High-level radioactive waste management: R&D Challenges for the 21st Century

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Background: State-of-the-art at the start of the 21st Century

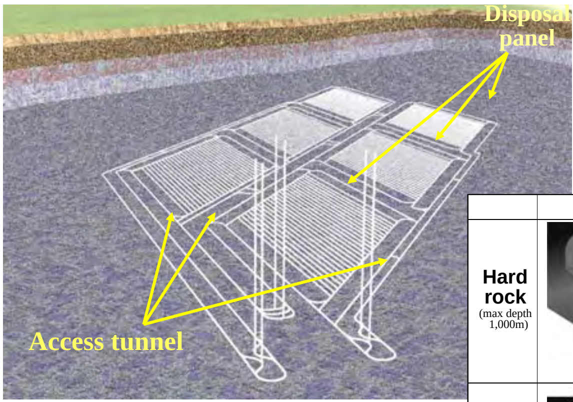
International:

- Consensus: Geological disposal of HLW is the only practical option (“alternatives” unrealistic / unacceptable)
- Progress in national programmes considerably delayed by lack of acceptance / political commitment

Japan:

- Basic feasibility documented (H3 / H12)
- NUMO established and siting initiated using volunteering approach
- Law defines basic responsibilities, but regulations and guidelines still missing

H12 Concept: idealised / site-generic



Repository layout

Emplacement of waste package

	Pit disposal	Tunnel disposal
Hard rock (max depth 1,000m)		
Soft rock (max depth 500m)		

The Challenge: Goals for the end of the 21st Century

International:

- **Many successful ongoing or completed repository projects worldwide**
- **Nuclear waste management “established” safe technology; little public concern**
- **Increasingly seen as attractive local industry (high benefits to community, low environmental impact)**

➔ Competition between communities / countries to host regional facilities

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The Challenge: Goals for the end of the 21st Century

Japan:

- NUMO repository #1 closed and under institutional control
- NUMO repository #2 fully operational (50% full)
- DIA site characterisation ongoing for repository #3
- HLW repositories integrated within national (or regional / international) management plan for all radioactive wastes

➔ Within a mature industry, R&D continues to optimise the repository system in the light of developments in science & technology and to maintain the large, experienced workforce required

The Challenge: Japanese goals for mid 21st Century

Optimisation

- NUMO repository #1 fully operational (25% full); maybe re-licensing ongoing
- PIA site characterisation(s) ongoing for repository #2
- HLW repositories becoming integrated within national management plan for all radioactive wastes

➔ R&D is strongly focused to serve the needs of the implementer (using first experience to improve designs and procedures and to develop a stronger safety case), the regulator (monitoring and inspecting operations, review of the safety case) and the local public (clear information on key scientific and technical issues)

The Challenge: Japanese goals for 2025

Synthesis

- NUMO repository #1 site selected; licensing process started; DIA characterisation ongoing
- Decision on second DIA site; continue characterisation for repository #2 or abandon?
- 2 decades of experience at Mizunami & Horonobe; decision to continue generic work or focus on site-specific facilities?

➔ R&D serves the needs of the implementer (site-specific concept analysis to support selection, documentation for licensing), the regulator (review of the license application) and the local public (independent information on concerns)

The Challenge: Japanese goals for 2015

Integration

- NUMO repository #1 DIAs selected on the basis of parallel characterisation of a number of PIAs
- Safety assessment of site specific RCs key input for selection process
- Experience from Mizunami & Horonobe provides input for planning of site-specific URLs

➔ Safety case arguments developed by the implementer and reviewed by the regulator focus on integration of information from the field, URLs, specialist labs, natural analogues and fundamental, mechanistic models

Site selection and characterisation

Special challenges set by:

- Volunteering process; potentially
  - Several PIAs
  - Diverse host rocks and geological settings
  - Parallel characterisation
- Very short timescale
  - Selection of PIAs within a couple of years
  - Selection of DIA(s) within 5 years
- Requirements for openness & transparency

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Repository design and engineering

Special challenges set by:

