Comparison of Gaussian and Lagrangian Plume Modeling of Doses for Guidance in Microreactor Physical Protection System Design

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Outline

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- Results
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  - Resulting Peak ICRP 60 Effective Dose at Radial Distances
- Conclusion and Application to Micro and SMR Licensing
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Peach Bottom BWR Units 2 and 3 - Constellation Energy Nov 2010

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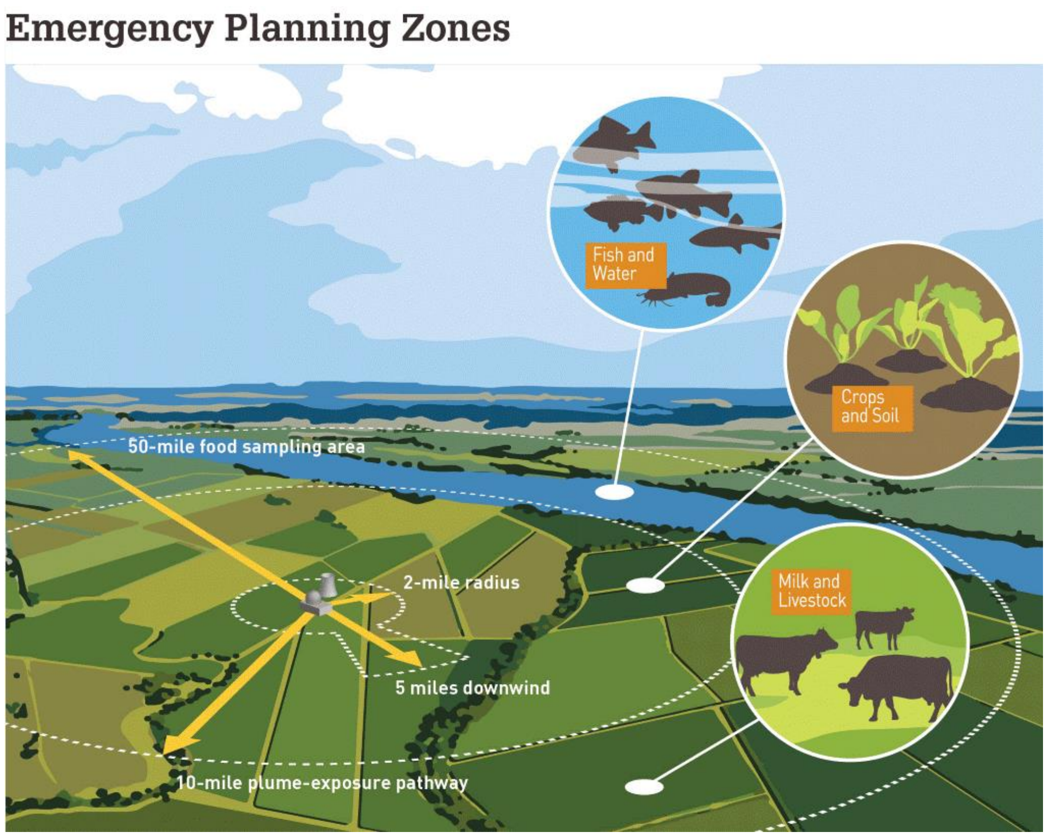
Objectives

- Working alongside Texas A&M to develop a risk informed consequence driven Physical Protection System (PPS) appropriate for micro and SMRs.
  - Texas A&M is creating a plausible accident scenario in MELCOR for a heat pipe micro reactor
- Goal is to enable a more appropriately sized PPS for advanced reactor designs while maintaining constant or reduced risk associated with future reactor constructions.
- Improve safety of surrounding population with dose-based risk informed boundaries rather than empirically defined distances
- Reduce initial construction and recurring operating costs for plant operators



Emergency Planning Zones – NRC Emergency Preparedness Maps

Background: NRC – 10 CFR 50.34 and 10 CFR 50.47 (1980)

- 50.34 – Describes general EPZ radius surrounding a facility
  - 10 miles for plume exposure, 50 miles for ingestion pathways
  - Determined from a conservative estimate that in worst case scenario no immediate life-threatening doses will occur
- 50.47 – Requires that Total Effective Dose Equivalent at exclusion zone boundary cannot exceed 25 rem after two hours, 25 rem total at low population boundary
  - Simulation consists only of external exposure, TEDE will be ICRP 60 ED using EPA FGR 15 coefficients
  - Focusing on scalable EPZ radii using 1 rem threshold, 25x less than maximum allowable

