



Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

Beyond EPZs: Nuclear Emergency Management Frameworks when using Site Boundary Emergency Planning Zones

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Outline

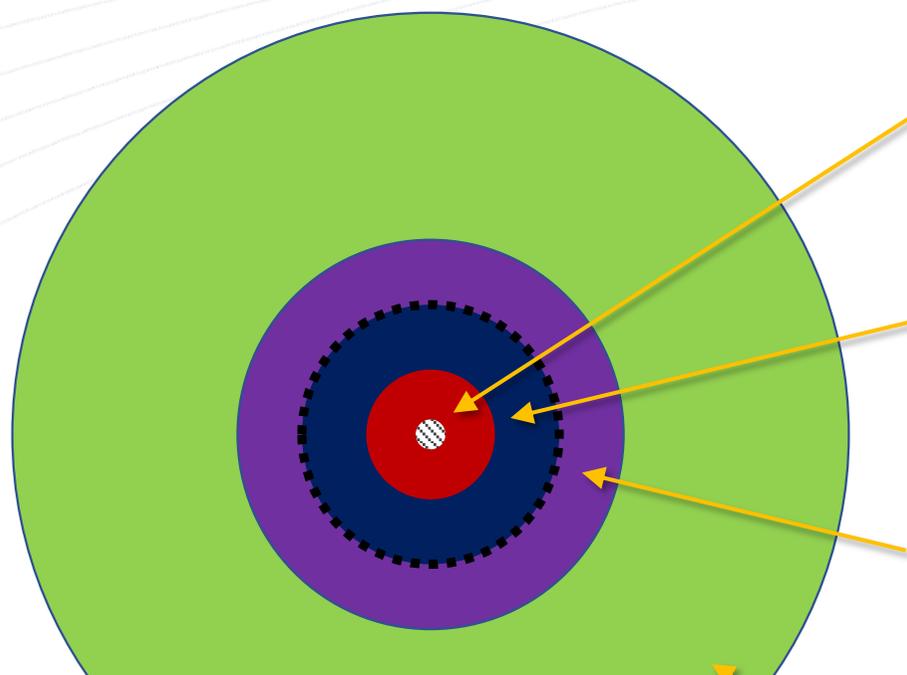
1. Concept of Operation for Site Boundary Emergency Planning Zones (EPZs) and Reactive vs Proactive Response
2. Case Study: High Temperature Gas Reactor
3. Use of Operational Intervention Levels (OILs) as Primary Triggers in a Reactive Strategy



'Site Boundary' EPZ Framework and Reactive vs Proactive Response



Emergency Planning Zones and Distances – Current Framework



Automatic Action Zone (AAZ): Area surrounding the plant where pre-planned actions are taken by default upon declaration of a general emergency. Aim to prevent deterministic health effects. (IAEA analog is Precautionary Action Zone, PAZ)

Detailed Planning Zone (DPZ): Area where pre-planned actions are taken as needed based on known reactor conditions, predictive modeling, and environmental monitoring. Aim to reduce stochastic health effects. (IAEA analog is Urgent Action Zone, UPZ)

..... Limit of “EPZ” per IAEA definition

Contingency Planning Zone (CPZ): Area where contingency planning & arrangements in advance to allow protective actions to be extended past DPZ as needed. (IAEA analog is Extended Planning Distance, EPD)

Ingestion Planning Zone (IPZ): Area where arrangements are made to protect the food chain and restrict the distribution of potentially contaminated products. (IAEA analog is Ingestion and Commodities Planning Distance, ICPD)

- Response frameworks should have a graded approach in their designs, while SMRs may be preparedness categories I or II under IAEA GSR Part 7 [1].

Emergency Planning Zones – ‘Site Boundary’ Framework

IF a ‘site boundary EPZ’ can be justified, then what would the EPR framework look like?



