Current status of LLW buried disposal business and efforts to advance technology

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Preface

- JNFL's Low-Level Radioactive Waste Burial Center has been in operation since 1992, and the No. 2 Waste Burial Facility since 2000.
- Approximately 330,000 drums of waste have already been buried.
- In August 2018, the company applied for a business change permit for the expansion of the No. 3 waste burial facility and received the permit on July 21, 2021.
- The review is based on the "Regulations Concerning Standards for Location, Structure and Equipment of Class II Landfill Facilities enacted in 2013 (partially amended in December 2019) by NRA(Nuclear Regulation Authority).
- This section provides an overview of the facility and its design.

Progress of LLW disposal business

- 1984 July — FEPC(The Federation of Electric Power Companies of Japan) chairman asked the Aomori Governor and the Rokkasho Mayor for establishment of three nuclear fuel cycle facilities.
- 1985 Apr. — The Governor and the Mayor accepted the FEPC's proposal.
- 1985 July — Establishment of JNFI (the former company of JNFL)
- 1988 Apr. — Application for business permission (for construction & operation of No.1 disposal facility)
- 1990 Nov. — Its approval & start-up of construction of the Rokkasho LLW Disposal Center
- 1992 July — Merger between JNFS and JNFI (precursors of JNFL), Establishment of JNFL
- 1992 Dec. — Start-up of The Rokkasho LLW Disposal Center (No.1 disposal facility)
- 1997 Jan. — Application for the change of business (for construction & operation of No.2 disposal facility)
- 2000 Oct. — Its approval & start-up of the No.2 disposal facility
- 2013 Dec. — NRA establish "Standards for the Location, Structure, and Equipment of Category 2 Waste Disposal Facility"
  NRA :The new regulatory body, reorganized after the Fukushima-Daiichi Accident
- 2018 Aug. — Application for the change of business (for construction & operation of No.3 disposal facility)
- 2021 July — Its approval & start-up of the No.3 disposal facility

Classification of radioactive waste

<table>
<tr><th colspan="4">Type of waste</th><th>Example of waste</th><th>Disposal method</th></tr>
<tr><td rowspan="6">Waste from Nuclear Fuel Cycle Facilities</td><td rowspan="4">Waste from NPPs</td><td colspan="2">Waste below clearance level(treatable as non-radioactive material)</td><td>Most waste from decommissioning NPPs, etc.</td><td>Recycling/disposal as non-radioactive material</td></tr>
<tr><td rowspan="4">LLW</td><td>Very low-level radioactive waste (L3)</td><td>Concrete, metal, etc.</td><td>Trench disposal
Near-surface disposal without engineered barriers</td></tr>
<tr><td>Relatively low-level radioactive waste (L2)</td><td>Solidified liquid waste, spent equipment, consumables, etc.</td><td>Disposal at concrete vault
Near-surface disposal with engineered barriers</td></tr>
<tr><td>Relatively high –level radioactive waste (L1)</td><td>Control rod, Core-internals, Solidified liquid waste, etc.</td><td>Intermediate depth (over70m) disposal with engineered barriers</td></tr>
<tr><td rowspan="2"></td><td>Relatively much volume of long half-lifetime nuclides</td><td>Solidified fuel assembly parts, etc.</td><td rowspan="2">Geological disposal (over 300m)</td></tr>
<tr><td colspan="2">High-level radioactive waste</td><td>Vitrified waste</td></tr>
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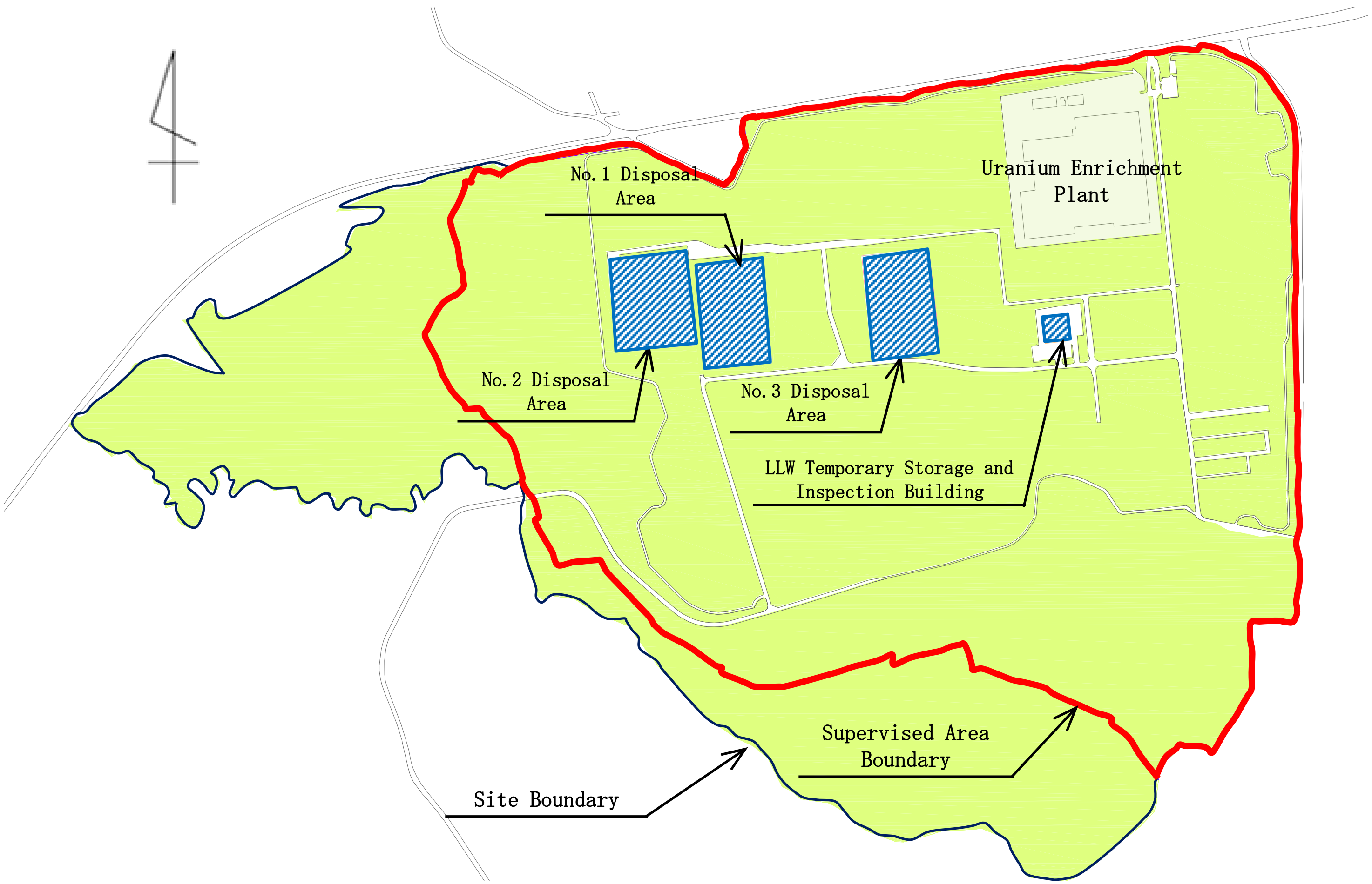
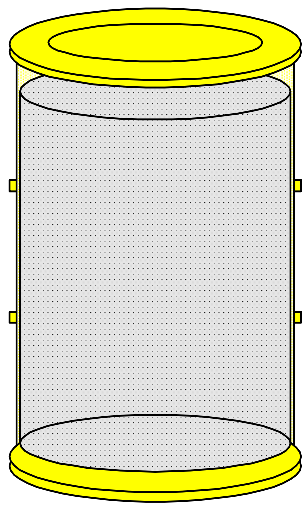
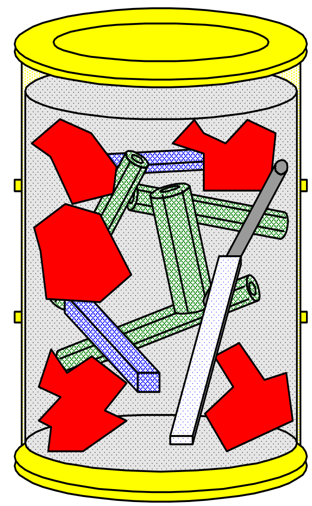
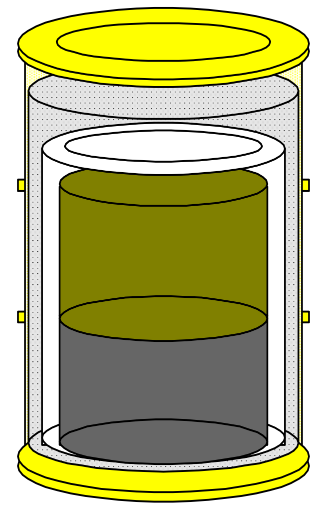
Rokkasho LLW Disposal Center

