2019 Huron-Kinloss Nuclear Waste Symposium

NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

7th Case Study

(Safety of a Deep Geological Repository)

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Purpose

- To describe how we assess postclosure safety of a DGR in a hypothetical sedimentary geosphere

Agenda

- Safety Case
- Conceptual Design
- Scope and Scenarios
- Conservatisms and Assumptions
- Assessment Tools and Methodology
- Results

Safety Case *(cont'd)*

- The **Safety Case** is an integrated collection of arguments and evidence that together demonstrate the safety of the facility
- The Safety Case addresses all aspects of safety:
  - Conventional Health and Safety
  - Transportation Safety
  - Preclosure Safety
  - Postclosure Safety
- The portion addressing Postclosure Safety will include a Safety Assessment, a Geosynthesis, information on R&D support, information on Natural Analogues and more

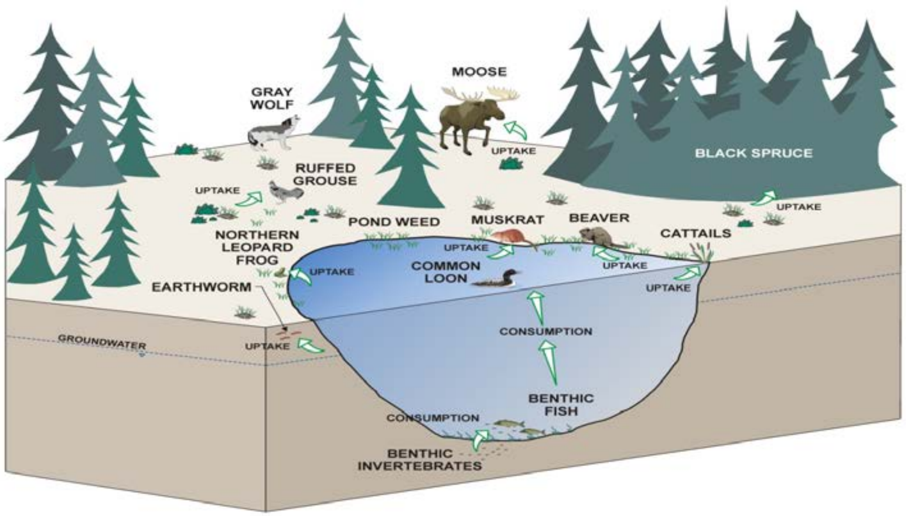
Safety Case *(cont'd)*

- It will be subjected to peer review (national and international reviewers)
- It will be subjected to independent review and checking by the CNSC
- Licenses will not be granted until the CNSC is satisfied that the health and safety of the public, the workers and the environment are protected

Safety Case *(cont'd)*

Postclosure Safety Assessment

- provides a quantitative estimate of the ability of the repository to isolate and contain the hazard posed by the used fuel in the long term
- Uses computer models of the repository, the surrounding host rock and the biosphere
- Follows guidance in CNSC REGDOC–2.11.1, Volume III 'Assessing the Long Term Safety of Radioactive Waste Management'
- Considers
  - The effects on people due to radiological and non-radiological hazards
  - The effects on the environment due to radiological and non-radiological hazards



Safety Case *(cont'd)*

Safety is determined (in part) by comparing estimated effects against approved acceptance criteria.

Radiological Criteria

- Dose limit for public exposure is 1 mSv/a (background dose rate is 1.8 mSv/a)
- Dose constraint below the regulatory limit of 0.3 mSv/a is adopted and is consistent with ICRP / IAEA recommendations
- Radiological criteria also established for non-human biota

Safety Case *(cont'd)*

Hazardous Substances Criteria

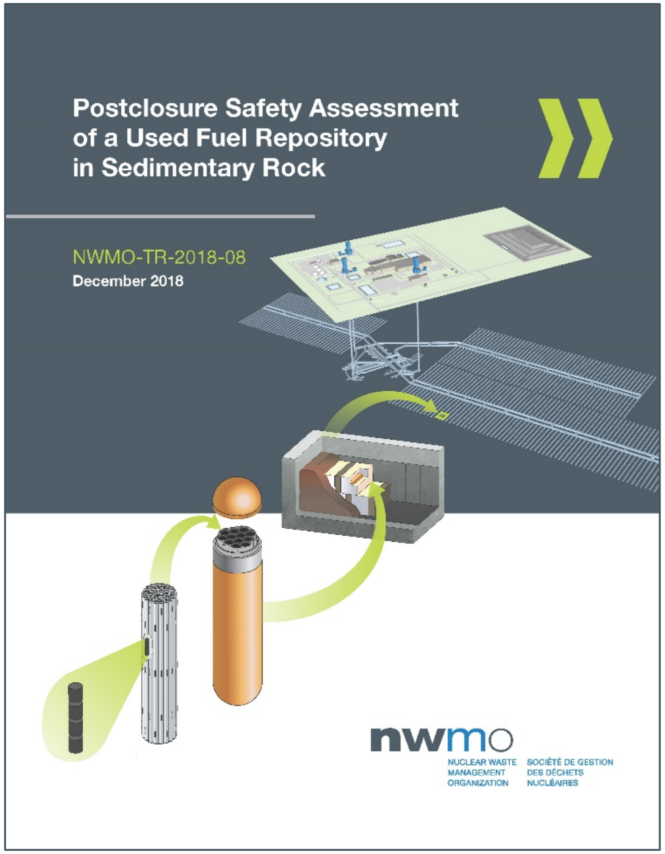
- NWMO has proposed interim acceptance criteria for the protection of persons and the environment consistent with the CCME and MOE
- Acceptance criteria are developed for five environmental media: Surface water, groundwater, soil, sediment and air

If margins between criteria and estimated dose rates are deemed insufficient, key assumptions are examined and iteration with design and operations may occur to implement improvements

Safety Case *(cont'd)*

Structure of the 7CS Report (704 pages)

- Executive Summary
- Chapter 1 – Introduction
- Chapter 2 – Description of the Hypothetical Site
- Chapter 3 – Used Fuel Characteristics
- Chapter 4 – Repository Facility Conceptual Design
- Chapter 5 – Long-Term Evolution of the MBS
- Chapter 6 – Scenario Identification and Description
- Chapter 7 – Postclosure Safety Assessment Contaminant Transport
- Chapter 8 – Postclosure Safety Assessment Gas Generation and Transport
- Chapter 9 – Treatment of Uncertainties
- Chapter 10 – Natural Analogues
- Chapter 11 – Quality Assurance
- Chapter 12 – Summary and Conclusions
- Chapter 13 – Special Terms