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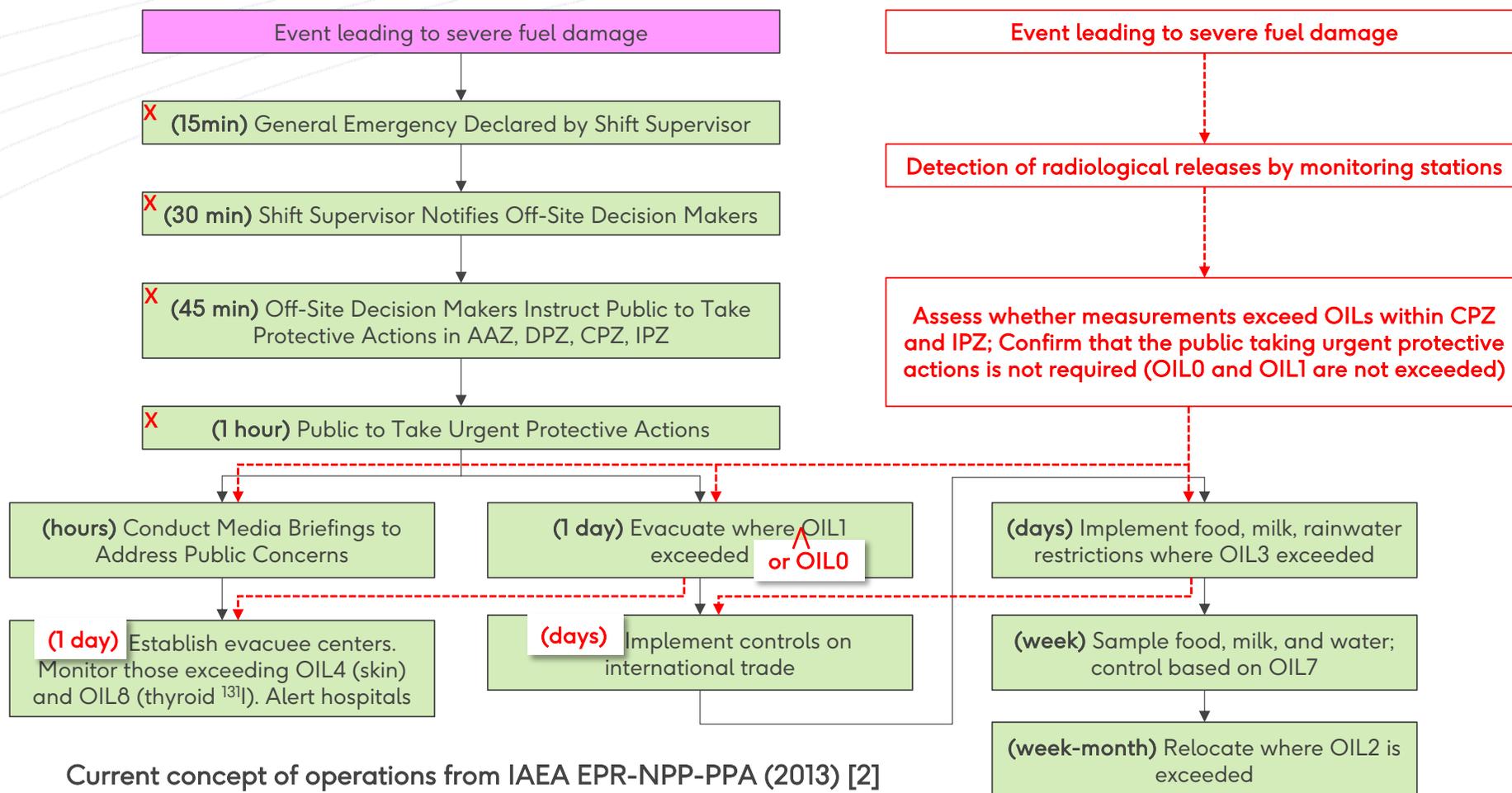
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- This may allow reactive rather than proactive response. Requires some risk tolerance for longer times to implement protective actions.

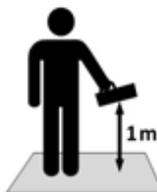
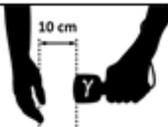
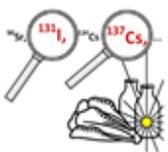
'Site Boundary' EPZ Framework



Current concept of operations from IAEA EPR-NPP-PPA (2013) [2]
and modification for 'Site Boundary' EPZ framework [3].

Operational Intervention Levels

- OILs are criteria that allow for the prompt implementation of response actions on the basis of **monitoring results** that are **readily available** during a nuclear emergency.
 - Used to quickly infer whether doses are projected to exceed allowable limits.
- IAEA (2017) published new set of OILs and methodology for their derivation *based on published LWR source terms* [4].
- In a 'site boundary' EPZ framework, exceeding an OIL value with a monitoring measurement would be the primary trigger for implementing protective actions.
- Need to develop OIL_{0γ} (integrated cloud shine gamma measurement) as a new metric to account for dose from passing plume.

| OIL | Default OIL value | Monitoring type | Charts in section |
|--------------------------------|---|---|-------------------|
| OIL1 _γ | 1000 μSv/h |  | 2.6.1 |
| OIL2 _γ | 100 μSv/h (for the first 10 days after reactor shutdown) 25 μSv/h (later than 10 days after reactor shutdown ^a or for spent fuel) | | |
| OIL3 _β | 1 μSv/h |  | 2.6.2 |
| OIL4 _γ ^c | 1 μSv/h | | |
| OIL4 _β ^c | 1000 cps ^d |  | 2.6.2 |
| OIL7 | 1000 Bq/kg of I-131 and 200 Bq/kg of Cs-137 |  | 2.6.3 |
| OIL8 _γ | 0.5 μSv/h |  | 2.6.4 |