- Volunteering process
  - RC needs to be tailored to sites
  - Potentially, range of options in each site
- Emphasis on practicality
  - Must be feasible using existing technology
  - Safety and QA essential
- Requirements for openness & transparency
- Requirements for acceptance (e.g. retrievability)

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Performance assessment: codes

Operational safety:

- Quantitative evaluation of conventional and radiological hazards
- Feedback to repository design

Post-Closure safety:

- Much greater realism (comparison of sites and concepts)
- Direct representation of time-evolution of engineered and natural barriers
- Relevant model biospheres (Japan-specific)

PA: Data / system understanding(1)

Operational safety

- Integration of information from underground construction and nuclear industry
- Special emphasis on detailed description of perturbation scenarios

PA: Data / system understanding(2)

Post-closure safety

- Integration of near-field analysis
  - Improved understanding of RN release & transport processes
  - Validation database for complex multi-component systems (e.g. glass-steel-bentonite)
- Site-specific far-field analysis
  - Rigorous “geosynthesis” (QA!) to derive site characteristics
  - Consistent representation of flow-paths on macro and micro scales
  - Explicit definition of time-evolution scenarios (including geosphere-biosphere interface)

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R&D challenges – examples (1)

- Improved understanding of RN release & transport processes
  - Solubility, speciation, sorption & diffusion data inconsistent
  - Fundamental basis of thermodynamic approach poor
    - Need to edit databases / reactions
    - Kinetic data even more limited
  - Lack of understanding limits robustness
  - Geochemical analogues suggest approach possibly greatly over-conservative

  ➔ A novel approach is needed

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R&D challenges – examples (2)

- Validation database for complex multi-component systems (e.g. glass-steel-bentonite)
  - Multicomponent experiments
  - Integrated laboratory, in-situ and natural analogue programme
  - Large physical scale and long timescale studies essential
  - Development & use of state-of-the-art analytical technology
  - Careful synthesis of data with full analysis of uncertainties
  - QA!

R&D challenges – examples (3)

- Rigorous “geosynthesis” (QA!) to derive site characteristics
  - Integration throughout planning, site characterisation & data synthesis
  - Multi-disciplinary teams including experts in all key areas (geology, hydrogeology, geophysics, geochemistry, …)
  - Close links with end-users (design engineers, PA teams)
  - Generalists to carry out both integration and review (esp. for regulator)
  - Quality management!

R&D challenges – examples (4)

- **Consistent representation of flow-paths on macro and micro scales**
  - **Hydrogeology evaluated on scales of 10s or 100s of km**
  - **Solute retardation analysis (sorption, matrix-diffusion) requires detail on cm scale (or finer)**
  - **PA traces solute transport paths through EBS, EDZ, host-rock, surrounding formations and into the biosphere**

  ➔ **To integrate these requirements, a novel approach is needed**

R&D challenges – examples (5)

- **Explicit definition of time-evolution scenarios (including geosphere-biosphere interface)**
  - **PA considers a million-year time horizon**
  - **The EBS, geosphere and biosphere will evolve dramatically over this period**
  - **Distinct events and continuous evolution should both be considered**
  - **The biosphere can only be evaluated with idealised representations, but major evolution (e.g. GBI in coastal sites) should be explicitly considered**

  ➔ **Again a novel approach is needed**

The Challenge: Infrastructure

The next 3 decades should provide:

- Site-specific repository designs based full understanding of how characteristics of engineered and natural barriers can be combined to develop a robust safety case
- The methodology and technology to carry out all characterisation work and resultant geosynthesis with rigorous QA and transparency
- Well tested designs and procedures to ensure safety and quality of repository construction and operation

➔ Establishing required databases and practical experience requires state-of-the-art, specialist R&D facilities (allowing work with radionuclides, direct access to the deep underground environment)

The Challenge: Human Resources!

