Prospective Activities of Regulatory Safety Research and Development on Sub-Surface and Near-Surface Disposal

I. Background of Safety Policies Based on the Risk-informed Approach Concerning Sub-Surface and Near-Surface Disposals
II. Planned Concept of Sub-Surface Disposal Facility to be Assessed
III. Overview of “Guides for the Safety Assessment of Sub-Surface Disposal after the Termination of the Institutional Control Period (Draft)”
IV. Procedure of Regulation Support Research and Development on Sub-Surface Disposal
V. Major Current Regulatory Safety R&D on Sub-Surface Disposal and Key Technical Issues
VI. Prospective Activities of Regulation Support R&D in the Future

February 23, 2010
Hiroto Kawakami
Japan Nuclear Energy Safety Organization (JNES)
I. Background of Safety Policies Based on the Risk-Informed Approach Concerning Sub-Surface and Near-Surface Disposals

Safety case and FEP analysis
Compilation of results from the analysis of all factors that may affect the safety of disposal facilities and of the arguments that support safety
IAEA safety requirement “Disposal of Radioactive Waste” (SSR-5)
OECD/NEA international FEP list

Optimization of radiation protection within dose constraint and risk constraint for potential exposure
- Aggregated approach
- Dose/probability disaggregated approach
ICRP Pub81

Risk-informed approach

Classification of scenarios into three categories

Reactor safety goal 10-6/year
I. Risk-Informed Approach

Inherent Risk of Radioactive Waste Disposal and Difference from Reactor System

- (1) Allowance for exposures that may happen in a longer period beyond the reach of control
- (2) Longer design life of engineered barriers that are expected to provide safety functions
- (3) Allowance for the increased uncertainty with long-term prediction
- (4) Longer period for natural barriers expected to provide safety functions
- (5) Allowance for greater hypotheses in long-term safety assessment

Appropriate Selection of Burial Depth and the Reduction of Human Intrusion Risk

The burial depth should be deeper with the increased potential hazards from the radioactive waste in order to reduce the possibility of human intrusion.

IAEA safety guideline “Classification of Radioactive Waste” (GSG-1)
Comparison among Different Dose Criteria in the World

1. Risk-Informed Approach

ICRP (20-100 mSv/yr)
Severe and often critical condition, where exposure control measures may be disintegrated.

Radiation Review Council - Public's exposure by inadvertent human intrusion (20 mSv/yr max.)

ICRP dose constraint, natural process (300 μSv/yr)
Radiation Review Council - natural process (300 μSv/yr max.)

U.S.A EPA - YM (150 μSv/yr)

U.S.A EPA - YM groundwater (40 μSv/yr)

Switzerland - highly probable scenario (100 μSv/yr)

U.S.A EPA - YM whole body except the thyroid gland (25 mrem/yr)

U.S.A - LLW, thyroid gland (75 mrem/yr)

U.S.A EPA - YM (1 mSv/yr) after 10,000 years

France - HLW, basic scenario (250 μSv/yr)
(No criterion is specified for unlikely scenarios, but the dose level must be sufficiently lower than the deterministic impact level.)

U.S.A - LLW, whole body except the thyroid gland (25 mrem/yr)

Germany - non-exothermal (300 μSv/yr max.)

Hypothetical

Finland - the maximum exposure limit for HLW and the maximum public exposure level for LLW (100 μSv/yr)

Low frequency (Risk: 10^-3 / up to human life) (Occurrence frequency: 10^-2-10^-1 / assessment period) Assessment period: 1 million years

UK (Risk: 10^-6/yr, approx. 20 μSv/yr)

Sweden (Risk: 10^-6/yr, 14 μSv/yr max.)

UK - LLW, human intrusion (3-20 mSv/yr)

Finland - LLW, accident event (5 mSv/yr)

U.S.A EPA - YM (1 mSv/yr) after 10,000 years

Finland - the mean exposure level for HLW and the public exposure level for LLW (1-10 μSv/yr)

I. Risk-Informed Approach

Compiled from Nuclear Safety Commission “Criteria on Radioactive Waste Disposal in Foreign Countries” (RW 24-1) with some revisions

RW: Special Committee on Radioactive Waste and Decommissioning
II. Planned Concept of Sub-Surface Disposal Facility to be Assessed

Overview of the underground structure of a waste disposal facility

- Cavern for disposal
- Peripheral tunnel
- Access tunnel
- To ground facilities
- Concrete pit
- Low diffusivity layer
- Low permeability layer (bentonite)
- Approx. 18 m
- Approx. 13 m
- Approx. 12 m
- Approx. 14 m
- Cross-sectional view
- Longitudinal sectional view

Compiled based on information from "Report on Discussions Concerning Sub-Surface Disposal" (RW17-4) produced by the Federation of Electric Power Companies
Radioactive Wastes Planned for Disposal

MOX fuel

Uranium fuel

Spent fuel

Recovered uranium and plutonium

Reprocessing plants

MOX fuel fabrication

Uranium enrichment and fuel fabrication

Nuclear power stations

Near surface concrete pit disposal
Near surface trench disposal

Geological disposal (vitrified waste)
Geological disposal (hull end-piece, etc.)
Near surface concrete pit disposal
Near surface trench disposal

Sub-surface disposal

<Examples of waste>

Reactor internals
Channel box (CB)
Control rod

Reactor internals
Control rod
Burnable poison (BP)

Spent resin

Low level waste

High level waste

Low level waste

Examples of waste

Incombustibles
Low level concentrated liquid waste
Fire resistant stuff
Combustibles

Note: CB and BP come also from reprocessing plants.

Quantities and Characteristics of Radioactive Waste for Sub-Surface Disposal

**Total: Approx. 34,000 tons**

- **Waste from nuclear power stations:**
  - Activated/contaminated metals, etc. (10,000 tons, 28%)
  - Graphite (1,500 tons, 4%)
  - Burnable poison (280 tons, 1%)
- **Spent resin** (4,800 tons, 13%)
- **Channel boxes** (6100 tons, 16%)

**Characteristics of the waste**

<table>
<thead>
<tr>
<th>Characteristics of the waste</th>
<th>Typical examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large quantity of activated metals</td>
<td>- Channel boxes (BWR)&lt;br&gt;- Control rods (PWR control rods and hafnium control rods)&lt;br&gt;- Reactor internals (BWR/PWR)&lt;br&gt;- Graphite (GCR)</td>
</tr>
<tr>
<td>Inclusion of significant quantities of nuclides with a long half life</td>
<td>Typical examples of nuclide with a long half life:&lt;br&gt;C-14: 5.73E+03 years&lt;br&gt;C-36: 3.01E+05 years&lt;br&gt;Ni-59: 7.6E+04 years&lt;br&gt;Nb-94: 2.03E+04 years</td>
</tr>
<tr>
<td>Generation of large quantities of gas</td>
<td>- Generation of gas from the corrosion of metals&lt;br&gt;- Generation of gas from the radiolysis of water&lt;br&gt;- Generation of gas from the decomposition of organic matter</td>
</tr>
<tr>
<td>Inclusion of substances that may have impacts on engineered barriers</td>
<td>Nitrates and sulfates</td>
</tr>
<tr>
<td>Inclusion of important nuclides that are difficult to measure</td>
<td>Most nuclides except Co-60</td>
</tr>
</tbody>
</table>

Compiled from: Federation of Electric Power Companies
“Quantities and Radioactivity Concentration Levels of Waste for Intermediate Depth Disposal (C2 11-1)
Radioactivity Concentration Decay Curve of Waste in a Sub-Surface Disposal Facility

Operational waste from power stations (activated metal)

Waste from JNFL

Waste for sub-surface disposal contains significant quantities of nuclides with a long half life. The verification of the safety of sub-surface disposal facilities, therefore, requires the safety assessment over a long period. It is important that the safety assessment should address the impacts from geological uplift, erosion and sea level change if such phenomena are likely to take place around the site in a long term.