Background: NRC – Preliminary 10 CFR 53 Rulemaking (2022)

- Currently in the early stages of CFR 53 drafting and rulemaking
  - Ongoing discussions on changes to requirements in site boundaries and possible variable sizes depending on risk informed analysis
- Facility EPZs licensed under § 53 no longer are set at 10-mile radii
  - Instead under § 53.1309, EPZs are drawn to meet the standards designated by § 53.855
  - Primarily informed by "radiological consequences from a hypothetical, unmitigated event... [resulting] in offsite doses below the values in § 53.210"
  - Dose thresholds being 25 rem TEDE as described in § 50.47
  - However, for better safety, the following examples will use a 1 rem threshold

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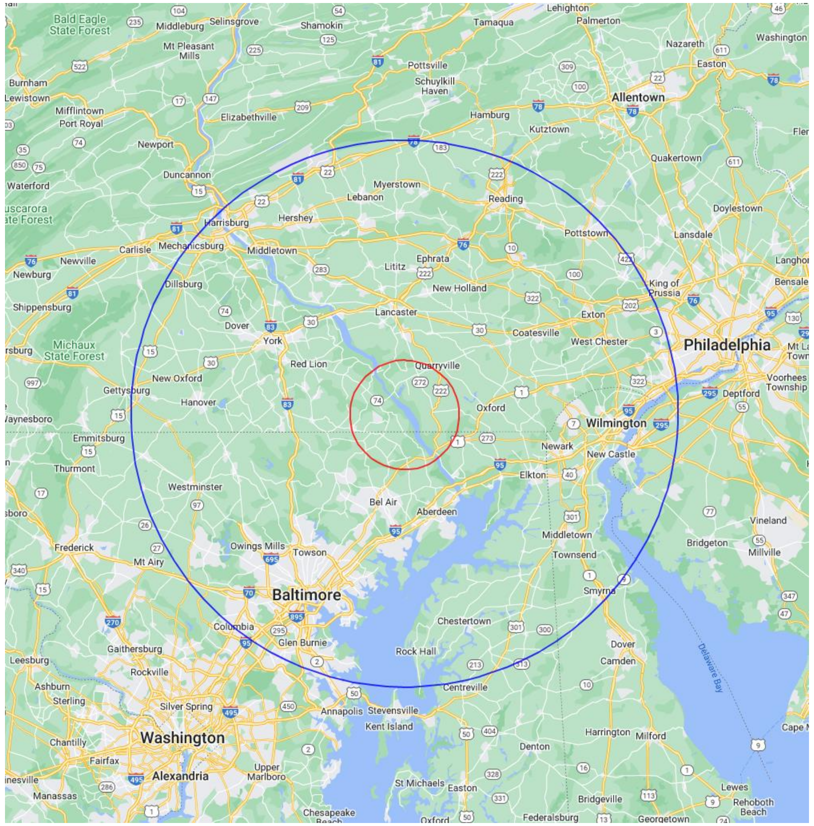
Methodology: SOARCA Peach Bottom Unmitigated LTSBO Scenario

- Following an earthquake, plant experiences total loss of offsite power
- Onsite AC power sources are degraded
  - Backup diesel generators fail to start
  - Onsite DC batteries provide enough to supply 4 hours of shutdown operations
- Upon exhaustion of DC battery capacity, emergency cooling systems shut down and core experiences runaway heating and a release
- No mitigation of accident progression beyond that required in § 50.54 (hh).
  - Further mitigation can include obtaining and connecting offsite functioning generators and extending RCIC lifetime to 24 hours



