Estimating Post-Radiological Contamination Scenario Local to Regional Scale Cesium-137 Ambient Impacts from Wildfire

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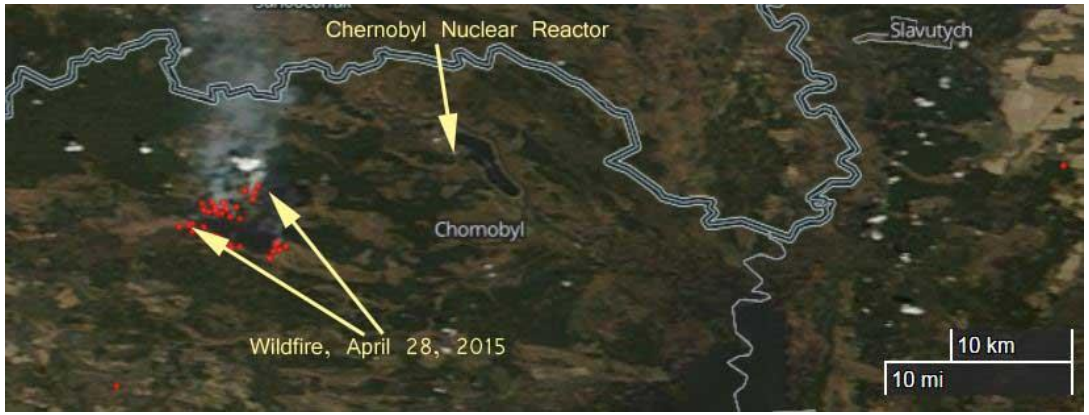
Motivation for Modeling Wildfire Impacts

- Better characterization of specific fires will result in better estimates to compare against human exposure/health outcomes
- Improved regulatory decision making related to Clean Air Act programs and other air quality assessments
  - O_3/PM National Ambien Air Quality Standard (NAAQS) reviews, NAAQS exceptional events demonstrations, O_3 /PM NAAQS implementation, air toxics assessments (NATA), and Regional Haze Rule plans for Class I areas
- Extensive work has been done and more planned to evaluate model predictions of smoke from wildfires (transport and chemical evolution)

Motivation for Modeling Post-Contamination Events

- Understanding potential impacts from a post-radiological contamination event from wildfire to nearby urban areas may allow for 1) better prioritization of remediation (forest vs. urban area focused efforts) and 2) anticipate potential exposure in downwind population if a wildfire happened in a contaminated area