### Classification of Safety Assessment Scenarios and their Assessment Objectives

<table>
<thead>
<tr>
<th>Scenario category</th>
<th>Assessment objective</th>
<th>Standard dose value (Chapter 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Likely scenarios (Chapter 5)</td>
<td>Scenarios that address highly probable, normally expected events These scenarios account for a series of changes that are reasonably expected to take place in the repository system and exposure pathways, or affect the characteristics thereof, in the future based on the evaluation of conditions in the past and present. These scenarios are used for assessing how well the basic design concept and policy for the repository system are configured to control the dose, arising from such changes, as low as reasonably achievable.</td>
<td>10  (\mu) Sv/yr</td>
</tr>
<tr>
<td>Less-likely scenarios (Chapter 6)</td>
<td>Scenarios that address variations that are relatively improbable but are important in the context of safety assessment These scenarios are used for assessing how well the repository system design is configured to address various uncertainties. General uncertainties in safety assessment, including uncertainties concerning properties of the geological environment, are addressed by these less-likely scenarios.</td>
<td>300  (\mu) Sv/yr</td>
</tr>
<tr>
<td>Rare natural event scenarios (Chapter 7)</td>
<td>Scenarios that address highly improbable, natural phenomena Even after including the scenarios that address relatively improbable events, there remain some uncertainties. Rare natural event scenarios are used for verifying that no additional special measure for radiation protection is deemed to be required even after giving attention to such remaining uncertainties</td>
<td>10mSv/yr~100mSv/yr</td>
</tr>
<tr>
<td>Inadvertent human intrusion scenarios (Chapter 8)</td>
<td>These scenarios address inadvertent human intrusion events. These scenarios are used to verify that adequate measures are taken to reduce the possibility of human intrusion and to control the exposure dose as low as reasonably achievable. These scenarios are also used to verify that no additional special measure for radiation protection is deemed to be required even after choosing a conservative assessment approach.</td>
<td>Residents: 1mSv/yr<del>10mSv/yr Intruders -defined individual intruders (e.g. workers): 10mSv/yr</del>100mSv/yr</td>
</tr>
</tbody>
</table>

The distinction between likely and less-likely scenarios is as reported in Nuclear Safety Commission “Basic Concept of Safety Regulation on Low-Level Radioactive Waste Disposal (Interim Report)” (July 12, 2007).

The “human intrusion and rare events scenario” in the above-mentioned interim report is now classified further into “rare natural events” and “inadvertent human intrusion scenarios”
Chapter 2 - Setup of Conditions for Long-Term Evolution Concerning the Geological Environment

2.2 Setup of Conditions for Phenomena Caused by Plate Motions
   - Formation of magma
   - Deformation of geological structures
     - Tectonic earthquakes
     - 2.2.2 Earthquakes and fault Movements

2.3 Setup of Conditions for Phenomena Caused by Climate Change
   - Changes in solar radiation, air currents and ocean currents
     - 2.3.2 Ambient temperature and precipitation
       - 2.3.3 Groundwater recharge volume

2.4 Setup of Conditions for Related Phenomena to Both Plate Motions and Climate Changes
   - Changes in the erosion base level
     - 2.4.1 Geomorphological changes
       - 2.4.3 Surface water flows
       - 2.4.2 Groundwater flows

### Chapter 3 - Setup of Conditions for Biosphere in the Future

**Step 1**

**Review Assessment Context**

**Biosphere system pre-defined by explicit legislation or guidance?**

- **No**
  - Identify and justify primary components of biosphere system(s)

- **Yes**
  - Describe pre-defined biosphere system(s)

**Step 2**

**Biosphere system change to be considered?**

- Describe constant biosphere system(s)

- Identify and justify selection of mechanisms causing change

- Identify potential impacts on the biosphere system

- Identify qualitatively different possible futures

**Step 3**

**Select approach to represent biosphere system change**

- **Non-sequential**
  - Select appropriate biosphere systems
  - Describe alternative non-sequential biosphere systems

- **Sequential**
  - Select appropriate biosphere systems and transitions
  - Describe sequential biosphere systems

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**Stylization of exposure pathways in the case of inadvertent human intrusion:**

1. For residents around the site (exposure pathways do not differ from the case of natural migration)
2. For individual intruders (to be defined specifically)

**Stylization of exposure pathways in the case of natural events:**

1. Pathways of exposure by the use of water from river water, etc. (lake water, river water or stream water)
2. Pathways of exposure by land use (riverside area, terrain covered with sediments from river, dried lake bed, land surface near the uplifted repository, etc.)

- Pathways of exposure by land use (by inhabitation)
- Pathways of exposure by land use (by construction)

**IAEA** “Reference Biospheres” for solid radioactive waste disposal Report of BIOMASS Theme 1 of the BIOsphere Modelling and ASsessment (BIOMASS) Programme (IAEA-BIOMASS, July 2003)
Chapter 4 - Setup of Conditions for the Disposal Facilities

Structures and Components of Disposal Facilities

- Disposal Facility
  - Ground facilities
    - Receiving facility, etc.
    - Underground facilities
      - Access and peripheral tunnels
      - Cavern for disposal
      - Support and lining (*)
        - Backfill
        - Plug
        - Low permeability layer
          - Cavity filler
        - Low diffusivity layer
          - Concrete pit (*)
          - Compartment filler
          - Waste container (*)
          - Waste Form (*)
          - Support and lining (*)
    - Ground surface: Receiving facility, radiation management facility, etc.
Concepts of Multiple Barrier Structures of Sub-Surface Disposal Facilities and Their Protective Functions

Multiple barriers

Engineered barriers

Protective functions of engineered barriers

Low permeability
Low diffusivity
Sorption coefficient
Low leaching rate

Natural barriers

Protective functions of natural barriers

Physical isolation
Chemical retardation

Other features (physical resistance against inadvertent human intrusion)
### III. Report Overview - Chapter 4

**Guides for the Setup of Conditions of Disposal Facilities for Different Time Periods**

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Protective functions / characteristics of engineered barriers and the environmental conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Transient period</strong> Time up to the stable conditions or the settling of changes in the states of the repository and the peripheral geological environment</td>
</tr>
<tr>
<td></td>
<td><strong>Period during which safety depends much on multiple barrier functions</strong> In this period, evolutions in the repository conditions are expected to be slow, because of the long-term stability of the geological environment.</td>
</tr>
<tr>
<td></td>
<td><strong>Period during which natural barrier functions are expected to play a major role</strong> In this period, the impacts of internal and external factors, which are difficult to exclude or reduce their effects from the setup of repository conditions, become manifest.</td>
</tr>
<tr>
<td></td>
<td><strong>Period during which the repository is expected to come close to the ground surface</strong> In this period, the repository is expected to come close to the ground surface as a result of phenomena such as uplift, erosion and sea level change</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Policies concerning the setup of conditions</th>
<th>protective functions of engineered barriers:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Retardation of nuclide migration</td>
</tr>
<tr>
<td></td>
<td>- Physical resistance against inadvertent human infusion</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Properties of engineered barriers:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Low permeability</td>
</tr>
<tr>
<td>- Low diffusivity</td>
</tr>
<tr>
<td>- Sorption coefficient</td>
</tr>
<tr>
<td>- Low leaching rate</td>
</tr>
<tr>
<td>- Other properties (mechanical properties, etc.)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Setup of the environmental conditions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Temperature (heat)</td>
</tr>
<tr>
<td>- Hydraulic conditions</td>
</tr>
<tr>
<td>- Dynamic conditions</td>
</tr>
<tr>
<td>- Chemical conditions</td>
</tr>
</tbody>
</table>

### Post-closure phases

- Ensure that engineered barriers are expected to withstand damage and degradation sufficiently well even when subjected to nonuniform progress of transient.

