Radioactive Waste Management

Developing understanding of disposability of heat generating spent fuels:

Key challenges & possible compliance needs

IGD-TP EF7 - Working Group 4 ‘Spent Fuel Characterisation’

Robert Winsley & Cristiano Padovani

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Overview

- UK inventory of high heat generating waste
- UK thermal dimensioning capability
  - Example application to support and optimise GDF designs and our operational schedule
- UK capability to understand likelihood and consequences of post-closure criticality
  - Example application to demonstrate low likelihood of post-closure criticality
- Brief mention of our UK consequence of criticality modelling capability
- Possible compliance requirements/needs to underpin SF disposal

Inventory

UK inventory of high heat generating waste (HHGW) includes:

- vitrified High Level Waste from SF reprocessing
- Advanced Gas cooled Reactor (AGR) SF that is not reprocessed
- SF from Sizewell B **(PWR SF)**
- New build SF from potential UK new build programme (**NNB SF)**
- “Exotic” fuels (includes fuels from research and defence activities)
- Magnox SF (if not reprocessed)
- mixed-oxide **(MOX SF)** (from potential future re-use of UK plutonium)

- UK GDF programme not yet site specific, research therefore considers waste disposed of in three illustrative host rocks: Higher Strength Rock (HSR), Lower Strength Sedimentary Rock & Evaporite

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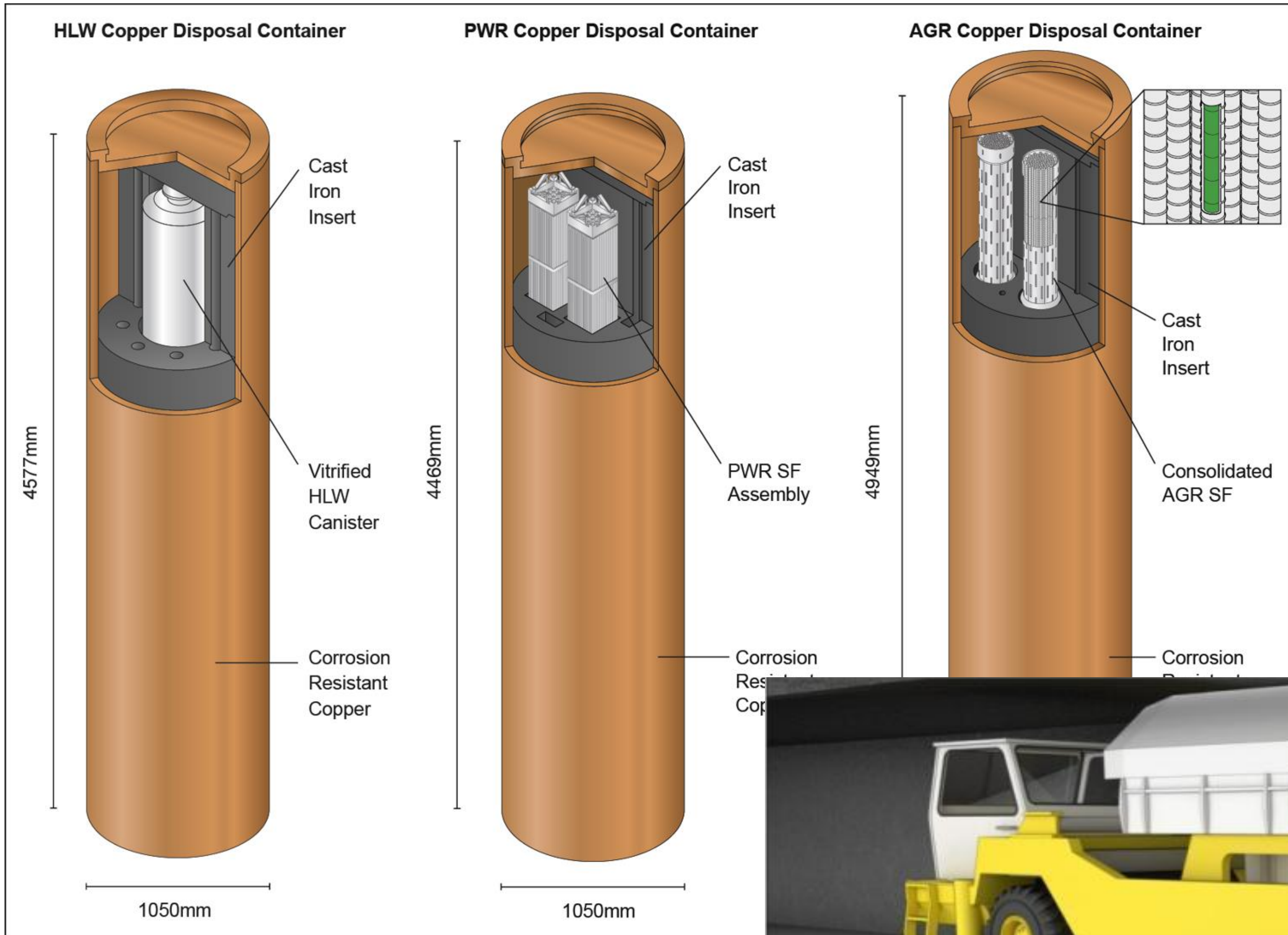
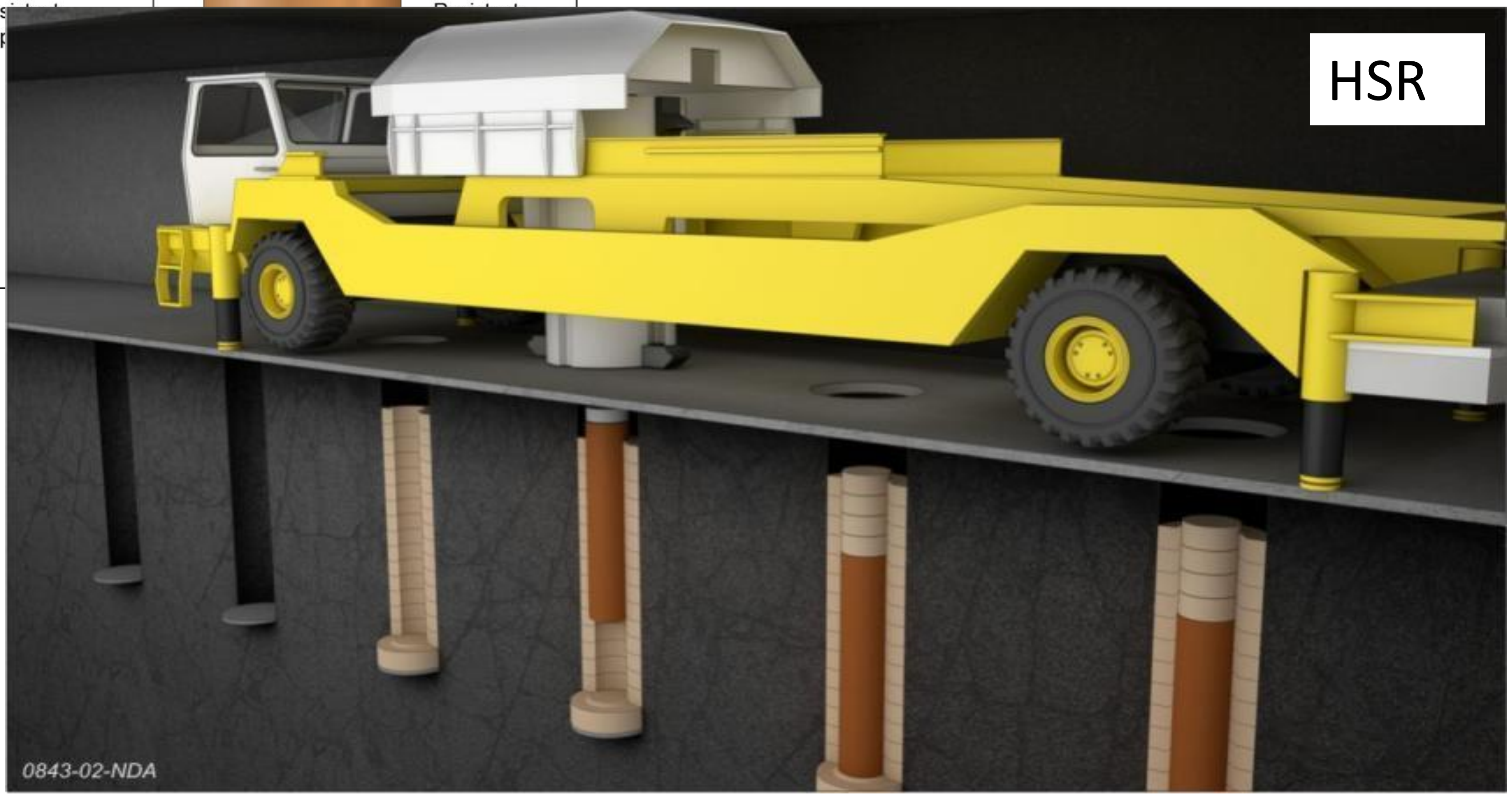
Focus on SF disposed of in HSR