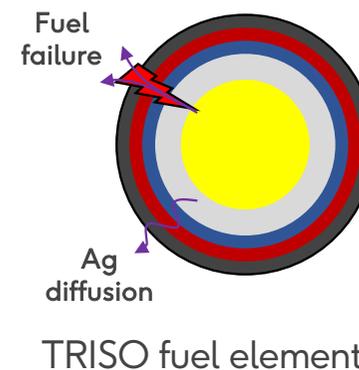


Case Study: High Temperature Gas Reactor

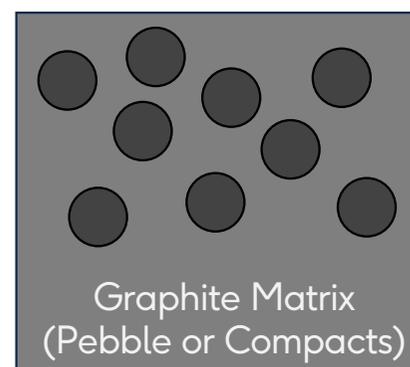


Radiological Source Term – Inventory and Release Mechanisms

- High temperature gas reactor or heat pipe reactor designs are most likely to be deployed in remote sites.
 - There are 10-100 MWe designs currently in CNSC vendor design review in Canada.
 - Potential use for electricity + heat, including community, mining, industrial sites.
 - Common feature: use of TRISO fuel, with hallmark ability to experience very high temperatures and still limit fission product releases.
- Possible bounding accidents with reactor (Zhou 2024 [5]; Petti 2013 [6]) or spent fuel involves:
 - High temperature diffusion releases of fission products from fuel.
 - Oxidation of activation products in graphite during air ingress scenario.



- FP inventory in fuel.
- Intact outer layers effectively block diffusion of most nuclides (except Ag).
- Other nuclides need failed layers to escape.



- Activation products from contaminants in graphite (^{14}C , tritium, ^{60}Co , etc.).
- Graphite oxidation during air ingress scenarios volatilizes species.