Extrapolation based on scientific and technological bases and findings

Define conditions based on the evaluation of physical properties specific to barrier materials and functions inherent to natural barriers, assuming a conservative approach to uncertainties.

- Define conditions that accord with the setup of conditions for the near-surface geological environment.

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The illustrations of various phases are taken from "Policies Concerning the Setup of Long-Term Conditions for Engineered barriers (draft)" (Document No. 15-2 for the Class-2 Waste Burial Disposal Subcommitte) from the Central Study Institute of Electric Power Industry.
# Chapter 5 - Setup of Likely Scenarios

<table>
<thead>
<tr>
<th>Likely scenarios for groundwater</th>
<th>Transient period</th>
<th>Period during which safety depends much on multiple barrier functions</th>
<th>Period during which natural barrier functions are expected to play a major role</th>
<th>Period during which the repository is expected to come close to the ground surface</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Assessment of reliability of the multiple barriers arriving at intended conditions.)</td>
<td>Likely scenario for groundwater Assessment of the robustness of protection by the engineered and natural barriers</td>
<td>Likely scenario for groundwater Assessment of the robustness of protection, provided mainly by the natural barriers</td>
<td>Likely scenario for groundwater Assessment of impacts from weathering and erosion, assuming the state of mixing with the surrounding soil</td>
</tr>
<tr>
<td>Likely scenarios for gas migration</td>
<td>Likely scenario for gas migration -If the waste package is not capable of containment: This scenario is used for assessing impacts from the radioactive gas and from the generation and migration of radioactive radiolysis gas. -If the waste package is capable of containment: This scenario is not used.</td>
<td>Likely scenario for radioactive gas migration Assessment of impacts from the generation and migration of radioactive gas Likely scenario for hydrogen gas migration Assessment of impacts from the generation of hydrogen gas by radiolysis and from the generation and migration of hydrogen gas from the corrosion of metals</td>
<td>Likely scenario for gas migration Assessment of impacts from the gas generation under the conditions of physically damaged engineered barriers and chemical environmental changes</td>
<td>(Separate assessment of impacts from radon)</td>
</tr>
<tr>
<td>Likely scenarios for land use</td>
<td>[Present land use] Likely scenarios for land use (if there is any land that can be used after contamination along or around rivers and lakes in the downstream) [Land use in the case topographical changes due to sea level change are considered] Likely scenarios for land use Assessment of impacts from the use of dried lake beds in the downstream (impacts from construction and impacts from inhabitation) [Land use in the case a terrain covered with sediments from uplift and erosion is considered] Likely scenarios for land use Assessment of impacts from the use of a terrain covered with sediments from uplift and erosion (impacts from construction and impacts from inhabitation)</td>
<td></td>
<td></td>
<td>[Land use in the case the repository is expected to come close to the ground surface] Likely scenarios for land use Assessment of impacts from the use of contaminated land (impacts from construction and impacts from inhabitation).</td>
</tr>
</tbody>
</table>
Radioactive Material Migration Pathways to the Biosphere and Their Assessment by Different Scenarios

Groundwater scenarios: Migration by groundwater

Land use scenarios: Direct or indirect contact with residual radioactive materials on rocks or in soils

Gas migration scenarios: Migration forced by gas buoyancy or pressure

All pathways of radioactive nuclides to the biosphere must be addressed (considering migration by liquid, gaseous and solid media).
Evolution of the Likely Scenario for Groundwater through Different Time Periods

**Likely scenario for groundwater addressing the transient period**
- This scenario is used for confirming the reliability of the multiple barriers arriving at intended conditions.
- Groundwater in the outside tries to flow into the space of the engineered barriers.

**Likely scenario for groundwater addressing the period during which safety depends much on multiple barrier functions**
- This scenario is used to verify that the best available technologies are employed to control the dose as low as reasonably achievable by redundant safety features provided by the engineered and natural barriers.

**Likely scenario for groundwater addressing the period during which natural barrier functions are expected to play a major role**
- This scenario is used to verify that the protective functions of the natural barriers, assisted by the functions of engineered barrier components with their inherent properties, will play a major role in controlling the dose as low as reasonably achievable.

**Likely scenario for groundwater addressing the period during which the repository is expected to come close to the ground surface**
- This scenario is used to verify the absence of any significant residual radioactivity even in the case of the repository coming close to the ground surface, causing the deteriorated repository system to mix with the surrounding soil.

Likely scenarios are used to perform assessments on highly probable and normally expected events with most probable parameters to verify that adequate measures are taken to control the dose as low as reasonably achievable in each time period.
Evolution of the Likely Scenario for Gas Migration through Different Time Periods

- **Transient period**
  Assessment of impacts from the radioactive gas and from the generation and migration of radioactive radiolysis gas

- **Period during which safety depends much on multiple barrier functions**
  i. Assessment of impacts from the generation and migration of radioactive gas
  ii. Assessment of impacts from the generation of hydrogen gas by radiolysis and from the generation and migration of hydrogen gas from the corrosion of metals

- **Period during which natural barrier functions are expected to play a major role**
  Assessment of impacts from the gas generation under the conditions of physically damaged engineered barriers and chemical environmental changes

- **Period during which the repository is expected to come close to the ground surface**
  (Independent assessment for radon-related impacts)

Waste packages for sub-surface disposal are not expected to contain any radioactive gas except for very small quantities of Tritium and methane gas, but do contain large quantities of metals. Therefore, the impacts of the hydrogen gas from the corrosion of these metals on the integrity of engineered barriers need to be assessed. In addition, in the case of the repository coming close to the ground surface, the impacts of radon, as a progeny nuclide from uranium-series nuclides, need to be assessed.
Evolution of the Likely Scenario for Land Use through Different Time Periods

① Present land use:
(if there is any land that can be used after contamination along or around rivers and lakes in the downstream)

② Land use in the case topographical changes due to sea level change need to be considered:
Assessment of impacts from the use of dried lake beds in the downstream (impacts from construction and impacts from inhabitation)

③ Land use in the case a terrain covered with sediments from uplift and erosion:
Assessment of impacts from the use of a terrain covered with sediments from uplift and erosion (impacts from construction and impacts from inhabitation)

④ Land use in the case the repository is expected to come close to the ground surface:
Assessment of impacts from the use of contaminated land (impacts from construction and impacts from inhabitation)
Assessment of Impacts from the Repository Coming Close to the Ground Surface as a Result of Phenomena Such as Uplift, Erosion and Sea Level Change

① The repository may come closer to the ground surface and to the weathering susceptible zone as a result of phenomena such as uplift, erosion and sea level change.