Radial 10 (Red) and 50 (Blue) Mile EPZ – Google Maps

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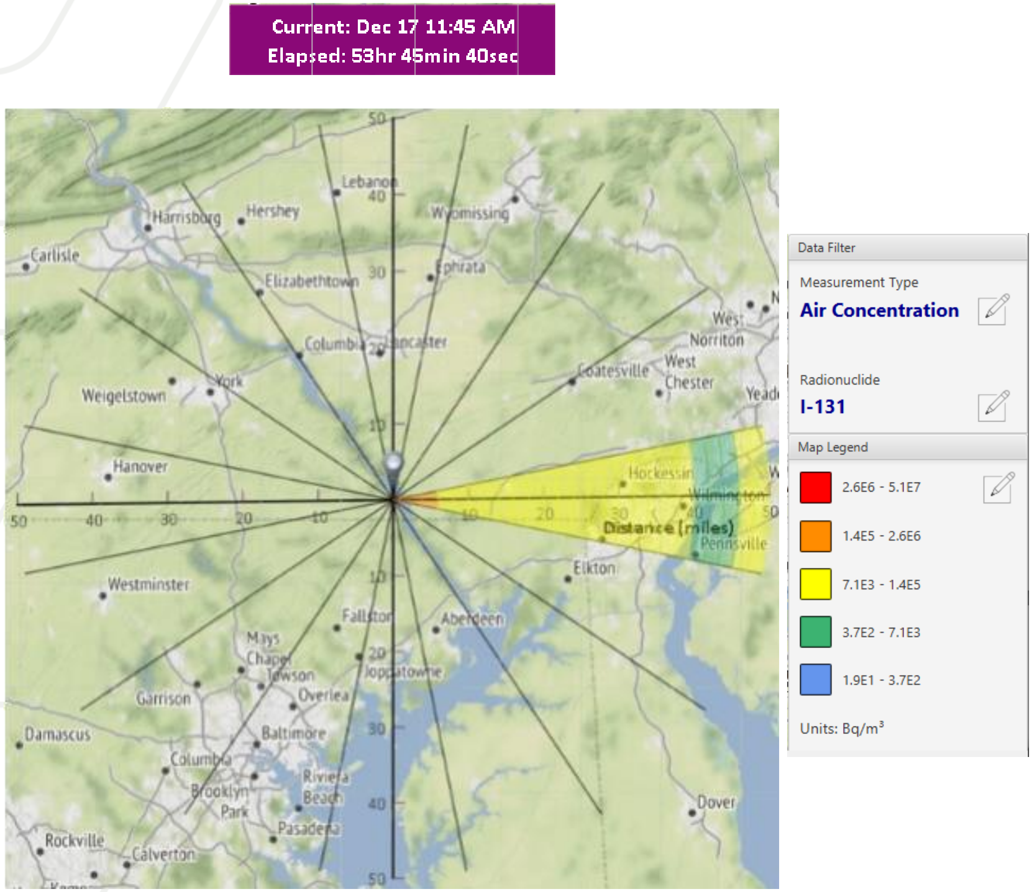
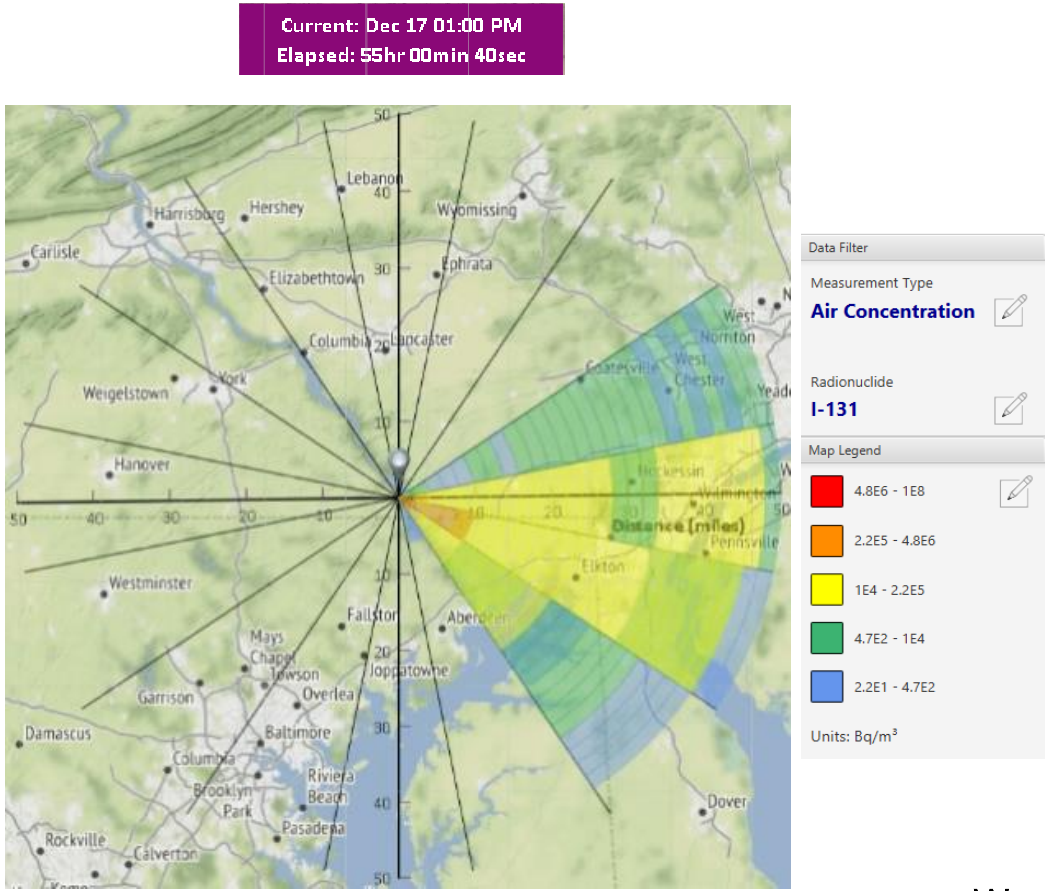
Methodology: Scope of Simulation and Parameters