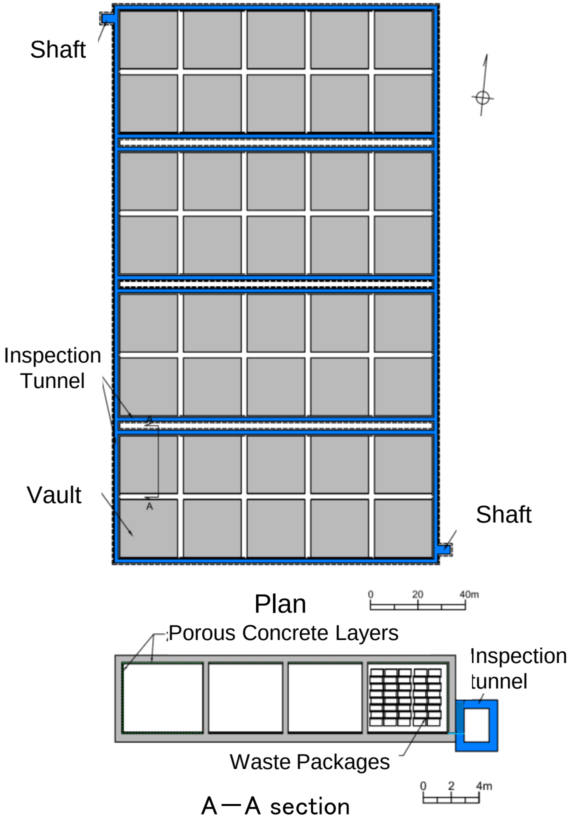


Waste

Facility	No.1	No.1、No.2、No.3	
Type of waste	Homogeneously-solidified waste	Solidified dry active waste	
		Encapsulated waste package	Melting-solidified waste package
Image of waste package			
Target waste	Condensed liquid, spent resin, etc.	Dry active waste	Dry active waste
Solidified material	Cement, asphalt or plastic	Mortar	Mortar

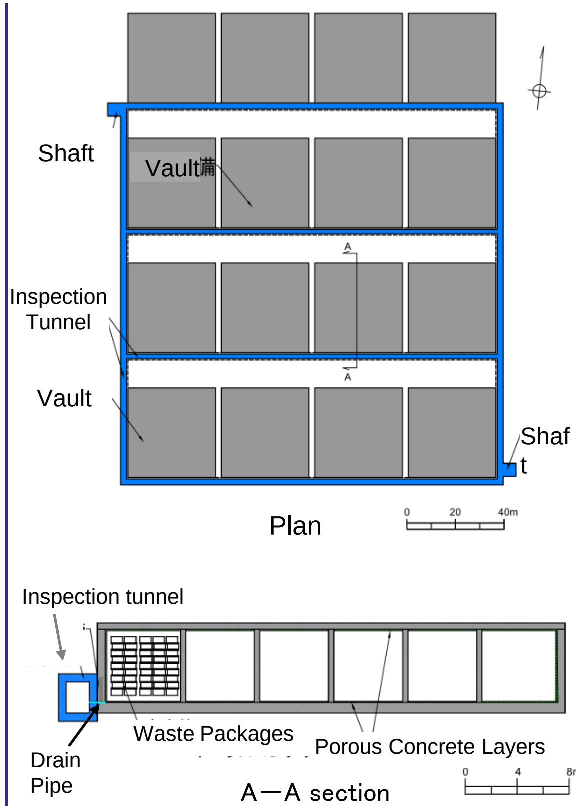
Outline of Disposal Facility

No.1



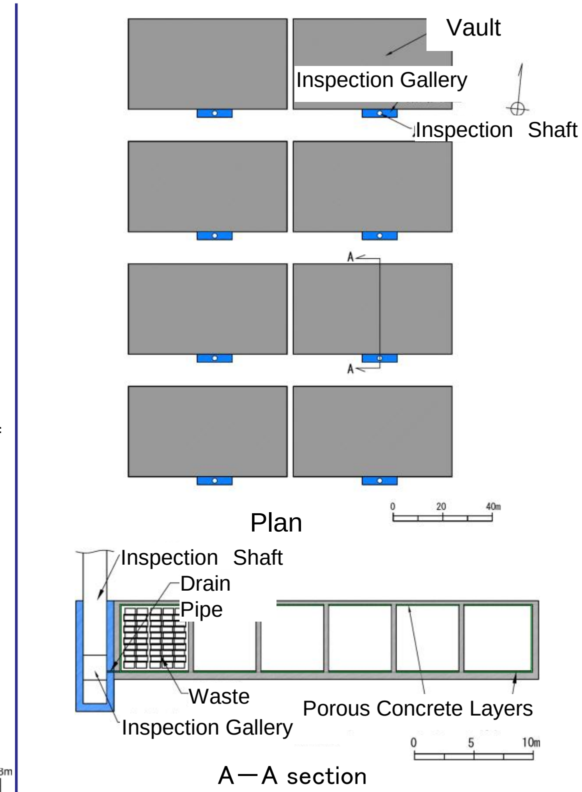
- 40Vault（1Vault：24m × 24m × 6m）
- 16block／1Vault
- Waste Package ：320drums／1block
- Total Capacity ：204,800drums
- Arrangement ：8colum × 5row × 8layers
- Waste :: Solidified dry active waste

No.2



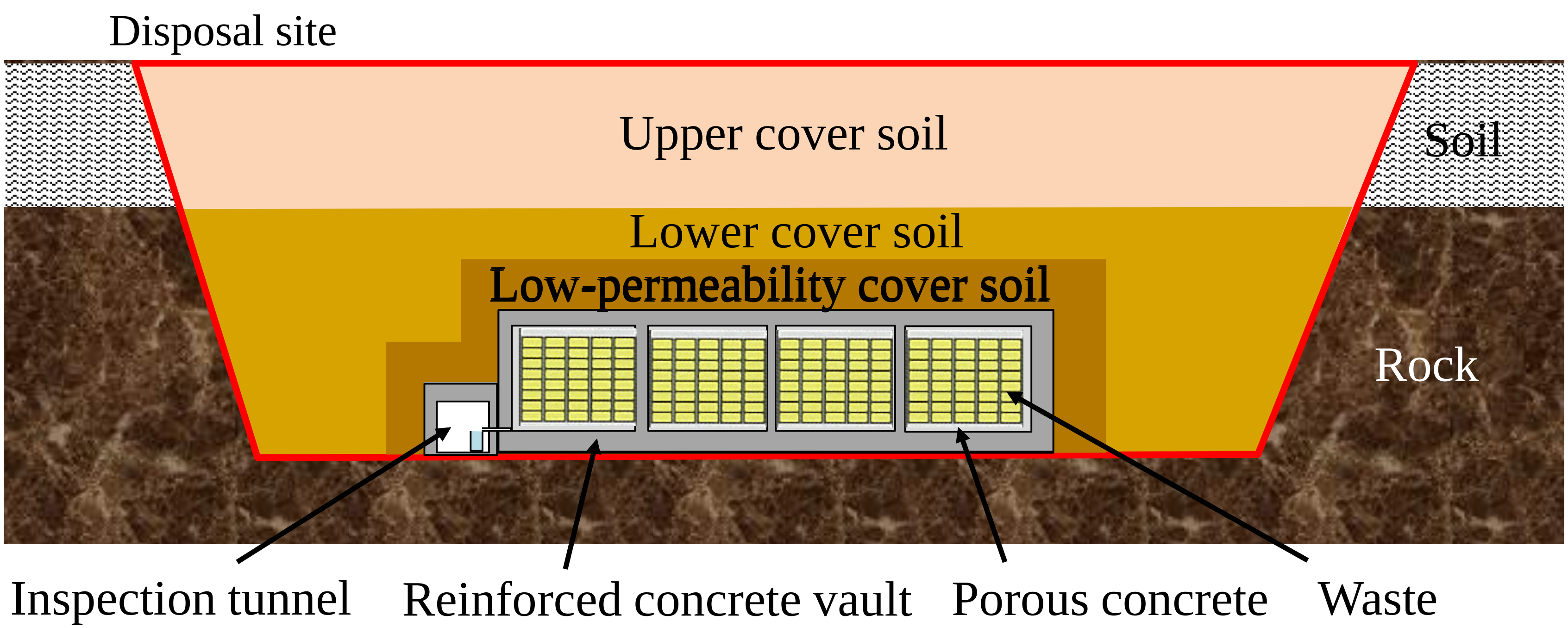
- 16Vault（1Vault：36m × 37m × 7m）
- 36block／1Vault
- Waste Package ：360drums／1block
- Total Capacity ：207,360drums
- Arrangement ：8colum × 5row × 9layers
- Homogeneously-solidified waste
  Waste :: Solidified dry active waste

No.3



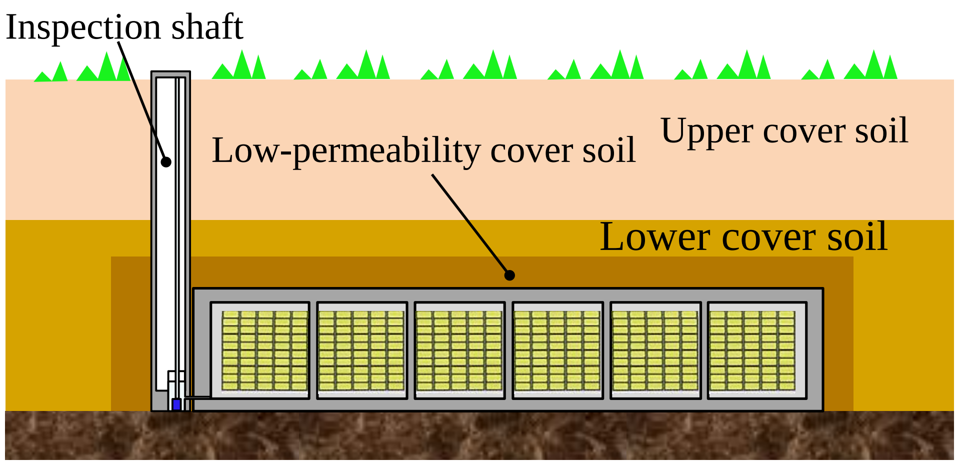
- 8Vault（1Vault：64m × 37m × 7m）
- 66block／1Vault
- Waste Package ：400drums／1block
- Total Capacity ：211,200drums
- Arrangement ：8colum × 5row × 10layers
- Waste :: Solidified dry active waste