Conceptual Design

Isolated

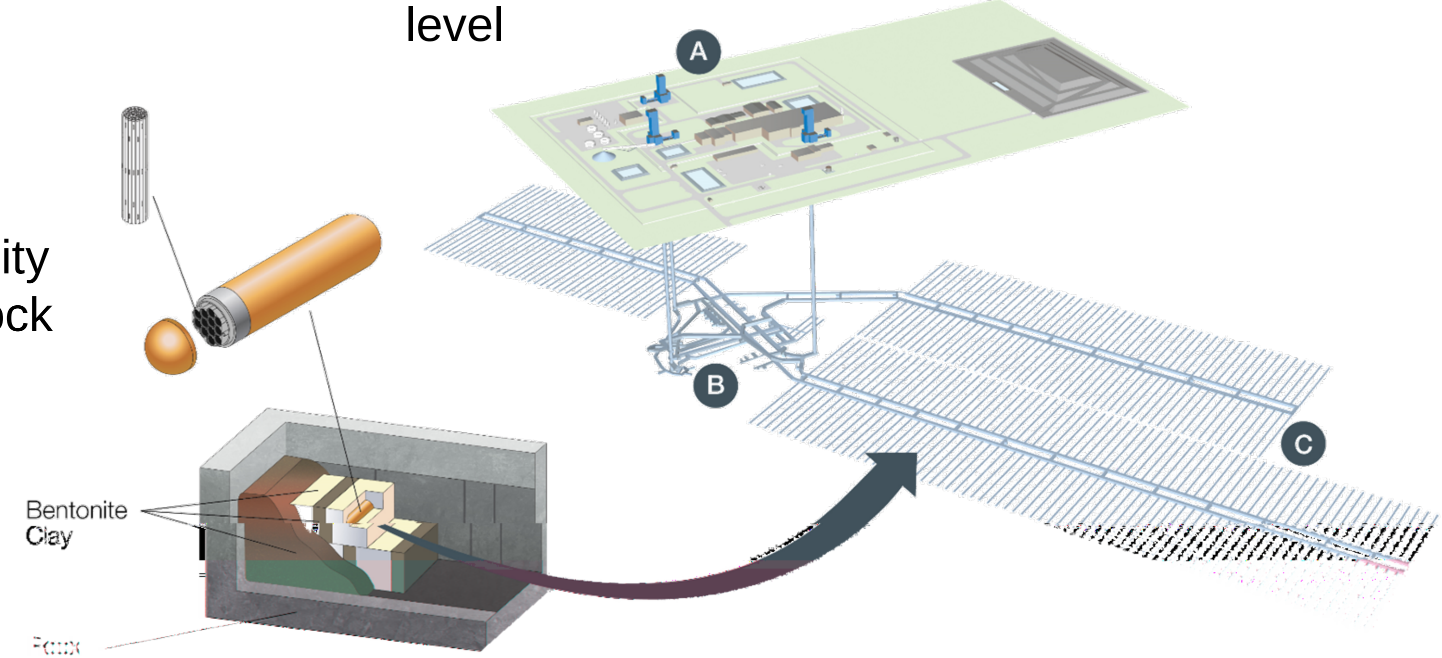
- Deep repository (500 mBGS)

Multiple barriers

- Durable waste form (UO_2 in fuel bundle)
- Robust corrosion-resistant container
- High-density bentonite seal
- Low-permeability sedimentary rock

Stable and predictable

- Extent and age of rock formation
- Deep groundwaters are old and not mixing with surface waters
- Low seismicity
- Minimal glaciation perturbation at repository level



Conceptual Design *(cont'd)*

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Scope and Scenarios

Scope:

Safety assessment does not try to predict the future, but considers the consequences of a range of scenarios

As per CNSC REGDOC–2.11.1:

Normal Evolution Scenario:

- Most likely evolution of site, repository and containers
- Includes earthquakes and glaciation
- Reference Case assumes all repository components function as anticipated
- Examines a range of sensitivity cases ranging from likely to unlikely
- Deterministic Sensitivity Cases developed to test the effectiveness of the multiple barrier system (e.g., increased fuel dissolution, high radionuclide solubility, low sorption in the geosphere)

Scope and Scenarios *(cont'd)*

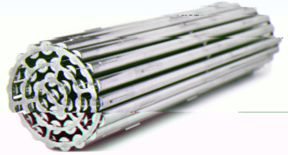
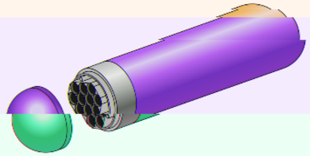
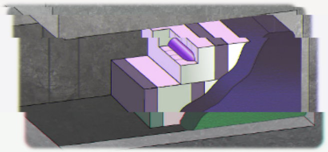
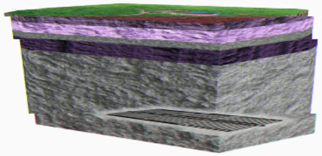
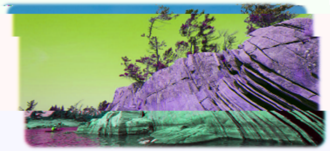
Disruptive Event Scenarios:

- Unlikely and "What If" events
- These scenarios check the robustness of the specific site and repository design
- Range of situations where container may be compromised (e.g. all containers fail, degraded seals, undetected fault, poorly sealed borehole)
- As per CNSC REGDOC–2.11.1, also considers Inadvertent Human Intrusion
- Other potential Disruptive Scenarios were ruled out on various grounds (e.g., no volcanic activity in the area, far from the coast, no minerals at site) or very low probability leading to low calculated risks (e.g., meteor strike).
- Similar scenarios have been identified in other international programs

Scope and Scenarios *(cont'd)*

Probabilistic Analysis:

- Explores uncertainties and ranges in parameter values, allowing for one to draw conclusions about model sensitivity as well as test inherent variability in model data
- Uses a Monte Carlo random sampling strategy that considers a full range of parameter values
- Assess the overall uncertainty in the Base Case
- Assess the overall uncertainty across all parameters

Fuel Barriers	Container Barrier	Buffer, Backfill, Seals	Geosphere Barrier	Biosphere
				

Likely

Reference Case: The repository system performs as expected for the assessment timeframe.