The next 3 decades are critical:

- NUMO's repository may be the first in the world focused on vitrified HLW and a volunteer siting approach
- The HLW repository will develop in parallel to other projects (Rokkasho L/ILW, TRU, "RI" wastes)
- Many licensing steps will require development and application of regulations and guidelines

➔ High demand for executive staff with long-term, multi-disciplinary experience supported by expert teams with state-of-the-art R&D facilities

3 decades ago: starting a career in nuclear waste

2 decades ago: old PNC offices - Preparation of H3

A decade ago – Entry review

The first director of a NUMO repository

The head of the regulatory organisation

…and the JNC R&D support team

Finally – to get the best people, be at the front!

In key areas, Japanese R&D groups should be world-leaders:

- Tectonics and active-fault analysis
- EBS design & optimisation
- RN chemistry / geochemistry
- Solute transport in heterogeneous rocks
- Natural analogues
- …

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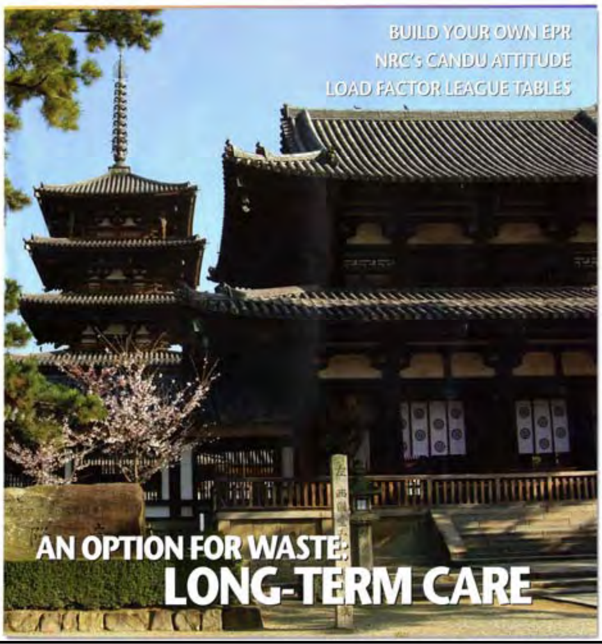
Grabbing the front page – Nuclear Engineering International



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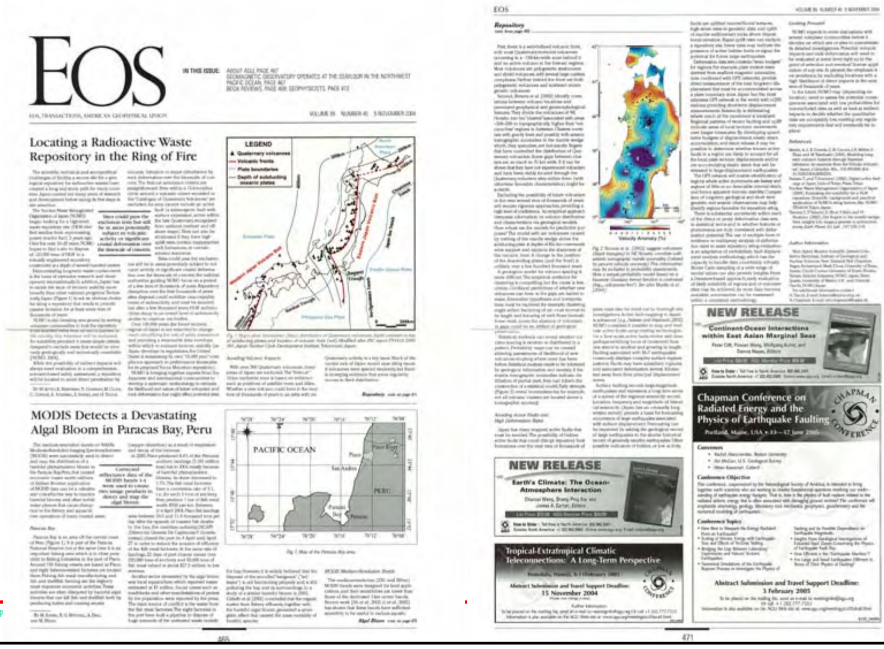
Another front page - Eos


EOS

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