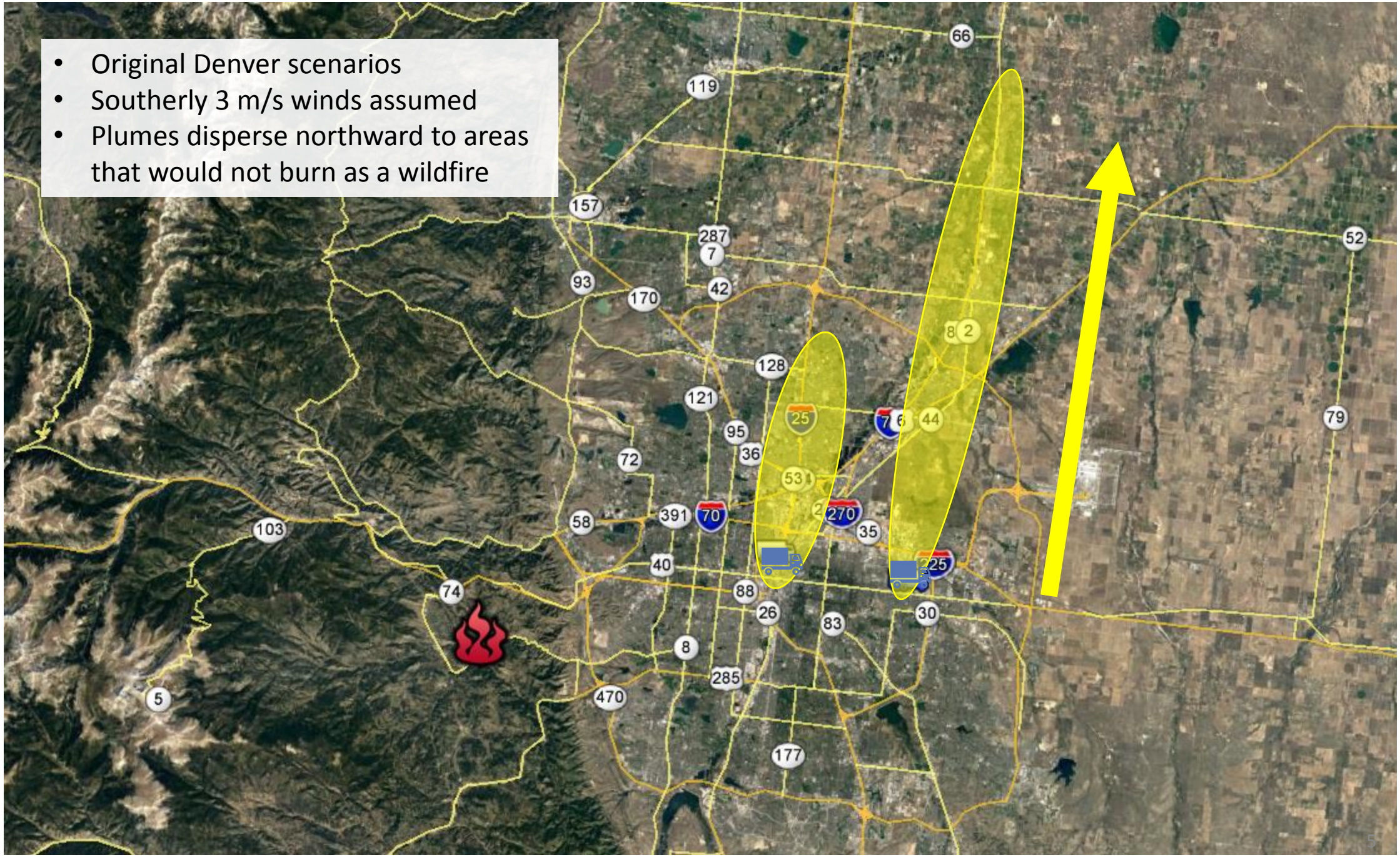


http://wildfiretoday.com/2015/04/28/wildfire-burns-within-10-miles-of-chernobyl-nuclear-reactor/

http://wildfiretoday.com/2017/05/06/firefighters-faced-with-wildfire-in-radioactive-area-near-fukushima-nuclear-power-plant/

Denver Scenario

- Truck dirty bomb hypothetical incident scenario for Denver 2012
- Wide Area Recovery and Resiliency Program (WARRP) 2011/2012
  - Collaborative program between DHS and Denver Urban Area Security Initiative (UASI)
  - Interagency initiative intended to reduce time and resources required to recover wide urban areas following a catastrophic chemical, biological, or radiological incident
  - Outcomes for this process include operationally relevant solutions to support recovery activities and improved understanding to address public health strategies and challenges
- Modeled post-radiological (WARRP) incident wildfire re-emission of Cesium-137 near Denver


• Original Denver scenarios
• Southerly 3 m/s winds assumed
• Plumes disperse northward to areas that would not burn as a wildfire
66
119
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287
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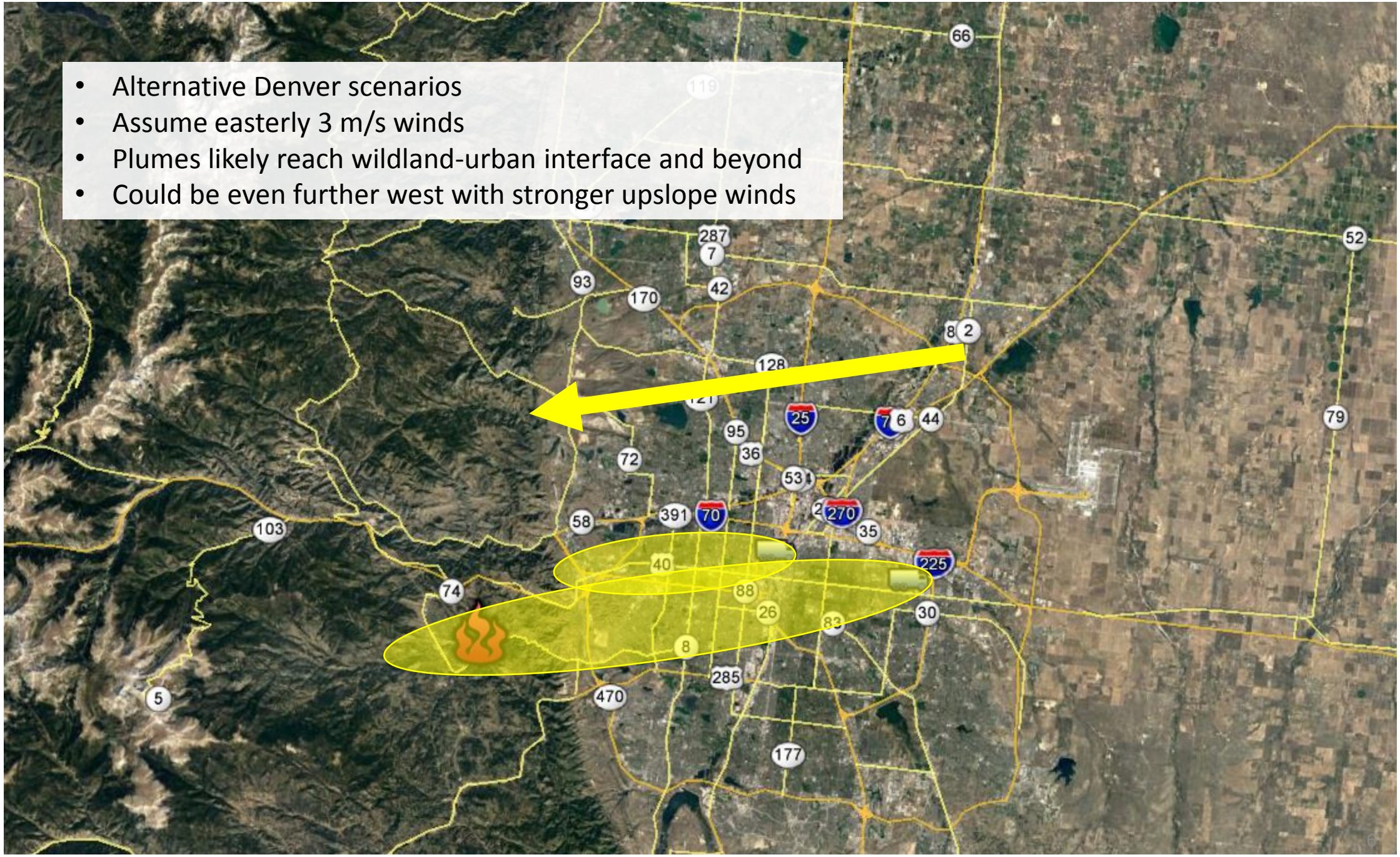
• Alternative Denver scenarios
• Assume easterly 3 m/s winds
• Plumes likely reach wildland-urban interface and beyond
• Could be even further west with stronger upslope winds
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177

