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Emergency Planning Zones for Small Modular Reactors

Marti Jeltsov
KBFI Nuclear Science and Engineering
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Scope

- Why EPZ?
- On EPZ and radiation protection regulation
  - International (IAEA, Euratom)
  - National (US, UK, Can, Est)
- Typical SMR features
- EPZ for the reviewed SMR designs
- TVA Early Site Permit example
- Conclusions

Why is EPZ required in the first place?

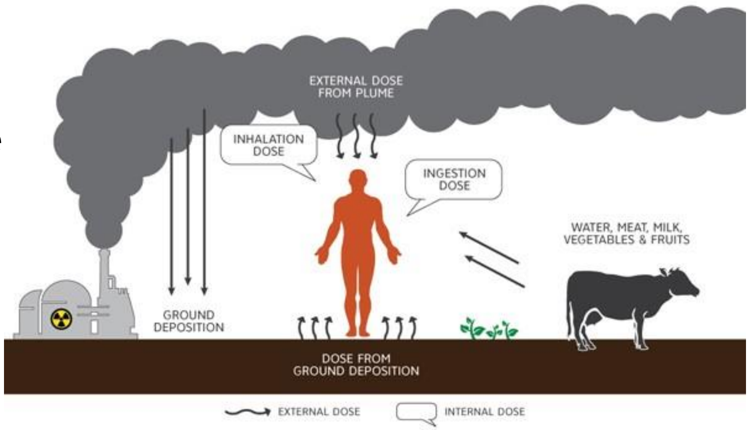
- The goal of emergency preparedness and response (EPR) is to be adequately ready for effective protection of the people and environment

- Emergency Planning Zones (EPZs) are an important element of effective EPR in case of nuclear emergency allowing to act gradually in time and space (divide-and-conquer)

- EPZs allow to pre-define the protective actions to mitigate the most likely consequences of a radiation emergency

What is EPZ?

- Zones around a nuclear reactor that are prepared to respond to an emergency.
  - Shorter-term plume exposure pathway
  - Longer-term ingestion exposure pathway



- EPZs depend on:
  - **Technology** (source term, safety systems)
  - Radiation protection regulation (generic dose criteria, EALs, OILs, ...)
  - Site (meteorology, topography, hydrology, ...)
  - Local considerations (infrastructure, population, public acceptance, ...)
  - Definition and determination methodology (prescriptive vs **risk-informed/performance-based**)

Site Evaluation	Plant Design	Postulated initiating event
Source term	Safety analyses	Infrastructure characteristic
Dose Criteria	Public and political policy	Offsite consequences

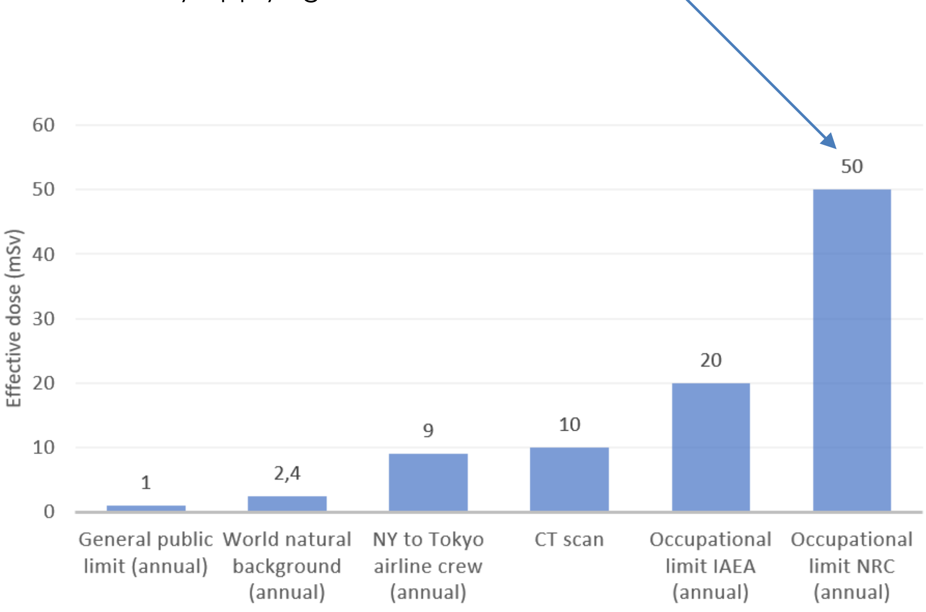
Radiation protection

- Based on ICRP
- IAEA = CNSC = EURATOM
  - Up to 50 mSv / year
  - Up to 100 mSv / 5 years

