Development of a pre-siting safety case for spent nuclear fuel disposal based on Taiwan's crystalline rock

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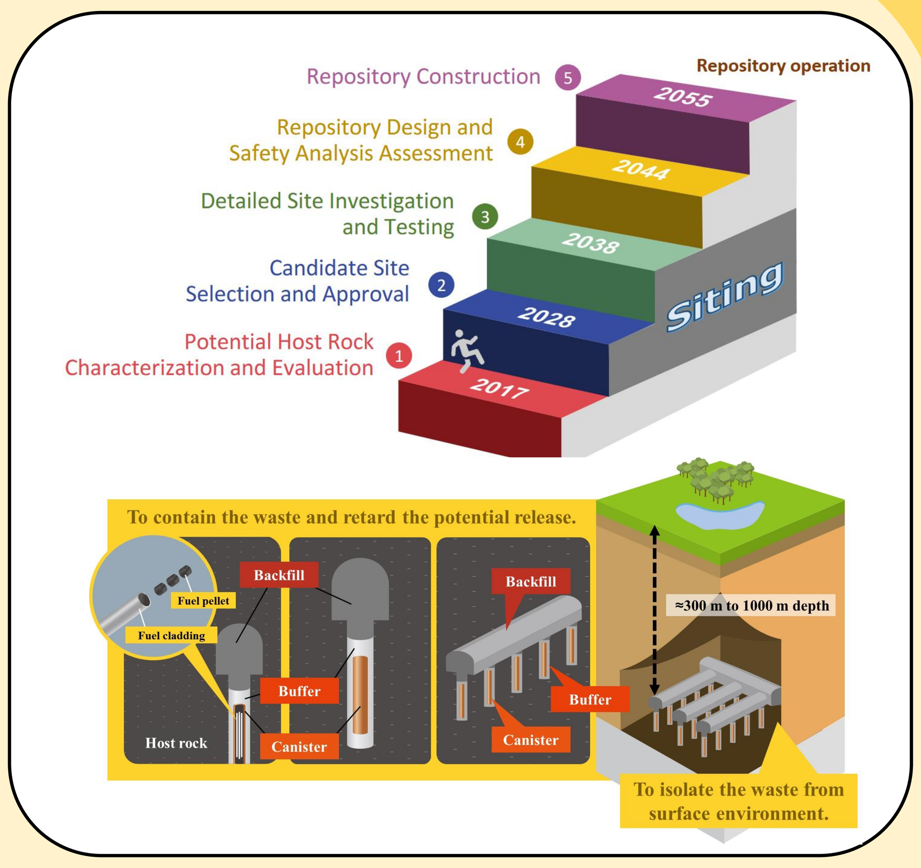
Taiwan Spent Nuclear Fuel Final Disposal (SNFD) Program

- Taiwan Power Company (TPC) had safely operated six nuclear reactors for 40 years. As Taiwan's spent nuclear fuel (SNF) producer, TPC is responsible for managing all the SNF and proposed the **SNFD** program in 2004.
- The SNFD program has **five stages**, aiming to complete the construction and operation of a disposal repository by 2055.
- The focus of the first stage was potential host rock characterization and evaluation, which was completed and presented in the SNFD2017 report in 2017. TPC concluded the **crystalline rock within Taiwan's mainland and offshore islands is feasible**.
- For the development of Engineered Barrier System (EBS) models and localized research, TPC referred to the KBS-3 concept developed by Sweden's SKB.