- CFR 50.34 and current § 53.855 specify that TEDE cannot exceed 25 rem for a representative individual standing at the boundary
  - Results are not population weighted
  - Only early consequence from external exposure simulated
- Inventories of plume released are representative of the 1.3 GWe BWR reactors located at Peach Bottom, not an advanced reactor design
- Two separate days were simulated: Dec 15, 2015 and May 27, 2021
  - December date selected arbitrarily for a normal, if slightly cloudy, winter week
  - May date selected for the slight amount of precipitation over the week
  - Weather history obtained from NOAA's NAM 12km gridded data sets

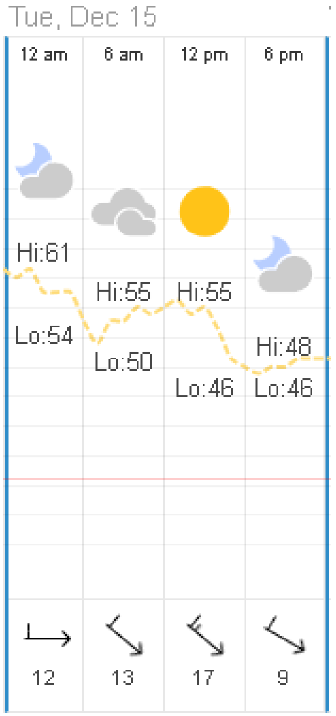
Results: Gaussian and Lagrangian Plume Winter Weather