Disposal Facility (Rokkasho No.1)



Cover Soil

No.3



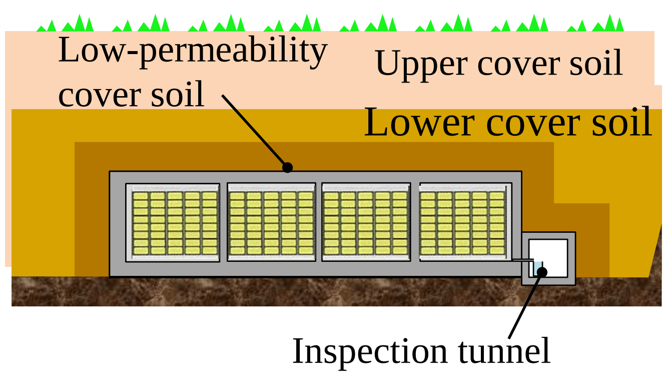
specification

Low-permeability cover soil
- bentonite sand mixture
- 2m

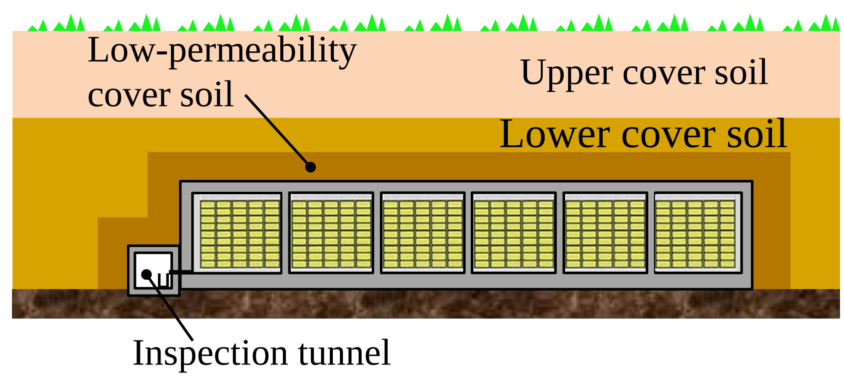
Lower cover soil
- locally-produced soil & clay
- 2m

Upper cover soil
- locally-produced soil
- To grand surface

No,1

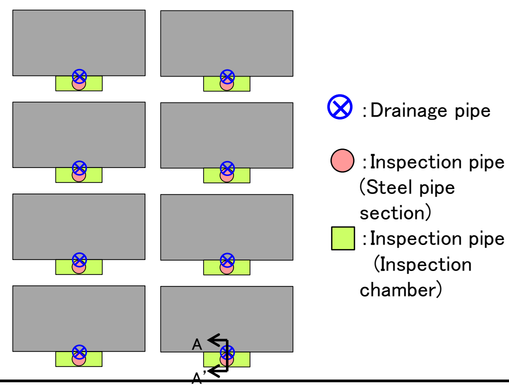
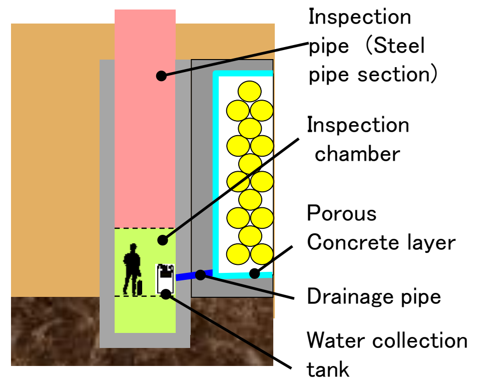
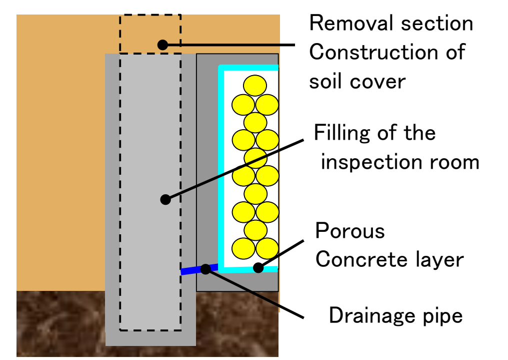
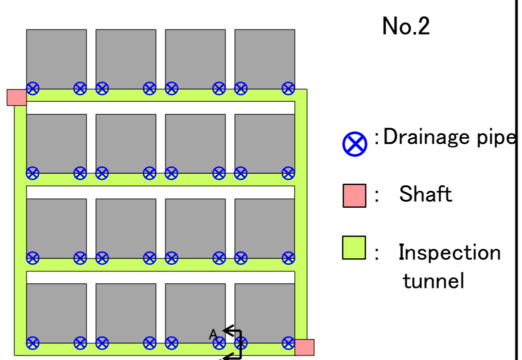
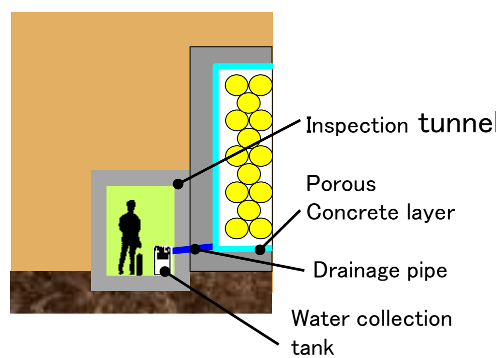
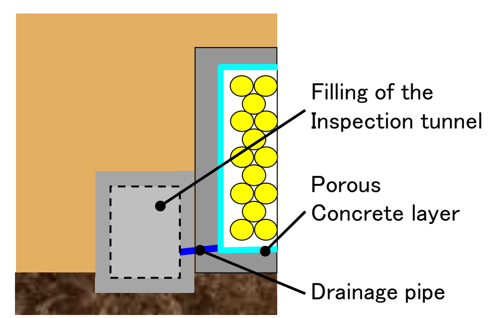


No.2



Drainage monitoring system

The waste packages should be installed in such a way that water entering the burial facility can be drained and collected during the period between the start of acceptance of the radioactive waste to be buried and the completion of the soil covering.

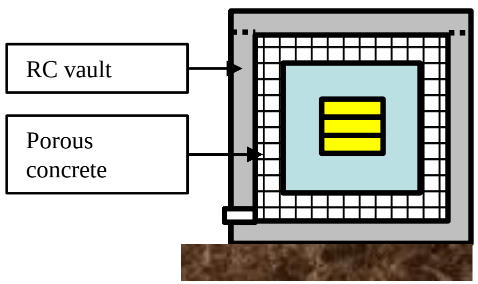
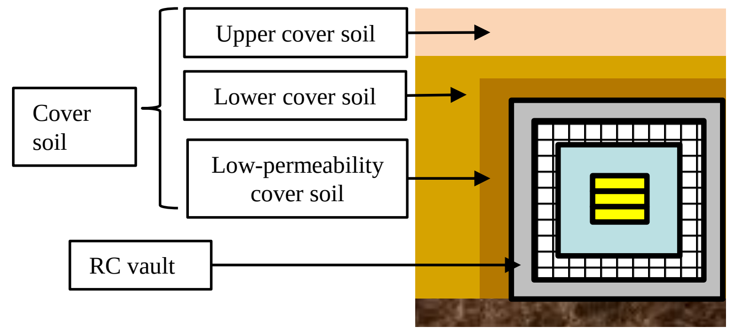
	Plan image	A-A' cross section (when soil lining is applied)	A-A' cross section (after completion of soil lining)
Inspection Pipe (No.3)			
Inspection tunnel (No,1、2)			

Operation and Control Stage

Completion of soil covering▽ Start of decommissioning Phase▽

Phase	Start of acceptance～ Completion of soil covering	Completion of soil covering～decommissioning Phase
time	27 years after the start of burial (In case of No. 3)	300 years after completion of covering
Concept	Prevention of leakage by burial facilities, etc.	Migration control by burial facilities and surrounding soil, etc.
Management details	• Establishment of burial preservation area, installation of tags at the burial site / Patrol and inspection of the burial site, repair of buried facilities and soil cover, etc. • Restoration of buried facilities and soil cover, etc. / Environmental monitoring • Periodic evaluation, etc., and monitoring of groundwater conditions related to the functions of engineered and natural barriers necessary for such evaluation, etc. • Monitoring of groundwater conditions related to the function of engineered barriers and natural barriers necessary for periodic evaluations, etc.	
	• Establishment of a perimeter monitoring zone • Monitoring of radiation dose and concentration of radioactive materials in groundwater in the vicinity of the boundary of the monitoring area • Prohibit the use of stream water, restrict excavation, and prohibit habitation.	
	• Drainage by drainage/monitoring facilities • Monitoring of no leakage (drainage/monitoring facilities)	• Monitoring of leakage (near buried site, near site boundary)