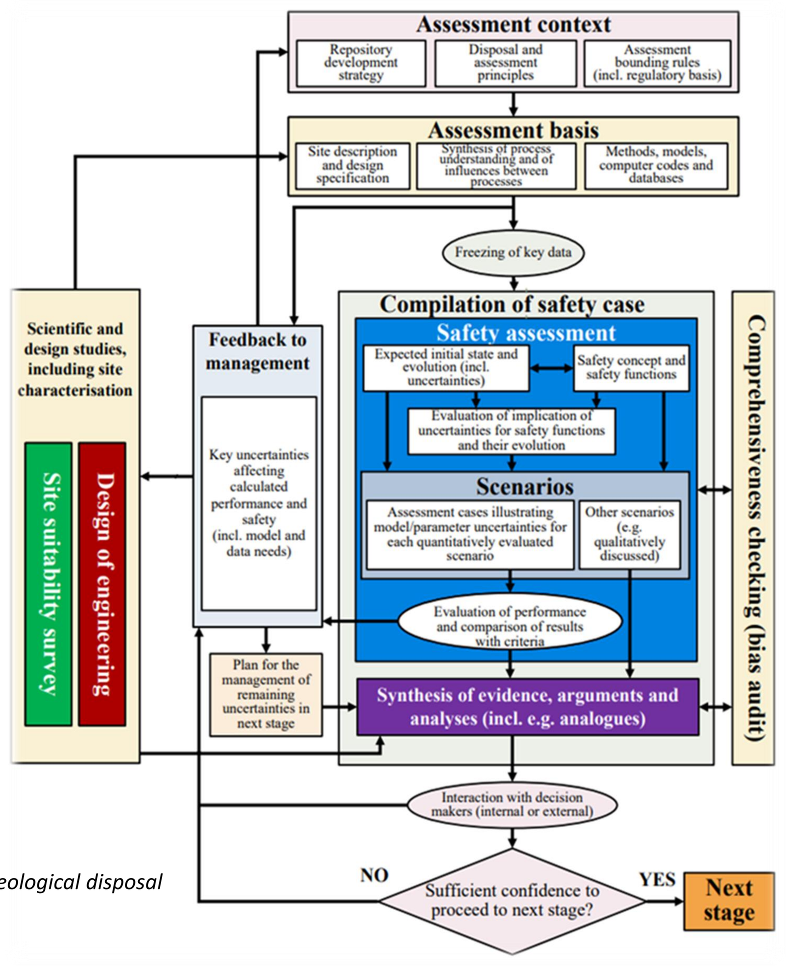
Introduction

- This study illustrates a hypothetical Site Descriptive Model (SDM) is proposed for Pre-siting Safety Case, based on its characteristics, elaborates the repository design and Engineered Barrier System (EBS) to satisfy the required safety functions.
- Demonstrate the long-term safety of the hypothetical disposal site following closure, ensuring the radiological impact on the biosphere remains acceptable.
- Integrate the above information to identify technical issues requiring further improvement and define the critical Research and Development (R&D) work needed for geological characterization, repository design, and safety assessment.