Fuel dissolves very slowly, and only if water ever reaches it.	Copper is exceptionally stable under repository conditions.	Swelling clay seals against water flow	Deep rock conditions remain unchanged for many millions of years.	Conditions aboveground have essentially no impact on the reposit

Sensitivity Cases: Assume components do not function as expected, causing variations in repository performance.

Base Case

y well for maximum	Radioactivity appears in buffer immediately upon container failure	Undetected defects lead to 10 container failures over one million years	Water reaches fuel immediately upon container failure	Repository at 500 m depth; groundwater density effects ignored	Water-suppl located

[redacted]

Conservatisms and Assumptions

Container Failure:

	Realistic	"Base Case"
Copper coating defect?	All containers will be inspected; Ongoing R&D for QA / QC; QC passing though-copper defect (3mm) is unlikely, perhaps unrealistic	QC passes containers with relatively large defects (>2mm)
Defect allows groundwater to contact inner steel?	Wait >74 million years (small defect, ~0.8mm; low groundwater sulphide, <1µM)	1000 years, first container; additional container every 100,000 years; 10 defective containers breach within assessment timeframe, one million years
Defect allows groundwater to enter the container?	Wait another 140,000 years – 2 million years (small defect, ~1mm)	0 years
Container fills with water?	Continue waiting for >10,000 years	0 years
Groundwater passes the Zircaloy cladding, contacting the used fuel?	Possibly	Yes
Corrosion-generated hydrogen inhibits fuel dissolution?	Most likely	No
Corrosion products clog the defect?	Yes	No
Breached container sufficiently intact to provide some degree of containment?	Yes, for another several 100,000 years	No

Conservatisms and Assumptions *(cont'd)*

Dose Consequences:

	Realistic	"Base Case"
People living close by?	Unknown	Yes, above the repository; Farming family raises livestock and crops on the surface above the repository
Using a deep well?	Unlikely	Yes, over 200 m deep; Farming family drinking water, household water, and irrigation water all come from a deep well
Where is the well?	Unknown	Worst possible location
Where are hypothetically breached containers?	Unknown	Worst possible location

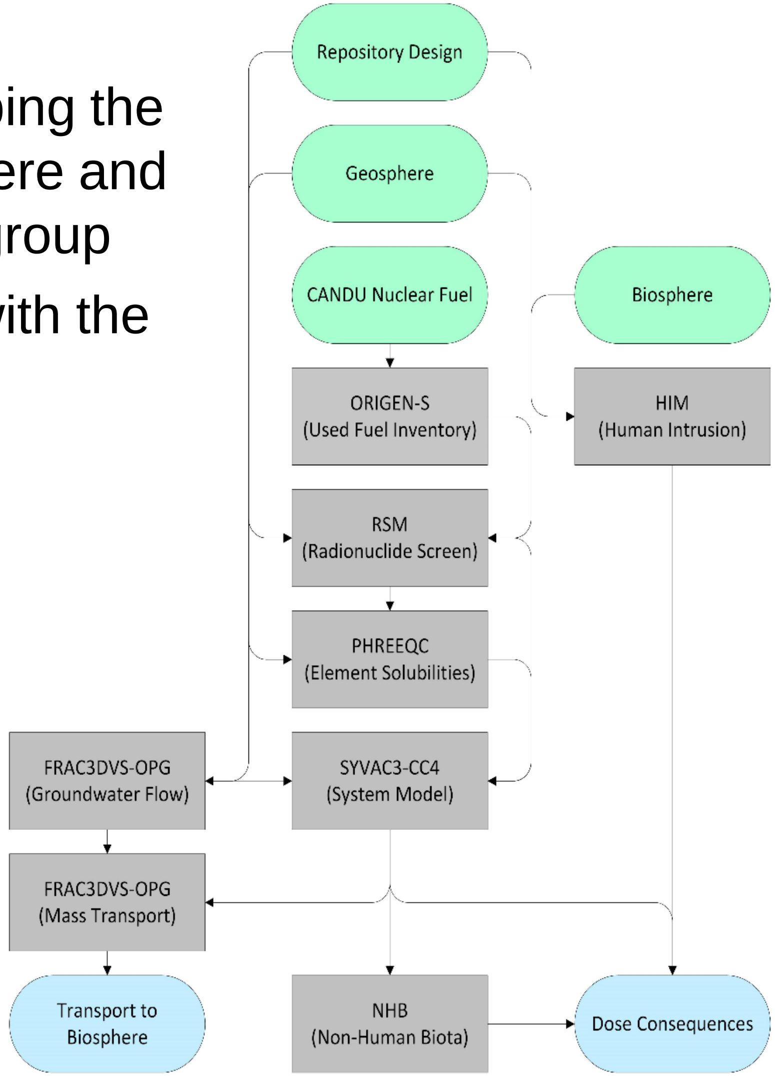
Conservatisms and Assumptions

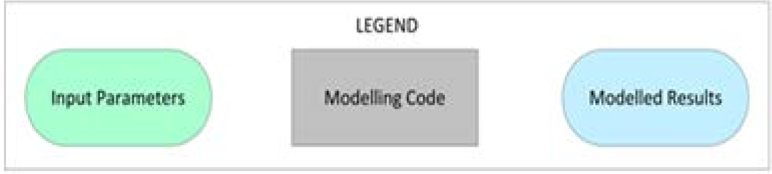
Some Key Assumptions:

- People in the future are similar to people of today
- Should protect future people to the same degree that we protect ourselves
- People in the future behave plausibly, with characteristics that maximize exposure
- A self-sufficient farm family unknowingly lives on top of the repository and:
  - Grows all their food on top of the repository
  - Obtains all their drinking water from a deep well
  - Well is in the location that maximizes the uptake of repository contaminants
- If it can be shown that this hypothetical family is safe, then real families would be safer

Assessment Tools & Methodology

- Hundreds of input parameters describing the repository design, geosphere, biosphere and lifestyle characteristics of the critical group
- Several specialized codes are used with the most significant being:
  - RSM
  - FRAC3DVS
  - SYVAC3-CC4
- Outputs include transport to the biosphere and dose consequences





Assessment Tools & Methodology *(cont'd)*

Screening Analysis (RSM)