SF disposal concept in HSR





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SF disposal challenges:

1. Thermal management
    - Conservative to assume all SF at maximum credible burnup
2. Demonstrating criticality safety
    - Conservative to assume that all fuel is ‘fresh fuel’ or non irradiated

- Both of these ‘challenges’ likely yield compliance/GDF acceptance criteria
    - particularly if you want to optimise you facility or relax conservative assumptions

Thermal management

Thermal Dimensioning Tool (TDT)

RWM needed to be able to:

- Understand the influence of heat on engineered barrier systems for a range of generic disposal concepts being considered in the UK
- Advise waste producers of any thermal constraints that may impact on the packaging of these wastes

Thermal Dimensioning Tool (TDT) has been developed to:

- perform thermal dimensioning for a range of HHGW disposal concepts
- use analytical/semi–analytical expressions to solve relevant heat conduction problem when allied to simple geometrical configurations of the waste (fast and easy to use)
- complement (and validated by) more detailed models

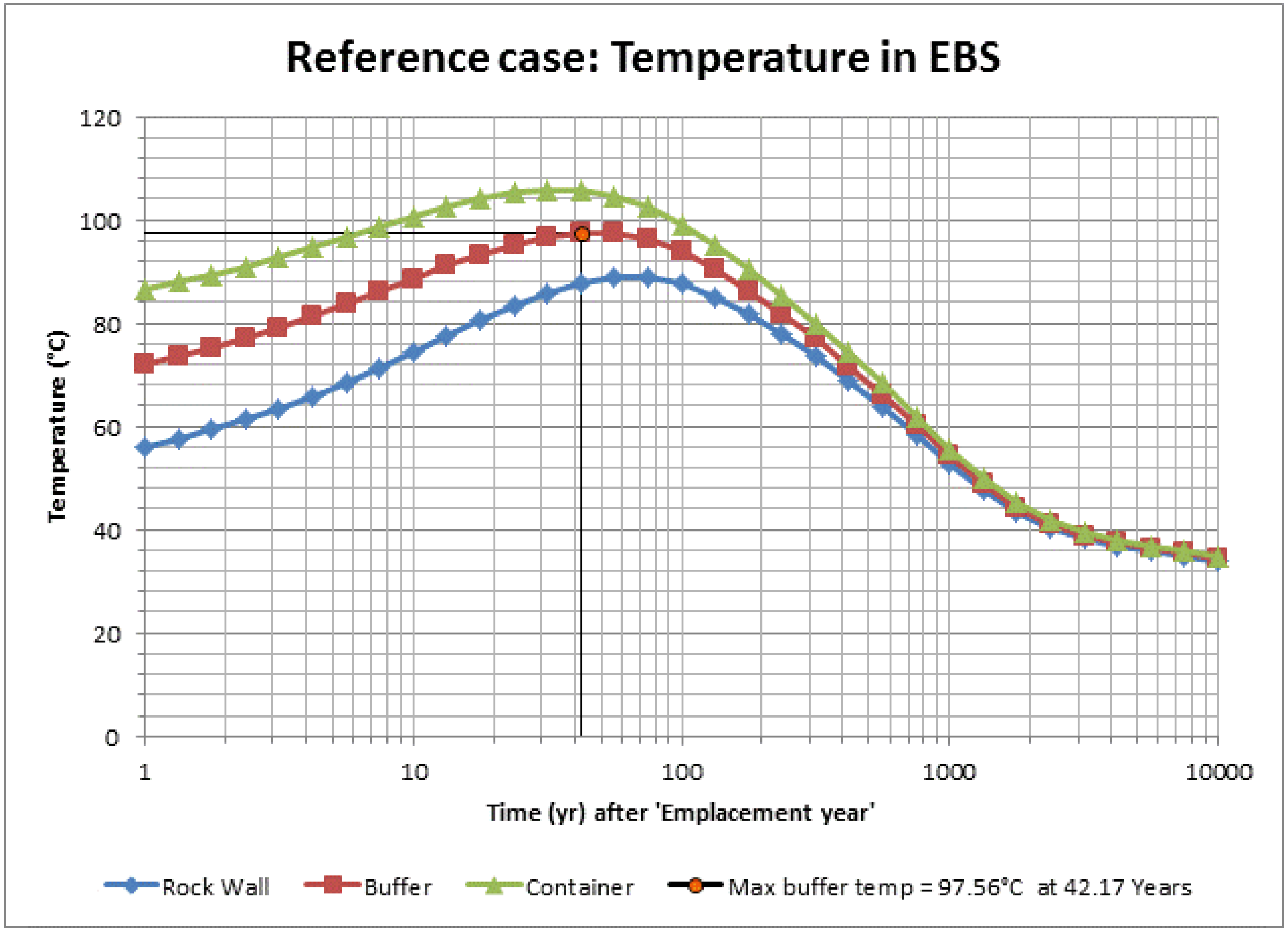
Inputs required for thermal dimensioning