Pre-siting Safety Case

I. Methodology

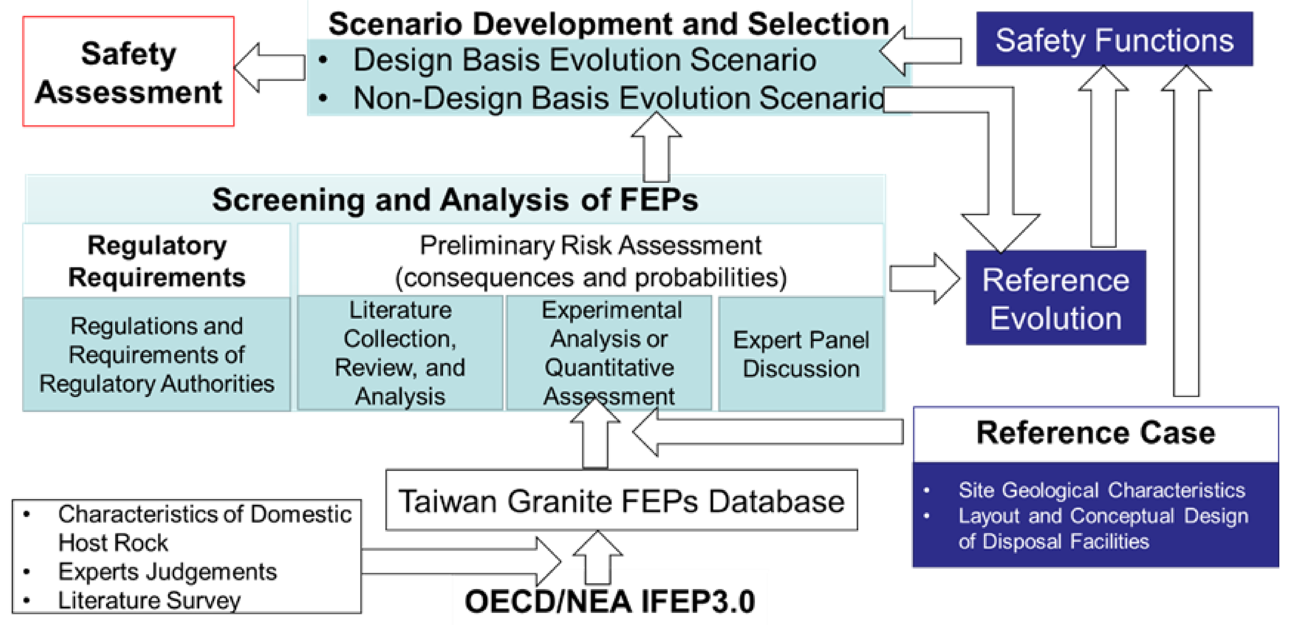
- Adherence to the International Atomic Energy Agency's safety standards, forming the global baseline for nuclear safety assessment.
- Referencing to the IAEA guidelines and NEA MeSA safety assessment methods (NEA, 2012) for systematically establish the safety assessment process.



Ref: NEA (2012). Methods for safety assessment of geological disposal facilities – Outcomes of the NEA MeSA initiative. Nuclear Energy Agency, OECD.

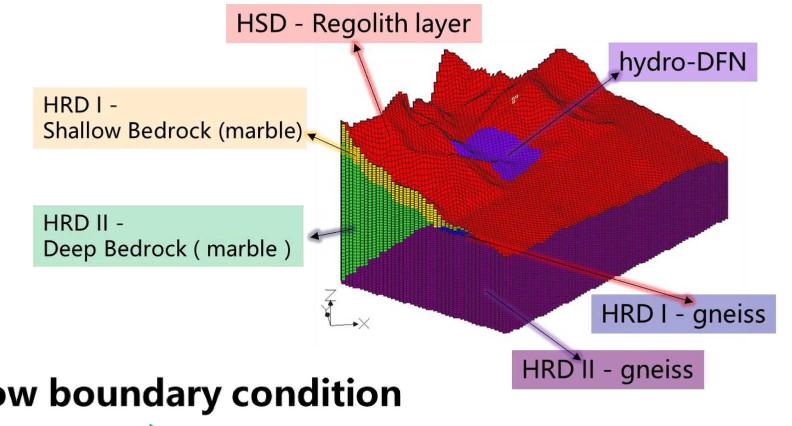
II. Systematic Scenario Development

- TPC adapted NEA IFEP 3.0 to established a Features, Events, and Processes (FEPs) system for Taiwan's environment.
- This system is used to systematically identify all future events (e.g., earthquakes, uplift) and processes (e.g., corrosion, radionuclide migration) that could affect repository safety and used for evolution analysis.