Los Angeles Scenario

- Based on a hypothetical nuclear power plant release incident for Los Angeles (2011)
- Modeled post-incident wild fire re-emission of Cesium-137 using 2016 meteorology and an actual fire (Sand fire) from that year

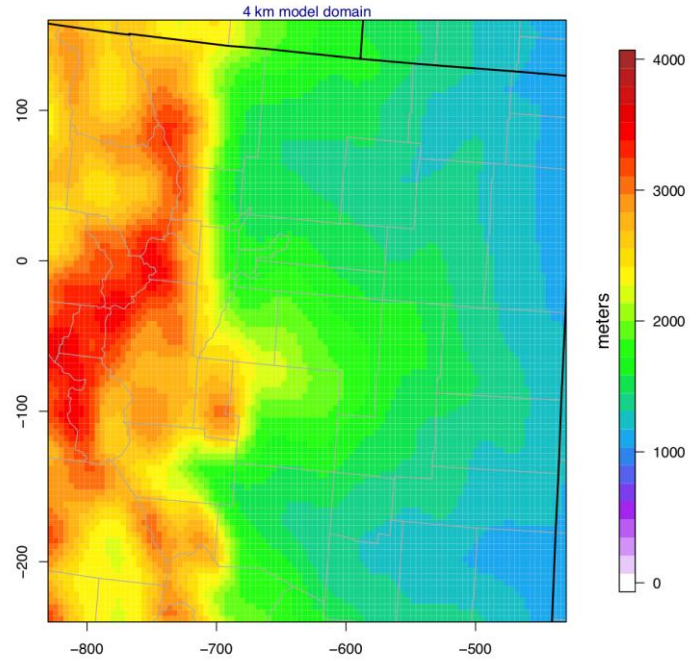
https://upload.wikimedia.org/wikipedia/commons/5/56/Sand_Fire_July_24.jpg

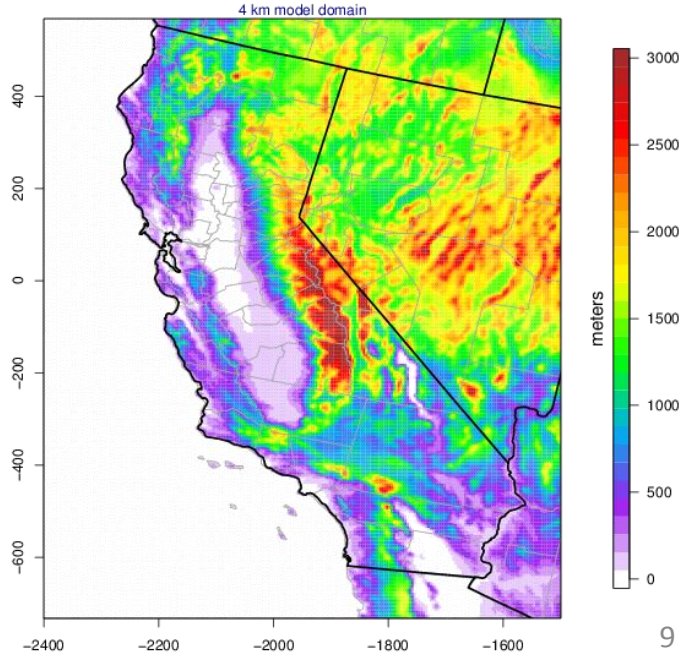
http://www.dailymail.co.uk/news/article-3705316/Smoke-layer-ash-cover-Los-Angeles-huge-20-000-acre-wildfire-burns-control-north-city-forces-1-000-residents-abandon-homes.html