Radiological Source Term – Summary

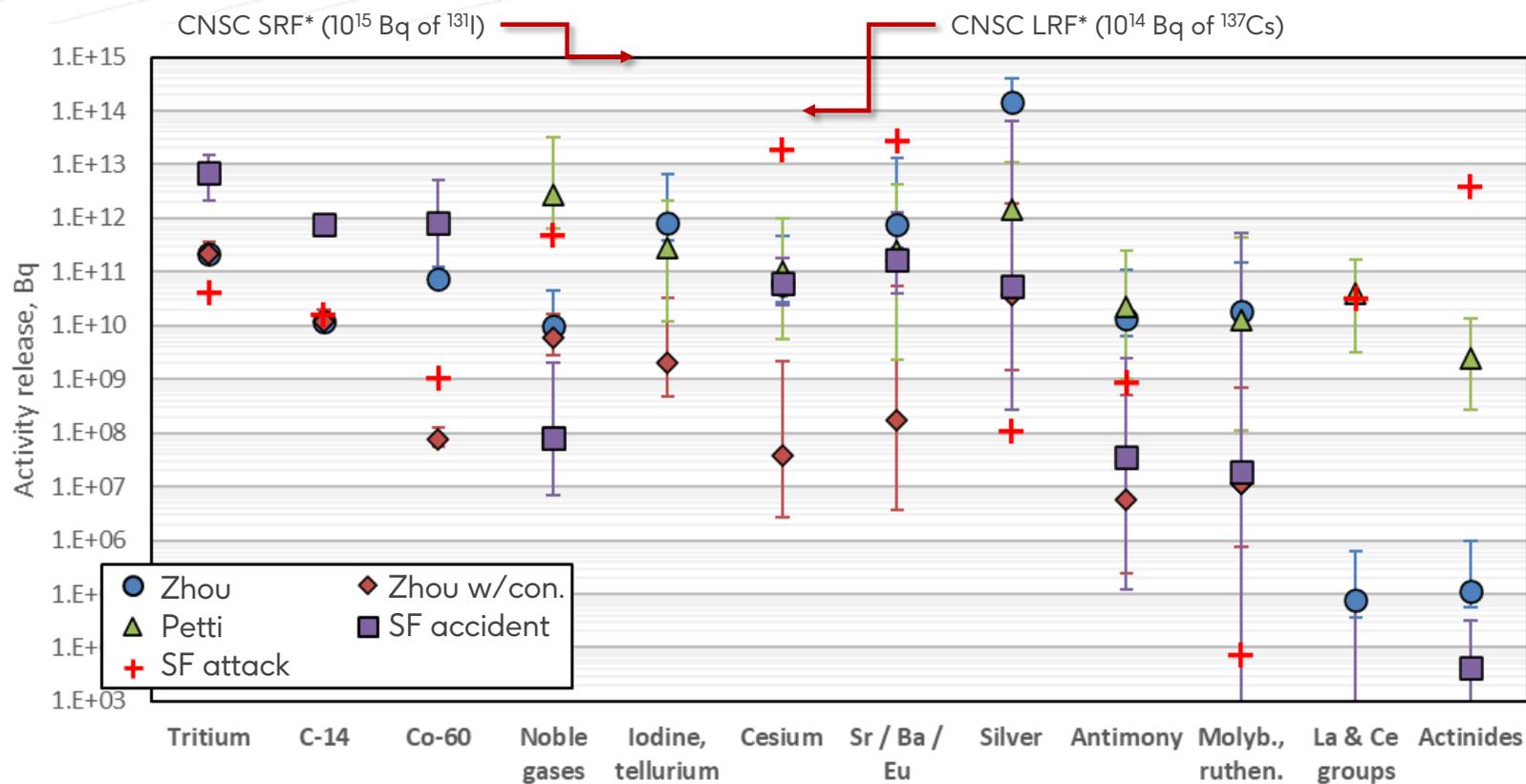


Figure: Summary of radionuclide release in screening scenarios.

Early Phase Dose Consequences to the Public

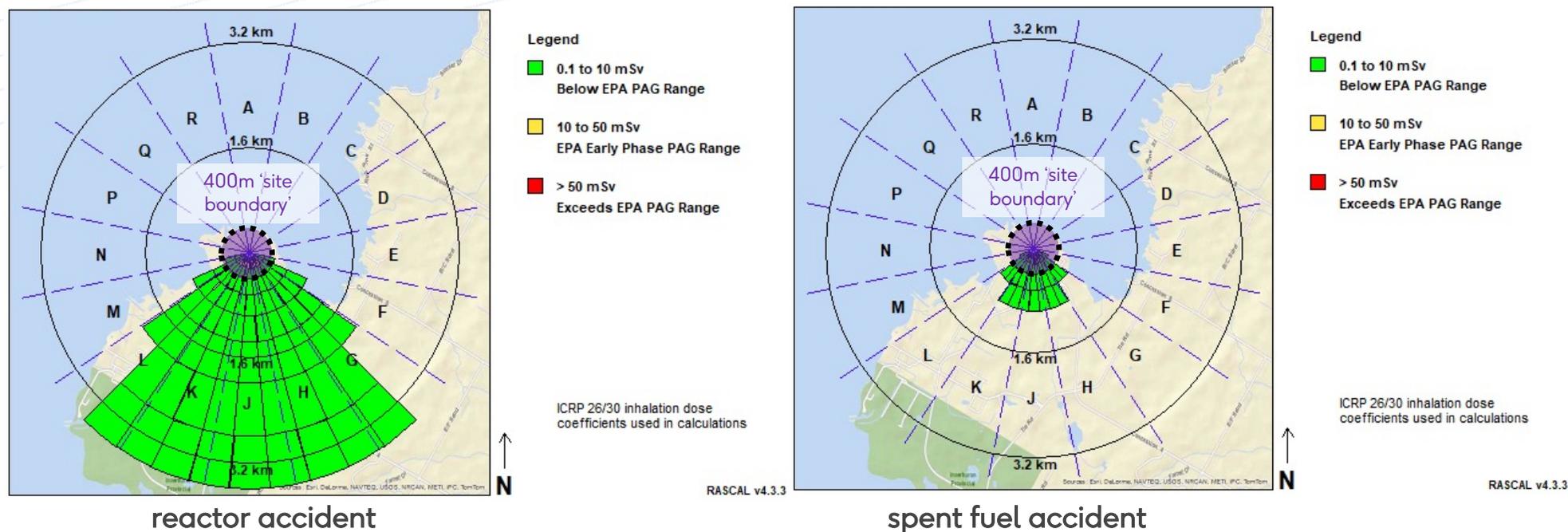


Figure: RASCAL dose consequence calculations of screening scenarios.

- Exceeding protective action guidelines (100 mSv evacuation, 10 mSv sheltering) unlikely for accident scenarios.