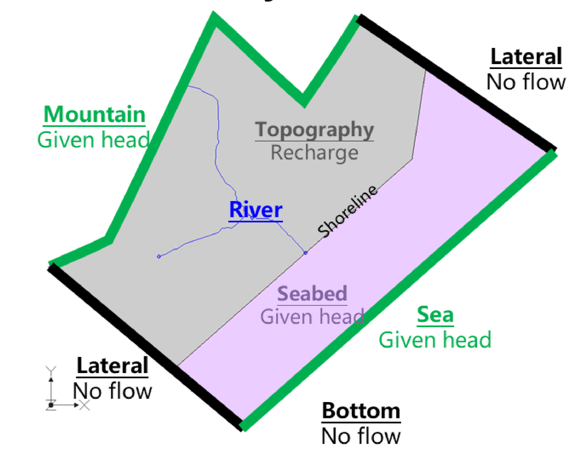


III. Hypothetical SDM (Site Descriptive Model)

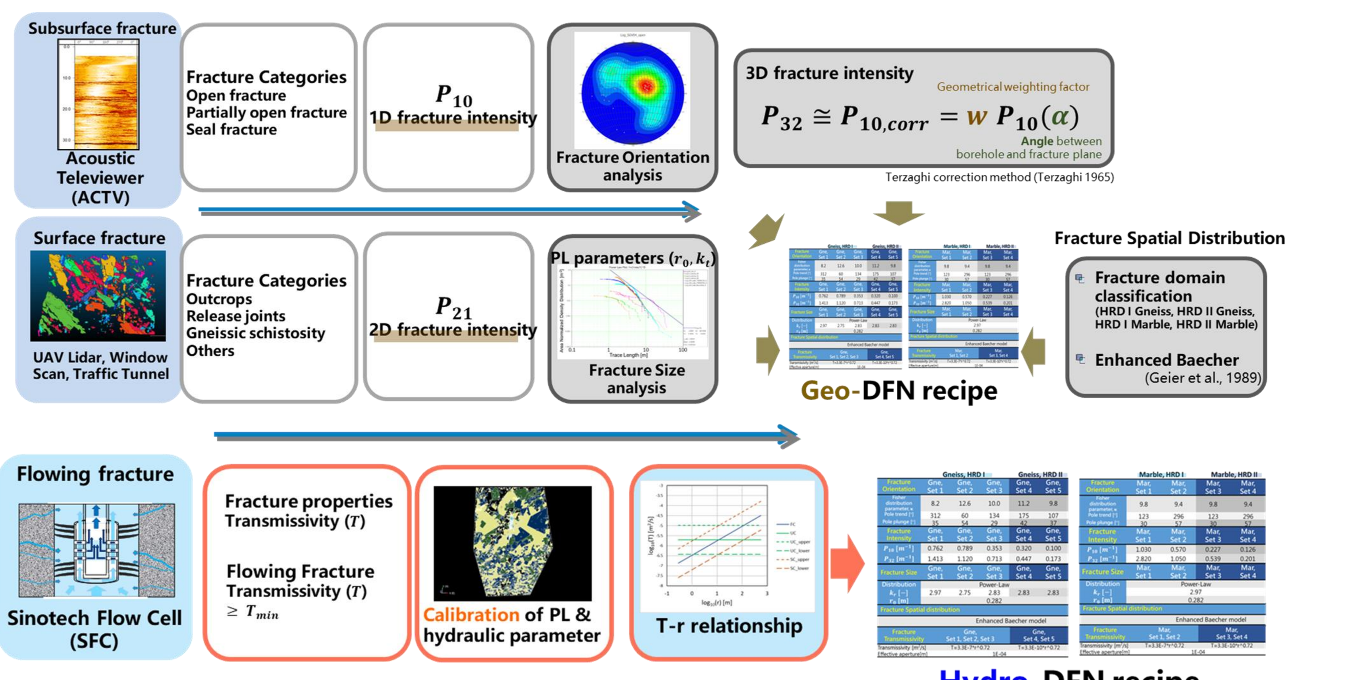
- The SDM range includes land and part of the sea.
- The boundaries are simplified to straight lines, and there is a stream located in the middle area of the model.
- Input rock mechanical parameters of marble and gneiss.