- Estonia's natural background levels are slightly higher than world average
  - Estonia ~3 mSv
  - Kerala Coast in India 12.5 mSv
  - Northern Iran 260 mSv

- Life-saving operation limits are higher (250 mSv in the US)

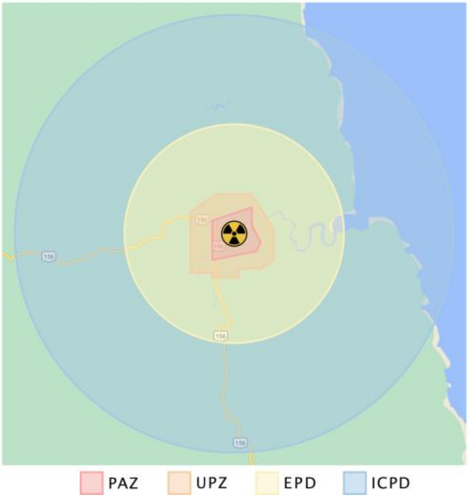
Reduction to 20 mSv was not required since average annual dose to occupational workers in 1987 was already below 20 mSv, ensured by applying the ALARA.

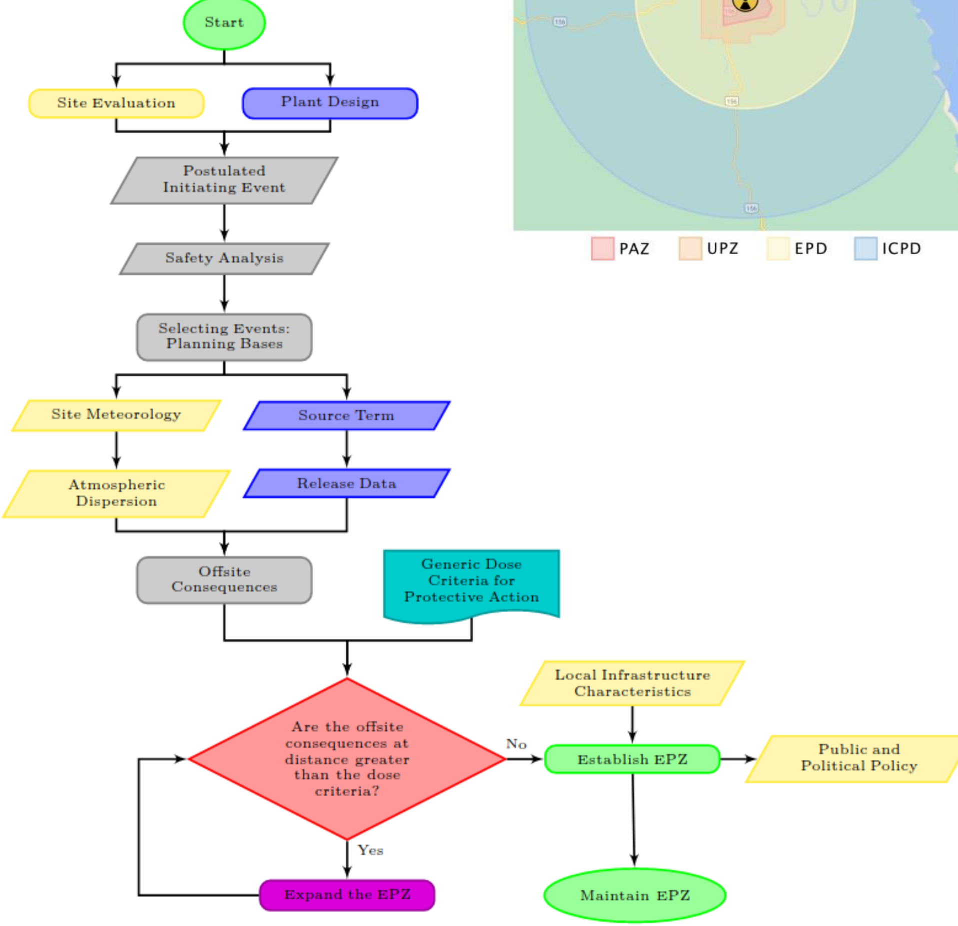


EPZ by IAEA

- 2 Emergency Planning Zones
  - Precautionary Action Zone (PAZ)
  - Urgent Protective action planning Zone (UPZ)
- 2 Emergency Planning Distances
  - Extended Planning Distance (EPD)
  - Ingestion and Commodities Planning Distance (ICPD)