Long Term (1st year) Dose Consequences to the Public

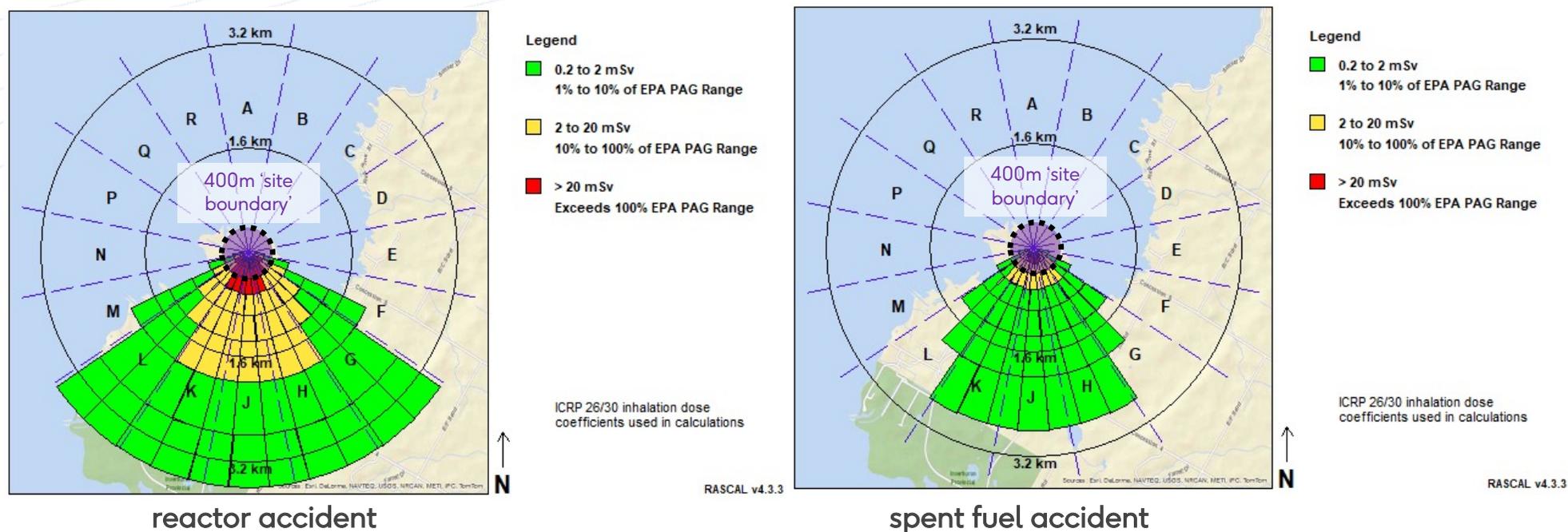


Figure: RASCAL dose consequence calculations of screening scenarios.

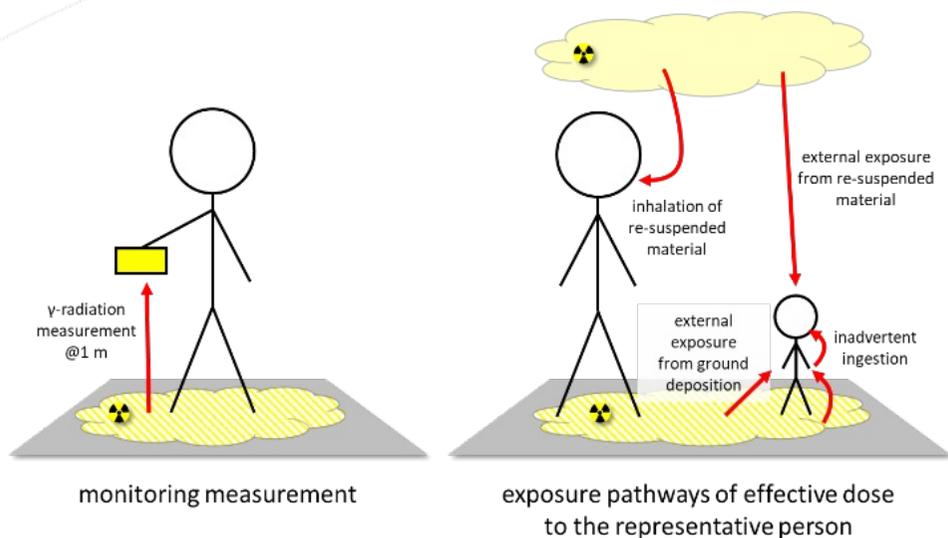
- Exceeding longer-term protective action guidelines (100 mSv relocation, 1-10 mSv food restrictions) possible.
- While **Urgent EPR** can be justifiably reduced, **Recovery Phase EPR** may still be necessary; fewer urgent time constraints allow for a more *reactive* paradigm within the contingency and ingestion planning zones.