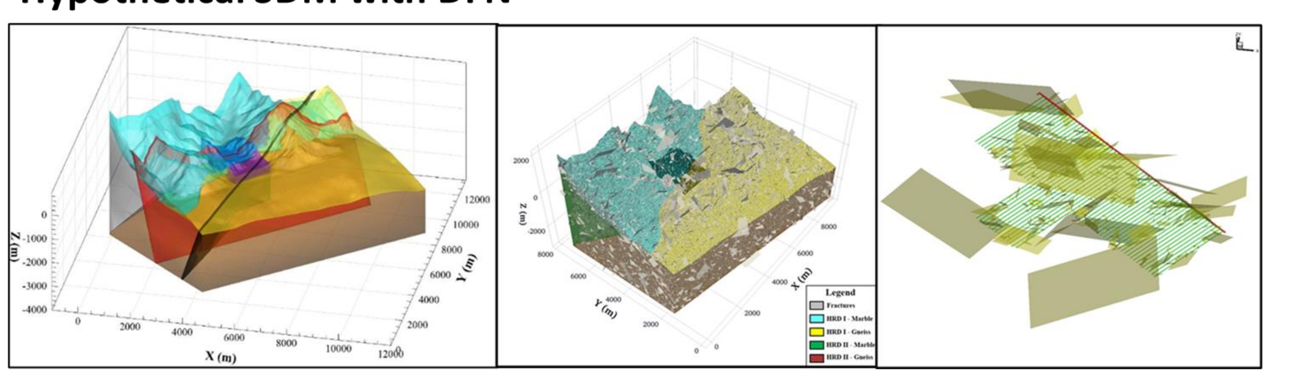
Flow boundary condition



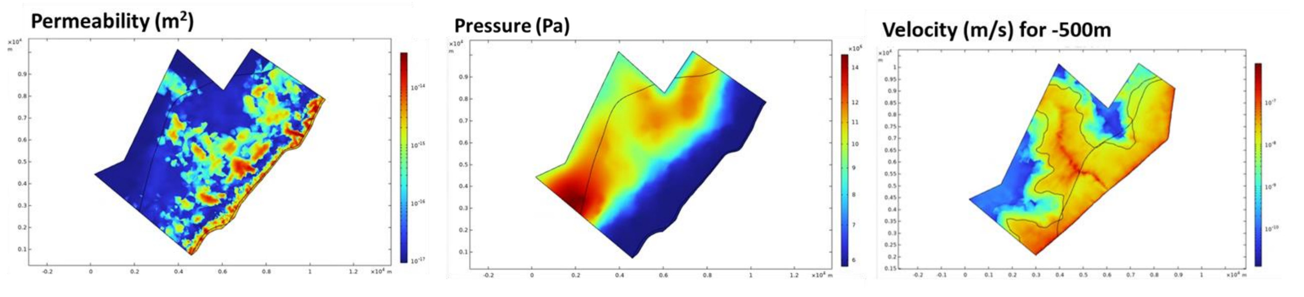
- Fracture data analysis (Subsurface, Surface, Flow meter).
- Data from different fracture domain.
- Establishment of Geo-DFN and Hydro-DFN recipe.



Hypothetical SDM with DFN

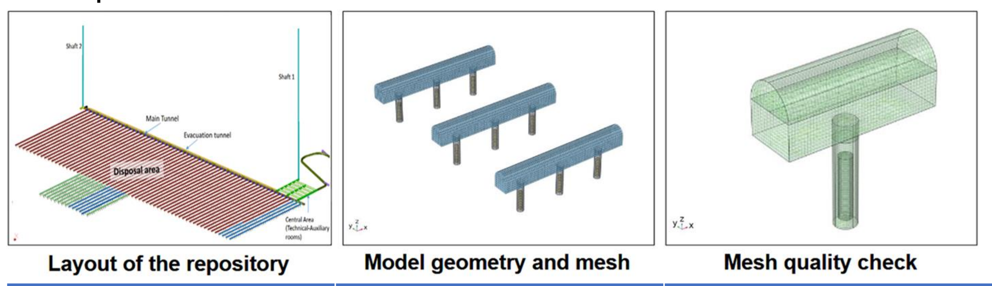


- A three-dimensional SDM with the DFN was completed, and the long-term predictions for flow rate, pressure head, and permeability were all consistent with expectations.