Gaussian



Lagrangian



Weather in Lancaster PA – TimeAndDate.com

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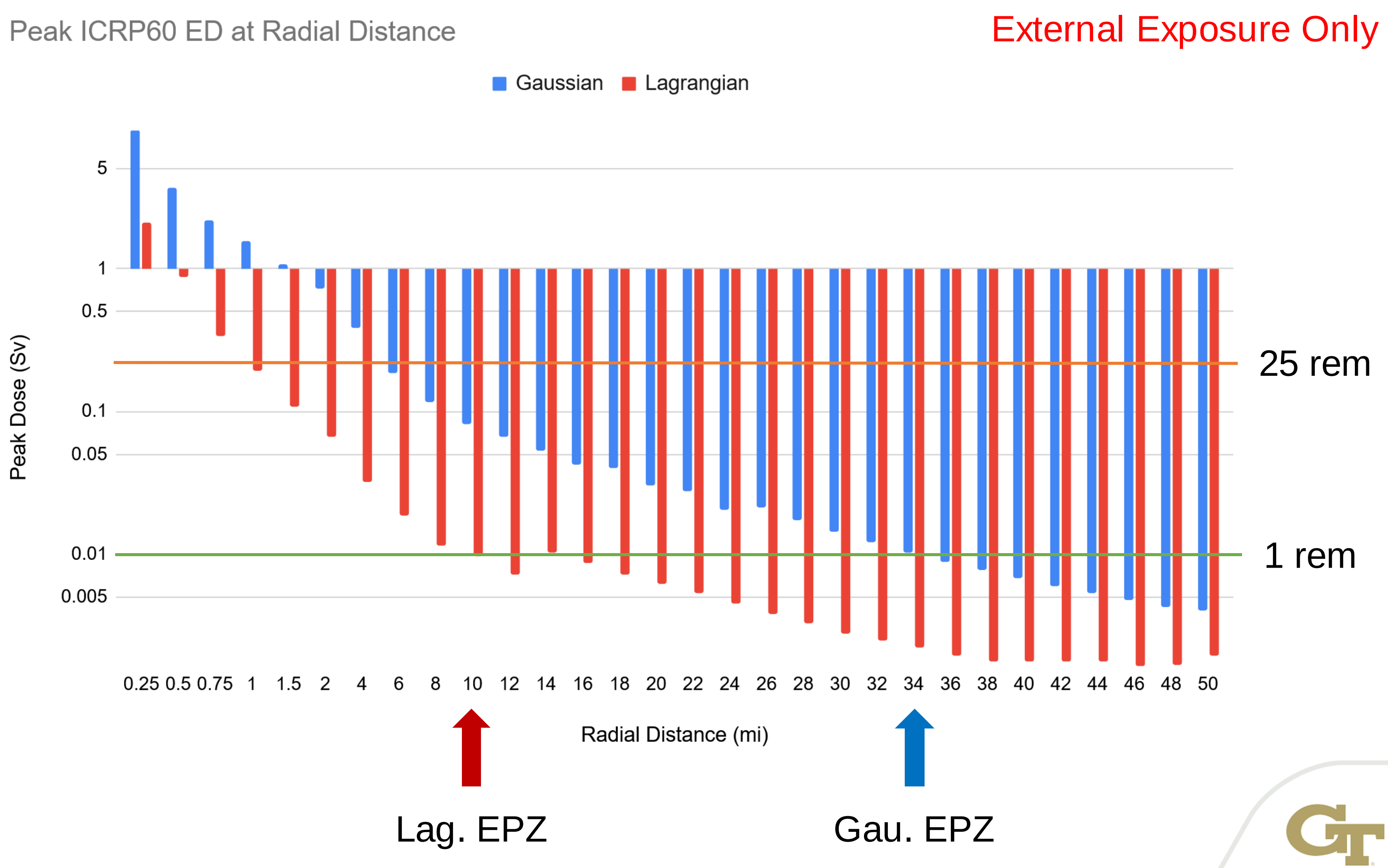
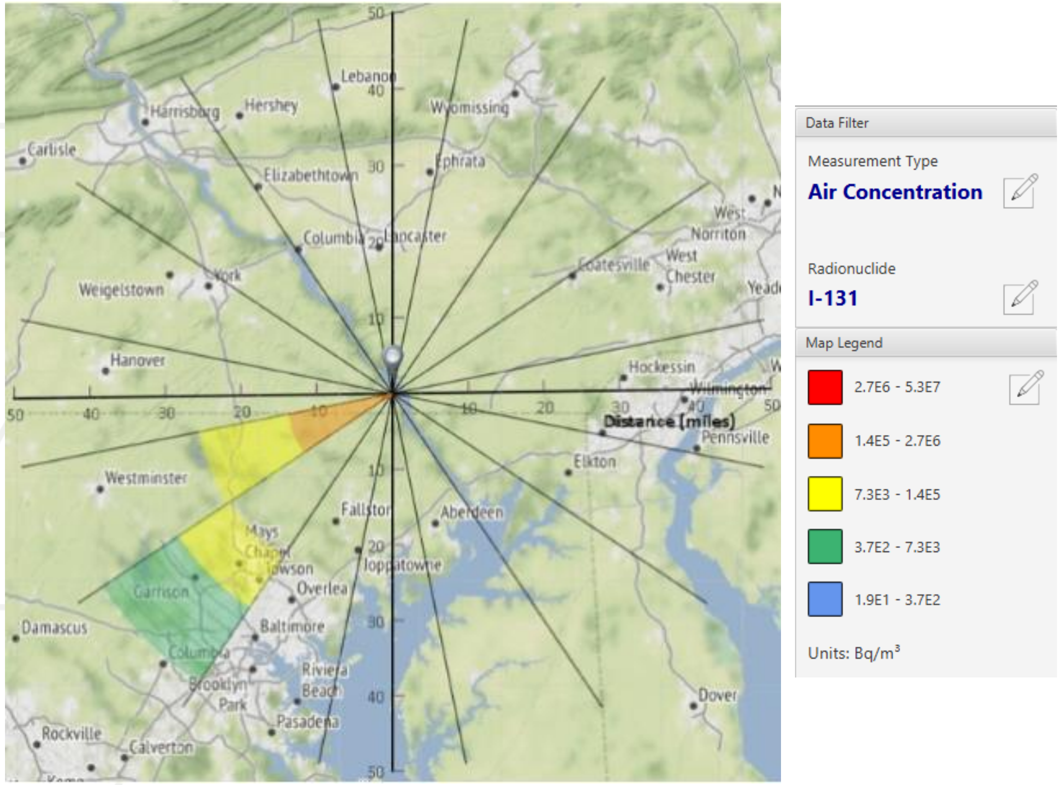
Results: Radial Distance Peak ICRP 60 Effective Dose Winter