Operational Intervention Levels as Primary Trigger



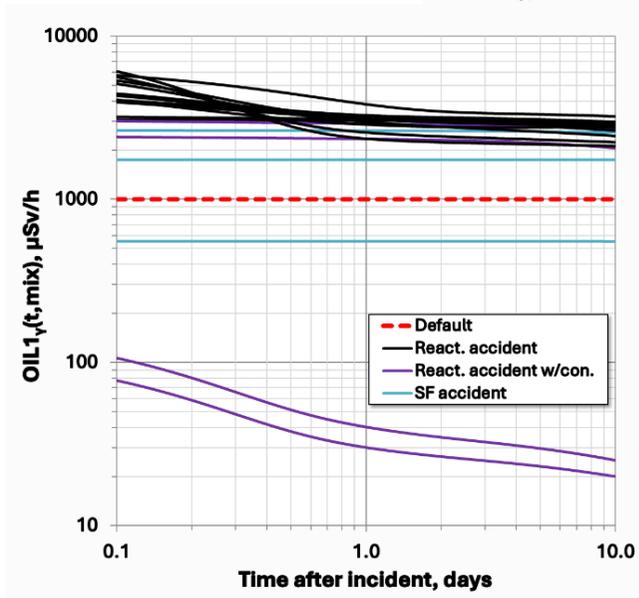
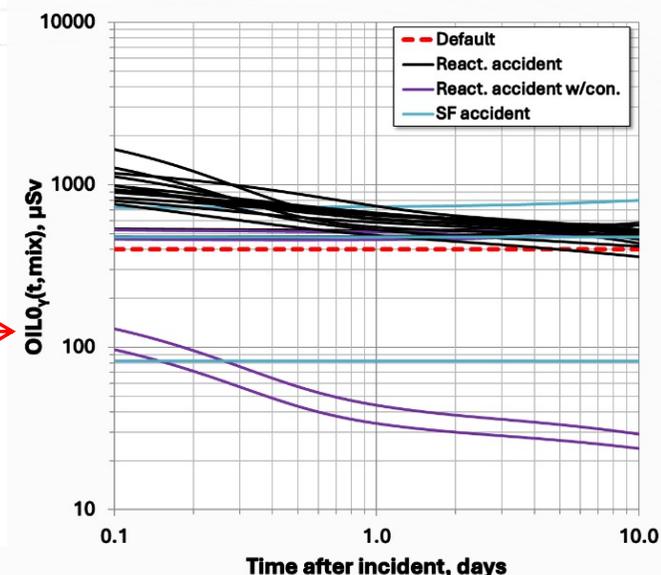
OIL_{0y} and OIL_{1y} for Triggering the Evacuation/Sheltering

Urgent Protective Actions



Monitoring measurement and exposure pathways for the ground contamination scenario for OIL_{1y}.

New! →

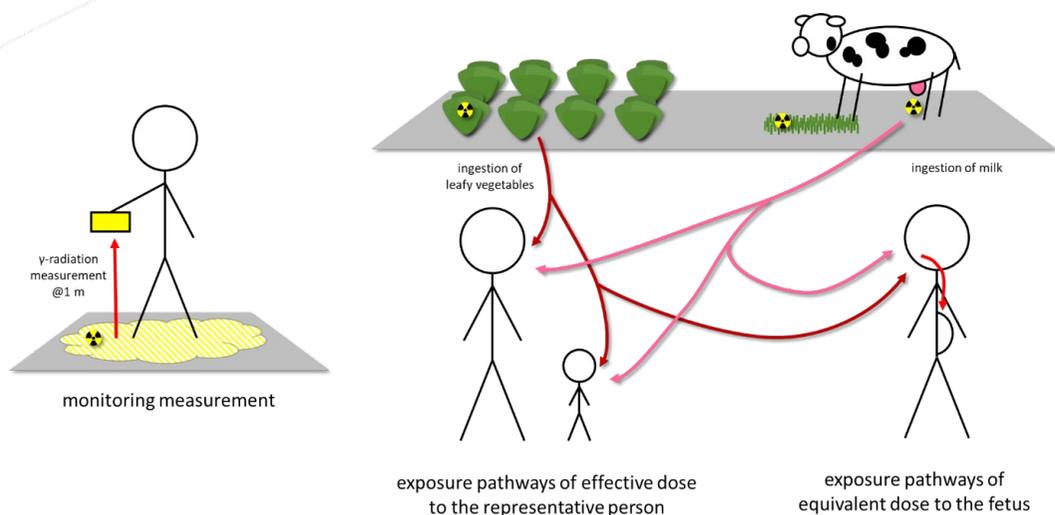


OIL_{0y} values (evacuation due to initial plume passage).