② It is assumed that, in the weathering susceptible zone, the deteriorated repository system is mixed with the surrounding soil. According to the velocity of uplift, radioactive nuclides are released from the repository system to the weathering susceptible zone.

③ As exposure pathways, it should be assumed that radioactive nuclides are carried from the weathered zone by the flow of groundwater, which is sustained by the rainwater recharge, until they are discharged to rivers, streams, etc.

The distribution of radioactivity concentration in the weathered zone should be considered.

④ Typical uses of land use on the ground surface above or around the closed repository should be considered.

The Likely scenario should address land use on the ground surface above or around the closed repository other than groundwater scenario to ensure the verification of the absence of any significant risk from residual radioactivity scenario.

Construction
- Direct radiation impacts from the excavated spoil
- Inhalation of dust particles from the excavated spoil

Inhabitation
- Direct radiation impacts from the excavated spoil
- Inhalation of dust particles from the excavated spoil

Ingestion of crops
- Impacts from the ingestion of agricultural products (by inhabitants)

Groundwater flow sustained by rainwater recharge
Weathering susceptible zone
Discharged to rivers, streams, etc.

Excavation by construction activities

Typical uses of land use on the ground surface above or around the closed repository:
- Construction activities
- Inhabitation
- Ingestion of crops

Construction - Direct radiation impacts from the excavated spoil - Inhalation of dust particles from the excavated spoil
Inhabitation - Direct radiation impacts from the excavated spoil - Inhalation of dust particles from the excavated spoil
Ingestion of crops - Impacts from the ingestion of agricultural products (by inhabitants)
### Chapter 6 - Setup of Less-likely Scenarios

<table>
<thead>
<tr>
<th>Transient period</th>
<th>Period during which safety depends much on multiple barrier functions</th>
<th>Period during which natural barrier functions are expected to play a major role</th>
<th>Period during which the repository is expected to come close to the ground surface</th>
</tr>
</thead>
</table>
| Less-likely scenarios for groundwater | (Assessment of factors that cause variations to the initial construction conditions) | -Typical less-likely scenarios for groundwater  
-Scenario for the partial loss of barrier functions  
Robustness assessment that assumes the partial loss of barrier functions with the aim of assessing the robustness of multiple barriers and the aim of assessing the importance of individual protective functions | -Typical less-likely scenarios for groundwater  
-Scenario for the partial loss of barrier functions | -Typical less-likely scenarios for groundwater  
-Alternative less-likely scenario for groundwater  
Use of an alternative model for representing the weathered zone  
-Scenario for the safety assessment margins against uncertainties |
| Less-likely scenarios for gas migration | - Typical less-likely scenarios for gas migration  
-Less-likely scenario for radioactive gas migration  
-Less-likely scenario for hydrogen gas migration | - Typical less-likely scenarios for gas migration | (Separate assessment of impacts from radon) |
| Less-likely scenarios for land use | [Present land use]  
-Typical less-likely scenarios for land use  
[Land use in the case topographical changes due to sea level change are considered]  
-Typical less-likely scenarios for land use  
-Scenario for the partial loss of barrier functions  
[Land use in the case a terrain covered with sediments from uplift and erosion is considered]  
-Typical less-likely scenarios for land use  
-Scenario for the partial loss of barrier functions | [Land use in the case the repository is expected to come close to the ground surface]  
-Typical less-likely scenarios for land use  
-Alternative less-likely scenario for groundwater  
Use of an alternative model for representing the weathered zone  
-Scenario for the safety assessment margins against uncertainties | |

In order to ensure that the repository system design adequately accounts for various uncertainties, less-likely scenarios are prepared to address various factors contributing to variations, which are relatively unlikely but still important in the context of safety assessment conducted with the likely scenarios. Less-likely scenarios are used to verify that it can reasonably be judged that the impacts from such variations will remain limited and the repository system is robust enough to withstand them.

General uncertainties in safety assessment, including uncertainties concerning properties of the geological environment, are addressed by these less-likely scenarios.
Guides for the Safety Assessment for less-likely Scenarios

- Analysis of factors that cause variations from the likely scenarios
  - Preparation of plural less-likely scenarios for each likely scenario

- Completeness in the identification of variation factors
  - The setup of conditions is preceded by the identification of variation factors by FEP analyses, etc.

- Probability and scientific reasonability of variation factors
  - If sufficient quantities of statistical data are available, use them to select values in the 97.5% one-sided confidence interval.
  - If sufficient quantities of statistical data are not available for addressing uncertainties in long-term safety assessment, make the best use of available scientific and technological findings to set up conditions with sufficient allowances based on a conservative approach.
  - If several parameters largely affect the assessment results, it is useful to evaluate the uncertainties with such parameters by a probabilistic method to verify reasonability in the setup of conditions.

- Assessment of the repository system robustness
  - A partial loss of safety functions is assumed to verify that the repository system does not depend excessively on any single safety feature.
  - However, it is not necessary to assume the absence of contributions from the components that have sufficiently demonstrated their reliability or from inherent properties of materials, etc., provides that such contributions are expected to persist through environmental changes, etc. Rather, scenarios should be designed to address uncertainties in long-term safety assessment.

Example of statistical data on the distribution coefficient

Aoki et al., "Study on uncertainty of safety assessment parameters for intermediate depth disposal (Ⅲ)
Example dose calculation" Autumn, 2009, AESJ
### Examples of Scenarios to Be Addressed by less-likely Scenarios for Groundwater Prepared for the Period during Which Safety Depends Much on Multiple Barrier Functions

<table>
<thead>
<tr>
<th>Waste package</th>
<th>Engineered barriers</th>
<th>Natural barriers</th>
<th>Biosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Leaching rate</td>
<td>Low permeability</td>
<td>Low diffusivity</td>
</tr>
<tr>
<td>Likely scenarios for groundwater</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Typical less-likely scenarios for groundwater</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Scenario for the partial loss of barrier functions of engineered barriers</td>
<td>□</td>
<td>□</td>
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</tr>
<tr>
<td>Scenario for the partial loss of natural barrier functions of natural barriers</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

- □: Addressed by likely scenarios for groundwater.
- □: Addressed by typical less-likely scenarios considering variation factors that are relatively improbable but are important in the context of safety assessment.
- □: Addressed in conservative assessment procedures that assume a partial loss of functions for the verification of robustness. (Such assessments are performed for radioactive materials with important safety implications and for the functions required for the protection of such materials based upon FEP analyses for actual site.)
Chapter 7 – Setup of Rare Natural Event Scenarios

- Assessment of extreme degradation by thermal or chemical effects by volcanic and igneous activities
- Assessment of mechanical failure by earthquakes and fault movements
- Formation of a short-cut pathway through the engineered and natural barriers
- Penetration of magma through the repository system
- Volcanic and igneous activities

Even after including the scenarios that address relatively improbable events, there remain some uncertainties. Rare natural event scenarios are used for verifying that no additional special measure for radiation protection is deemed to be required even after giving attention to such remaining uncertainties.
# Chapter 8 - Setup of Inadvertent Human Intrusion Scenarios