Safety Features and Structure of Disposal Facility

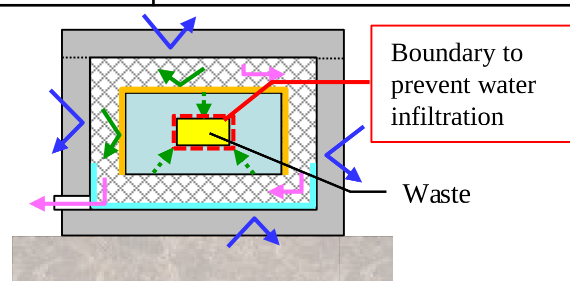
Safety functions	Before closure	
	Period until covering soil	Period after covering soil
Containment	○ (RC vault and porous concrete layer)	–
Migration retardation	–	○ (RC vault and cover soils)
Shielding	○ (RC vault)	○ (Cover soils)
Conceptual diagram		

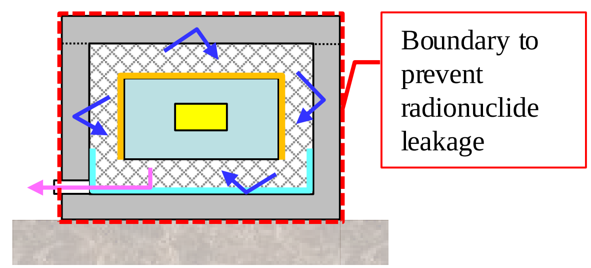
<Remarks> ○: functions are expected, –: functions are not expected, ( ): elements providing functions

Design of Containment

Elements	Legend		Expected safety functions			
	Part	Water movement	Prevention of water infiltration		Prevention of radionuclide leakage	
Reinforced concrete			○	Preventing water infiltration through vault	○	Preventing leakage through vault
Internal waterproof (bottom)			○		○	
Porous concrete			○	Draining infiltrated water	○	Collecting contaminated water
Filing mortar			○	Preventing contact between waste and water	–	
Internal waterproof (top, side)			○		–	

Conceptual diagram

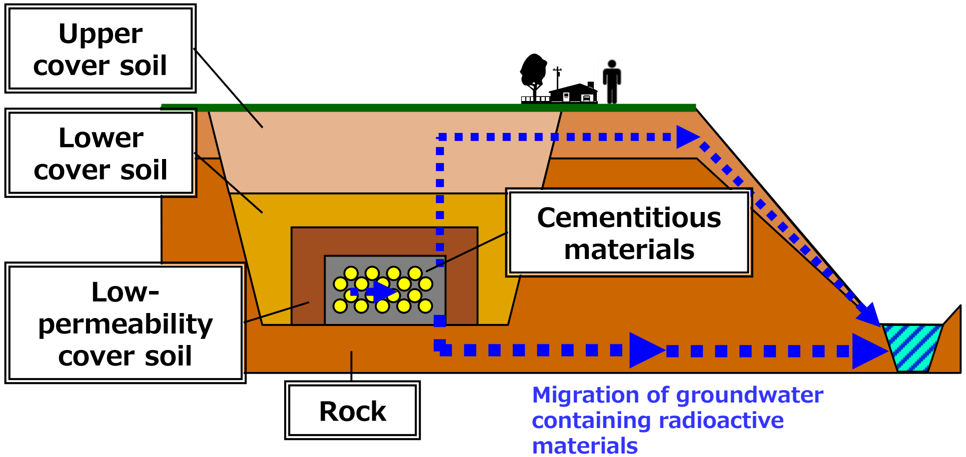




Migration Control Function

Design Concept of Migration Control Functions

Part	Expected function	
	Low-permeability*1	Adsorption *2
Upper cover soil	−	○
Lower cover soil	○	−
Low-permeability cover soil	○	○
Rock	○	○
Cementitious materials	−	○



*1 : Low permeability reduces groundwater inflow to buried facilities
*2 : Delays the migration of radioactive materials due to sorption properties