- IAEA SMR Regulator's Forum found that the existing methodology is applicable to SMRs

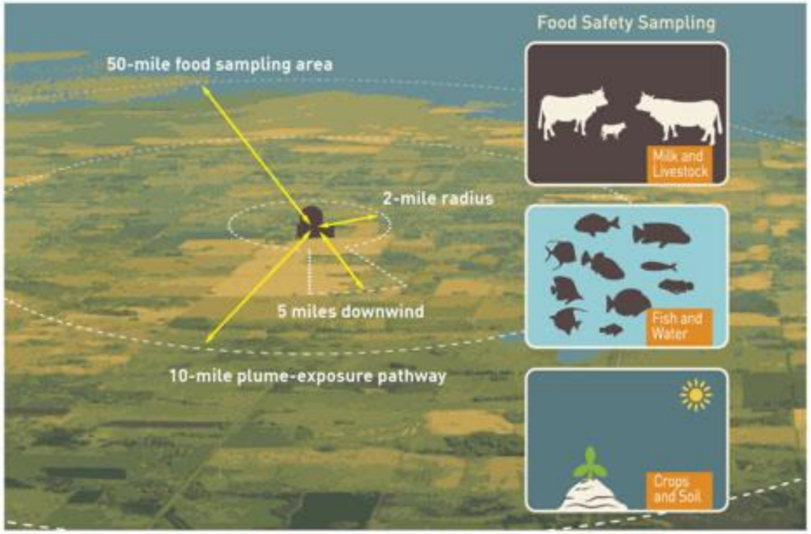




EPZ in US by NRC

- Current situation (from 1978) (prescriptive)
  - 10-mile plume exposure
  - 50-mile ingestion exposure
  - Case-by-case basis for gas reactors and for reactors with an authorized power level less than 250 MW thermal
  - Exemptions possible: TVA ESP
- New guidelines under review:
  - Performance-based (Mechanistic Source Term)
  - Technology-inclusive
  - Risk-informed
  - Consequence oriented
  - **Scalable Plume Exposure Pathway (TEDE threshold 10 mSv in 96 hrs)**
  - **If Plume Exposure Pathway within the site-boundary then no off-site REP mandated**
  - **No Ingestion Exposure Pathway EPZ required, just planning**