<table>
<thead>
<tr>
<th>Scenario name</th>
<th>Boring scenarios</th>
<th>Tunnel excavation scenarios</th>
<th>Extensively exploited land use scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario for the direct boring and core observation</td>
<td>- Verify the adequacy of radioactivity concentration of each waste package.</td>
<td>- Verify the adequacy of radioactivity inventory in each cavern.</td>
<td>- Verify that, even in the case of the repository coming close to the ground surface, the impacts from the inventory (and the radioactivity concentration) of radioactive materials with a long half life will not result in a dose that exceeds the dose guides suggested by the guideline.</td>
</tr>
<tr>
<td>Scenario for the formation of a short-cut of migration pathway</td>
<td>- Verify the adequacy of radioactivity inventory in each cavern.</td>
<td>- Verify the adequacy of the engineered barrier capability for retarding the migration of radioactive materials.</td>
<td></td>
</tr>
<tr>
<td>Scenario for the pumping of groundwater from a bore hole near the repository</td>
<td>- Verify the adequacy of radioactivity inventory in each cavern and the adequacy of the engineered barrier capability for retarding the migration of radioactive materials.</td>
<td>- Verify the adequacy of the engineered barrier capability for retarding the migration of radioactive materials and of the duration in which this capability is maintained.</td>
<td></td>
</tr>
</tbody>
</table>

## Scenarios for inadvertent human intrusion:

- These scenarios are used to verify that adequate measures are taken to reduce the possibility of human intrusion and to control the exposure dose as low as reasonably achievable. They are also used to verify that no additional special measure for radiation protection is deemed to be required even after choosing a conservative assessment approach.
- In order to confirm the safety of residents around the site, events connected with stylized human actions are analyzed using the most probable assumptions for following related natural processes, and therefore, these scenarios serve the purpose of verifying the probability of such impacts being successfully reduced. A conservative assessment approach, which properly accounts for uncertainties, is required for verifying the adequacy of sub-surface disposal and that no additional special measure for radiation protection is deemed to be required.
- The dose for individual intruder(s) should be estimated according to a stylized scenario, for both cases of the most probable assumptions and the conservative ones in order to estimate the maximum dose and to verify that no additional special measure for radiation protection is deemed to be required.
### Scenario for the excavation of a tunnel near the repository

- **Objective cavern:** Based on a conservative approach, assume that a tunnel is excavated across the most conservative point along a line that runs perpendicularly to the group of caverns for disposal.
- **Concentration of radioactive materials in the drainage from the tunnel:** Assume that all radioactive materials released from caverns near the tunnel flow into the tunnel.

### Scenario for the excavation of a tunnel through the repository

- **Objective cavern:** Assume the excavation of a tunnel through a single cavern for disposal. However, if two or more cavities exist on a straight line at the same depth with little distance from each other, for example, consider the total length of all these cavities.
- **Timing of excavation:** Assume that the tunnel is excavated at a time when it has become impossible to recognize the presence of engineered barriers.
- **Excavation technique:** Based on the current technology, assume a general and reasonable excavation technique that is likely to be used in consideration of the geological features (particularly of rocks) of the chosen site.
- **Geometry of excavated spoil storage place:** Make assumptions in consideration of the common geometry of spoil storage place presently chosen for the safety measures.

### Conditions to be assumed in the assessment of the adequacy of mitigation measures

- The assessment may require the setup of probable assumptions concerning the hydraulic gradient for the case that assumes the excavation of a tunnel above the repository and the inherent properties of engineered barriers.

### Conditions to be assumed in the assessment of the adequacy of sub-surface disposal

- The assessment may require the setup of conservative assumptions concerning the hydraulic gradient and the inherent properties of engineered barriers leading that larger quantities of radioactive materials may migrate.

### Exposure pathways and the residents around the site

- Assume that the drainage from the tunnel is discharged directly to rivers, etc. Address the exposure of residents who use water from these rivers, etc.

### Exposure pathways and individual intruders

- none

### Exposure pathways and individual intruders

- Address the internal and external exposure of tunnel excavation workers.
### Chapter 9 - Termination of the Institutional Control Period

<table>
<thead>
<tr>
<th>Scenario Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Likely scenarios</td>
<td>By means of the safety assessment of likely scenarios, the applicant shall present the scientific grounds about the basic design and its policy for assuring that, at a sufficient probability, the risk will be limited to $10^{-6}$/year or less with the radiological impact of $10^{-6}$ Sv/year or less.</td>
</tr>
<tr>
<td>Less-likely scenarios</td>
<td>By means of the safety assessment of less-likely scenarios that are designed to address uncertainties in the conditions assumed by the likely scenarios, the applicant shall demonstrate that the radiological impact from such uncertainties will be limited to $300$ Sv/year or less.</td>
</tr>
<tr>
<td>Rare natural event scenarios</td>
<td>By means of the safety assessment of rare natural event scenarios that are designed to address rare natural event for further assurance, the applicant shall demonstrate that the radiological impact from rare natural events will not exceed 10 mSv/year fundamentally and never exceed 100 mSv/year, or, in other words, the applicant shall demonstrate that a further special measure for radiation protection will not always be required even after the occurrence of rare natural events.</td>
</tr>
<tr>
<td>Inadvertent human intrusion scenarios</td>
<td>By means of the safety assessment of inadvertent human intrusion scenarios, which should involve the setup of such scenarios according to stylized procedures, etc., the applicant shall demonstrate that the radiological impact from inadvertent human intrusion will not exceed the criterion of 1-10 mSv/year for residents around the site, and that the radiological impact on individual intruders will not exceed 10 mSv/year fundamentally and never exceed 100 mSv/year.</td>
</tr>
<tr>
<td>Transition into the post-institutional control phase</td>
<td>Based on the comprehensive review of the results of different types of safety assessment described above, it may be judged that the possibility of the proposed disposal business achieving a transition into the post-institutional control phase is sufficiently supported by scientific grounds.</td>
</tr>
</tbody>
</table>
IV. Procedure of R&D

Procedure of Regulation Support Research and Development on Sub-Surface Disposal

Analytical study and other work projects previously conducted or participated by JNES in support of the Nuclear Safety Commission

FEPC “Quantities and Radioactivity Concentration Levels of Power Station Waste That Exceeds the Upper Bounds of Radioactive Concentration for Near Surface Disposal Specified in the Ordinance” (BD 2-2-1; October 21, 2005)

JNES and RWMC “Examples for the Classification of Safety Assessment Scenarios Based on the Risk-Informed Approach” (BD 5-Reference 1; June 22, 2006)

Assignment from Subcommittee to Update BD 6-1 in reference to “Upper Bounds of Radioactive Concentration for Burial of Low Level Radioactive Solid Waste” (NSC; May 2007), etc.

