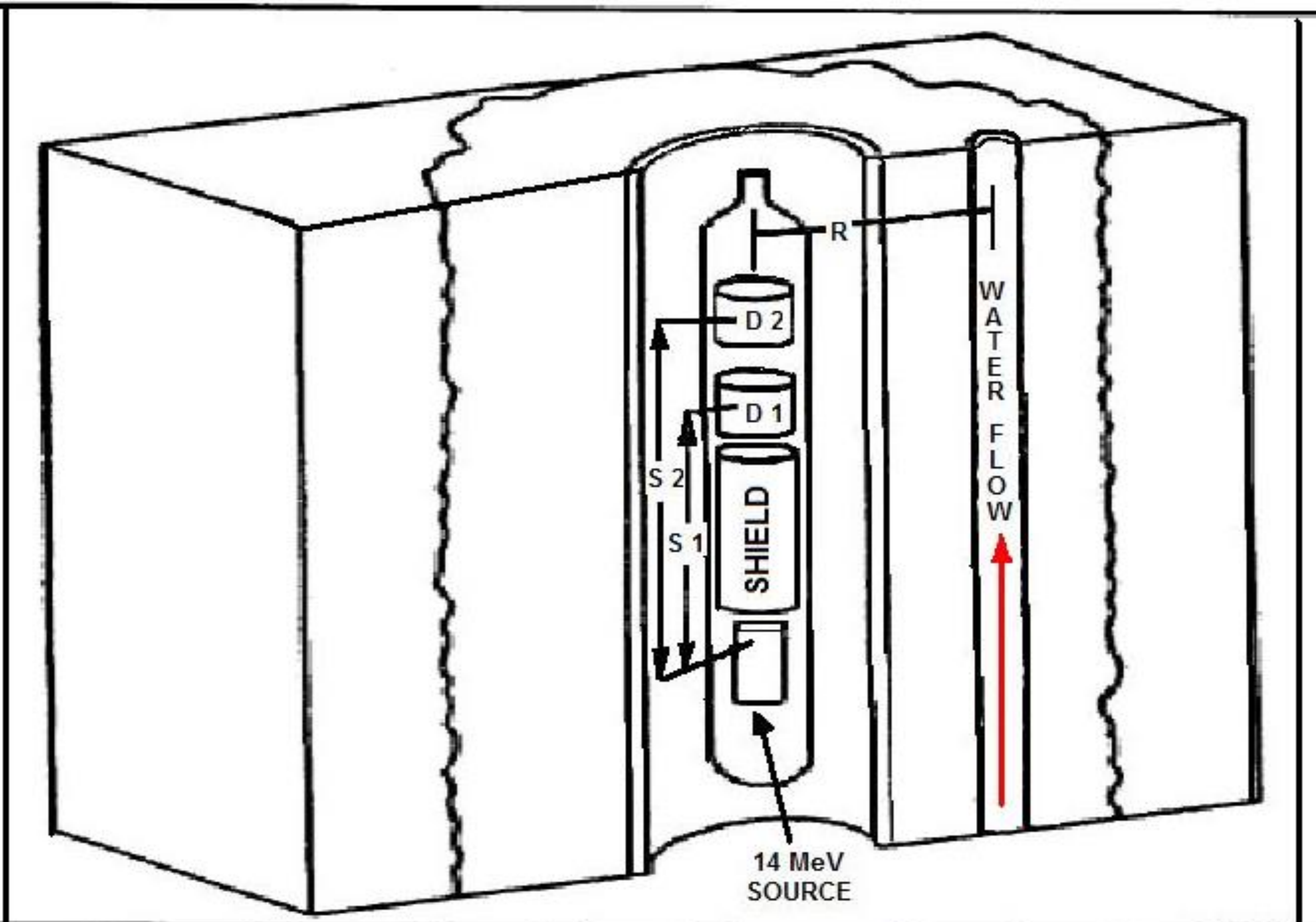
- **FLUID VELOCITY**

OA LOG EQUIPMENT

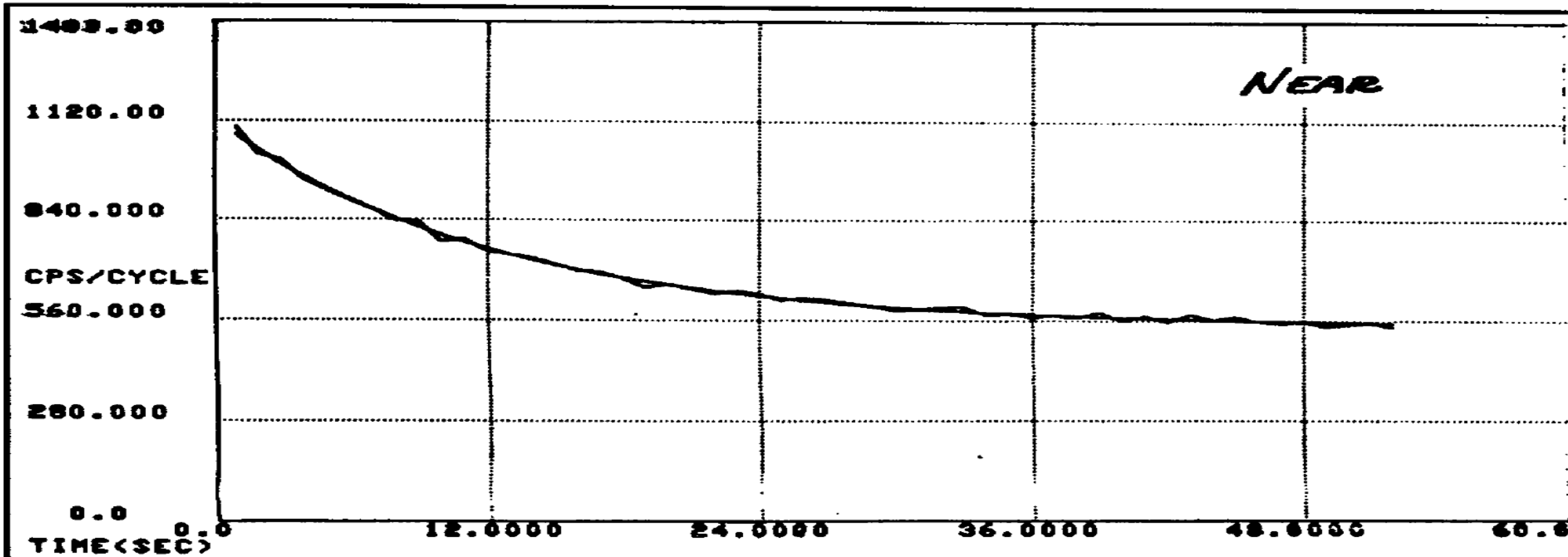
- NEUTRON SOURCE
- NEUTRON SHIELD
- 2 GAMMA RAY DETECTORS
  above source to detect upward flow
- TOOL SIZES
  1-3/4 to 3-5/8 inches X 34 to 26 feet
- COMPUTER ANALYSIS @ surface

OA LOG PROCEDURE

- RUN LOG @ NORMAL INJECTION RATE
- CALIBRATE INSTRUMENT
- RUN BASE GAMMA-RAY LOG
- LOG @ 10 FT. STOPS (5 MIN. EA.) START BELOW PERFS (NO FLOW)
  - RELEASE SOURCE
  - READINGS FOR 5 MINUTES
  - REPEAT 10 FEET UP HOLE