- Identifies radionuclides for more detailed analysis

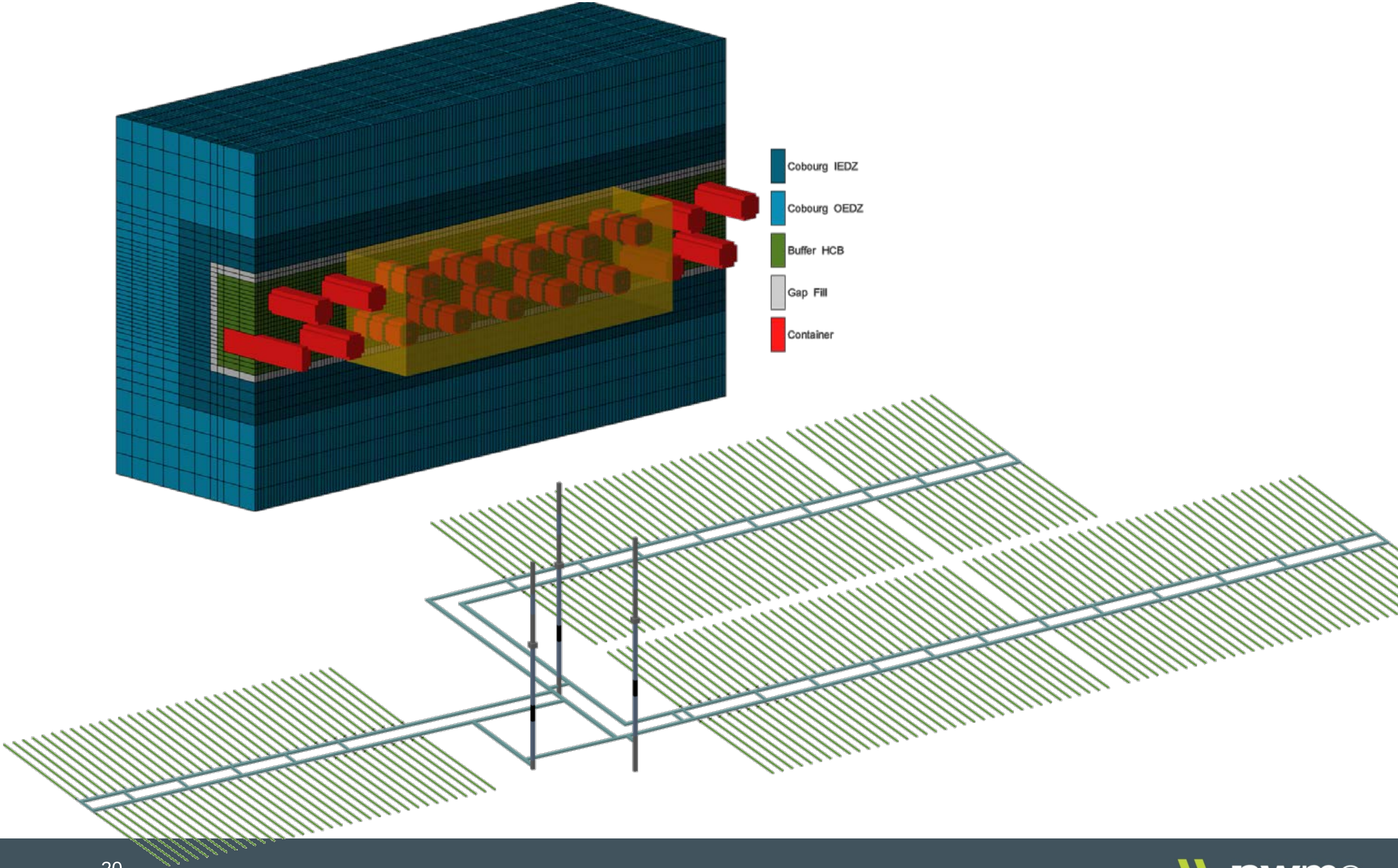
Detailed Geosphere Modelling (FRAC3DVS-OPG)

- Hydrogeological modelling (groundwater flow field)
- Radionuclide transport modelling (diffusion, advection, sorption)
- Used to better understand the geosphere and develop the system model

System Modelling (SYVAC3-CC4)

- Used for deterministic and probabilistic safety analysis
- Simulates the container, placement room, geosphere, and biosphere
- Internal doses (e.g. ingestion, inhalation) and external doses (e.g. groundshine, immersion) are calculated for a critical receptor