FEPC “Quantities and Radioactivity Concentration Levels of Waste for Sub-Surface Disposal (C2 11-1; Sep. 24, 2008)

JNES “Examples of Analysis Conducted with Typical Safety Assessment Scenarios for Low Level Radioactive Waste Disposal Facilities” (BD 6-1; September 19, 2006)

JNES “Update of Examples of Analysis Conducted with Typical Safety Assessment Scenarios for Low Level Radioactive Waste Disposal Facilities” (C2 7-1; May 2, 2008) in reference to JNES C2 3-2-2 with the inclusion of additional analyses based on comments from committee members

JNES “Reanalysis for the Examples of Analysis Conducted with Typical Safety Assessment Scenarios” (C2 11-2; Sep. 24, 2008)

BD: Burial Disposal Subcommittee of NSC; C2: Class-2 Waste Disposal Subcommittee of NSC
### IV. Procedure of R&D

#### key Safety Studies for Sub-Surface Disposal and Near Surface Disposal

<table>
<thead>
<tr>
<th>Fiscal year</th>
<th>~H21</th>
<th>H22</th>
<th>H23</th>
<th>H24</th>
<th>H25</th>
<th>H26~</th>
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</thead>
<tbody>
<tr>
<td><strong>Legal procedures for near surface disposal</strong></td>
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<tr>
<td>Near surface disposal</td>
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<tr>
<td>Studies on near surface disposal</td>
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<tr>
<td>- Establishment of analytical methodology for safety examination</td>
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<td>Specific procedures for the disposal of waste from research institutions, etc., and uranium bearing waste, etc., are to be discussed in reference to the disposal plans to be prepared in the future by the utilities, etc.</td>
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<tr>
<td>- Establishment of procedures for the confirmation of safety near surface disposal with or without engineered barrier</td>
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<tr>
<td>Disposal with engineered barrier</td>
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<tr>
<td>Confirmation procedures have been established for the disposal of homogeneous/uniform solidified waste package and filled-in solidified waste package</td>
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<tr>
<td>Business licensing application and safety examination</td>
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<tr>
<td>Examination of the burial disposal facility</td>
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<tr>
<td>Confirmation of waste package</td>
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<tr>
<td><strong>Legal procedures for sub-surface disposal</strong></td>
<td>NEC</td>
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<tr>
<td>Sub-Surface disposal</td>
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<tr>
<td>Studies on sub-surface disposal</td>
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<tr>
<td>- Listing of topics to be addressed by the safety examination and the establishment of analytical procedures</td>
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<tr>
<td>- Establishment of procedures for the confirmation of safety</td>
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<tr>
<td>Disposal without engineered barrier (waste from reactor facilities, etc.)</td>
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<tr>
<td>Specific procedures are to be discussed in reference to the disposal plans to be prepared in the future by the utilities, etc., and the specifications of new waste package</td>
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<tr>
<td>NEC Preparation of safety review guidelines</td>
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<tr>
<td>Preparation of judgment criteria for the safety review (as required)</td>
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<tr>
<td>Examination of the burial disposal facility</td>
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<tr>
<td>Periodical safety reviews</td>
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<tr>
<td>Business licensing application and safety review</td>
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<tr>
<td>Confirmation of waste package</td>
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</tbody>
</table>
Organizational Framework for Future R&D That Support the Regulation of Sub-Surface Disposal

Universities

JAEA - Safety Research Center

AIST - Core for Deep Geological Environment Research

Regulation-related organizations (regulation agencies, technical support organization, etc.)

Technical Support Organization - JNES

Information exchange

Utilities, etc.
- Electric power companies
- JNFL

Regulation Agency: NISA

Advices from the council

Important safety research plan

Reporting of research results

Information exchange

Academic societies
Roadmap for Safety Research for Sub-Surface Disposal

Governmental programs for basic research

Regulation agencies and regulation support organizations in overseas (IRSN, KINS, GRS, etc.)

Advices from the council

Information exchange

Joint research
Selection of Items To Be Addressed by Regulation Support R&D in the Future

Needs of NISA

“R&D items to be addressed for meeting the needs”
Overall listing of important items that are expected to require NISA’s technological judgments in the future

Establishment of evaluation methodology for safety features and behaviors of engineered barriers by engineering-scale model

1. “R&D items that remain unaddressed by other institutions” (*)
   Among the items identified as “R&D items to be addressed for meeting the needs,” those which have not been addressed by other institutions are selected.

Research and development for the safety of sub-surface disposal of reactor internals, etc.” Sub-Surface Disposal WG of the Special Committee of JAES (FY2006)

3. “R&D items that are already addressed by other institutions”
   Among the items identified as “R&D items to be addressed for meeting the needs,” those which are already addressed by other institutions are listed.

Note (*): The term “other institutions” refers to “institutions other than those which are engaged in regulation support researches.”

Preparation of data that support safety review
Preparation of analytical methodology for cross-checking
Preparation of later-stage regulatory procedures such as confirmation of waste package and facility examination

2. “Topics that should be addressed by NISA from an own standpoint”
   Among the items identified as “R&D items that have been addressed by other institutions,” those which should be addressed by NISA from an own standpoint (e.g. procedures for verifying the acceptability of assessment results produced by the utilities) are listed.

R&D Items to be addressed by regulation support organization in the future

Accumulation of domestic and international research results

Whatever resources that may contribute to the fulfillment of the NISA’s needs should be actively be used or shared after ensuring their qualities to support Safety Regulation.
V. Major Current Regulatory Safety R&D on Sub-Surface Disposal and Key Technical Issues

1. Safety R&D on Groundwater Flow Assessment
2. Safety R&D on Nuclide Migration Assessment
3. Safety R&D on Protection Capability Assessment of Engineered Barriers
Assessment using General Purpose Multidimensional Flow Analysis Code

Setup of the objective area, faults and repository location

Setup of the hydro-geological models for the objective area, boundary conditions, etc.

Groundwater flow analysis and the analysis of groundwater travel distance and time

Example of groundwater flow analysis results (profile at the elevation of -89m)

Example of groundwater migration pathway analysis results (determination of travel distance and time)
### Safety R&D on Groundwater Flow Assessment

<table>
<thead>
<tr>
<th>Assessment Objective</th>
<th>Analysis Code</th>
<th>Current Safety R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad area multi-dimensional groundwater flow assessment</td>
<td>General purpose multidimensional flow analysis codes: TOUGH2, Dtransu, MODFLOW</td>
<td>- JNES has been working toward the establishment of procedures for cross-check analysis. - JNES is preparing the Analysis Support System and Quality Assurance Support System to improve the reliability of cross-check analysis.</td>
</tr>
<tr>
<td>Near field multidimensional groundwater flow assessment</td>
<td>Same as the above</td>
<td></td>
</tr>
<tr>
<td>Groundwater flow assessment coupled with uplift, erosion and sea level change</td>
<td>Groundwater flow analysis code that accounts for upheaval, erosion and sea level change: 3D-SEEP</td>
<td>- JAEA Safety Research Center is consigned by NISA to develop the code mainly for the safety assessment of geological disposal. - At present, an experiment for verification of the code is jointly conducted by JAEA, AIST and INES at the JAEA’s Horonobe Underground Research Center.</td>
</tr>
</tbody>
</table>
V.1 Groundwater Flow Assessment

Verification of Groundwater Flow Analysis Code (3D-SEEP) That Accounts for Uplift, Erosion and Sea Level Change:

- **SAB-1 boring hole** (in the premises of the Horonobe Underground Research Center; 512m deep)
- **Coverage of the broad area groundwater flow analysis** by the Horonobe Underground Research Center
- **Proposed site for SAB-2 boring hole** in the recharge area (about 700m deep)
- **Proposed site for SAB-3 boring holes** in the discharge basin (total boring depth of about 300m); exact locations to be determined based on findings from activities in FY2009

**Legend:**
- Surrounding area
- Horonobe city
- Outlets

**Scope of broad area groundwater flow analysis in regulation support researches**

(40 x 60km)

**Features of 3D-SEEP Ver. 2:**
- Three-dimensional analysis of saturated-unsaturated infiltration flows
- Supports steady and unsteady state analysis.
- Allows consideration of density gradient of seawater, etc. (only in unsteady state analysis mode).
- Supports evolutionary changes of boundary conditions such as the water level, seawater level and rainwater recharge.