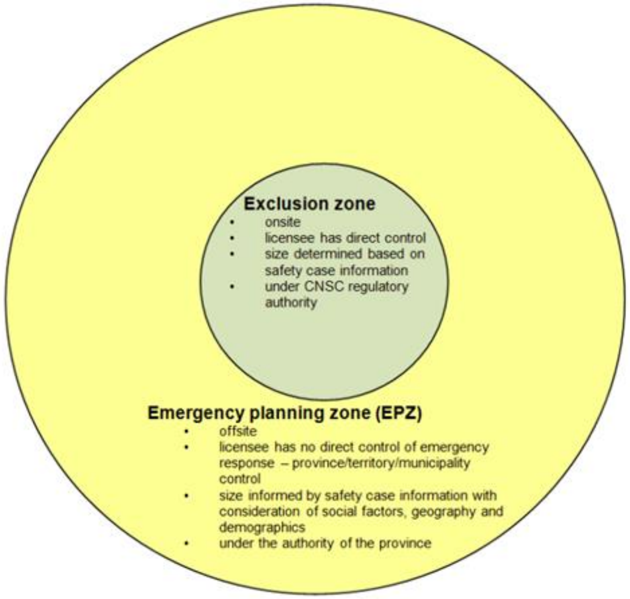
Emergency Planning Zones

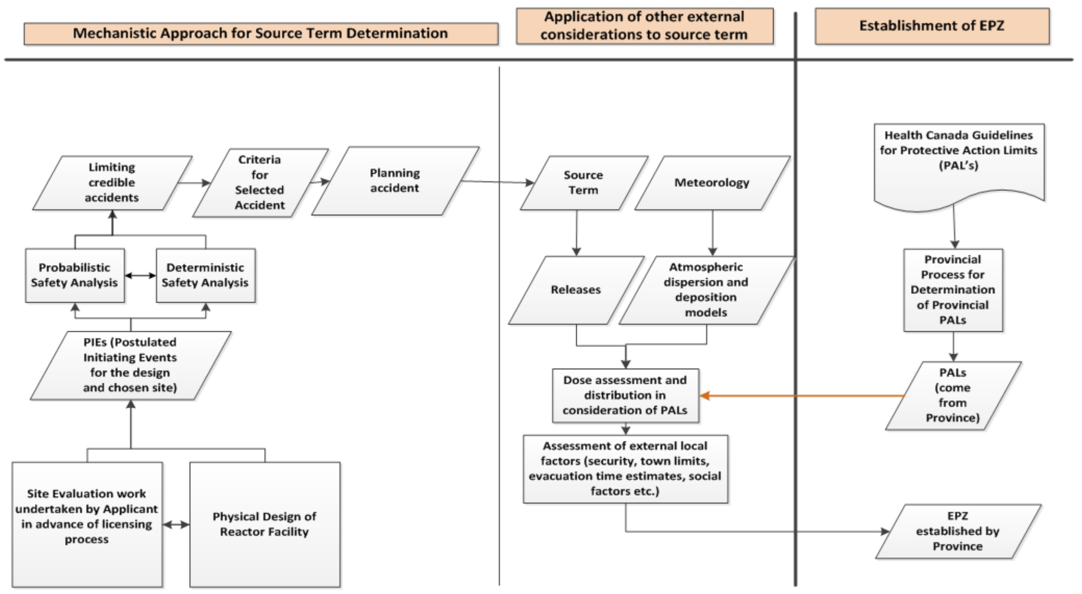


Note: A 2-mile ring around the plant is identified for evacuation, along with a 5-mile zone downwind of the projected release path.

EPZ in Canada by CNSC

- Exclusion Zone
  - Controlled by licensee
- Emergency Planning Zone
  - Protective actions planned for emergency
- Dimensions are case-specific
  - Based on risks associated with the technology
  - Collaboration between CNSC, Provinces, Healt Canada Applicants/Licensees

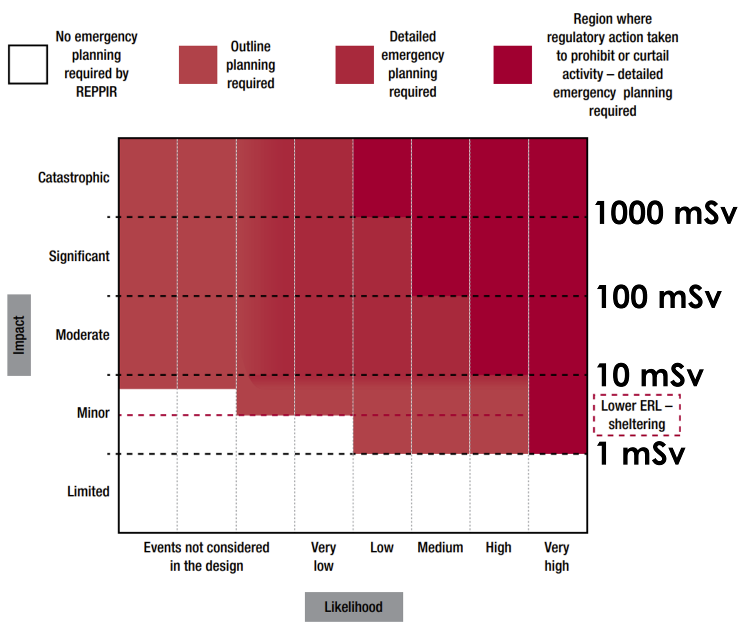




EPZ in UK by ONR

- DEPZ (Detailed Emergency Planning Zone)
  - Extendibility: in certain circumstances DEPZ can be extended
- OPZ (Outline Planning Zone)
  - Default 30 km for nuclear reactors