Assessment Tools & Methodology *(cont'd)*



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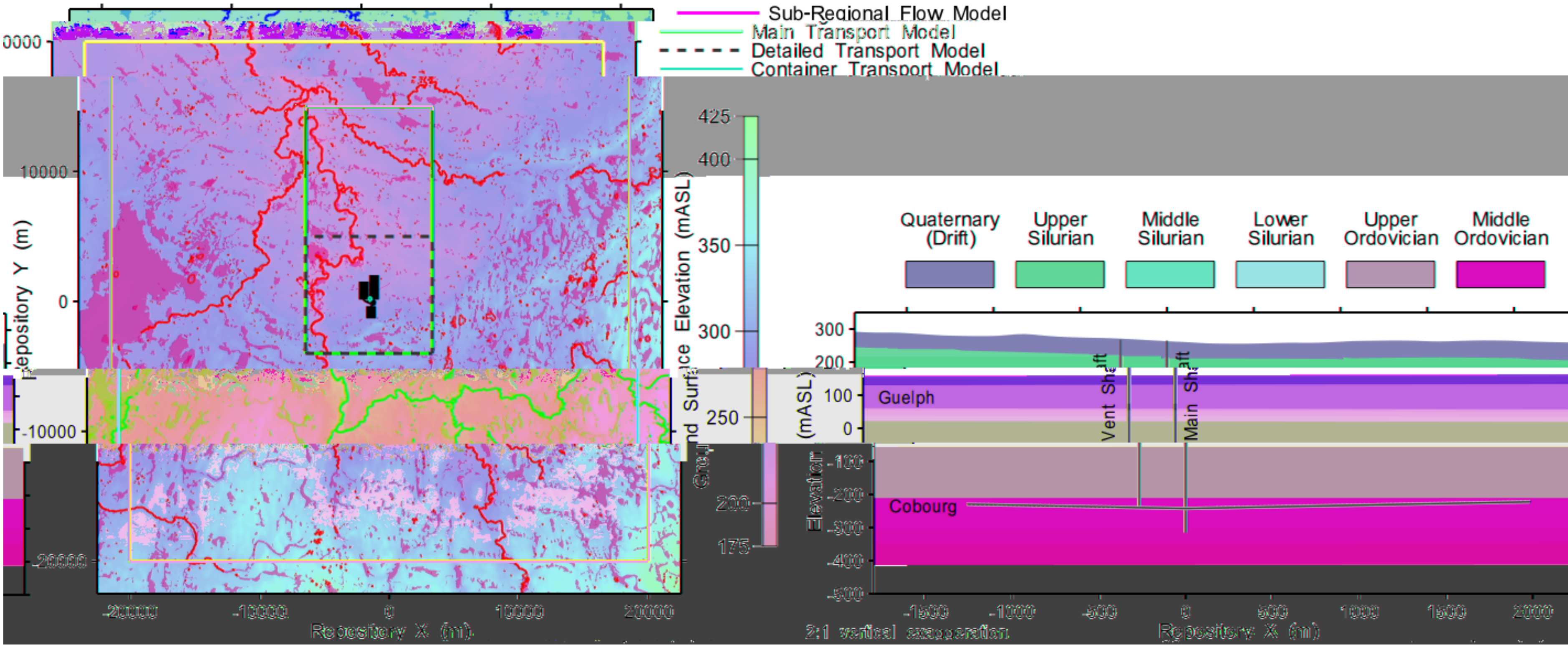
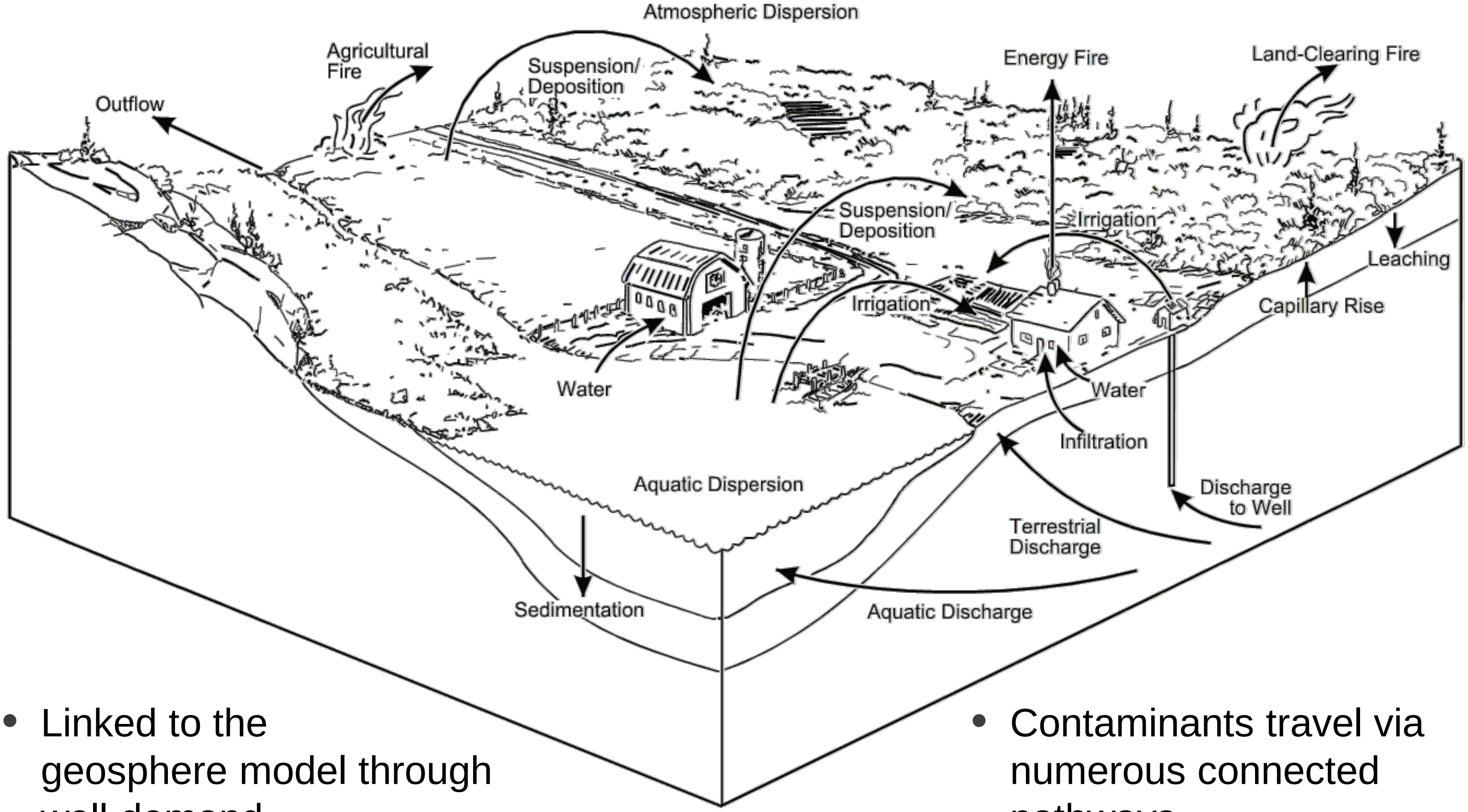
Assessment Tools & Methodology *(cont'd)*



Assessment Tools & Methodology *(cont'd)*



- Linked to the geosphere model through well demand
- Contaminants travel via numerous connected pathways
- Doses are calculated from environmental concentrations

Assessment Results

Doses to the “critical group” include the following dose pathways.

Internal doses to a person due to:

- Ingestion of food
- Ingestion of drinking water
- Ingestion of soil
- Inhalation

External doses to a person due to:

- Immersion in air
- Immersion in water
- Standing on contaminated ground
- Exposure to contaminated building materials

Assessment Results *(cont'd)*

Screening Assessment

- Stylized conservative model known as the RSM
- 251 radionuclides and 96 stable elements in the fuel and zirconium sheath
- Variety of cases to encompass Normal Evolution sensitivity cases
- Results in 31 radionuclides in the fuel, 1 from the Zircaloy and 9 chemically hazardous elements
- Parent radionuclides included in the assessment

Radionuclides (1)	
Fuel	
Single Nuclides	I-129, C-14 (2), Cl-36, Cs-135, Pd-107, Se-79, Sm-147, Tc-99,
Chain Nuclides	Am-241 → Np-237 = Pa-233 → U-233 → Th-229 = Ra-225 = Ac-225
	Pu-242 → U-238 = Th-234 → U-234 → Th-230 → Ra-226 = Rn-222 = Pb-210 = Bi-210 = Po-210
	Pu-239 → U-235 = Th-231 → Pa-231 = Ac-227 = Th-227 = Ra-223
	Pu-240 → U-236 → Th-232 = Ra-228 = Th-228 = Ra-224
Zircaloy	
Single Nuclides	C-14 (2), Cl-36