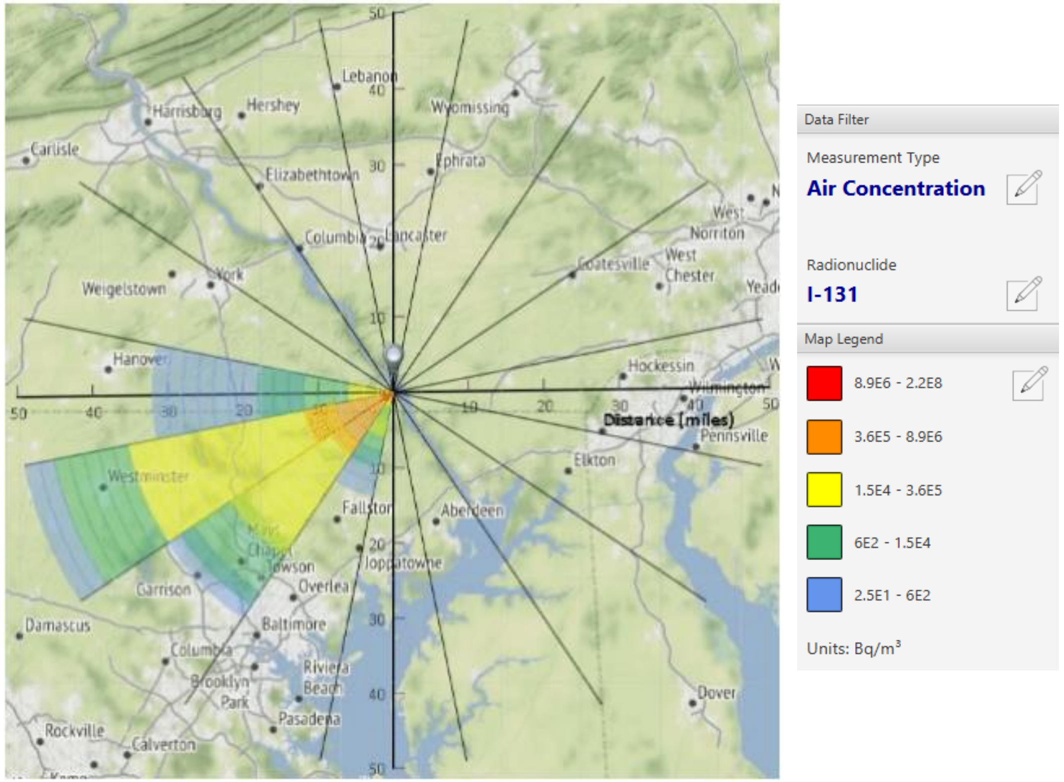
Results: Gaussian and Lagrangian Plume Spring Weather