- Original scenario for Los Angeles 2011
- Plumes disperses northwest to areas that could burn during a wildfire
- Fire represents the location of the 2016 Sand Fire

Model Background

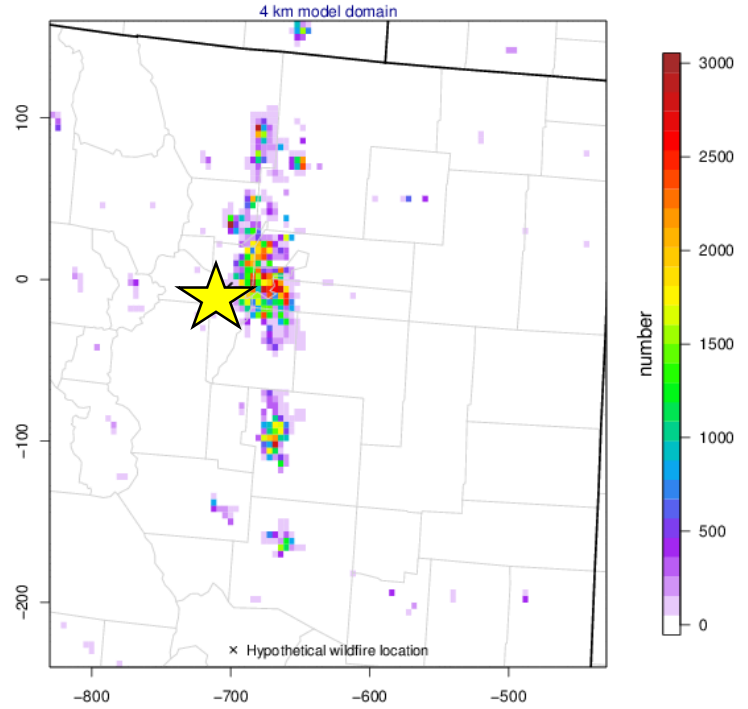
- Applied the Community Multiscale Air Quality (CMAQ) model v5.2 using 4 km sized grid cells
  - Eulerian photochemical grid model
- Model domains for Denver and California shown at right (color contours show terrain height)
- 4 km meteorology and emissions (including anthropogenic, biogenic, geogenic sources)
- Chemical specie inflow into these domains are based on model simulations for the same period covering a larger area (continental scale)