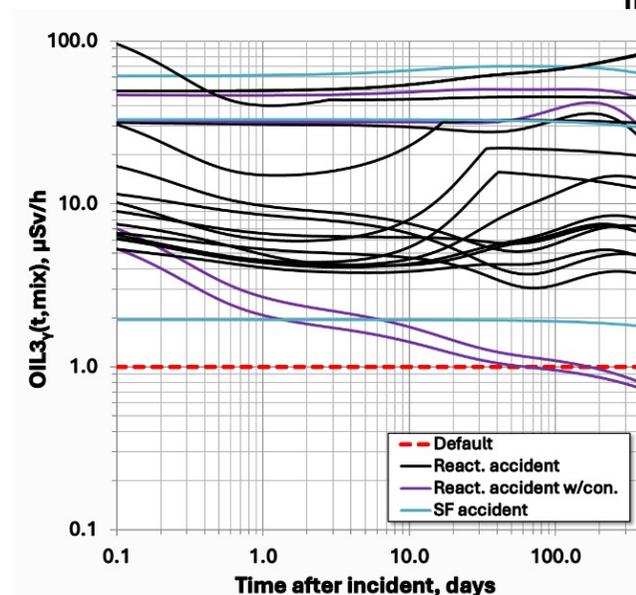
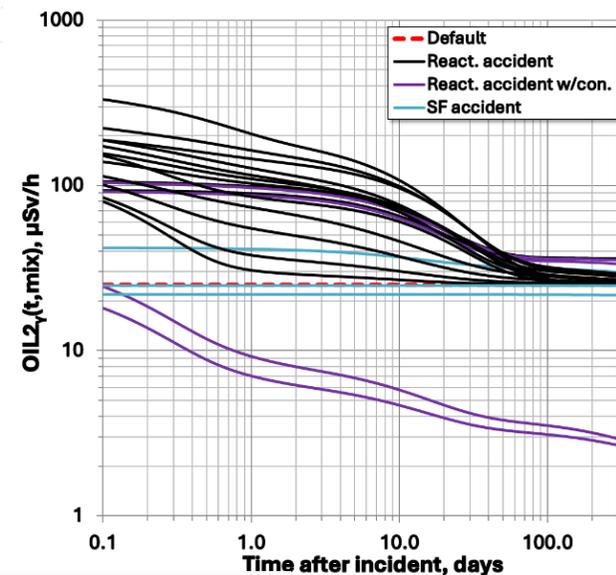
OIL_{1y} values (evacuation due to post-accident contamination).

OIL_{2γ} and OIL_{3γ} for Triggering Relocation and Food Restrictions

Early Protective Actions



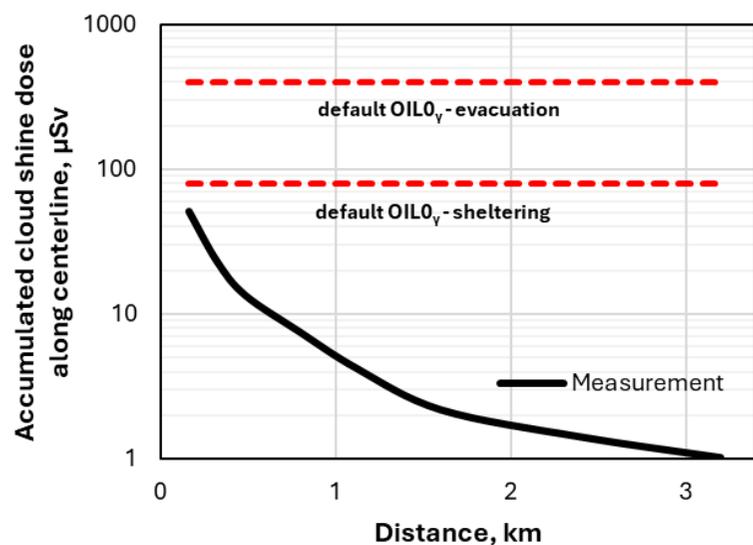
Monitoring measurement and exposure pathways for the food pre-analysis scenario for OIL_{3γ}.



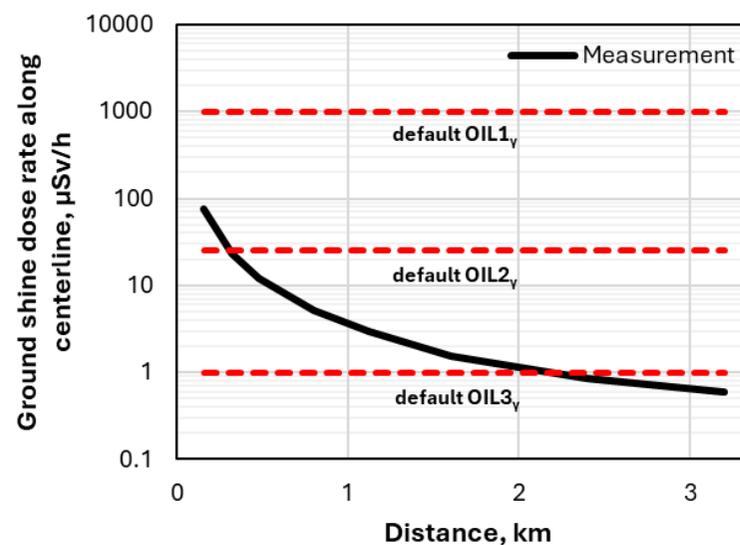
OIL_{2γ} values (relocation due to long-term contamination).