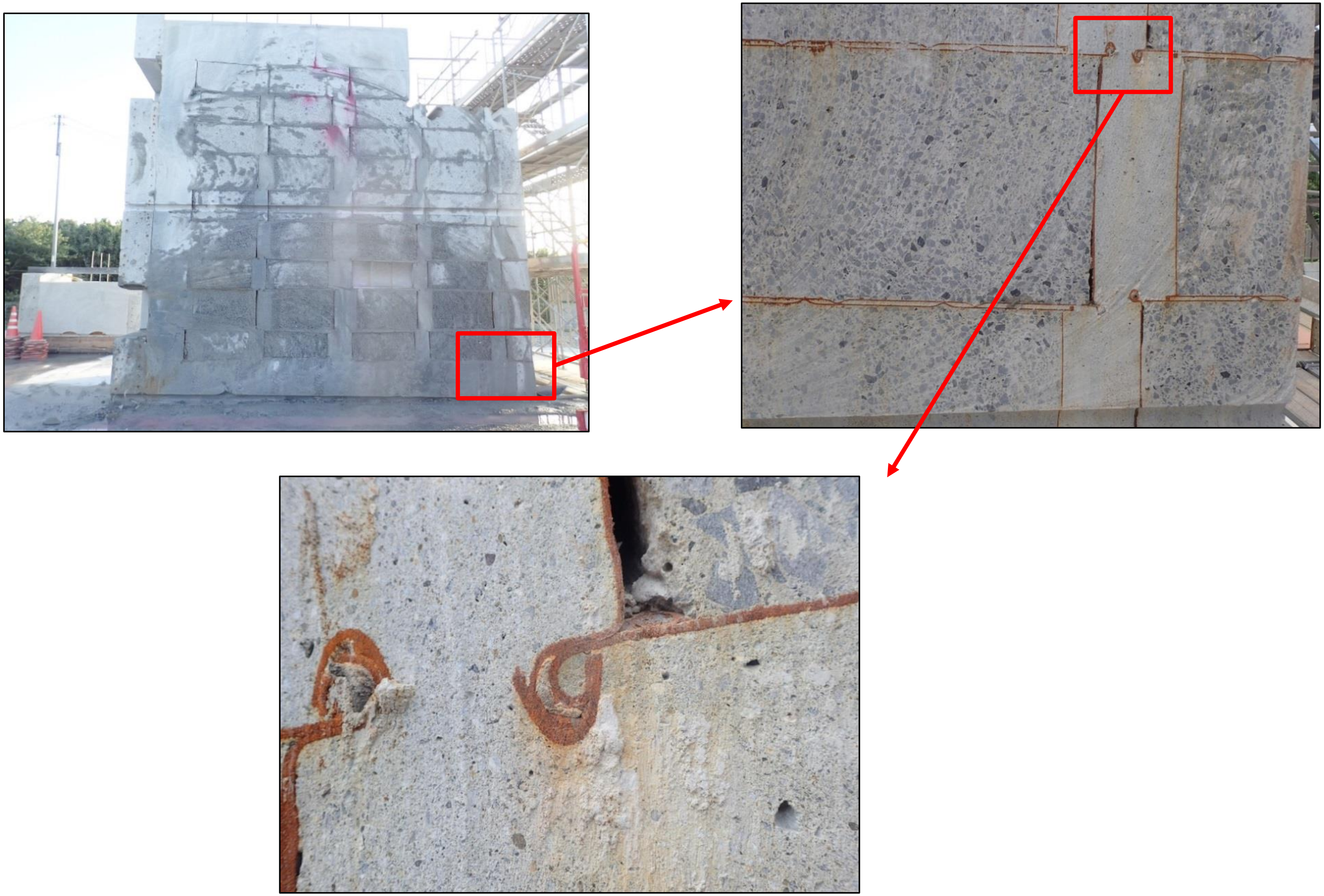
Mortar filling test

Mock-up facility

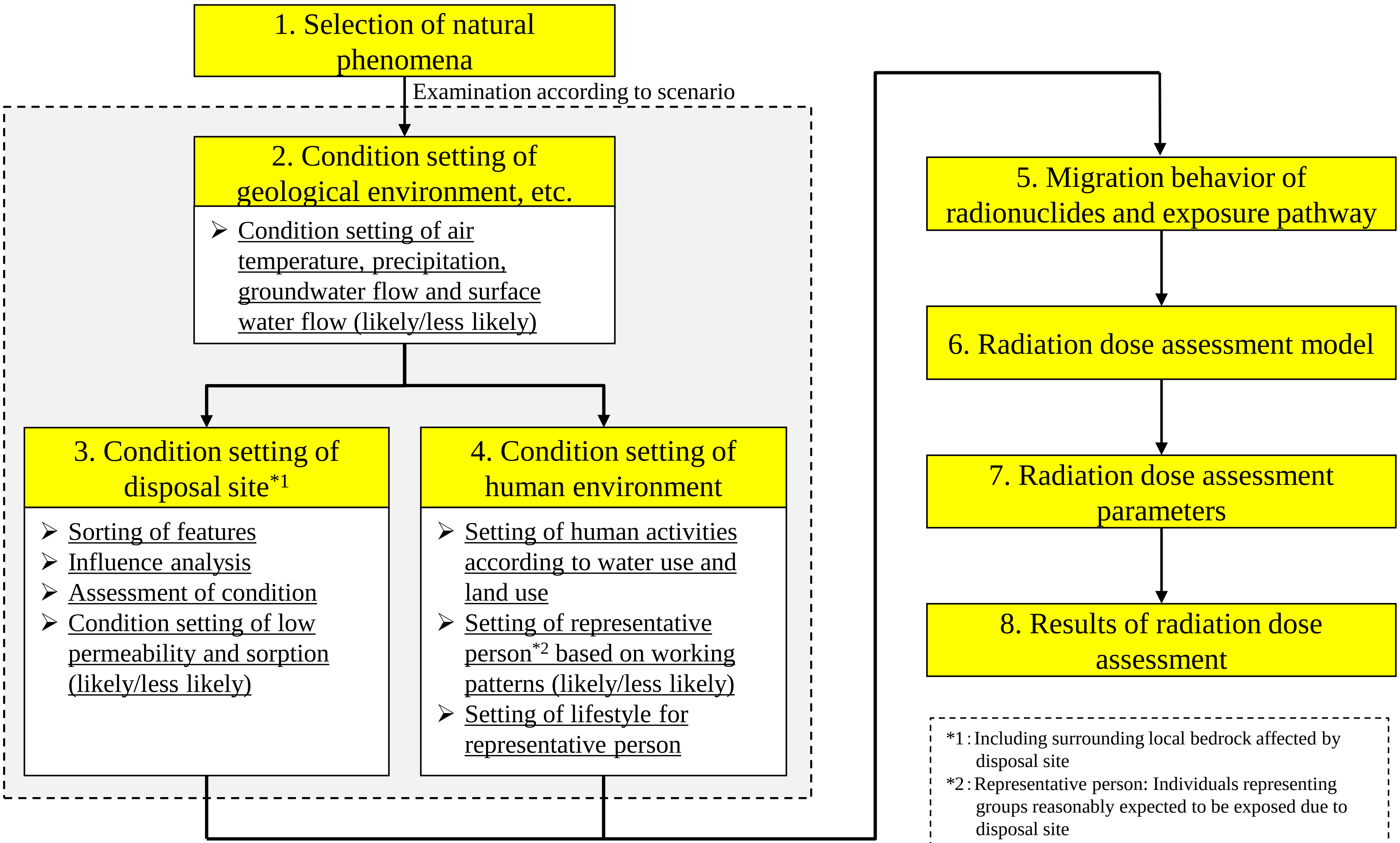
W/B (%)	S/B	Air (%)	Unit weight (kg/m³)							
			water W	Bonding material B			Fine aggregate S		Non-separable mixing agents in water	Super AE water reducer SP8HVM
				Moderate-heat cement	Blast furnace slag Micro powder	expansion	sand	Land sand		
55.0	3.17	5.0	252	458			1,454		1.1	4.58 B ×1.0 %
				131	307	20	872	582		

Mortar Composition

Mortar Filling Test



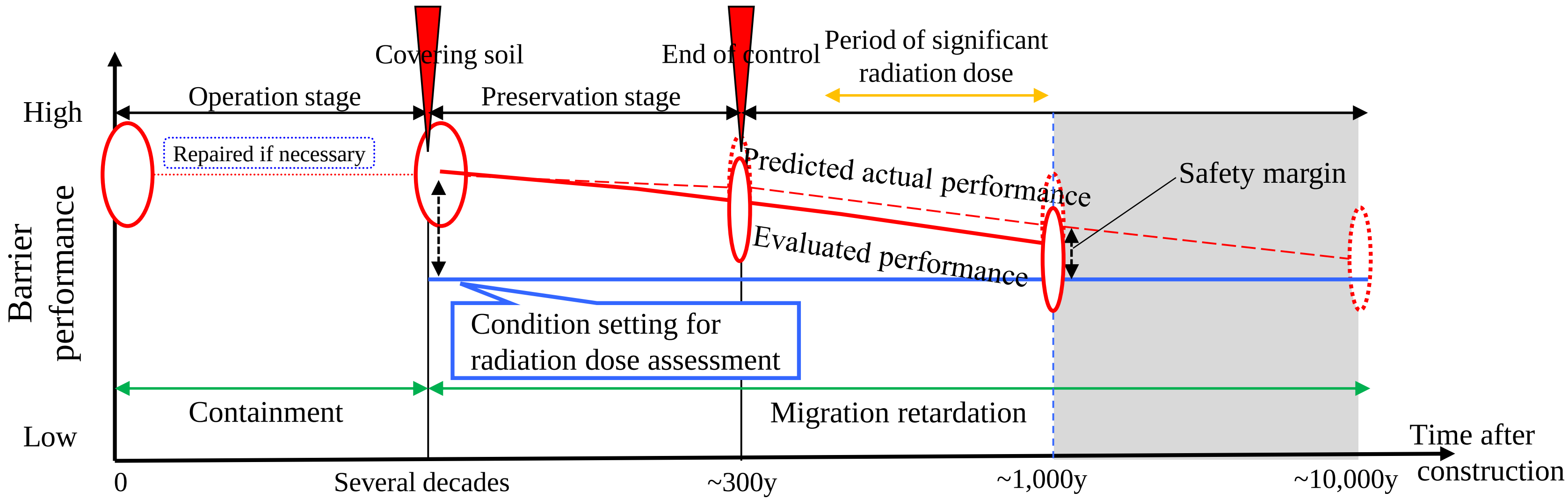
Safety assessment flow after control period



*1 : Including surrounding local bedrock affected by disposal site

*2 : Representative person: Individuals representing groups reasonably expected to be exposed due to disposal site

Conceptual diagram of changes in barrier performance over time in radiation dose assessment



Selection of Natural Phenomena

The phenomena that may affect the condition of waste disposal sites and living environment are comprehensively selected with reference to national and international standards and documents

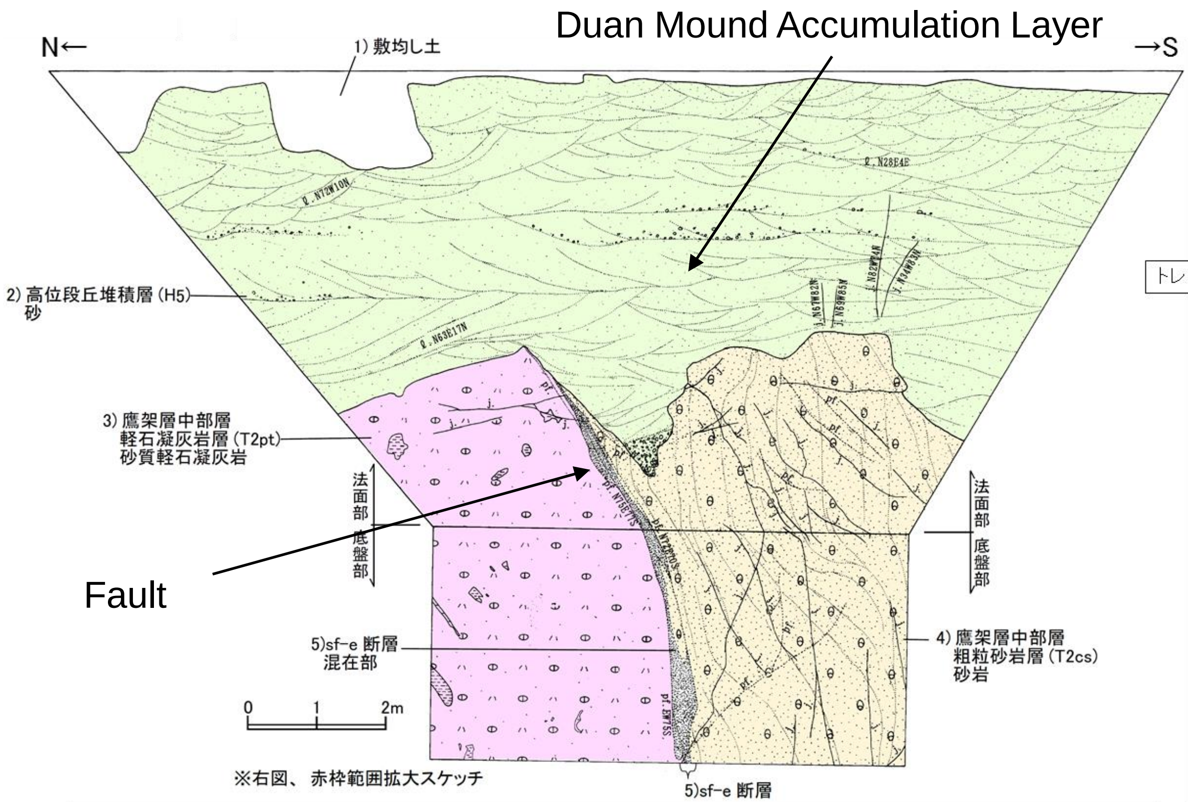
Natural phenomena that should be considered in setting the long-term conditions were selected (15 events).