- **disposal concept**
  - arrangement
  - buffer material
- **disposal container geometry**
  - inventory
  - decay storage and heat output
- **host rock type**
  - thermal conductivity and Specific Heat Capacity
  - spacing of deposition tunnels and disposal containers within tunnels
  - repository depth

Example output of TDT:
PWR SF in higher strength rock

Disposal container spacing at 6.5m centres and 25m tunnel spacing

Gives a buffer temperature of <100°C for legacy PWR SF



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TDT support for higher strength rock designs

500m long disposal tunnels

with 25m tunnel spacings

- 6.5m container spacings for legacy PWR SF
- Needs to increase to 9.5m container spacings for MOX and NNB SF
- based on a 100^{O}C buffer temperature limit

TDT peak temperature and time

	Legacy HHGW **PWR emplaced at 2080**	**MOX** **Emplaced at 2131**	**NNB SF** **Emplaced at 2145**
Higher strength rock	94˚C @56 years	100˚C @237 years	91˚C @100 years
	4x PWR SF assemblies per disposal container at 55GWd/tU	1x MOX SF assembly per disposal container at 50GWd/tU (initially 8% Pu)	3x UK EPR or AP1000 SF assemblies per disposal container at 65GWd/tU

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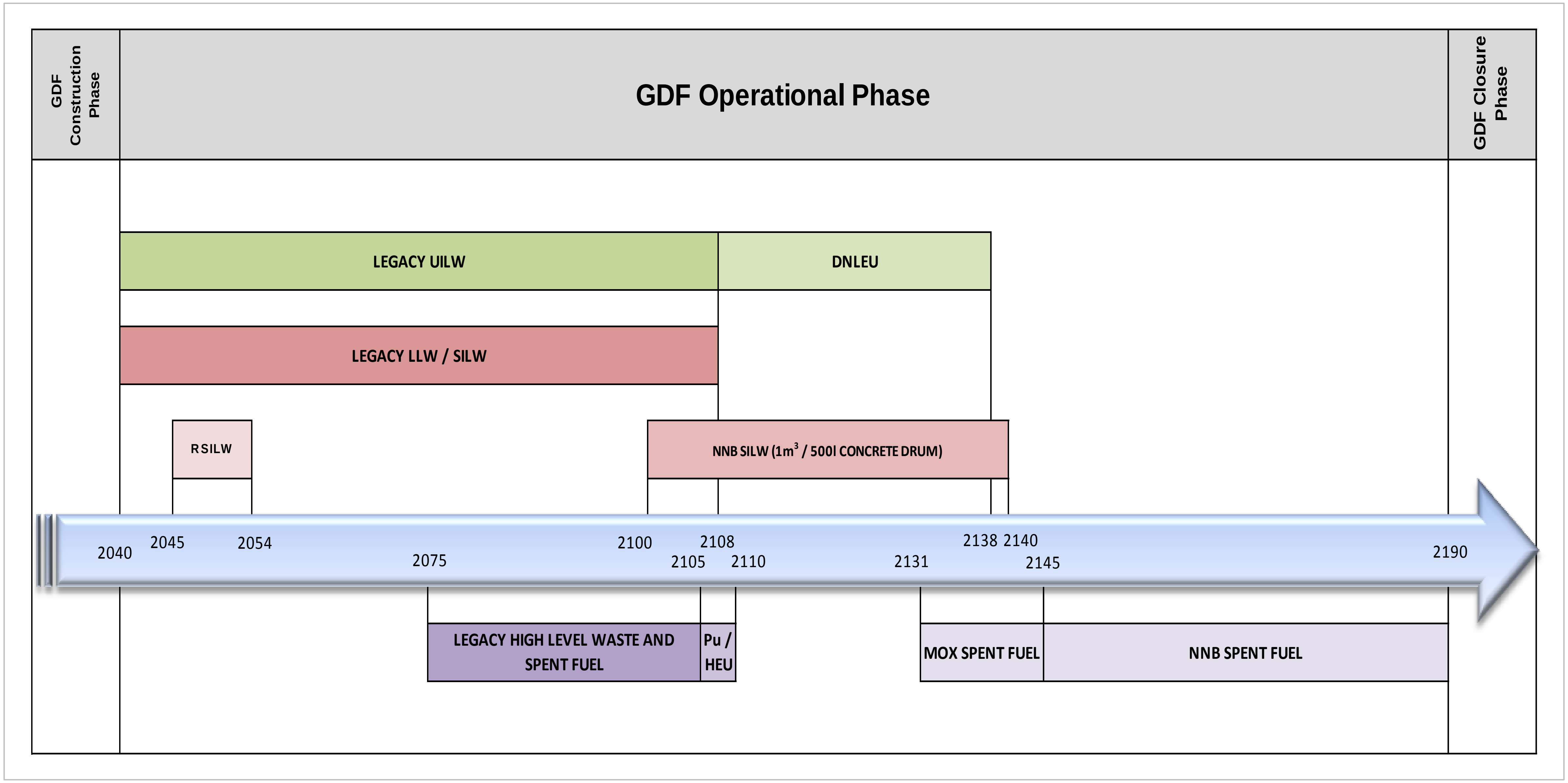
TDT to inform waste emplacement timings