OIL_{3γ} values (food restrictions due to long-term contamination).

Projected Triggers of OIL Values



Projected centerline cloud shine measurements from the initial plume passage, as compared to the sheltering and evacuation triggers using OIL_{0v}.



Projected centerline post-accident ground shine measurements, as compared to the triggers for evacuation (OIL_{1v}), relocation (OIL_{2v}), and food restrictions (OIL_{3v}).

Conclusion

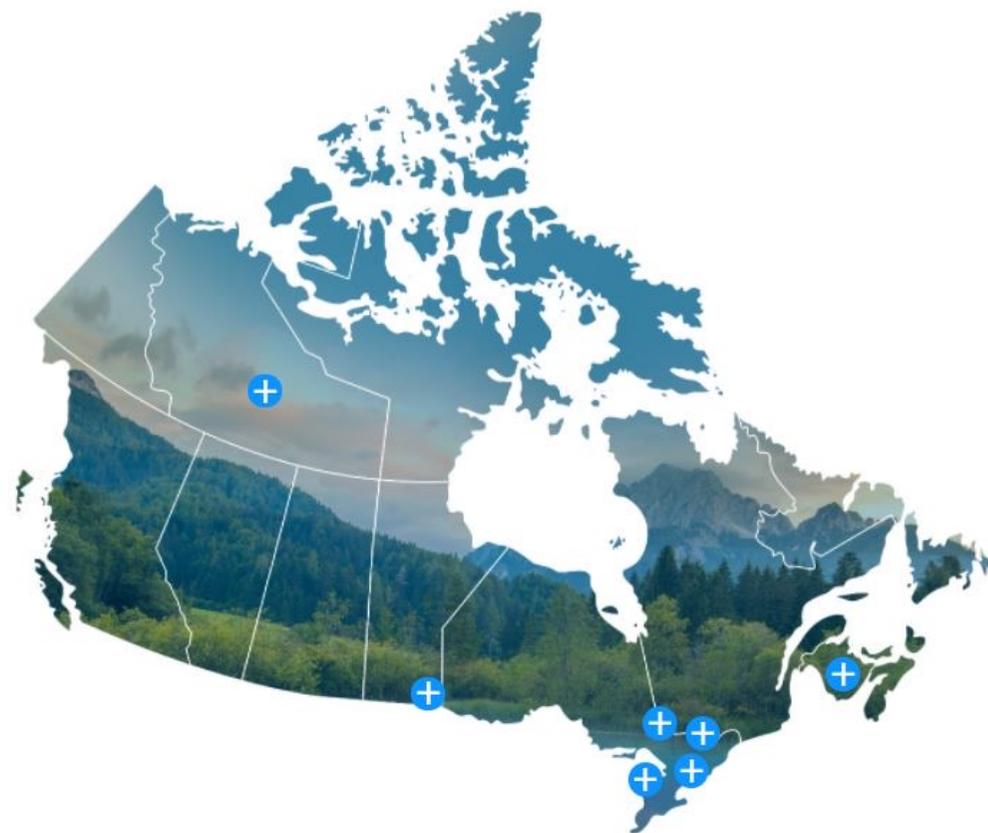
- Safety standards (e.g., IAEA GSR Part 7) allow for a graded approach. An alternative framework needed that allows the 5th level of defence-in-depth to be maintained in a way that is commensurate with the risk.
- Risk profile may allow for 'Site Boundary' EPZ framework, as demonstrated with HTGR case study.
- If the safety analysis can justify, there are only contingency and ingestion planning zones outside of site boundary, with response actions triggered by measurements.
 - Opens possibility for i) fewer on-site resources ii) centralized response supported by automated monitoring, iii) assessment procedures, iv) elimination of ITB. Most other requirements would stay in place (notification & interfaces, public communication, training & validation, etc.).



Thank you



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References: [1] IAEA GSR Part 7 (2015); [2] IAEA EPR-PPA (2013); [3] L. Lebel et al. "Beyond EPZs: nuclear emergency management frameworks when using site boundary emergency planning zones, with a case study on high temperature gas reactors", *Annals. Nuc.Eng.*, 2026; [4] IAEA EPR-NPP-OILs (2017); [5] F. Zhou et al. "Simulation of DLOFC Accident in a Generic Pebble Bed High-Temperature Gas-Cooled Reactor using MELCOR," *G4SR-5*, 2024; [6] D. Petti et al. "Representative source terms and the influence of reactor attributes on functional containment in modular high-temperature gas-cooled reactors," *Nuc. Tech.*, 2013.