Current: May 29 10:30 AM
Elapsed: 52hr 30min 40sec

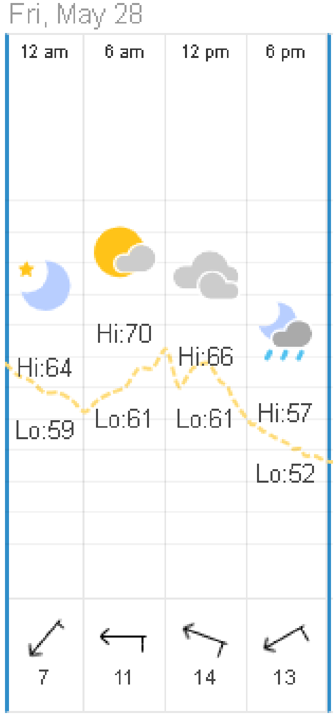


Gaussian

Current: May 29 11:00 AM
Elapsed: 53hr 00min 40sec



Lagrangian



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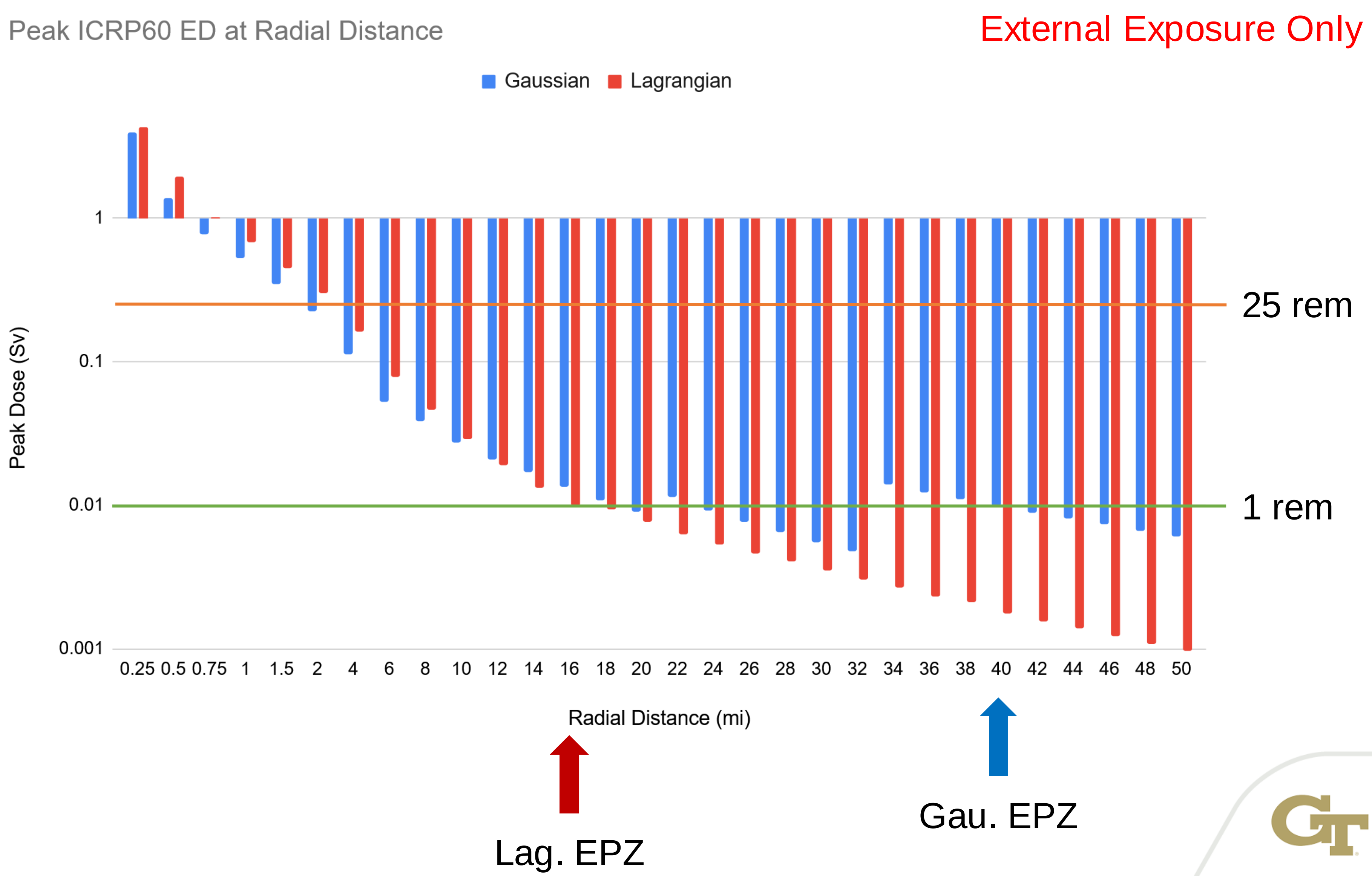
Results: Radial Distance Peak ICRP 60 Effective Dose Spring