**The project (up to FY2010) aims at verifying the analysis code in reference to boring data from a broad area (including both recharge and catchment areas) in the Horonobe region, which is characterized by noticeable geological activities that result in uplift, erosion and sea level change.**
<table>
<thead>
<tr>
<th>Nuclide Migration Assessment Methods</th>
<th>Assessment Objective</th>
<th>Current Safety R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula concerning the four important factors in groundwater scenarios</td>
<td>Simplified expression derived from the equation of nuclide diffusion by advection—Contributes to qualitative and quasi-quantitative understanding of major factors that impact the assessment of exposure dose</td>
<td>Suzuki et al., “A study on safety assessment methodology of radioactive waste disposal facility with multiple engineered barrier system”, Nuclear Power Backend Study, Vol.15, No. 2, pp. 87-98</td>
</tr>
<tr>
<td>One-dimensional nuclide migration modeling for groundwater scenarios with the consideration of the degradation of engineered barriers</td>
<td>Safety assessment models that account for various uncertainties about parameters and the impacts of the degradation on parameters that have major impacts on safety assessment</td>
<td>JNES “Reanalysis for the Examples of Analysis Conducted with Typical Safety Assessment Scenarios” (C2 11-2)</td>
</tr>
<tr>
<td>One-dimensional nuclide migration modeling with the consideration of changes in travelling pathways through natural barriers</td>
<td>Assessment models that account for evolutionary changes in travelling pathways and time due to uplift, erosion and sea level change</td>
<td>JNES “Reanalysis for the Examples of Analysis Conducted with Typical Safety Assessment Scenarios” (C2 11-2)</td>
</tr>
</tbody>
</table>
-Suzuki et al., “THE DEVELOPMENT OF HIGH PERFORMANCE NUMERICAL SIMULATION CODE FOR TRANSIENT GROUNDWATER FLOW AND REACTIVE SOLUTE TRANSPORT PROBLEMS BASED ON LOCAL DISCONTINUOUS GALERKIN METHOD”; Collection of Papers by the Japan Society of Civil Engineers, Vol. 65 No. 3, pp. 703-715, August 2009 |
### Formula Concerning the Four Important Factors In Groundwater Scenarios: $Di = Qi \times Ei \times Gi \times Bi$

<table>
<thead>
<tr>
<th>$Di$</th>
<th>$Qi$</th>
<th>$Ei$</th>
<th>$Gi$</th>
<th>$Bi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure dose (Sv/y)</td>
<td>Radioactivity inventory (Bq)</td>
<td>Performance indicator for the nuclide migration control capability provided by engineered barriers (1/y)</td>
<td>Performance indicator for the isolation provided by natural barriers (-)</td>
<td>Biosphere dose conversion indicator (Sv/Bq)</td>
</tr>
</tbody>
</table>

### Four factors that determine the exposure dose:
1. Radioactivity inventory of the disposed waste
2. Nuclide migration control capability of engineered barriers
3. Isolation provided by natural barriers
4. Biosphere dose conversion factor

#### Qi: gross radioactivity[Bq]

$$Ei = f(\xi, \eta_i, \lambda_i)$$

- $\xi$: leaching rate [-/y]
- $\eta_i$: migration rate [-/y]
- $\lambda_i$: decay constant [-/y]

$$\eta_i = \frac{Fa + Fd_i}{Fr_i}$$

- $Fa$: advection parameter [-/y]
- $Fd_i$: diffusion parameter [-/y]
- $Fr_i$: retardation parameter [-/y]

#### Gi

$$Gi = \left(\frac{1}{2}\right)^{\frac{T_{eff,i}}{T_{1/2,i}}} g(D)$$

- $T_{eff,i}$: effective travel time [y]
- $T_{1/2,i}$: half life [y]
- g(D): dispersion distance correction term

#### Bi

$$Bi = \mu_i \cdot C_{B,i}$$

- $\mu_i$: dose conversion factor [Sv/Bq]
- $C_{B,i}$: correction factor for dilution, concentration, etc., in the process of migration to the biosphere [-]

### Important parameters

| (1) Waste type | (1) Activated material leaching ratio | (1) Distribution coefficient for migration through natural barriers |
| (2) Permeability in the low permeability layer | (2) Permeability in the low diffusivity layer | (2) travel distance |
| (3) Effective diffusion coefficient in the low diffusivity layer | (3) Effective flow rate | (3) Migration coefficient for food products from lakes and rivers |
| (4) Distribution coefficient for migration through engineered barriers | (4) Dispersion distance | (1) Dilution volume |
| (5) Migration ratio through engineered barriers | | |

<table>
<thead>
<tr>
<th>$Di$</th>
<th>$Qi$</th>
<th>$Ei$</th>
<th>$Gi$</th>
<th>$Bi$</th>
<th>Important parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure dose (Sv/y)</td>
<td>Radioactivity inventory (Bq)</td>
<td>Performance indicator for the nuclide migration control capability provided by engineered barriers (1/y)</td>
<td>Performance indicator for the isolation provided by natural barriers (-)</td>
<td>Biosphere dose conversion indicator (Sv/Bq)</td>
<td>(1) Waste type</td>
</tr>
<tr>
<td>(1) Radioactivity inventory of the disposed waste</td>
<td>(2) Nuclide migration control capability of engineered barriers</td>
<td>(3) Isolation provided by natural barriers</td>
<td>(4) Biosphere dose conversion factor</td>
<td>(1) Activated material leaching ratio</td>
<td>(2) Permeability in the low permeability layer</td>
</tr>
<tr>
<td>(2) Nuclide migration control capability of engineered barriers</td>
<td>(3) Isolation provided by natural barriers</td>
<td>(4) Biosphere dose conversion factor</td>
<td></td>
<td>(4) Dispersion distance</td>
<td></td>
</tr>
</tbody>
</table>
One-Dimensional Nuclide Migration Modeling for Groundwater Scenarios

- Across different layers from the waste package layer to the bedrock, nuclides migrate by advection, dispersion and diffusion.
- Safety assessment is supported by one-dimensional modeling by GoldSim, in which the volumes of the concrete pit structure, low diffusivity layer and low permeability layer are.
- The uniform aggregate layer represents the backfill, support, lining and EDZ outside the low permeability layer under a single grouping.

Key technical issues concerning one-dimensional nuclide migration modeling for groundwater scenarios:
- Methods for enabling one-dimensional models to achieve equivalent and conservative representation of nuclide migration across a two-dimensional profile by advection and diffusion
- Modeling of the degradation of engineered barrier properties by aging and of the cracking of concrete
One-Dimensional Nuclide Migration Modeling with the Consideration of Changes in Migration Pathways through Natural Barriers

Key technical issues of addressing changes in migration pathways through natural barriers by one-dimensional nuclide migration modeling:

- Spatial changes in migration pathways through natural barriers and the shortening of migration pathways must be represented by changes in the travel length (or time) through natural barriers.
- Appropriateness of modeling by the combination of various elements of general purpose simulation code.
- Necessity to address denudation and deposition in the downstream watershed due to erosion.