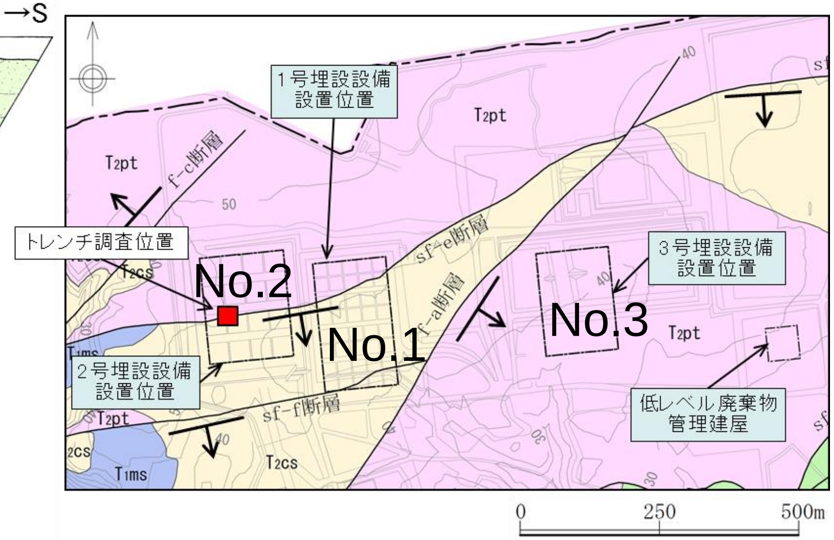
Event of origin	Long-term event	Item
Event caused by plate motion	Volcanic and igneous activity	(1) Volcanic effects (pyroclastic density flow, falling pyroclastic material)
	Earthquake/faulting activity	(2) Earthquakes, (3) Liquefaction , (4) Fault activities (ground deformation)
	Uplift/subsidence movement	(5) Uplift/sedimentation
Climate change-induced events		(6) sea level change, (7) temperature, (8) precipitation, (9) Amount of irrigation
Events caused by both plate motion and climate change		(10) Erosion, (11) Groundwater level, (12) Evapotranspiration, (13) River discharge
Other phenomena		(14)Biological events, (15)Changes in permeability

Events that have a direct impact on dose assessment parameters after considering the above events individually

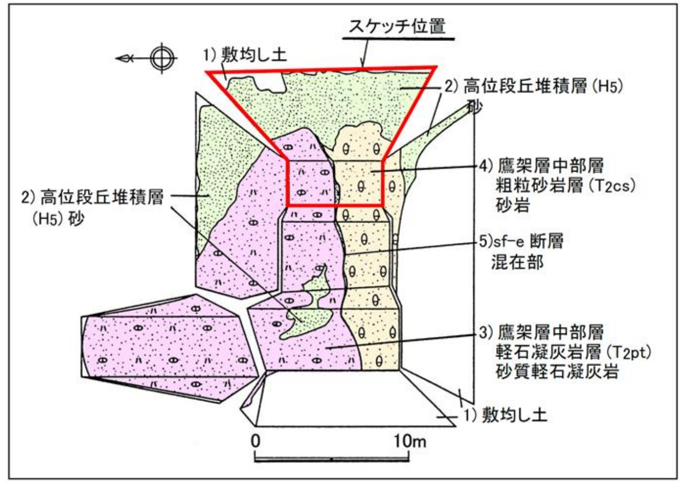
⇒ ①Temperature and precipitation changes, ②groundwater flow, ③evapotranspiration and ④surface water flow

Fault





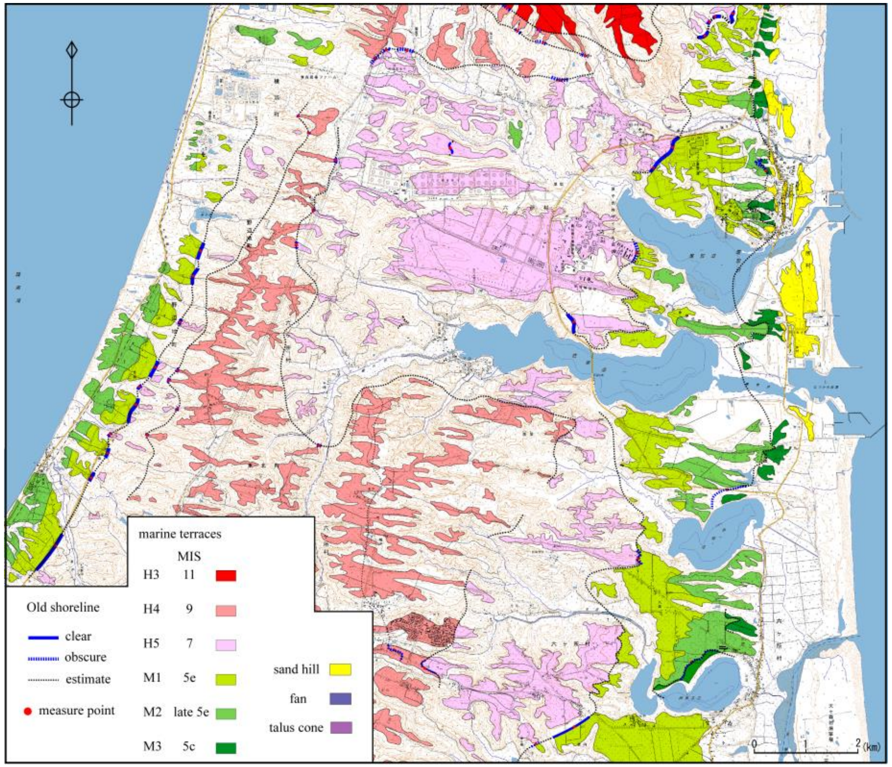
トレンチ調査位置図



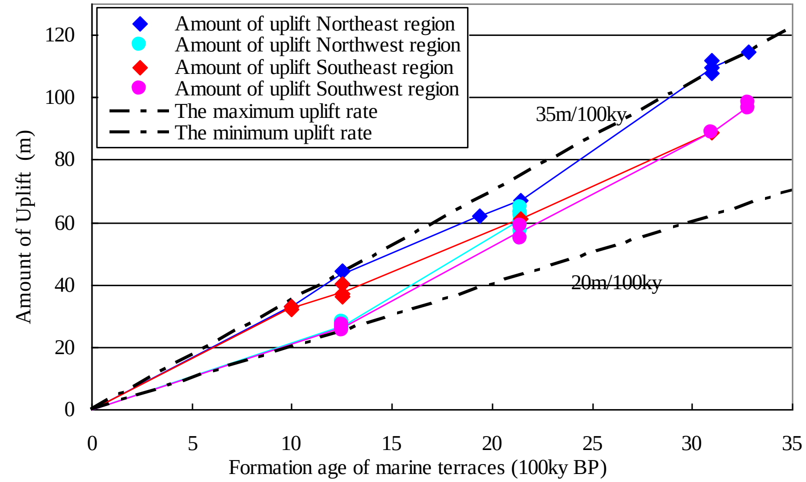
1) 敷均し土 : 造成に伴う敷均し土からなる。
2) 高位段丘堆積層 (H5) : 黄褐色～灰褐色を呈する中～粗粒砂からなる。所々に安山岩、チャートの亜角～亜円礫 (径 0.5cm ～ 10cm) を含む。葉理がみられる。
3) 鷹架層中部層 軽石凝灰岩層 (T2pt) 砂質軽石凝灰岩 : 塊状の灰白～黄灰色を呈する砂質軽石凝灰岩からなる。軽石片 (径 0.2cm ～ 2cm) を多く含み、一部に泥岩礫を含む。
4) 鷹架層中部層 粗粒砂岩層 (T2cs) 砂岩 : 暗黄灰色を呈する中粒～粗粒砂岩からなる。軽石片 (径 0.2cm 前後) や貝化石片を含み、葉理が発達する。
5) sf-e 断層 : 砂岩、砂質軽石凝灰岩等が混在した部分 (混在部) からなる。周囲の岩石に比べてやや硬質である。

ℓ. : 葉理
j. : 節理
pf. : 断層 (ゆ着した断層)

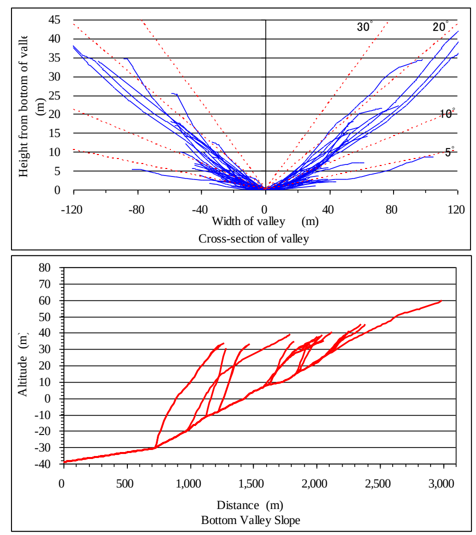
Topographic Change



Classification of terraces



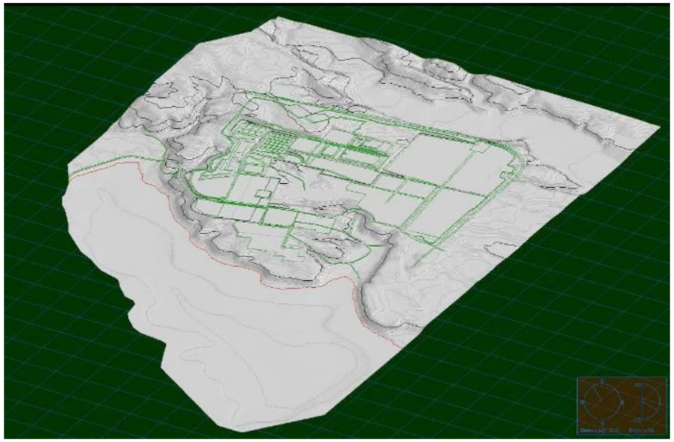
Uplift rate during last 400,000 years



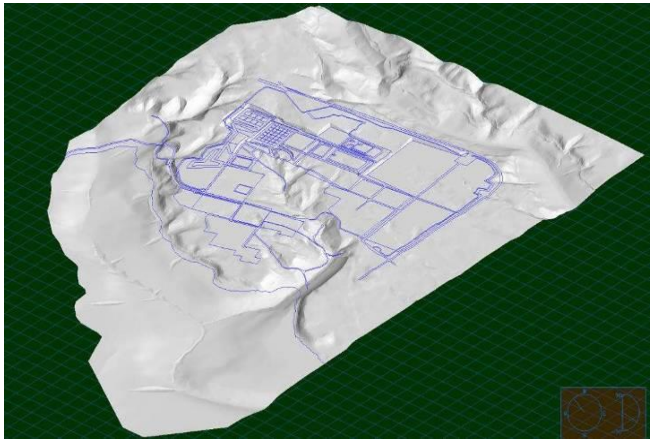
Similarities of along and across river cross sections for research area