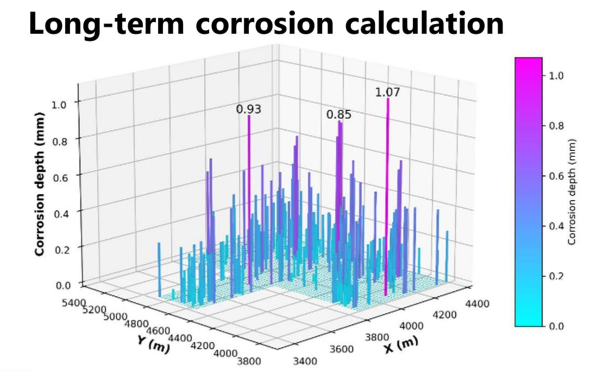
IV. Repository and EBS (Engineered Barrier System) Design

- The repository comprises 60 disposal tunnels and 3,205 disposal holes.

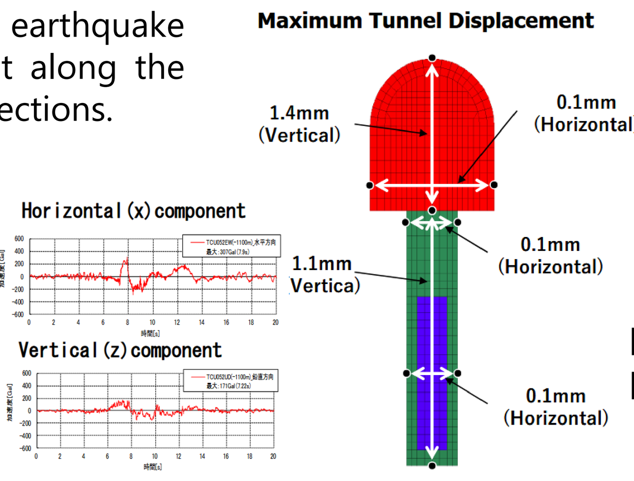


Depth(E.L.)	Hole	Tunnel Spacing
600m	12m	26m

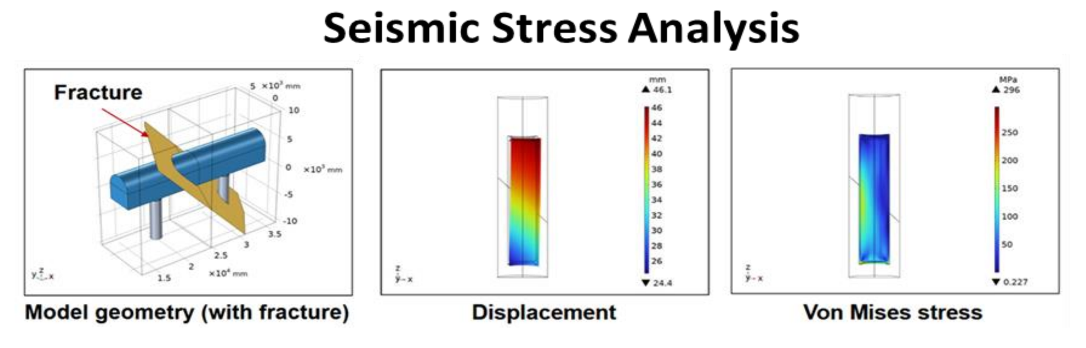
- The Sulfide is the main corrosive agent, producing Cu_2S and hydrogen.
- The main corrosion effect is uniform corrosion of the copper shell.
- The corrosion depth of the long-term corrosion source is about 1.07 mm (maximum).



- The Taiwan 1992 Chi-Chi earthquake waves were used as input along the Horizontal and Vertical directions.
- Maximum tunnel displacement at disposal tunnel is 1.4mm in vertical direction
- A maximum horizontal displacement of 4.3 mm was generated in the buffer and canister.