These are indicative timescales and may be subject to change

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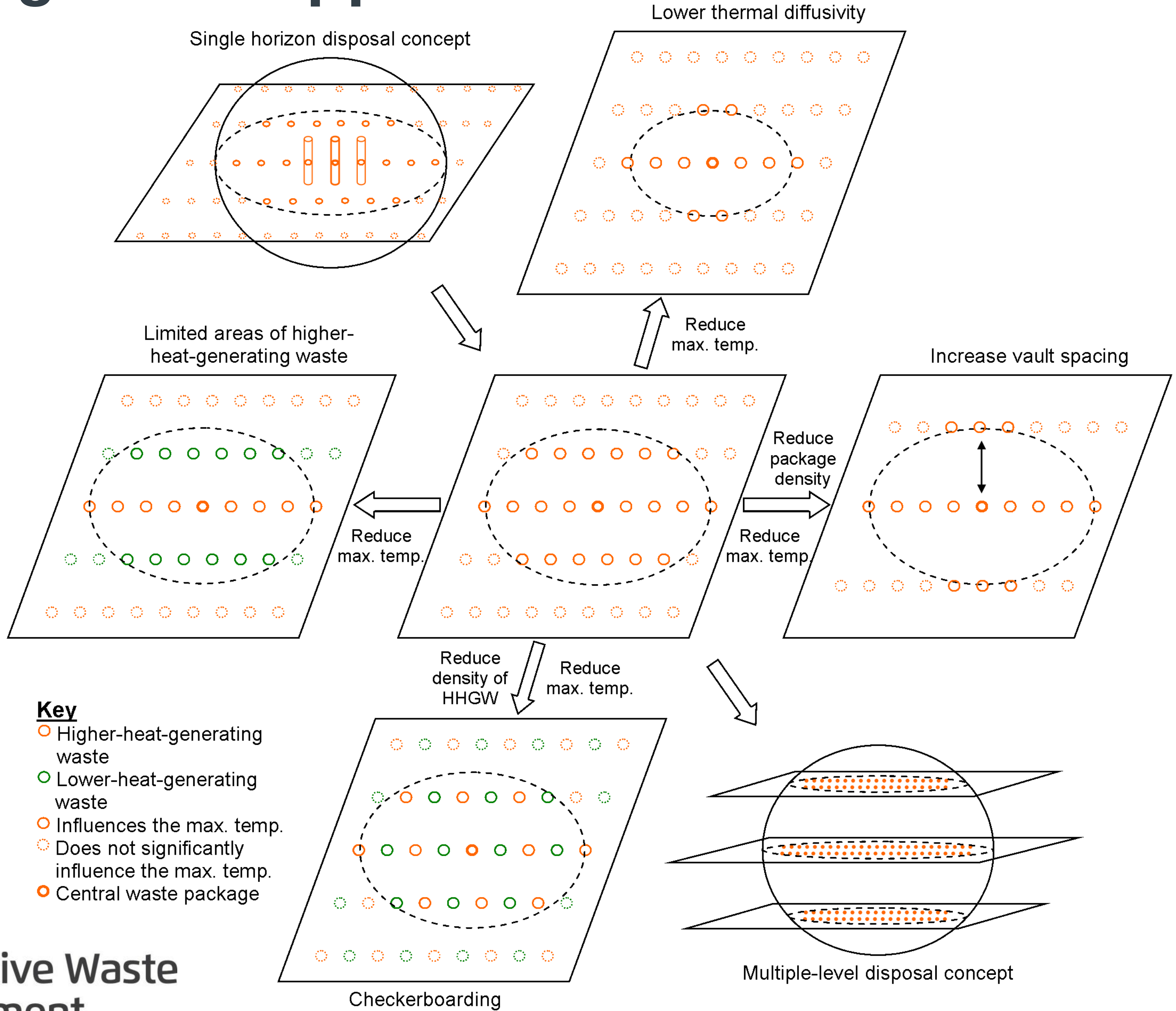
TDT to develop an overall thermal management approach



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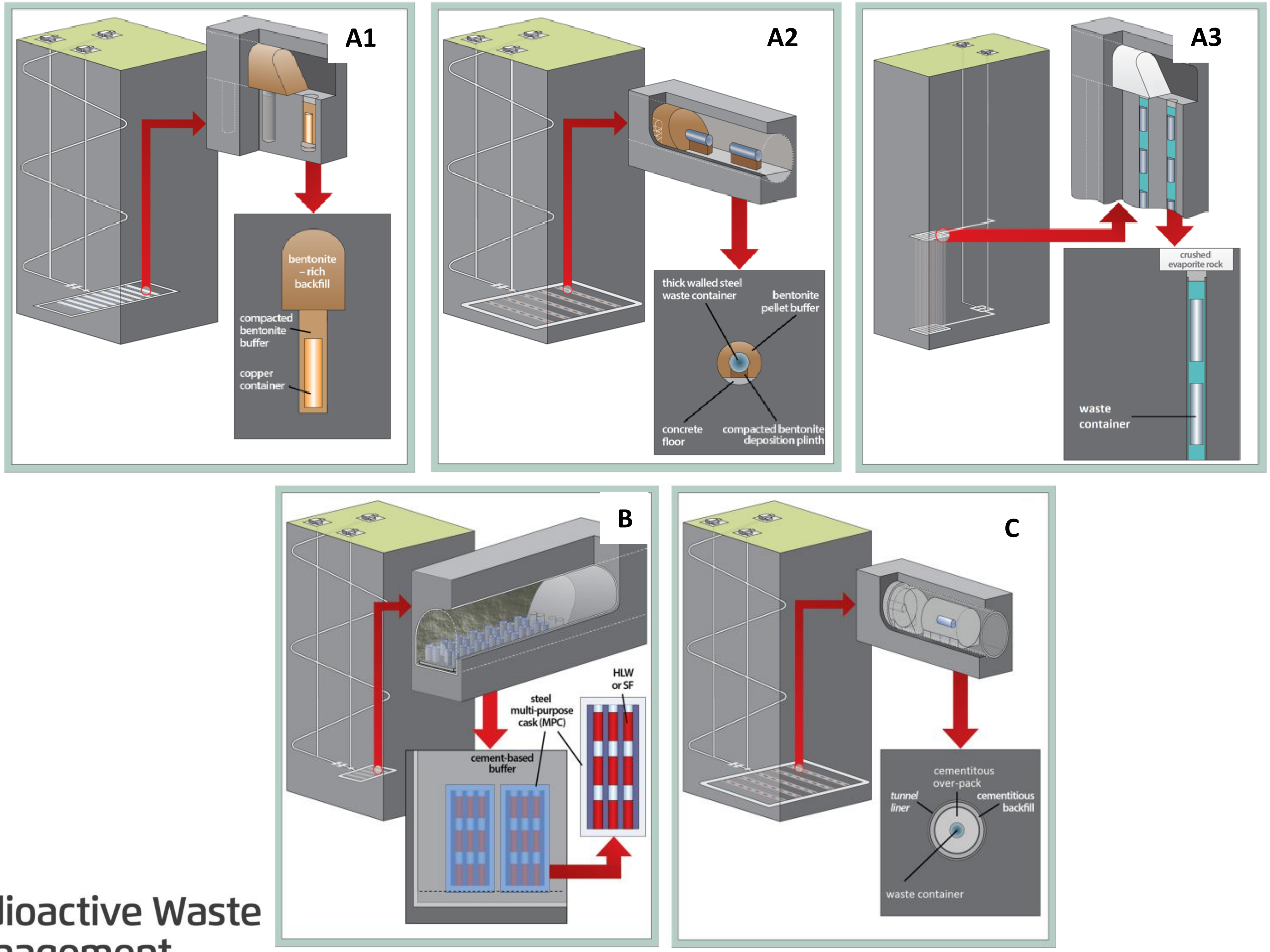
Also applied the capability to alternative disposal concepts