OXYGEN ACTIVATION TOOL SCHEMATIC



FILE NUMBER
25

DATA ACQUIRED
05-DEC-1990 11:38

DETECTOR = NEAR TDT-P

DEPTH = 2493.6 F

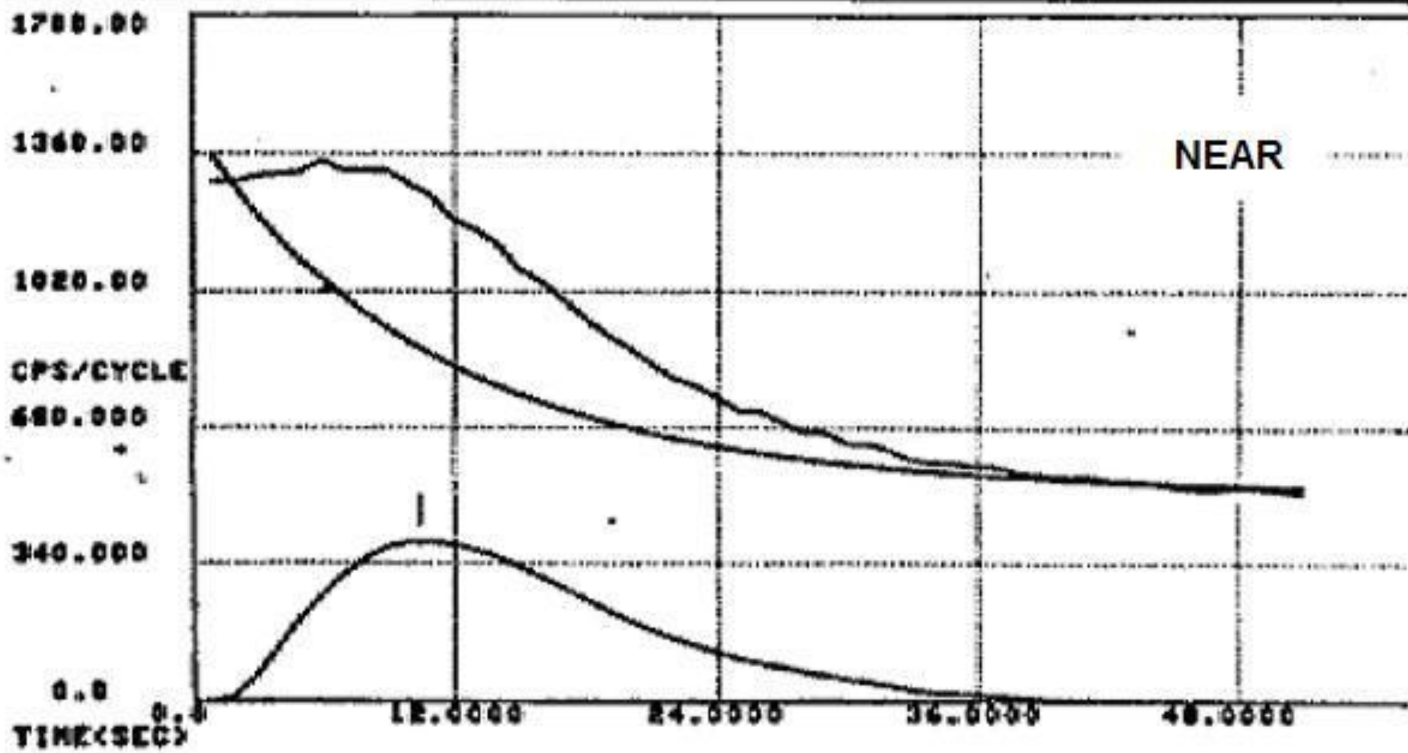
CASING SIZE = 7.000 IN
NEAR TCHK = 51377.0 CPS
NEUTRON ON TIME = 10.0 S

SFT TYPE = 178
FAR TCHK = 23345.0 CPS
NUMBER OF CYCLES SUMMED = 12

FLOW NOT DETECTED
FLOW VELOCITY = 0.0 FT / MINUTE
FLOW RATE = 0.0 BWPD

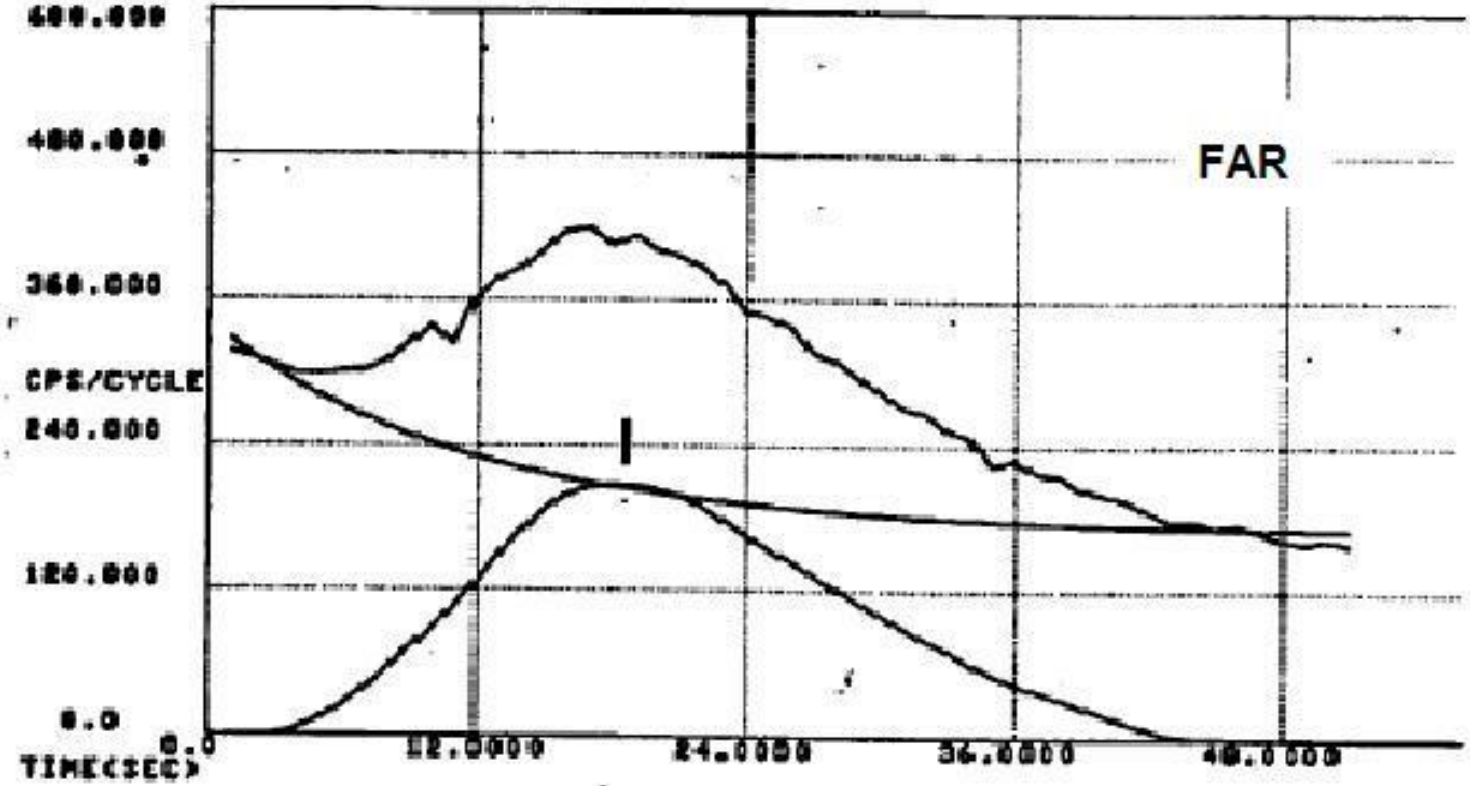
PEAK BACKGROUND SIGNAL =	556.9	+/-	1.3	CPS / CYCLE
PEAK STATIONARY SIGNAL =	548.7	+/-	4.8	CPS / CYCLE
TOTAL FLOWING SIGNAL =	0.0	+/-	0.0	COUNTS / CYCLE

Figure 31A. Mechanical integrity (near counter) at 2493.6 ft




```
FILE NUMBER                       DATA ACQUIRED
  44                              05-DEC-1990 10:23

    DETECTOR = NEAR TDT-P                   DEPTH =  3293.6 F

CASING SIZE      =   7.000 IN     SFT TYPE                 =  178
NEAR TCNK        = 43200.0 CPS    FAR TCNK                 = 21200.0 CPS