Stability and Buffering Capacity of the Geosphere for Long-term Isolation of Radioactive Waste , NEA 2009

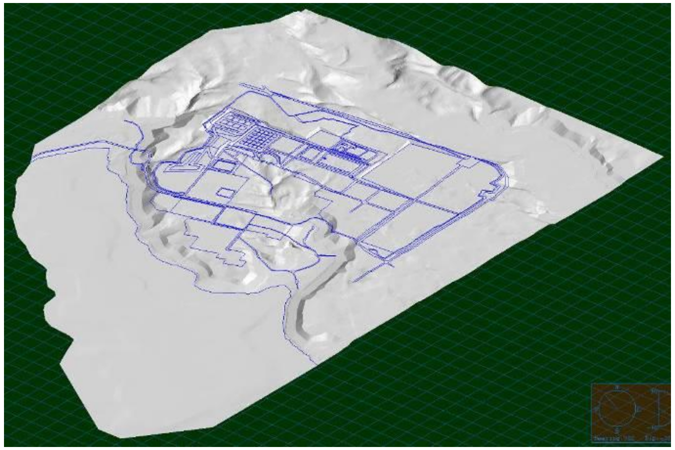
Bird’s eye view of topographic model



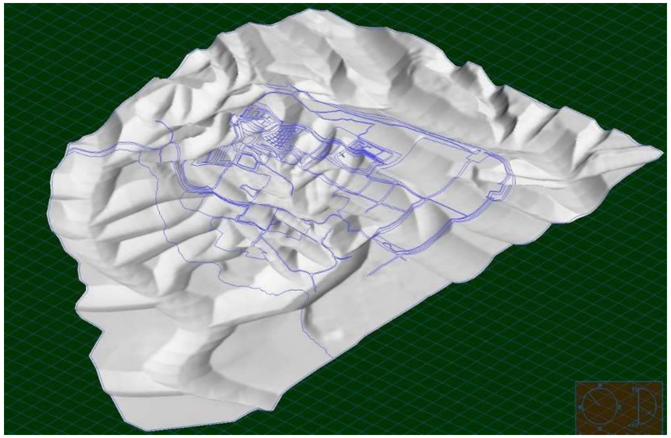
(present)



(Cooling climate case: after about 10,000 years)



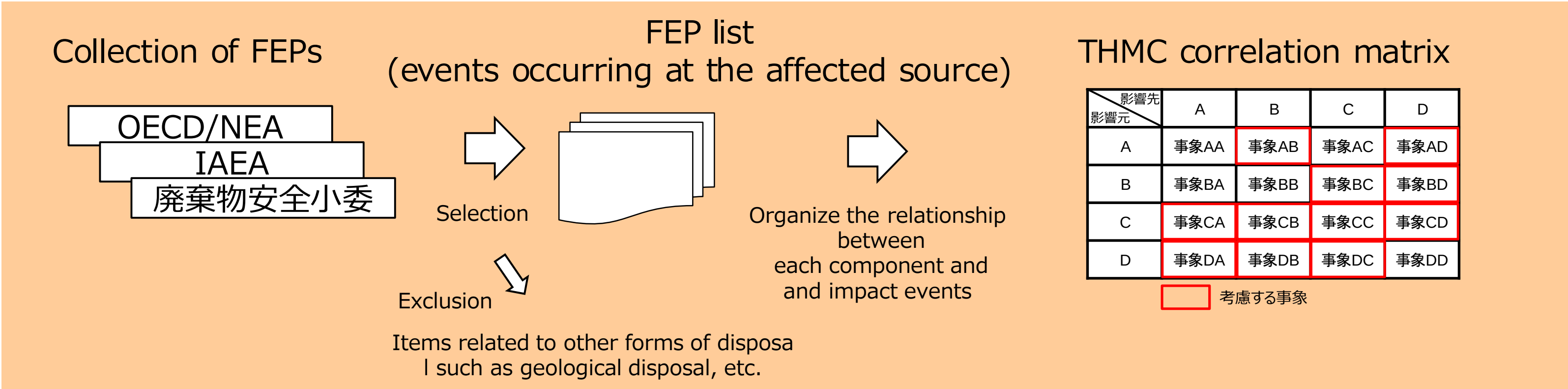
(warming climate case)



(Cooling climate case: after about 60,000 years)

Stability and Buffering Capacity of the Geosphere for Long-term Isolation of Radioactive Waste , NEA 2009

State Setting (Impact Event Analysis)



Extraction results from THMC matrix analysis (1/2)

Term	Major impact event	Migration Control Functions	Imp act	Impact Assessment Results
Heat	Decay heat	Low permeability Sorption	—	The amount of radioactive materials contained in the waste package to be buried is small, and the temperature is sufficiently lower than the temperature at which thermal transformation of each component occurs.
	Heat of hydration	Low permeability Sorption	—	The sorption of cementitious materials is not considered as an impact event, since the sorption is expected to occur after hydration.
	Temperature change	Low permeability Sorption	—	The temperature does not increase to the extent that thermal alteration occurs. The buried facilities after the completion of soil lining will be installed at a depth of about 20 m below the ground surface, which means that the temperature will not increase to the extent that thermal alteration will occur.
hydraulic	Groundwater Flow	Low permeability	○	Groundwater flow velocities in the vicinity of the waste burial site (bedrock and Quaternary layers) are sufficiently low to have an impermeable However, it is considered in "C (Chemistry) Reaction with groundwater".
		Sorption	○	The groundwater flow velocity in the vicinity of the waste burial site (bedrock and Quaternary layers) is sufficiently low to have no direct effect on the impermeable However, it is considered in "C (Chemistry) Reaction with groundwater".

State Setting (Impact Event Analysis)

Extraction results from THMC matrix analysis (2/2)

Term	Major impact event	Migration Control Functions	Impact	Impact Assessment Results
Mechanics	Expansion(metal corrosion, effect of salt)	Low permeability	○	Areas of altered permeability due to reduction in thickness and displacement may occur at the corners and other areas of impermeable soil cover.
	Gas generation	Low permeability	—	The results of permeability and permeability tests showed that there was almost no change in hydraulic conductivity of soil before and after gas breakthrough.
	Swelling pressure of bentonite	Low permeability	—	Swelling pressure of bentonite is not considered as an impact event because it is small compared to the surrounding ground pressure.
	Seismic	Low permeability	—	Mechanical deformation is very small compared to deformation of buried facilities due to metal corrosion. The design of the site is such that liquefaction is not likely to occur easily.
Chemistry	Reaction with groundwater	Low permeability Sorption	○	Dissolution of montmorillonite and calcium silicate hydrate and formation of secondary minerals may affect the low permeability of the impermeable soil cover, as well as the sorption of each barrier.
	Organic matter effect	Sorption	○	Cellulose decomposes under alkaline conditions and forms isosaccharinic acid, which forms complexes with radioactive materials. isosaccharinic acid, may affect the sorption properties of each component.
	Salt Effects	Low permeability Sorption	○	Dissolution of soluble salts in homogeneous and homogenous solidified products into groundwater causes changes in porewater quality. changes in the porewater quality. In addition, the reaction of each component with salt-dissolved porewater may lead to mineral dissolution and secondary mineral formation, resulting in alteration of the components.
	Colloidal effects	Sorption	—	The pore water of buried facilities is cement equilibrium water and is not an environment in which colloids can be dispersed stably.
	Microbial Effects	Sorption	○	Organic matter is mineralized by microorganisms in bedrock , and this should be taken into account when setting sorption potential.
	pyroclastic precipitate	Low permeability Sorption	—	The upper layer of the soil cover is thick enough to limit the extent of chemical influence (buffering effect) to the surface layer.

Mechanical Effects of Soil Cover

Evaluate the effect of soil cover on hydraulic conductivity using the DEM.
→ Based on the results of the evaluation, it is assumed that the hydraulic conductivity of the soil cover will not change, but the thickness of the soil cover will change in the mechanical impact.