- Dimensions are site-specific



6-7 km zone around Sellafield

Typical SMR features

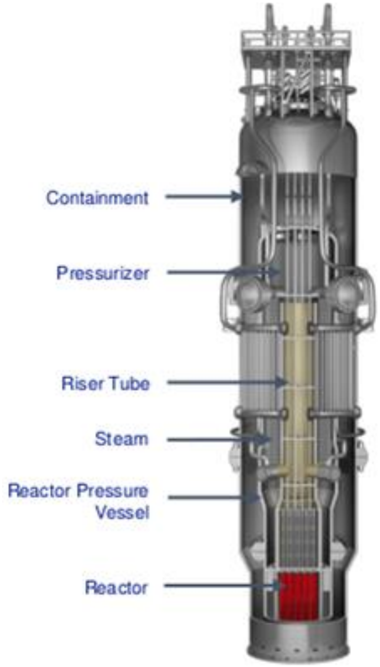
- **Small reactors and low power levels**. Reduced amount of radioactive material for potential releases to the environment. Reduced time response to an accident due to larger water inventory to power ratio. Reduced distances at which doses exceed accepted criteria.
- **No large LOCA**. Elimination of SRVs and use of RPV Isolation Valves (LWRs).
- **Passive operational and safety features**. Improved economics due to less components. Higher reliability of systems allow for extended "grace period" (no operator action) and "coping times" (time before depletion of onsite resources)
- **Modularity and multiple module facilities**. Source term is divided into smaller parts containing only a fraction of fuel compared to a large unit while still having a full set of safety systems in each module. Reduced risk of large offsite releases.
- **Improved containment functions**. With compact, high-pressure resistant, multi-wall, below grade and water-immersed containment structures potential offsite consequences of SMRs will be lower.
- **Separate operating and maintenance facilities**. This pertains to SMRs without on-site refuelling in which case the renewal of fuel (or whole reactor units) will take place in a dedicated facility.

SMR designs reviewed

Parameter	Reactor				
	BWRX-300	**NuScale**	**IMSR**	**MMR**	**UK SMR**
Developer	GE-Hitachi Nuclear Energy	NuScale Power ILLC	Terrestrial Energy Inc	Ultra Safe Nuclear Corporation	Rolls Royce
Thermal power (MW)	870	200	400	10	1300
Safety systems	Hybrid (passive + active)	Passive	Passive	Hybrid (passive + active)	Hybrid (passive + active)
Source term	Conservative appr: scaled large BWR	Conservative appr: scaled large PWR	Molten fuel, only noble gases released	Robust PRISM	Conservative appr: scaled large PWR
EPZ claim (m)	1000 (site boundary)	500 (site boundary)	< 500 (site boundary)	30/50	TBD