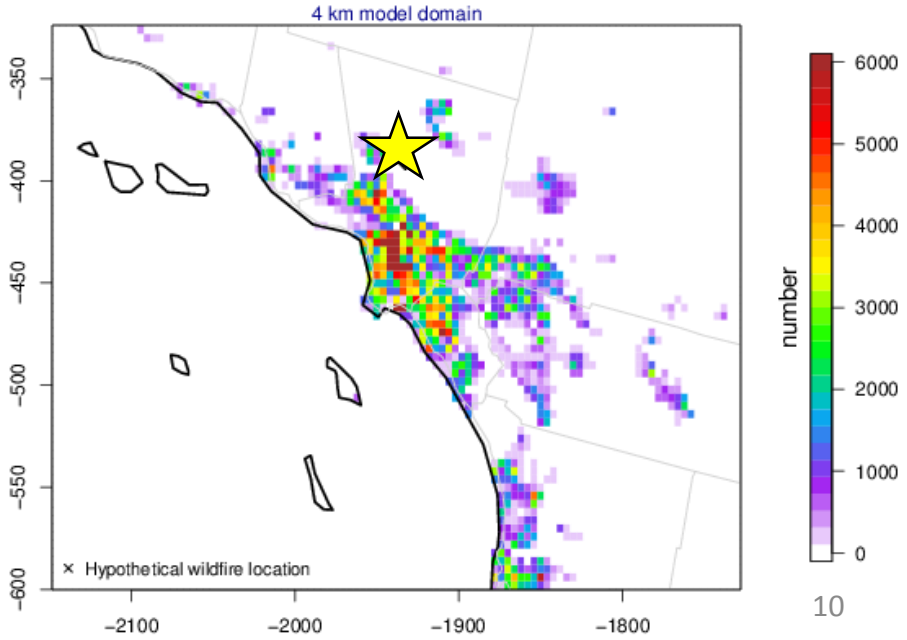




Wildfire Scenarios

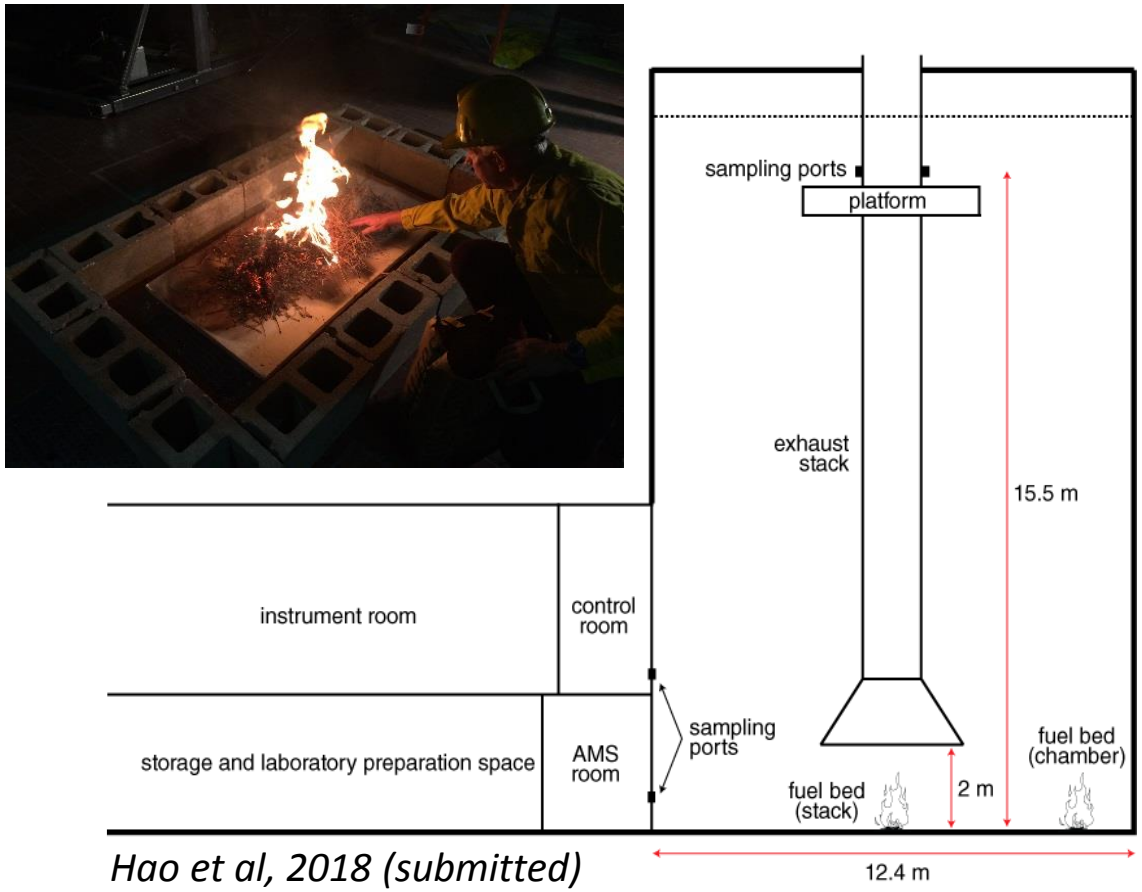
- Hypothetical wildfire scenario at the Denver wildland-urban interface (WUI) based on actual fire southwest of Denver in June 2013 (Royal Gorge Fire)
  - ~4,000 acre fire; 3 g of PM2.5 cesium-137 and 10 g of PMC cesium-137
  - Model period July 1 to 11, 2014
- Wildfire scenario for Los Angeles based on 2016 Sand fire
  - ~5,500 acre fire; 2 g of PM2.5 cesium-137 and 8 g of PMC cesium-137
  - Model period May 15 to October 1, 2016





PM Cesium-137 wildfire emissions

- PM cesium emissions based on Hao et al, 2018 (submitted)
- Focusing on litter fuel type
- Fuel (pine needles and peat) was doped with cesium then burned and measured at the Missoula Fire Science Laboratory
- Assumed PM2.5 (Aitken and accumulation modes) 0.0044% of total PM2.5 emissions from the wildfire
- Assumed coarse fraction of PM 0.091% of total coarse PM emissions from the wildfire
- Anticipating updated PM fraction data and/or emission factors from recent 2018 chamber burns at Missoula Fire Science Lab



Hao et al, 2018 (submitted)

PM Cesium-137 wildfire emissions

- Emission fraction of cesium to PM likely higher in laboratory testing compared to expected post-incident levels due to testing methods
- PM cesium-137 emissions adjusted downward based on a comparison of the Hao et al, 2018 (submitted) measurements of fuel contamination supporting the laboratory emissions measurements with multiple sources of post-incident cesium-137 deposition values
  - Literature review of post-incident cesium-137 litter fuel contamination levels near Fukushima and Chernobyl
  - Simple approximation of cesium-137 deposition from the Denver WARRP scenario

Post-incident Cesium-137 litter biomass contamination based on literature review

- Values measured near Fukushima and Chernobyl; vary based on time since incident and distance from incident
  - 13,000 Bq/m^2 (Takada et al, 2016)
  - 220,000 to 660,000 Bq/m^2 (Hashimoto et al, 2012)
  - Highest over 5 years: 377,000 Bq/m^2 (Imamura et al, 2017)
  - Measured amount in forest litter = 137,000 Bq/m^2; total combustible material 203,000 Bq/m^2 (Yoschenko et al 2006)
  - 880,000 Bq/m^2 (Kashparov et al 2000) – shown in the unit conversion example below

$$\left(\frac{880{,}000\ Bq}{m^2}\right)\left(\frac{2.7\ \times\ 10^{-11}\ curies}{1\ Bq}\right)\left(\frac{0.0114\ g\ cesium137}{curies}\right)\left(\frac{m^2}{0.000247\ acre}\right) = \frac{0.00109\ g\ cesium137}{acre}$$