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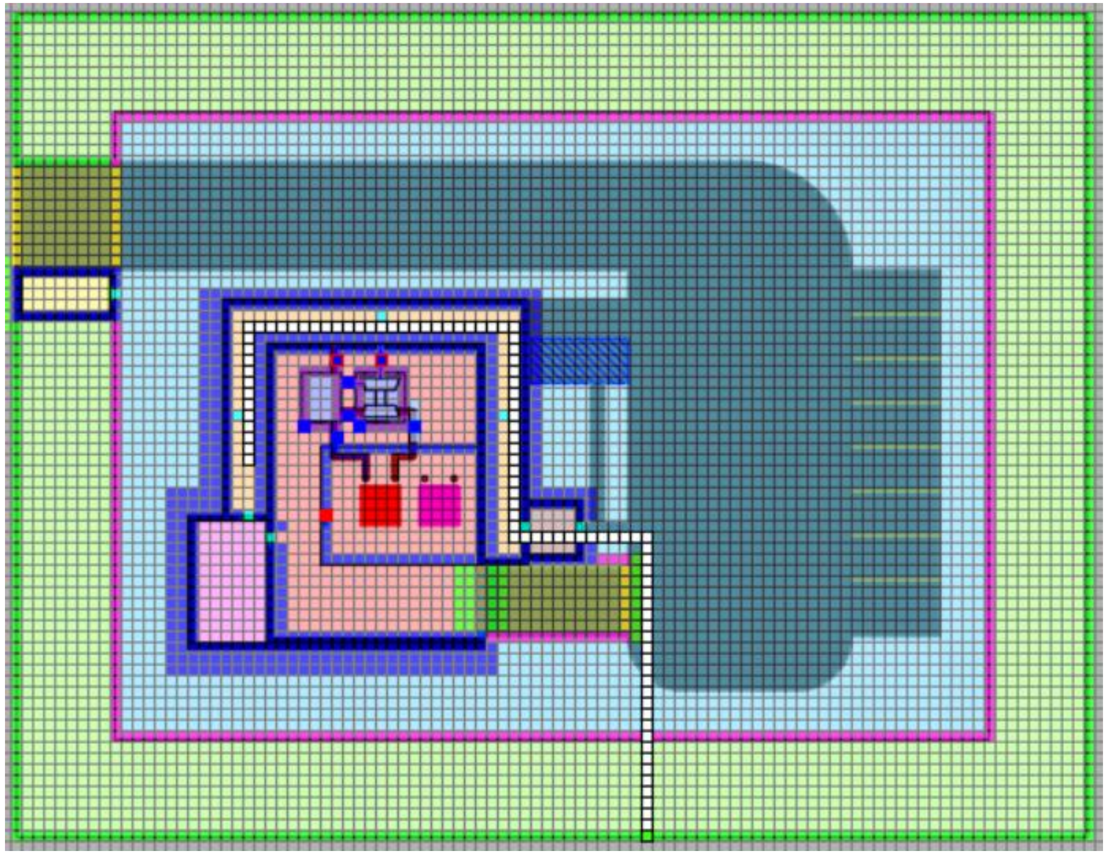
Conclusion: Application in SMR and Microreactor Licensing

- Distributions displayed in the previous two scenarios were representative of a release from a large 4,016 MWth (1,382 MWe) BWR
- SMRs and microreactors range below 100 MWe with proportionally less fuel mass that could be released during an unmitigated incident
- 10 CFR 53 contains language explicitly allowing for situations where EPZ radii could be designated at facility boundary
  - Resulting in no emergency planning beyond that required for safe operation of the nuclear power plant
  - No requirements for community emergency drills, distribution of potassium iodide, and the corresponding costs for planning and preparation
  - "Reconsider establishing the emergency planning zone at the site boundary, which, among other concerns, can significantly limit the ability of the public to establish standing to challenge siting..."

Next Steps

- Analysis of microreactor scenario
  - Texas A&M is developing a MELCOR scenario for an unmitigated accident using INL Heat Pipe Reactor Design A
- This work is a subset of a larger risk informed Physical Protection System
  - Improvements in PPS simulated in PathTrace result in changes to MELCOR accident progression for as input into MACCS
- Include internal dose assessment for a more comprehensive boundary comparison



Current floor plan of HPR facility in PathTrace. White trail is fastest hostile path to accessing critical infrastructure.

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