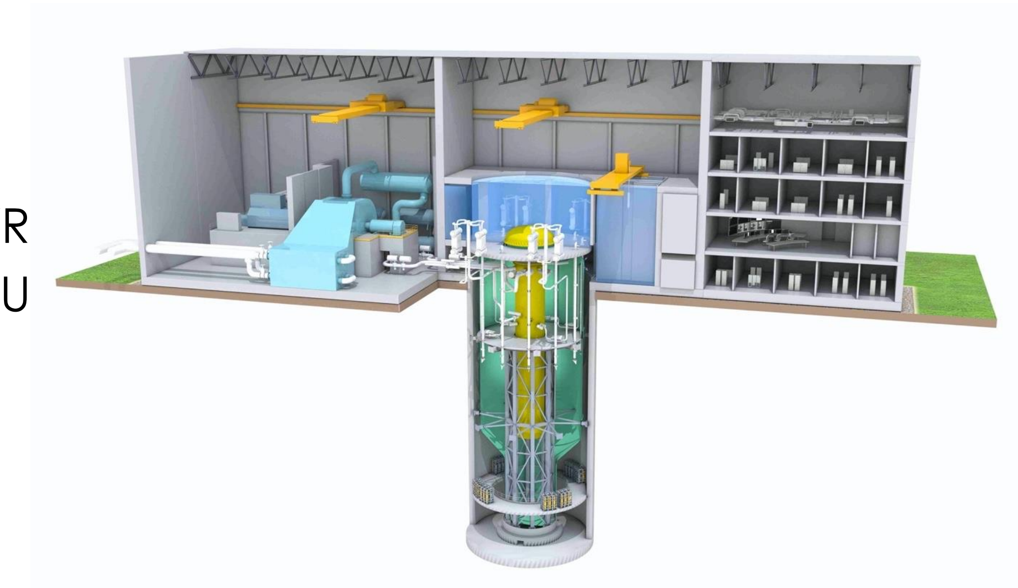
NuScale

- 50-77 MWe iPWR units
  - 4-12 unit plants
- Passive normal operation and safe systems
- Standard Design Approval by NRC in Sep 2020, pre-licensing in Can
- EPZ at 0.5 km / site-boundary due to
  - Simple design
  - Small source term
  - Multiple FP barriers
  - Independent modules

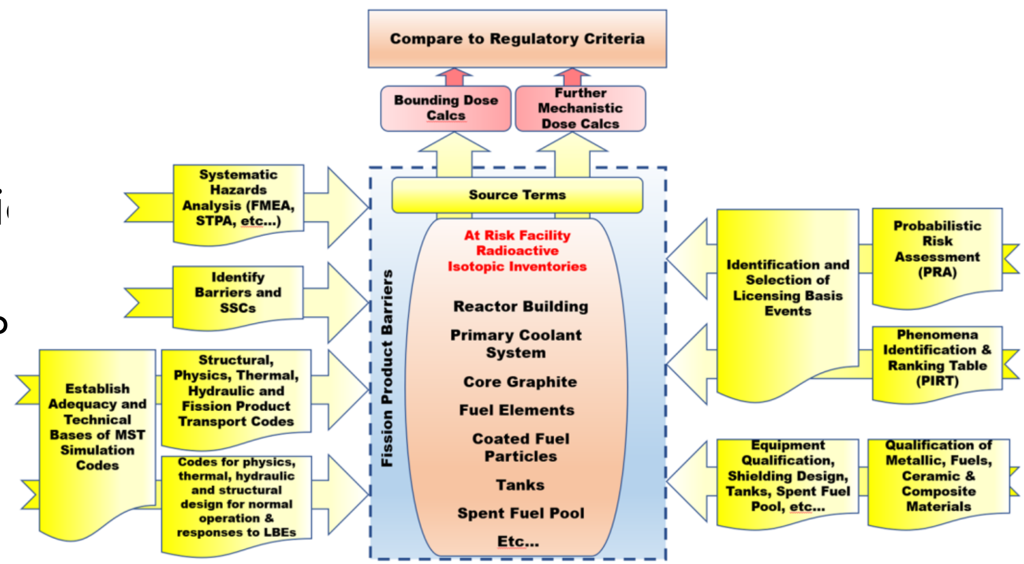


BWRX-300

- 300 MWe version of certified ESBWR
- Licensing through LTRs ongoing in U
  VDR in Canada
- Passive safety based on
  - Inherent margins (large structures, H2 volumes)
  - Passive Safety Class 1 systems



- Planning to use less conservative Mechanistic Source Term evaluati
  approach
- EPZs similar to TVA Clinch River ESP