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Criticality safety

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GDF evolution and the possible development of critical systems

- The GDF will include disposal of sufficient fissile material that could hypothetically under certain conditions lead to a criticality
- Criticality safety ensured during transport & operations by setting package safe fissile masses and/or by exclusion of moderator
- These controls also ensure criticality safety for a long period following facility closure
- However, conditions in a GDF will evolve, therefore to demonstrate continued post-closure criticality safety, we need to understand:

  1) under what conditions could criticality occur and what is the likelihood of these systems developing;

  2) what are the local consequences if critical systems do develop; and

  3) could hypothetical critical events degrade GDF post-closure performance.

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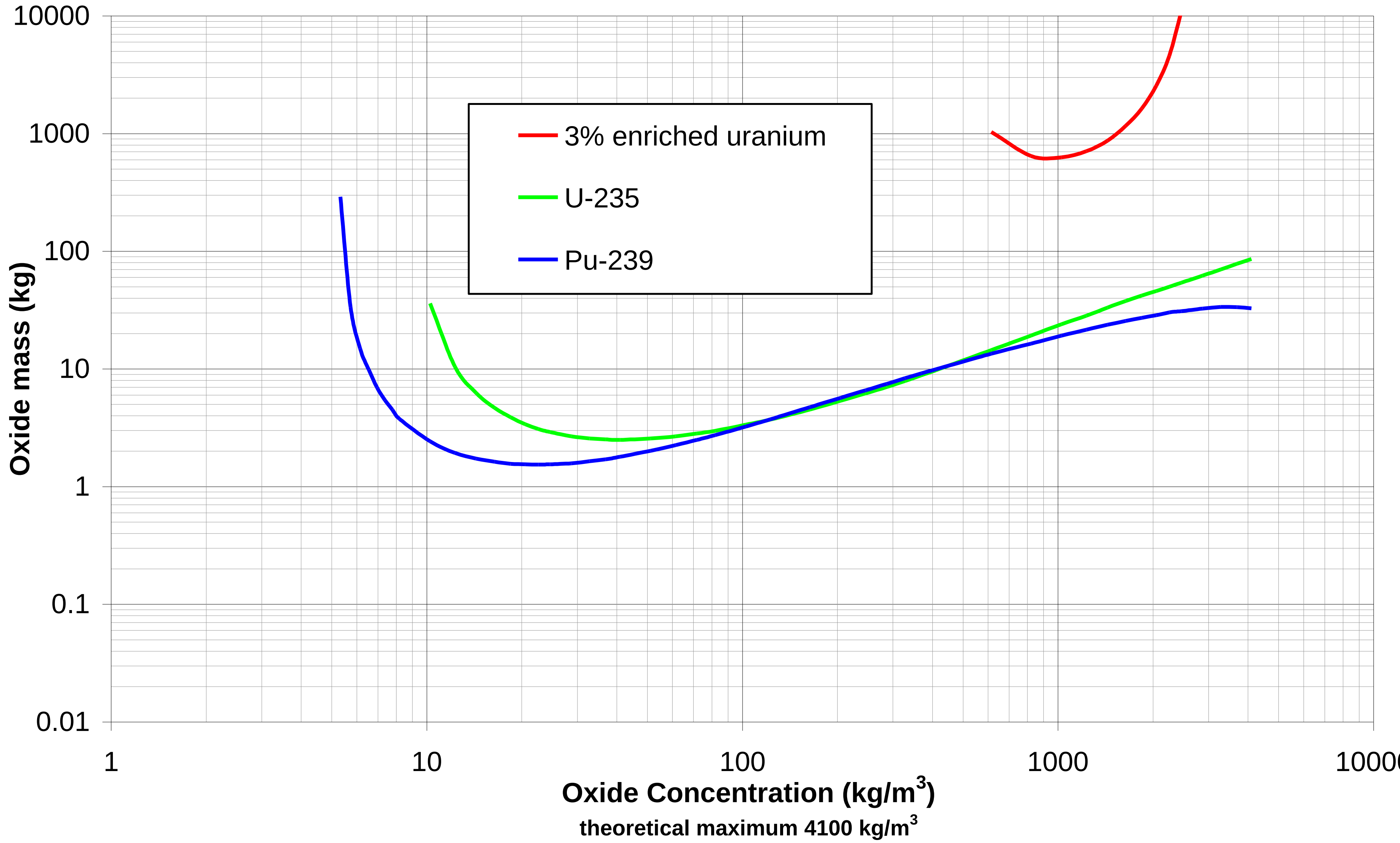
Conditions required for criticality