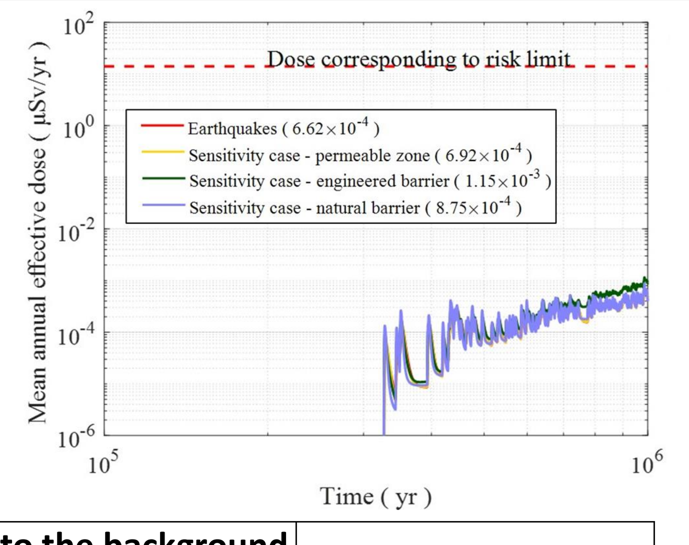
Seismic Stress Analysis



- In each seismic event, it accumulates smaller increments of slip.
- A fracture shear displacement of 5 cm is conservatively assumed in the simulation of the impact of the EBS.

V. Post-Closure Safety Assessment

- The transport resistance, advective travel time, velocity, equivalent flow rate, and equivalent initial flux at different time periods were applied to the SA.
- The integrity of the corrosion containment function remained intact.
- In Uplift of the repository case, the repository rises to a depth of approximately 300 m and the canister fails approximately 100,000 years.
- The Earthquakes and Sensitivity case adopt the current sea level, using probabilistic calculations (10,000 realizations), and assuming the buffer material is intact. The single exception is the engineered barrier case, which assumes advection in the buffer.
- Based on ICRP Publication 60 (ICRP, 1991), the radiation dose-to-risk conversion factor is 7.3×10^{-2} Sv^{-1}, corresponding to an annual effective dose limit.



Case		Peak mean annual effective dose [μSv/yr]	Occurrence time [yr]	Ratio to the background radiation [-]	Ratio with the risk [yr^{-1}]
Earthquakes		6.62×10^{-4}	9.86×10^{5}	4.73×10^{-5}	6.39×10^{-5}
Sensitivity	Permeable zone	6.92×10^{-4}	9.86×10^{5}	4.94×10^{-5}	4.46×10^{-5}
	Engineered barrier	1.15×10^{-3}	9.86×10^{5}	8.21×10^{-5}	5.88×10^{-5}
	Natural barrier	8.75×10^{-4}	9.86×10^{5}	6.25×10^{-5}	5.24×10^{-5}
Uplift of the repository		1.49×10^{1}	1.01×10^{5}	6.29×10^{-3}	9.51×10^{-5}

Conclusion

- This study adopts the main island of **Taiwan crystalline rock** data, and a **hypothetical reference case** was assumed to conduct a **Post-Closure Safety Assessment**.
- The Features, Events, and Processes (FEPs) analysis method is used to **identify characteristics** and **impacts of the multi-barrier system for long-term evolution**, considering all possible factors that could lead to radionuclide transport.
- The **high-probability** radionuclide release scenarios (including seismicity, corrosion, and repository uplift) were constructed.
- The initial thickness of the waste canister is approximately 50 mm, and even after long-term corrosion, it retains about 48 mm, which allows it to maintain long-term integrity.
- The results indicate that both the repository and engineering designs effectively fulfill the safety function and reduce the migration of radionuclides.
- Even under sensitivity scenarios, the post-closure risk of adverse effects on a critical group remains below the annual risk limit of **10^{-6}** as specified in Taiwanese regulations.