Notes: (1) Screened-in radionuclides are red
(2) Included for gas phase dose consequences
"=" signifies the radionuclides are in secular equilibrium

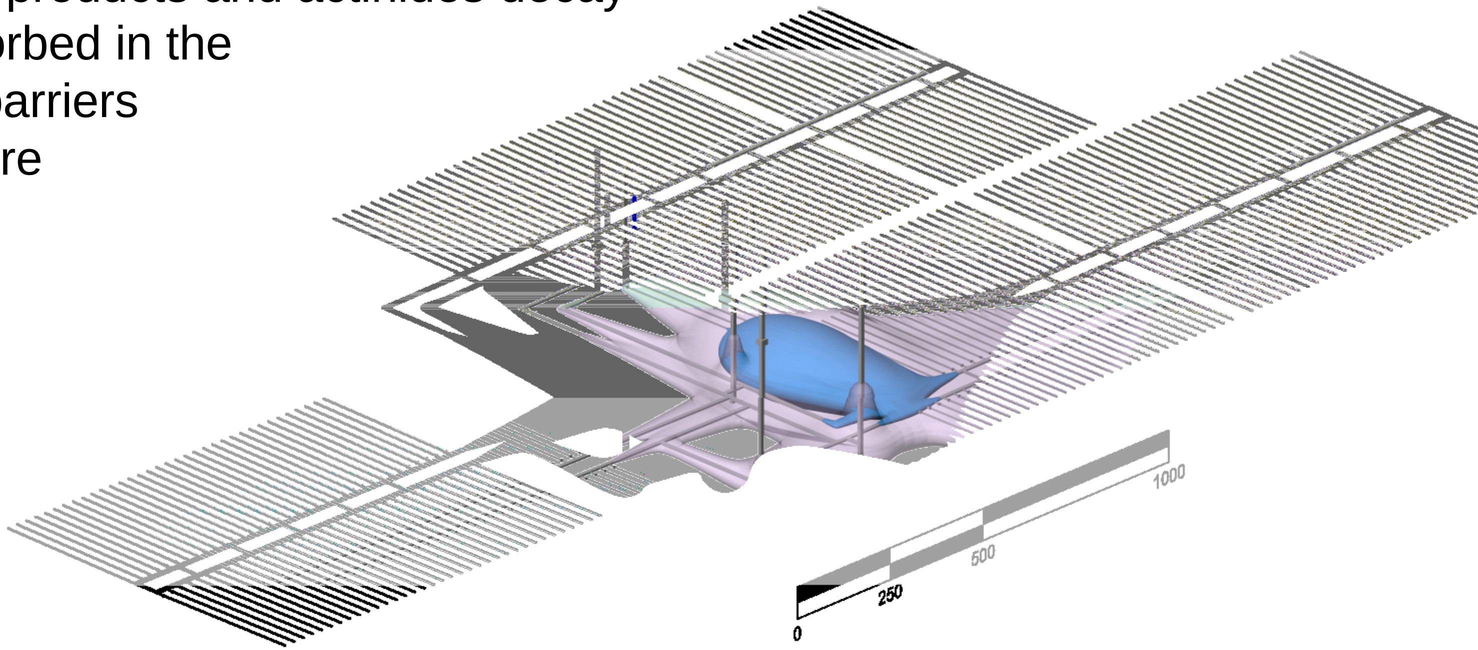
Chemically Hazardous Elements (1)	
Fuel	
Elements	Hg, Mo, Nd, Pd, Rh, Ru
Misc	Pd-107 → Ag Sm-147 → Nd Sm-148 → Nd