- Example criticality handbook curve for homogeneous spheres of optimally moderated fissile material in bentonite (highly conservative as it shows minimum concentration & mass required)



- Likelihood work considers possibility of reaching critical region (k_{eff} =1)
- Consequence work focuses on how criticality would progress & what the local consequences would be **IF** we reached these accumualtions (k_{eff} ≥1)

Criticality scenario construction

- **At disposal, all packages will be significantly sub critical**
- **Consider processes and events that could lead to material reconfiguration & accumulation under evolving GDF conditions**
- **Identify criticality scenarios:**

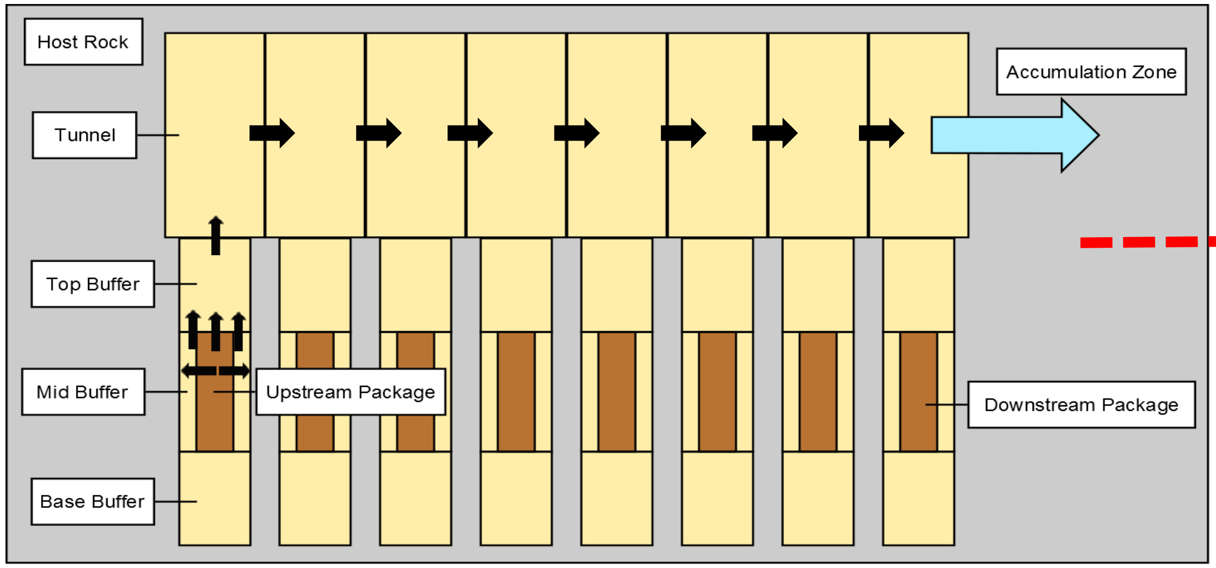
  1) in-package

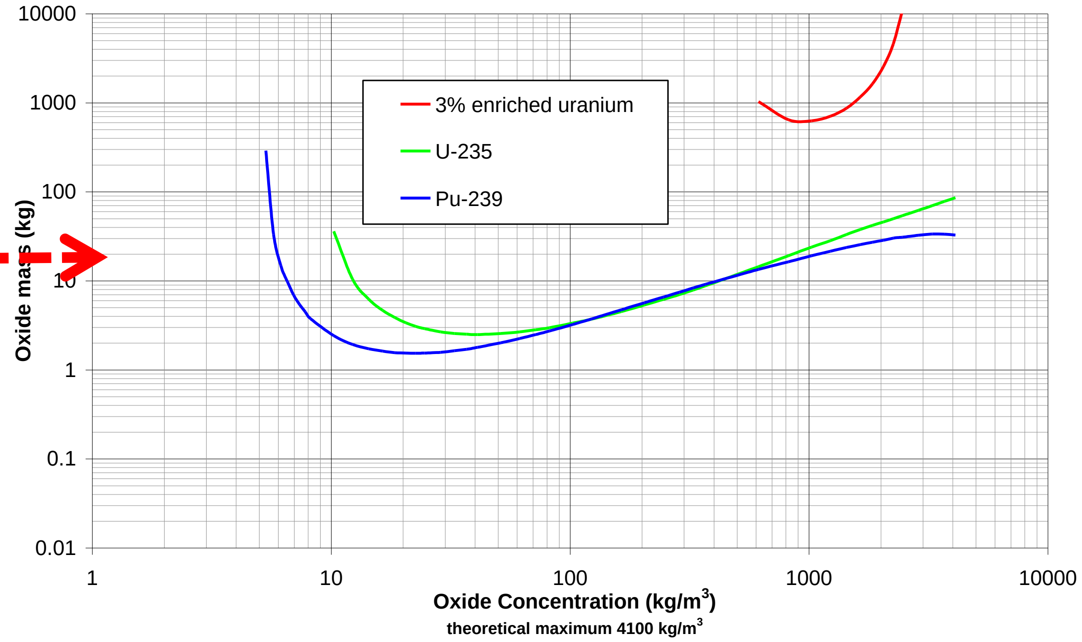
  2) accumulation outside of a single package

  3) accumulation from multiple packages

Assessment methodology

- **Likelihood of criticality**
  - Probabilistic model of barrier evolution & Pu and U migration (GoldSim)
  - Define parameter distributions that capture uncertainties
  - Sample over multiple realisations (1000)





- Compare calculated fissile material concentrations & masses in different regions with minimum values required for criticality