Post-incident Cesium-137 litter biomass contamination based on WARRP scenario

- A simplified estimate of Cesium-137 deposition from the WARRP plume provides another opportunity to adjust the laboratory emissions estimates
- The WARRP radiation scenario had a total release amount of 2,300 curies
- Assuming uniform deposition across the impacted area would result in 27 curies/km^2 or 0.00124 g cesium-137/acre which is comparable to the value based on measurements downwind of nuclear facility incidents (shown on previous slide)

Adjusting modeled Cesium-137 emissions

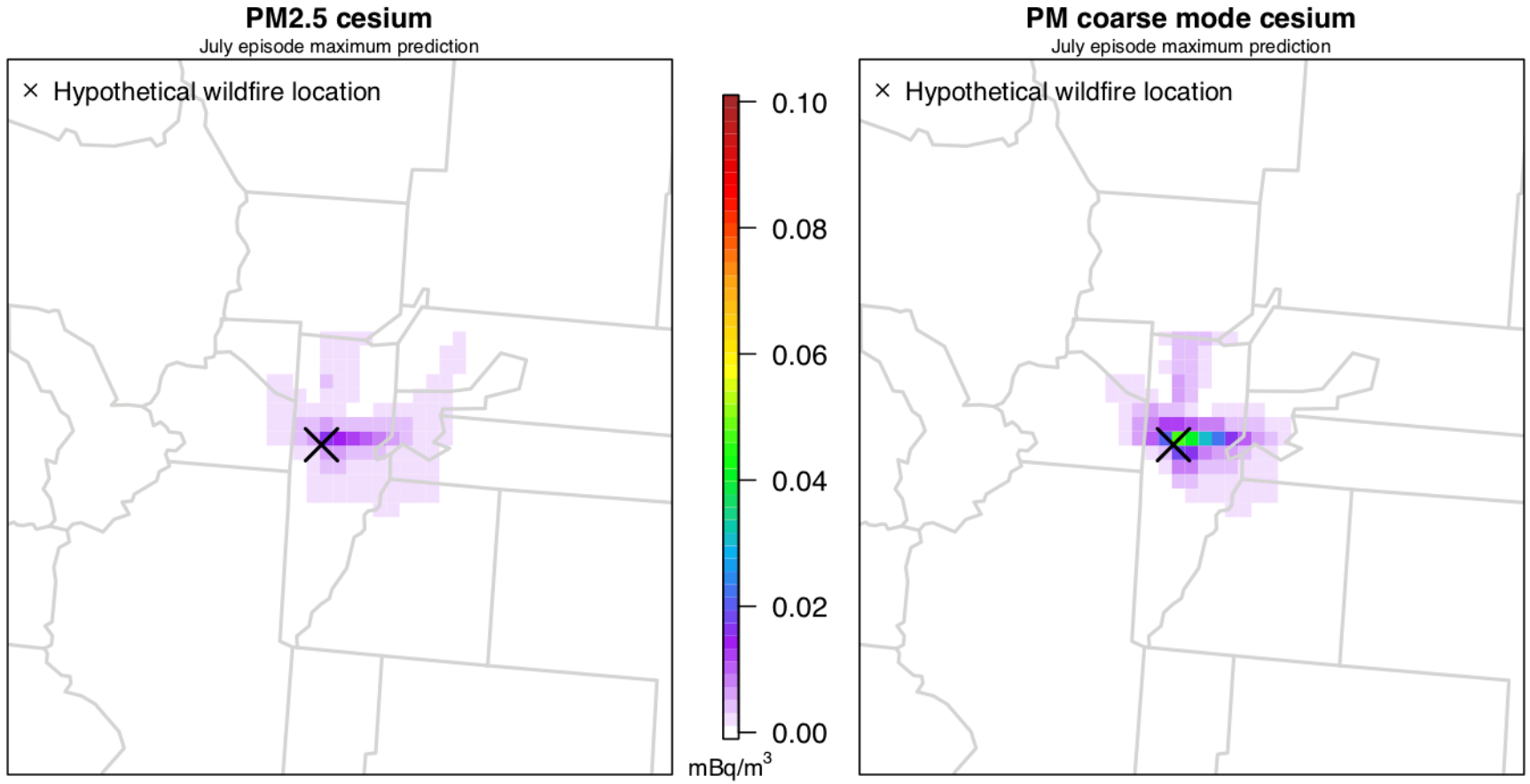
- Laboratory estimates of cesium per fuel (litter) were 0.01 to 0.024 g cesium/kg litter
- Apply estimate of kg/acre of litter for a specific fire based on data from U.S. Forest Service's Fuel Characteristics Classification System (FCCS) v2 module
  - A value of 12.8 tons litter/acre for the Denver hypothetical fire was extracted. A similar value was estimated for the Los Angeles area wild fire
  - 10.2 tons litter/acre for forests near Chernobyl (Yoschenko et al 2006)

$$\left(\frac{0.01\ g\ cesium137}{kg\ litter}\right)\left(\frac{12.8\ tons\ litter}{acre}\right)\left(\frac{907\ kg}{ton}\right) = \frac{116.1\ g\ cesium137}{acre}$$

- The ratio of 116.1 to 0.00109 is ~10^6 meaning a factor of ~10^{-6} should be applied to reduce emissions to account for the difference in laboratory cesium per fuel.