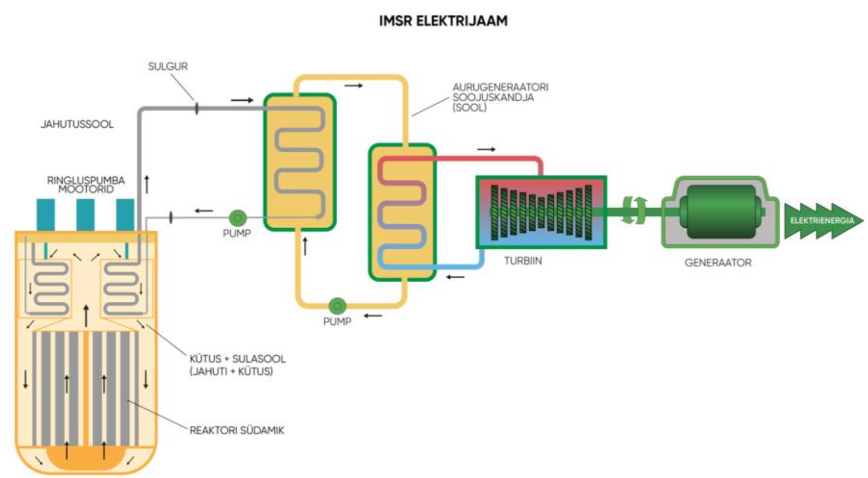


IMSR

- 195 MWe Molten Salt Reactor
- 7-year operating time
- Safety case based on molten salt fuel+coolant
  - Good thermal properties
  - Good retention properties
- Pre-licensing activities in US and Can

- Source term considers only noble gases, the rest bound by the salt

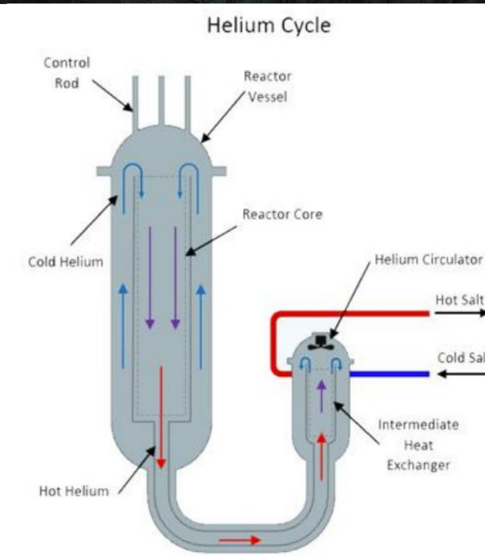
- Target EAB is site boundary
- Preliminary conservative SA show that the most bounding DBA results in a one order of magnitude lower dose than the regulatory limit at 200 metres



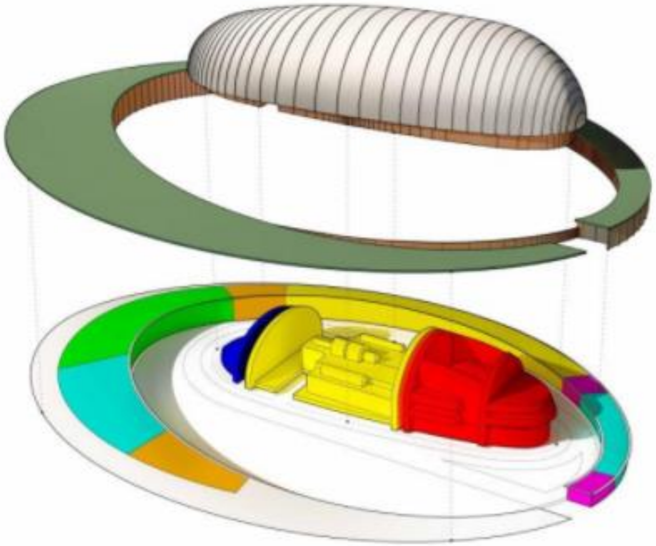
MMR

- Gen IV 15/30 MWth HTGR
- VDR, licensing in Canada
- Strong safety case around low power density and TRISO fuel
- 10/20 year refuelling cycle

- Exclusion boundary EPZ estimated to be 30 m from the RB
  - To be demonstrated with safety analysis
- No off-site evacuation or sheltering needed