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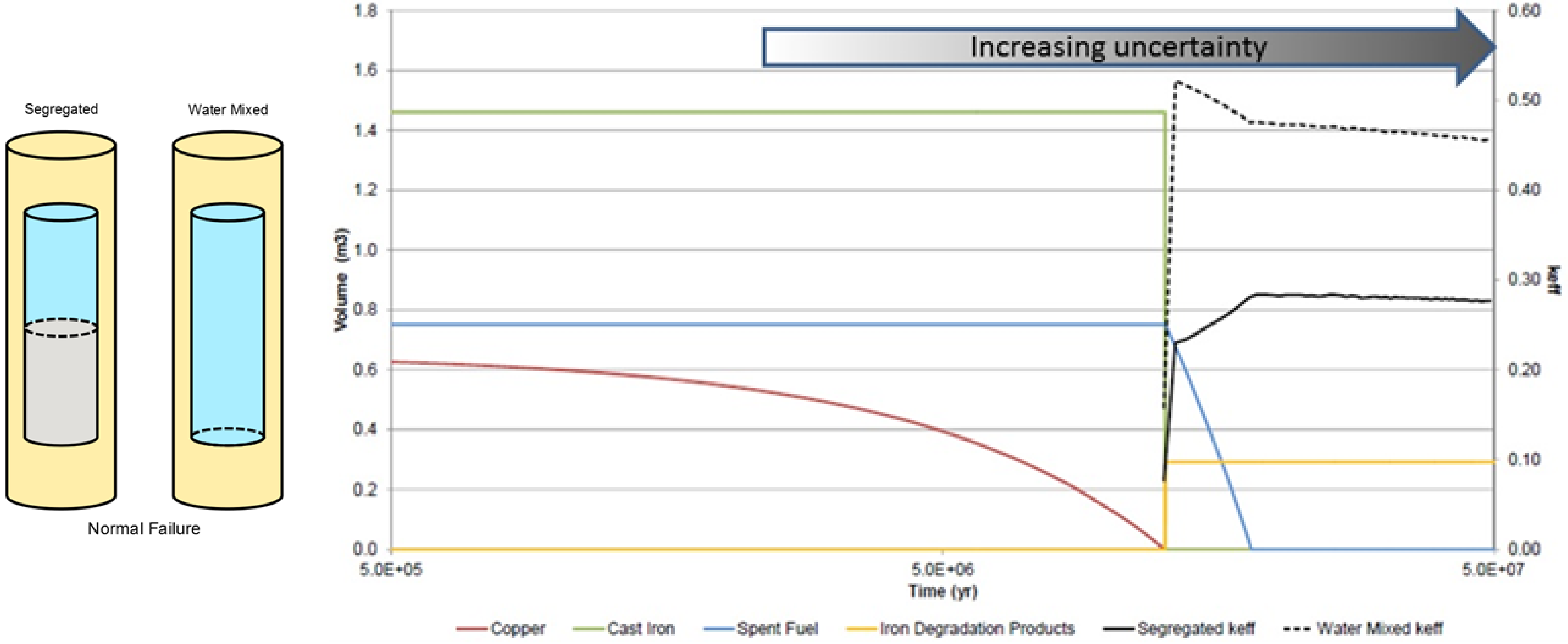
Example likelihood results – SF, in package scenario

- Volumes of package materials & how close the package gets to criticality (a k_{eff} of 1) for PWR SF package for a typical realisation (1 of 1000)



- Cannot have criticality until water enters a container
- Water cannot enter until Cu has corroded (by this time Pu decayed to U)
- Most U remains in solid form, some advected out of container over 10^8yrs
- Highest k_{eff} = 0.5, significantly sub-critical (note effective enrichment of 1.2% ^{235}U)

Likelihood results summary

Waste type	Scenario		
	In-package	Accumulation outside of package	Accumulation from multiple packages
PWR SF (disposed of in HSR geology)	**Only credible for fresh/low burn-up fuel** Not credible if assume PWR SF of typical burn-up Criticality possible following failure of fresh PWR fuel container (although fresh fuel disposal is not expected) Earliest Cu container failure assumed to occur after $2x10^5$ yrs.	**Not credible under the conditions assumed** Insufficient fissile material accumulation in bentonite, even if the fuel was un-irradiated	**Not credible under the conditions assumed** Insufficient downstream fissile material accumulation, even if the fuel was un-irradiated