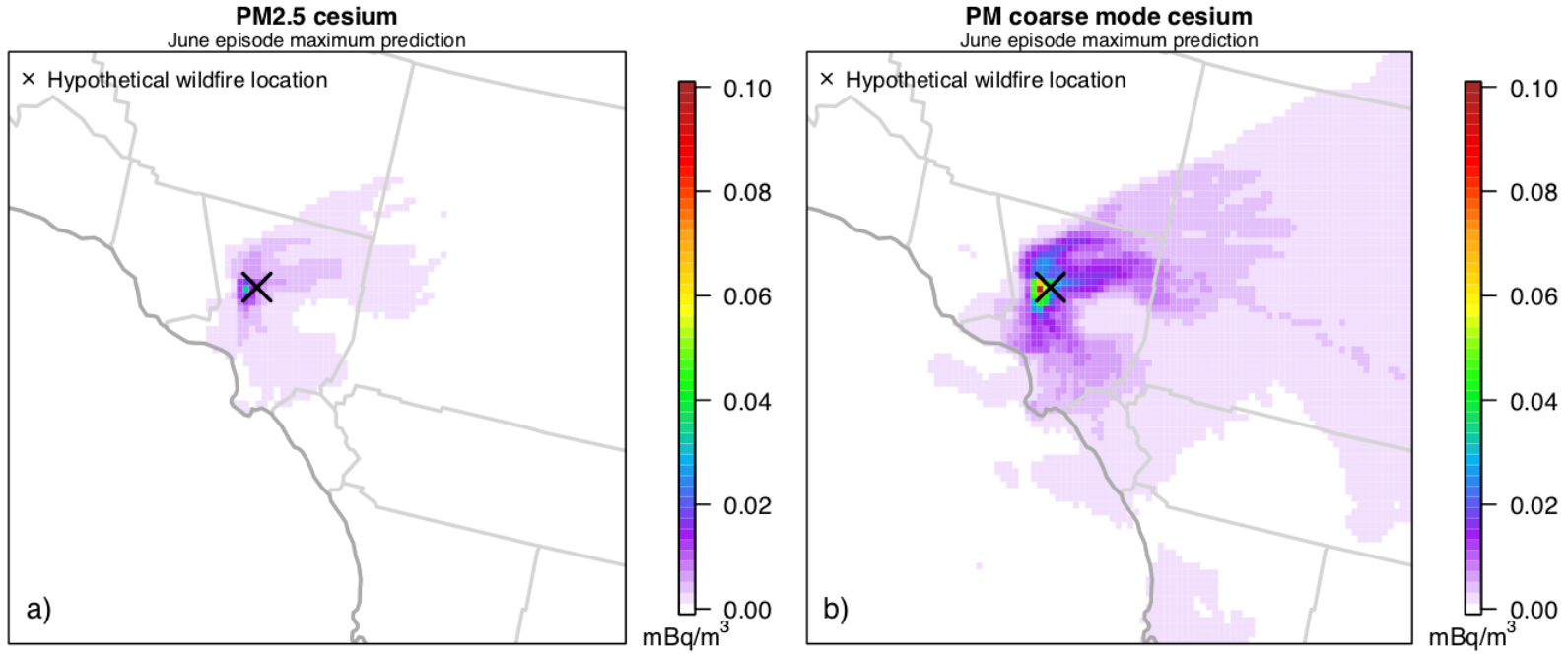
Preliminary Results

- Hourly concentration animation
- Episode maximum concentration
- Episode maximum exposure
- Population weighted episode maximum exposure