NEUTRON ON TIME  =    10.0 S      NUMBER OF CYCLES SUMMED  =   12

FLOW DETECTED
FLOW VELOCITY =   -1.0 FT / MINUTE
FLOW RATE     =   -1.0 BWPD

PEAK BACKGROUND SIGNAL =   533.9   +/-    1.5 CPS / CYCLE
PEAK STATIONARY SIGNAL =   456.6   +/-    4.3 CPS / CYCLE
TOTAL FLOWING SIGNAL   =  6403.3   +/-   40.1 COUNTS / CYCLE
```

SAMPLE AVERAGE SPECTRUM NEAR COUNTER



FILE NUMBER
44

DATA ACQUIRED
05-DEC-1990 18:23

DETECTOR = FAR TDT-P

DEPTH = 3293.6 F

CASING SIZE = 7.000 IN
NEAR TCHK = 43200.0 CPS
NEUTRON ON TIME = 10.0 S

SFT TYPE = 178
FAR TCHK = 21200.0 CPS
NUMBER OF CYCLES SUMMED = 12

FLOW DETECTED
FLOW VELOCITY = 3.0 FT / MINUTE
FLOW RATE = 277.9 BWPD

PEAK BACKGROUND SIGNAL = 173.3 +/- 1.0 CPS / CYCLE
PEAK STATIONARY SIGNAL = 160.8 +/- 2.8 CPS / CYCLE
TOTAL FLOWING SIGNAL = 4079.7 +/- 35.0 COUNTS / CYCLE

SAMPLE AVERAGE SPECTRUM FAR COUNTER

EVENT-TREE FOR INJECTION WELL LEAK