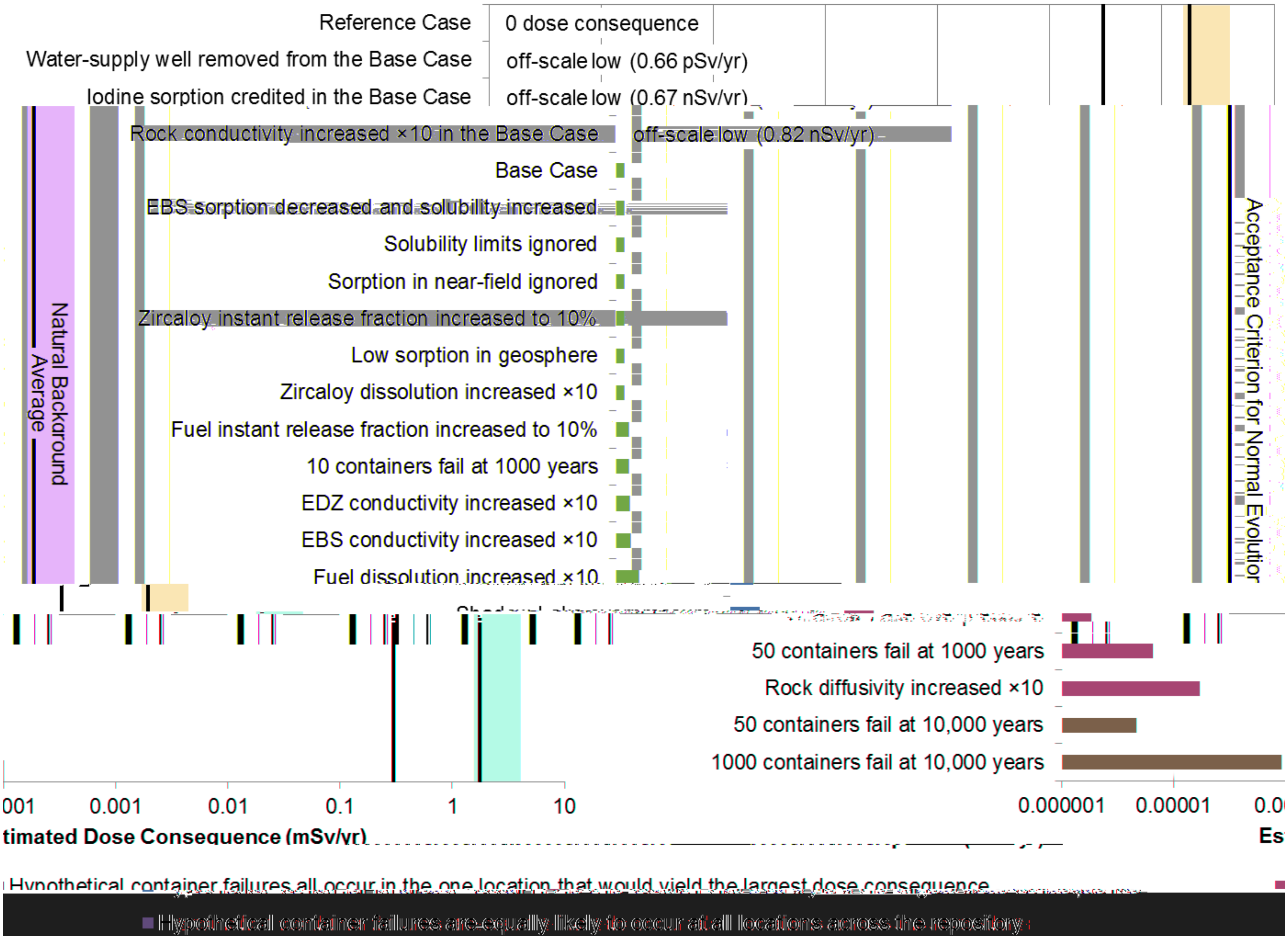
Note: (1) Screened-in elements are red

Assessment Results *(cont'd)*

Base Case

- Maximum impact is 1.2×10^{-6} mSv/a (1.2 nSv/a)
- I-129 is the dominant dose contributor
- I-129 is non-sorbing with a long half-life
- Other fission products and actinides decay and/or are sorbed in the engineered barriers and geosphere



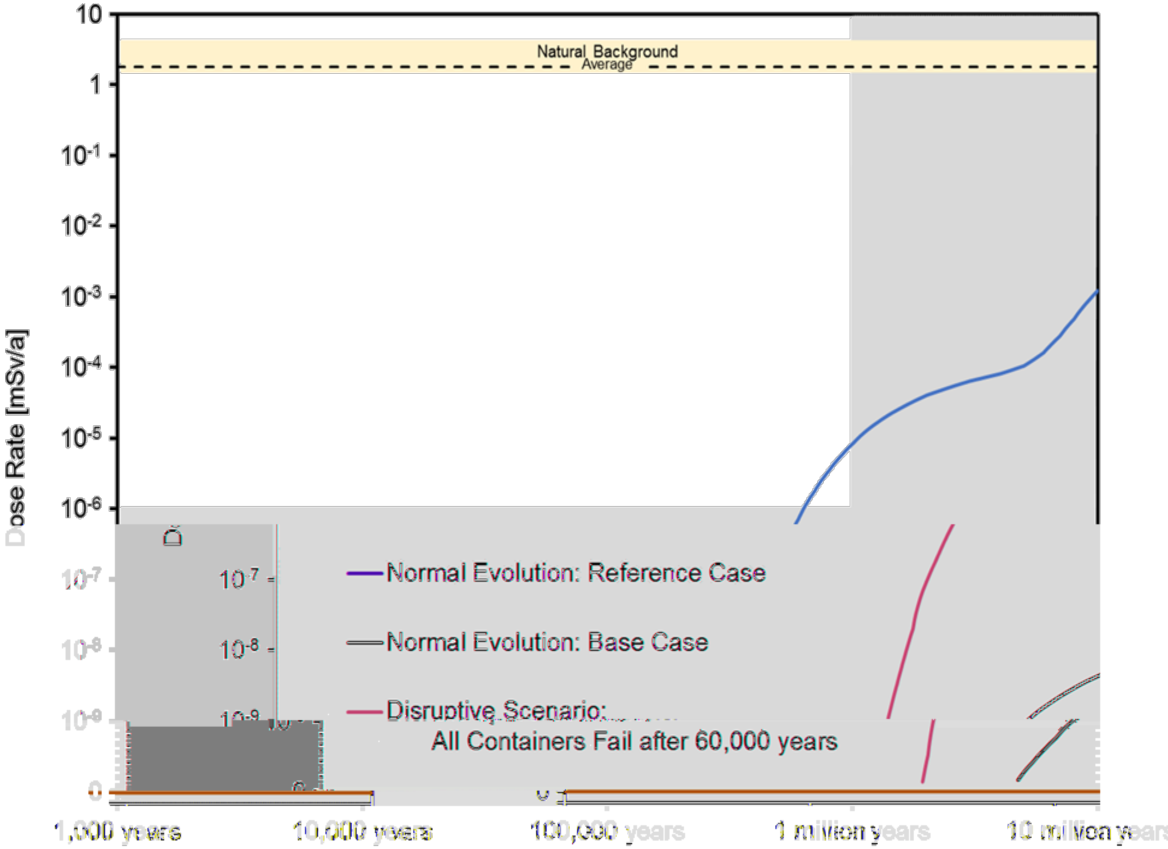


Reference Case
0 dose consequence
Water-supply well removed from the Base Case
off-scale low (0.66 pSv/yr)
Iodine sorption credited in the Base Case
off-scale low (0.67 nSv/yr)
Rock conductivity increased ×10 in the Base Case
off-scale low (0.82 nSv/yr)
Base Case
EBS sorption decreased and solubility increased
Solubility limits ignored
Sorption in near-field ignored
Zircaloy instant release fraction increased to 10%
Low sorption in geosphere
Zircaloy dissolution increased ×10
Fuel instant release fraction increased to 10%
10 containers fail at 1000 years
EDZ conductivity increased ×10
EBS conductivity increased ×10
Fuel dissolution increased ×10
50 containers fail at 1000 years
Rock diffusivity increased ×10
50 containers fail at 10,000 years
1000 containers fail at 10,000 years
Natural Backaround Average
Acceptance Criterion for Normal Evolution
0.001
0.01
0.1
1
10
0.000001
0.00001
Estimated Dose Consequence (mSv/yr)
Hypothetical container failures all occur in the one location that would yield the largest dose consequence
Hypothetical container failures are equally likely to occur at all locations across the repository

Assessment Results *(cont'd)*

All Containers Fail (Disruptive Scenario)

- Unlikely event leading to abnormal loss of containment
- Maximum impact is 0.01 mSv/a
- I-129 remains the dominant dose contributor