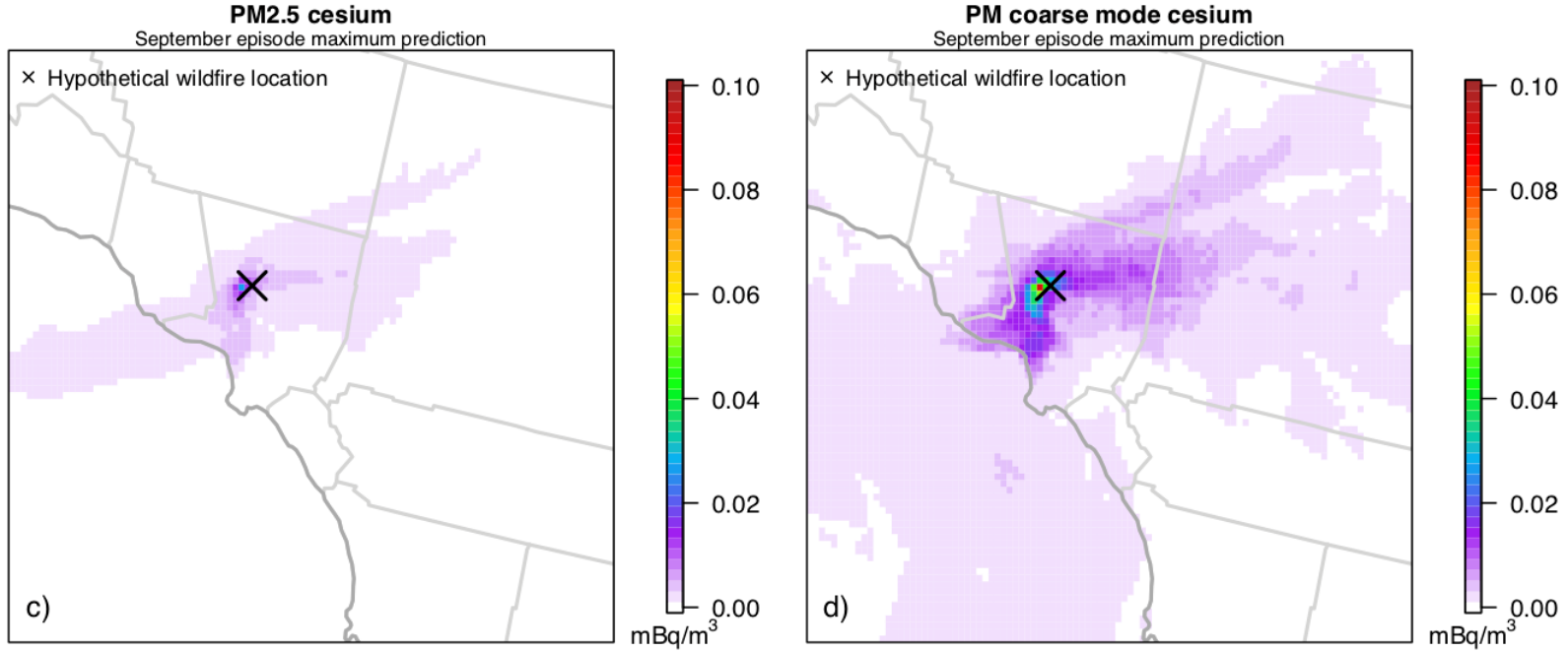


- Episode maximum modeled ambient concentration for Cesium-137 in fine (left) and coarse (right) particle modes
- Coarse fraction levels higher due to higher emissions outpacing higher dry deposition velocities
- Coarse emissions highly uncertain based on initial laboratory testing; results intended to be a conservative estimate

June time period →



September time period →



Calculating REMs from concentration

- The number for “pure” cesium-137 specific activity is 3.2×10^6 MBq/g
  - From the Mirion Radiological Reference Handbook
- Standard reference breathing rate for a worker = 1.2 m^3/hr
- From FGR 11*, using the annual limit on intake (ALI) for cesium-137, a reference individual will receive a 5 rem dose from every 6 MBq inhaled for cesium-137

$$Exposure\ \left(\frac{rem}{hr}\right) = \ Modeled\ Estimate\ \frac{\mu g}{m^3}\left(\frac{g}{10^6\ \mu g}\right)\left(\frac{3.2 \times 10^6 MBq}{g}\right)\left(\frac{1.2\ m^3}{hr}\right)\left(\frac{5\ rem}{6\ MBq}\right)$$

*Federal Guidance Report No. 11: Limiting Values Of Radionuclide Intake And Air Concentration And Dose Conversion Factors For Inhalation, Submersion, And Ingestion

Highlights

- Modeled post-incident ambient levels of PM2.5 cesium-137 from wild fires near these urban areas well below levels that would necessitate population evacuation or warrant other protective action recommendations such as shelter-in-place
  - May also suggest decontamination efforts focused on forests to be a lower priority
- While ambient concentrations tended to be highest in close proximity to the fire, highest impacts (person-rems) were downwind where wind flows moved smoke to high population areas
  - Seasonal variations in meteorology (wind flows) can have differential population impacts even in the same area as shown in the Los Angeles scenarios
- Resulting maximum ambient concentrations smaller than those modeled downwind of forest fire contaminated with Cesium-137 from Chernobyl (Yoschenko et al, 2006)
- Important caveats related to this assessment
  - Important to recognize physiological differences between workers general public (sensitive sub-populations)
  - Activity Median Aerodynamic Diameter (AMAD) and particle size comparability
  - This work provides no information about longer-term cumulative exposure from other types of post-contamination radiation with longer half-lives (e.g., nuclear bomb testing)

Next Steps

- Refine other model inputs for Denver and Los Angeles simulations
- Update cesium-137 emissions based on 2018 laboratory testing
- Refine process of adjusting emissions to reflect differences in laboratory methods and post-incident levels
- While this approach tends to be conservative already, some accounting for other types of contaminated fuels consumed during wild fire may be included

Disclaimer

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