(Uplift, erosion, etc.)
Multidimensional Nuclide Migration Modeling

Key technical issues concerning multidimensional nuclide migration modeling:

- Pursuit of higher accuracy by the improvement of numerical solution methods (better algorithms for lesser numerical dispersion values)
- Appropriateness of one-dimensional modeling of cases in which the line of hydraulic gradient does not perpendicularly go across the length of cavern
- Modeling of entire cavern (assessment of the independency of each cavity; assessment of the probability of interconnection due to EDZ and assessment also of the plug performance)

Migration behavior of radioactive materials in the presence of groundwater flow parallel to the length of cavern

In a cavern that does not have partitions, advection and diffusion may cause the radioactivity concentration to increase at the end of cavern.
V.3 Safety R&D on Protection Capability Assessment of Engineered Barriers
Assessment of Degradation of Cement Component(s)

① Leaching of hydrates from cement and the formation of secondary mineral products (Assess the impacts of the formation of pores due to leaching and the impacts of the swelling of secondary mineral products.)

② Appearance and growth of cracks due to changes in the stress field or due to degradation (caused mainly by the swelling of reinforcing bars and waste containers due to corrosion)

③ Impacts of pore water quality (Assess the impacts from salt water, soluble salts and nitrides and sulfides contained in waste package.)

④ Degradation by heat (Assess the impacts of heat from waste and the thermal impacts from igneous activities.)

Make use of relevant materials such as: Japan Society of Civil Engineers “Guides for the Setting of Nuclide Migration Assessment Parameters for Groundwater Scenarios in the Safety Assessment for Sub-surface Depth Disposal” (June 2008).
Safety R&D on Protection Capability Assessment of Engineered Barriers
Assessment of Degradation of Bentonite Component(s)

Bentonite component(s) degradation processes that require attention:

① The loss of compaction and low permeability feature of the bentonite layer with the fall of earth pressure due to uplift, erosion, etc. → JNES studies various properties of bentonite layers in exposed bentonite deposits (natural analogues).

② Loss of the low permeability feature due to chemical transformation (into Ca-type bentonite)

Photo: Bentonite deposit covered by the natural analogue study
Ultimate characteristics: inherent characteristics that can be still expected from bentonite under severe conditions produced by the combination of multiple degradation processes that should be assumed:

- Loss of compaction due to the flowage of bentonite into the pore of degraded cement component(s)
- Fall of earth pressure due to uplift or erosion, resulting in the loss of constraint on the swelling of bentonite
- Chemical degradation of bentonite (transformation into Ca-type bentonite)

[JNES is now conducting a column test (FY2009-2010).]

Test set for simulating the flowage of bentonite

- The test set is used to simulate the flowage of bentonite into degraded cement component(s), a process accelerated by the swelling of bentonite by groundwater. The experiment will enable the determination of inherent characteristics specific to bentonite (permeability, in particular) under poorly compacted conditions.

Simulation of critical conditions

- Backfill at sides (lining)
  - Increase of pores due to leaching
  - Decrease of strength

Low permeability layer (bentonite)
- Flowage into pores due to swelling
- Transformation into Ca-type accelerated by cement ingredients
Assessment of Engineered Barrier Performance in the Transient Period
Experiments for the Verification of Safety Margins for Engineered Barriers

- Engineering-scale (about 1/5) model (more than 100 years → about 2)
- Understanding of resaturation and gas migration behaviors in the low permeability layer

The following should be verified by this experiment for the verification of safety margins for engineered barriers using an engineering-scale model:

1. Stable preservation of the low permeability property
   → Using the engineering-scale model, it should be verified that the whole layer swells uniformly and the intended low permeability property is achieved without much dependence on local-scale properties.

2. Formation of gas breakthrough pathways by the growing gas pressure
   → The stress from gas pressure may concentrate at corners of the low permeability layer, producing breakthrough pathways even at a relatively low gas pressure. It should be verified that such will not spoil the integrity of engineered barriers.

3. Restoration of low permeability after the release of gas
   → It should be verified that breakthrough pathways are closed again and the low permeability property is restored due to the self-sealing property of bentonite.
VI. Prospective Activities of Regulation Support R&D in the Future

1. Safety Regulation According to the Level of Potential Hazard from Waste
2. Basic Design Reliability and Repository System Robustness
3. Ensuring of Total Safety Performance Taken in Consideration of Natural Barrier Performance
4. Preparation for Regulation Process after Safety Review
Safety Regulations According to the Level of Potential Hazard from Radioactive Waste

Based on the risk-informed approach, the safety regulations demand trench disposal, concrete pit disposal or sub-surface disposal depending on the level of potential hazard from each specific type of radioactive waste.

The contamination level of operational waste is extremely low because fuel failures are rare in recent light water reactors and the reactor water contamination level is low.

Key nuclides in waste for sub-surface disposal are difficult to measure. It is important to improve the accuracy of estimation based on calculations about activation.

FEPC: Quantities and Radioactivity Concentration Levels of Waste for Sub-Surface Disposal (C2 11-1; Sep. 24, 2008)
Basic Design Reliability and Repository System Robustness

Adequate choice of disposal depth and the robustness of engineered barriers

Robustness of the repository system by the employment of multiple barriers

Likely scenarios for groundwater

Less-likely scenarios for groundwater

Less-likely scenarios for land use

Likely scenarios for land use

Reliable basic design based on reliable estimations

The overall safety should be ensured by developing the basic design based on reliable predictions on highly probable and normally expected events with conservative approaches to both sides contradictory characteristics.
Ensuring of Total Safety Performance
Taken in Consideration of Natural Barrier Performance

Example of engineered-natural barriers combination that meets the standard dose values and ensuring of total safety performance

Objective nuclide: C-14 (half life: 5,730 yrs)
Initial radioactivity: 1.8E+15Bq
Exposure pathway: ingestion of food products from lake
### Preparation for Regulation Process after Safety Review

<table>
<thead>
<tr>
<th>Safety performance indicator</th>
<th>Waste Package</th>
<th>Engineered barriers</th>
<th>Natural barriers</th>
<th>Biosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total radioactivity inventory Qi: (Bq)</td>
<td>Migration control capability of engineered barriers: Ei (1/y)</td>
<td>Isolation capability of natural barriers: Gi (-)</td>
<td>Biosphere dose conversion factor: Bi (Sv/Bq)</td>
<td></td>
</tr>
</tbody>
</table>

#### Major factors that impact safety

<table>
<thead>
<tr>
<th>Waste package confirmation (JNES)</th>
<th>Waste characteristics</th>
<th>Retardation of nuclide migration</th>
<th>Dose conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radioactivity inventory</td>
<td>- Leaching rate</td>
<td>- Groundwater travel time</td>
<td>- Dose conversion factor</td>
</tr>
<tr>
<td>- Total radioactivity</td>
<td>Migration control capability of engineered barriers</td>
<td>- Retardation function</td>
<td>- Correction coefficient for dilution and concentration in the process of migration in the biosphere</td>
</tr>
<tr>
<td>- Radioactivity concentration</td>
<td>- Control of diffusion, control of permeation, and retardation of nuclide migration</td>
<td></td>
<td>Prevention of specific human activities, etc.</td>
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<td></td>
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<td>- Phased control</td>
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</tbody>
</table>

#### Confirmation by the regulatory authorities

<table>
<thead>
<tr>
<th>Waste package confirmation procedure</th>
<th>Facility examination (NISA, with the partial involvement of JNES)</th>
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<th>Approval of the operational safety program</th>
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#### Confirmation procedure

<table>
<thead>
<tr>
<th>Waste package confirmation procedure</th>
<th>Facility examination procedure</th>
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<th>Monitoring procedure</th>
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</table>

### Prospective Activities

- Waste package confirmation procedure
- Facility examination procedure
- Facility examination procedure
- Monitoring procedure
END

Thank you for your attention.