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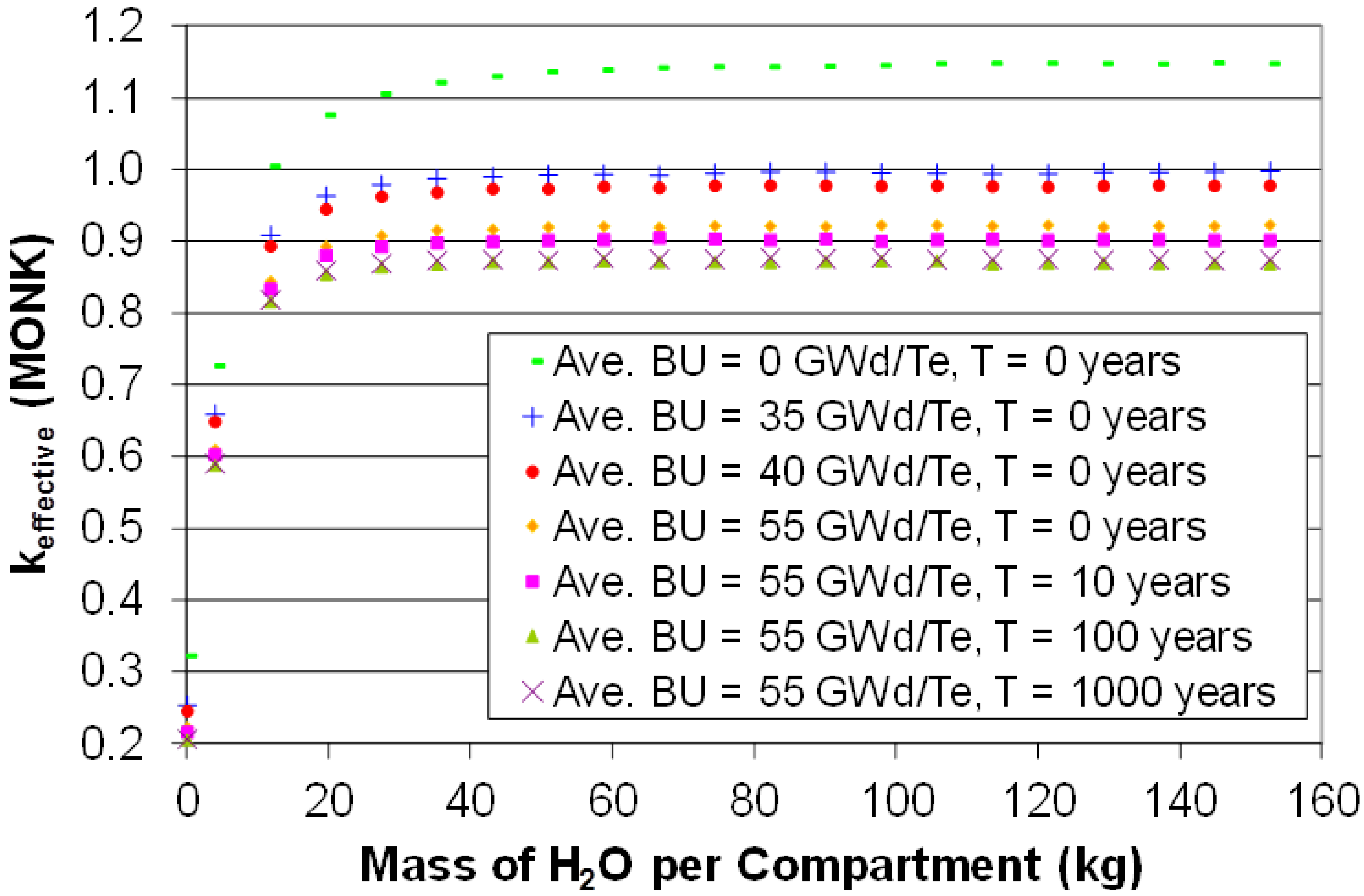
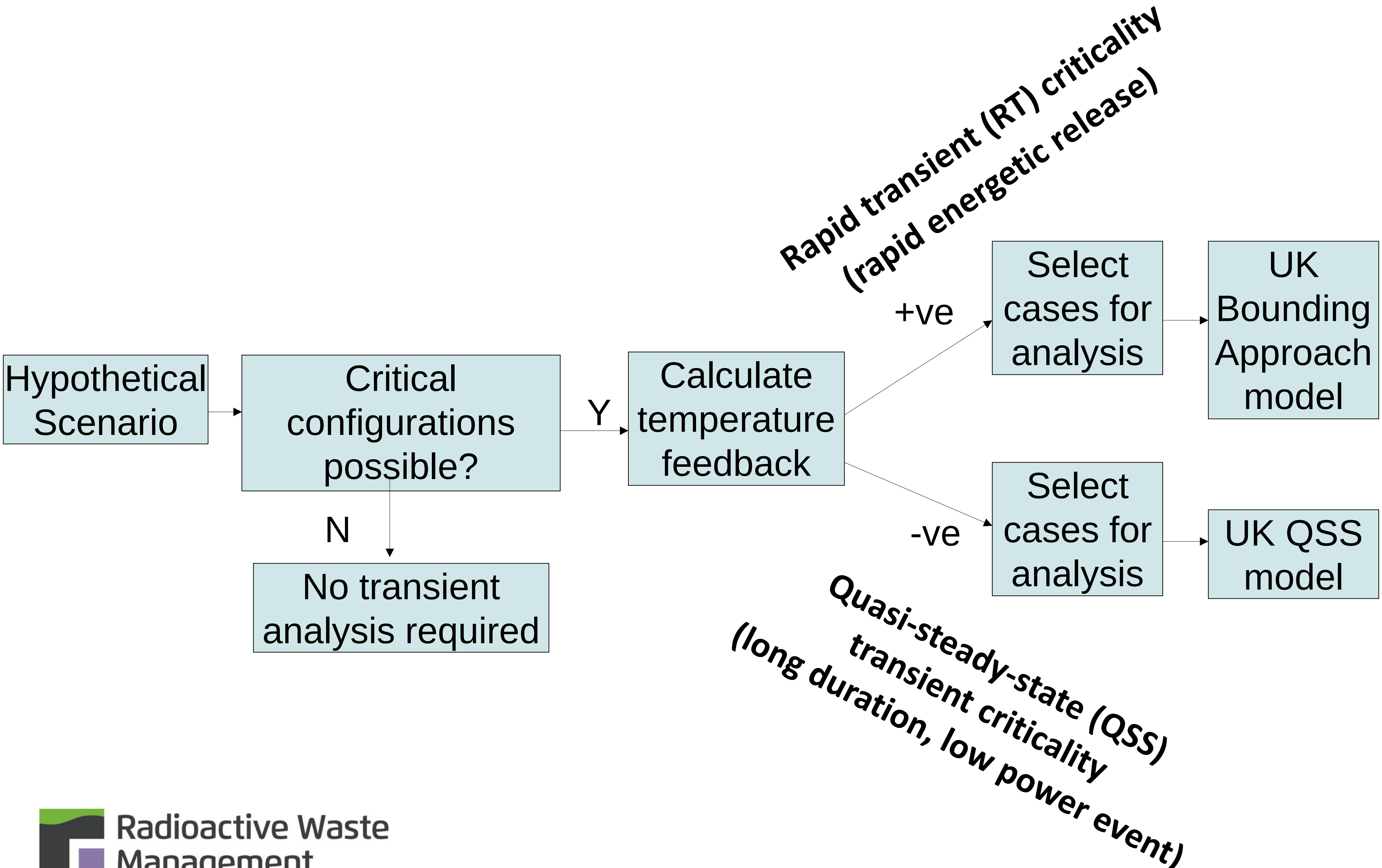
PWR SF in package flooding scenario

- Flooding of package containing PWR fuel considered (following failure)
- Fresh fuel assumed (as worst case) for disposal



- For fresh fuel, criticality possible with water ingress of ~11kg (~30cm of flooding)
- As irradiation of fuel increases, possibility of criticality reduces
- At burn-up of >35 GWd/Te fuel remains sub-critical

Methodology for consequence analysis



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Conclusions

Thermal management

- A thermal dimensioning tool (TDT) has been developed
  - TDT can inform the design of GDF
  - TDT can inform overall thermal management strategy

Criticality safety

- Probabilistic model developed to evaluate the likelihood of post-closure criticality scenarios
  - re-arrangement of materials in a waste package, accumulation of fissile material in the barriers outside of a waste package & accumulation from multiple packages
  - PWR SF remains sub-critical under flooded conditions. Accumulation of fissile materials from failed PWR SF containers insufficient to support criticality (assuming burn-up)
- Consequence of criticality models also developed (results not discussed here)

Possible compliance requirements

- Directly measure heat generation for sealed SF disposal containers?
- Fissile assay of sealed SF containers to demonstrate a minimum burnup?

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robert.winsley@nda.gov.uk

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