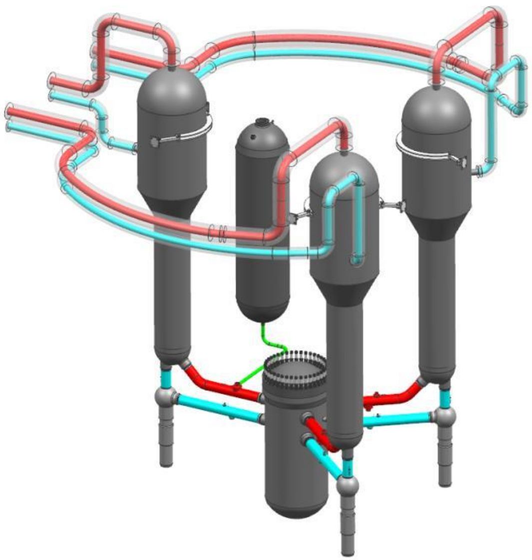
UK SMR



- 400-450 MWe PWR
- Conceptual design phase proceeding to GDA then licensing in UK
- Passive safety systems

- Only initial BE and DB source term has been derived (scaling OPEX data)

- No work has been done to estimate EPZ
  - Waiting for the response from IAEA SMR Regulator's Forum



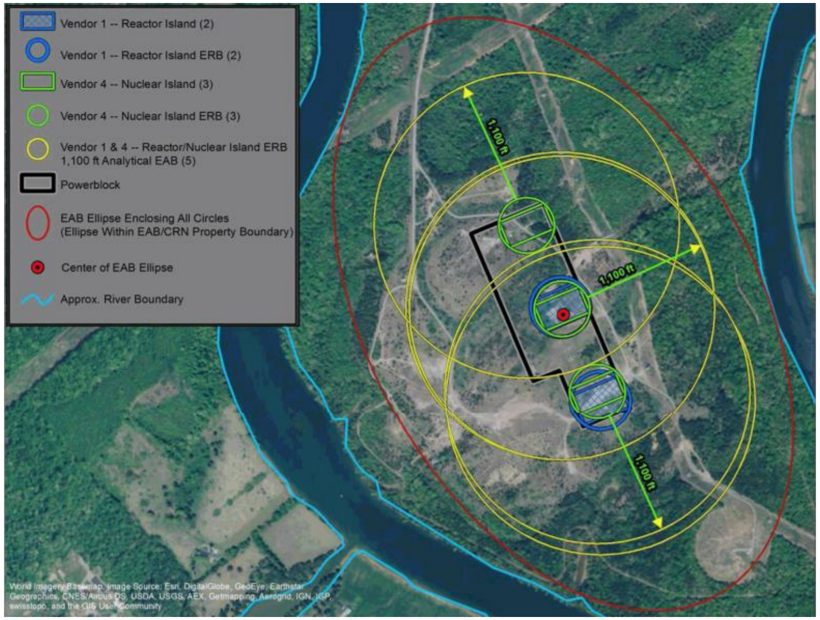
Tennessee Valley Authority (TVA) Early-Site Permit

- PPE of 4 conceptual LWR SMRs
    - mPower, NuScale, SMR-160, Westinghouse SMR
  - – passively safe with minimal or no reliance on offsite power, offsite water, or operator action for safety

- Surrogate source term
  - – Maximum 4-day total release per isotope + 25+% margin

- Exemptions requested to deviate from 10-mile PEP

- 2 EPZs confirmed (TEDE < 10 mSv)
  - – Site boundary (1 SMR meets the criteria)
  - – 2-mile radius (all 4 SMRs meet the criteria)
- No need for pre-planned off-site radiological emergency preparedness
  - – 1.61 km Low Population Zone (LPZ)



Conclusions

- Current regulations do not consider the advancements of SMRs (while appropriate for LLRWs), especially in the US
- The ongoing trend is to apply risk-informed, performance-based scalable EPZ calculation methods
  - Potential for future standardised approach for advanced SMRs (LWRs and other) as current prescriptive approach for LLRWs
- Based on scientific evidence (i.e. technology side), site-bounded EPZ claims are realistic.
  - Final answer will, however, depend on the local conditions.