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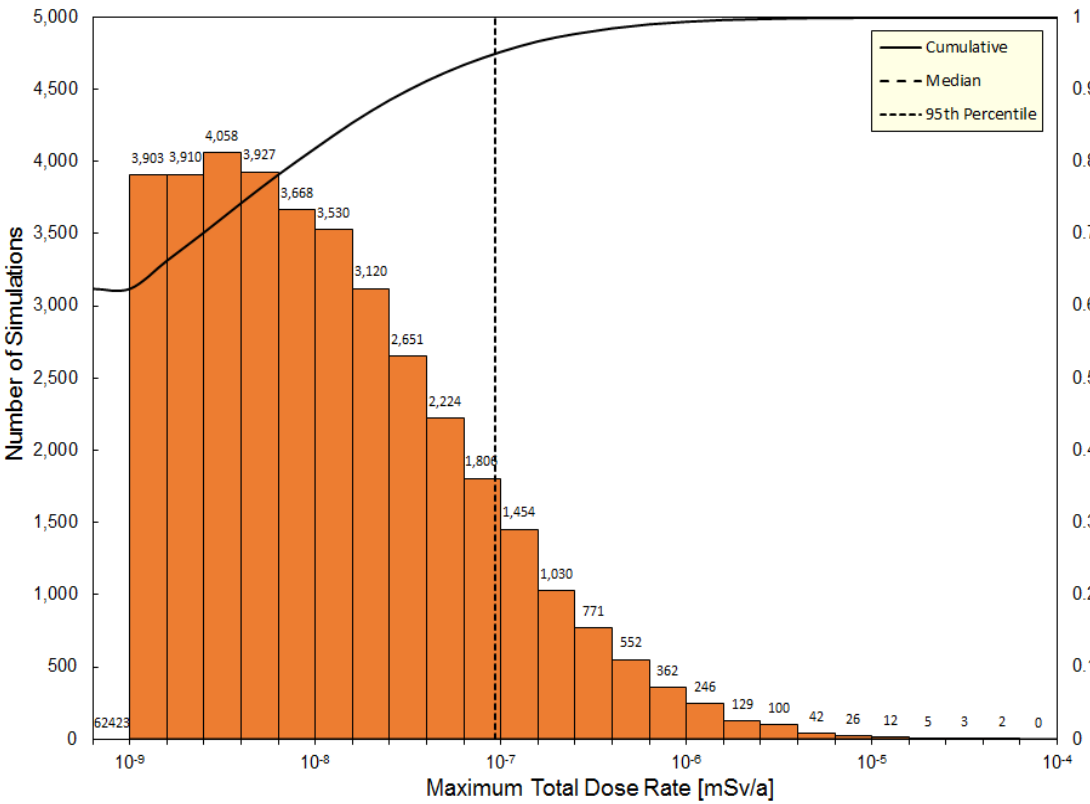
Assessment Results *(cont'd)*

Probabilistic Assessment

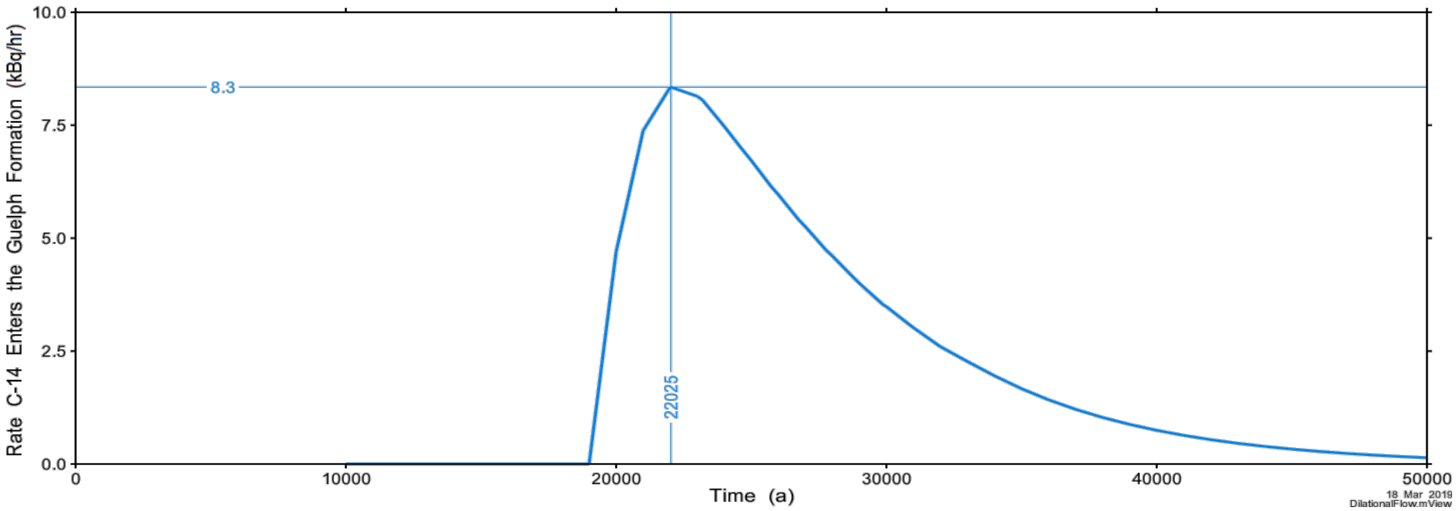
- Assessing uncertainty in the Base Case
- Median dose rate of 7.5×10^{-10} mSv/a (0.75 pSv/a)
- 95th percentile dose rate of 1.3×10^{-7} mSv/a (0.13 nSv/a)
- Highest dose cases controlled by iodine diffusion
- Many simulations have similar results to the Base Case suggesting many model parameters do not strongly influence results



Assessment Results *(cont'd)*

Gas Behaviour

- Extremely low rock conductivity may limit gas transport to excavation pathways
- Elevated gas-borne dose consequences? Elevated repository-gas pressure?
- Detailed studies of gas behaviour (extremely conservative assumptions) concluded:
  - Any hypothetical dose would be well below natural background radioactivity
  - Gas transport by dilational flow (limited modelling), pressures remain low



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Summary

- Conceptual design for a Deep Geological Repository in sedimentary rock
- Illustrative postclosure safety assessment
- Consistent with CNSC REGDOC–2.11.1
- Identifies assessment scenarios, models, and methods
- Results compared against interim acceptance criteria
- Normal Evolution, sensitivity cases,
  and probabilistic simulations
  all below radiological
  acceptance criteria by
  substantial margins