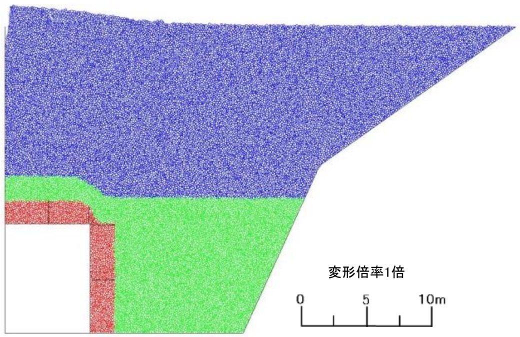
Phenomena	Type of waste	facility	Concept of phenomena
expansion	Solidified dry active waste	No.2,No,3	Assume that expansion occurs due to the metals corrode
		No.1	Assume that expansion occurs due to the reaction of soluble salts with cementitious materials
sink	Homogeneously-solidified waste	No.1	Assume that the leaching of soluble salt will create cavities in buried facilities and cause the cover to cave in

Mechanical Effects of Soil Cover

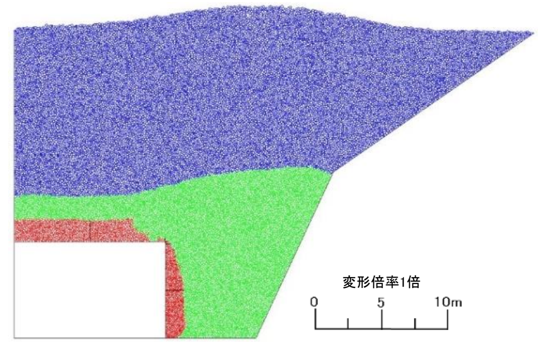
○ Approach to Setting Conditions for Assessment of Condition Changes (Mechanical Effects) after 1,000 Years

Item	Setting		Concept of setting
Metal corrosion rate	Less-likely scenario	Assume all metals corrode instantly	Uncertainties related to localized corrosion (pitting corrosion), dissimilar metal contact corrosion, and changes in environmental conditions should be considered. During the evaluation period of condition change after the start of decommissioning (after 1,000 years), it is assumed that the entire amount of corrosion, regardless of the corrosion type, will be instantaneous. The total amount of corrosion is assumed to be instantaneous, regardless of the corrosion type.
	Likely scenario	0.1μm/y	consider measurement errors inherent in corrosion rate measurement methods
Expansion factor	Less-likely scenario	4 times	The set metal types and amorphous hydroxides were set to account for variations in environmental conditions. The contamination rates of the other metal types were evaluated in a range of 0 to 50 %, and the corrosion expansion factor was less than 4 times for all of them.
	Likely scenario	3 times	The corrosion product of the representative metal type (iron) was set as Fe_3O_4 (magnetite), and the mixing ratio of other metal types to be considered was set in the range of 0wt% to 50wt%. The results of the evaluation of the corrosion expansion ratio of the mixed metals were as follows. The results showed that the corrosion expansion factor was less than 3 times in all cases.

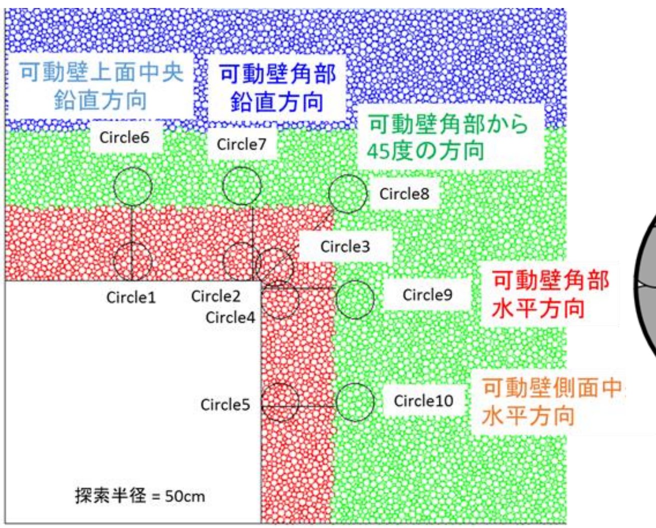
Density change in cover soil due to facility expansion

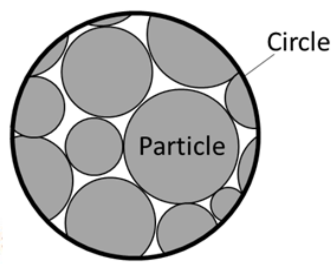


vertical：2.0m



horizontal：5.0m、vertical：1.0m



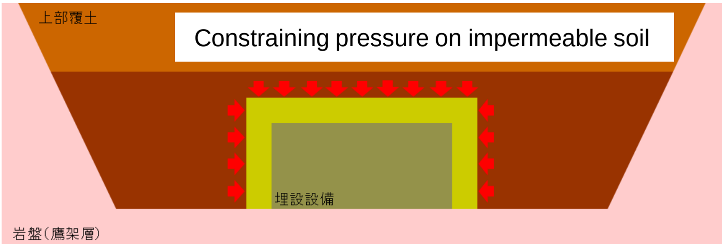


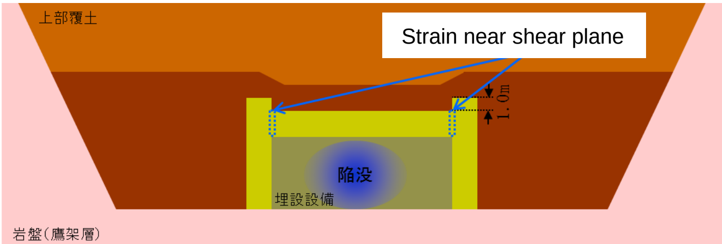
Differential Elemental Method

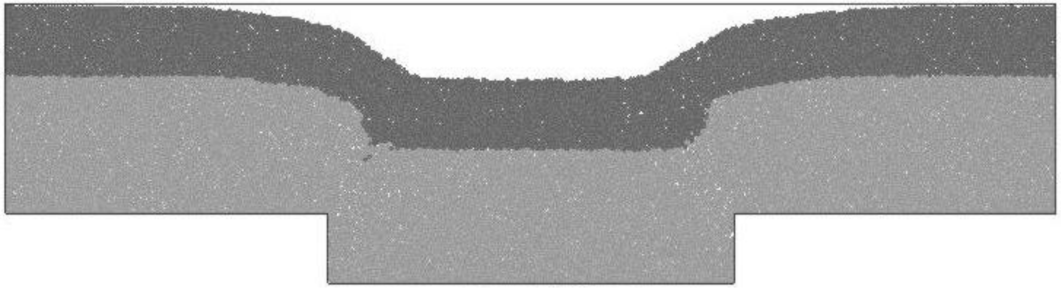
location	Deformation	
	Fig 1 vertical :2.0m	Fig 2 horizontal :5.0m、 vertical :1.0m
	Density increase (%)*1	
Circle1	-0.8	0.3
Circle2	-2.0	1.7
Circle3	12.3	12.3
Circle4	7.3	16.3
Circle5	21.8	30.9
Circle6	-0.9	-1.9
Circle7	-4.0	-7.1
Circle8	0.9	0.0
Circle9	-4.2	5.1
Circle10	7.8	11.5

*1 :negative values indicate a decrease in density

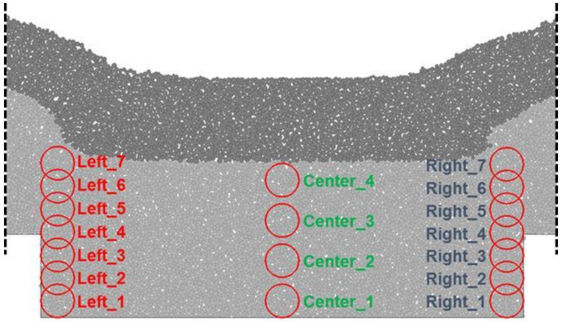
Density change in cover soil due to facility sinking







Analytical result



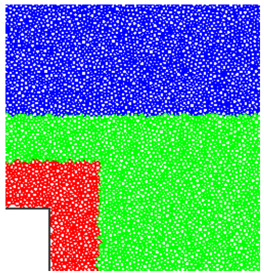
Density change

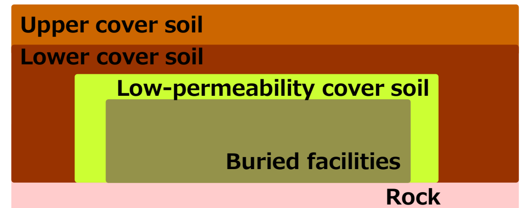
測定位置	Density increase (%)*1
Left_1	2.4
Left_2	-2.1
Left_3	-7.7
Left_4	-8.2
Left_5	-4.0
Left_6	-5.1
Left_7	-5.2
Center_1	8.6
Center_2	1.5
Center_3	2.6
Center_4	2.2
Right_1	6.7
Right_2	-4.4
Right_3	-2.6
Right_4	-5.0
Right_5	-5.5
Right_6	-1.5
Right_7	0.4

*1*1 :negative values indicate a decrease in density

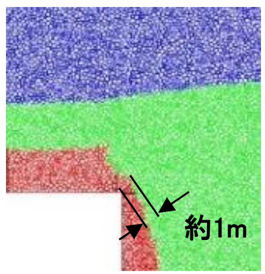
Mechanical Effects of Soil Cover

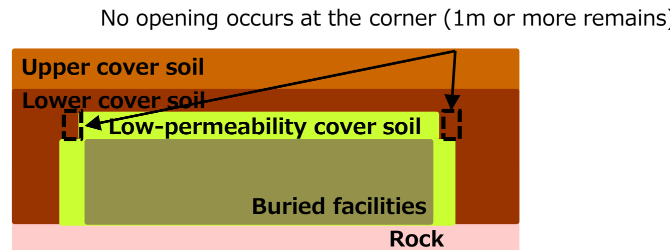
○ Evaluation of condition change (mechanical effects) of the soil cover (example of waste burial site No. 3)



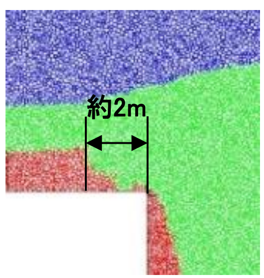


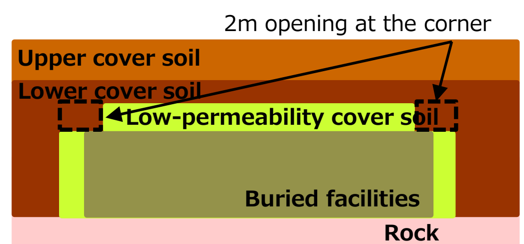
Initial setting





Likely scenario

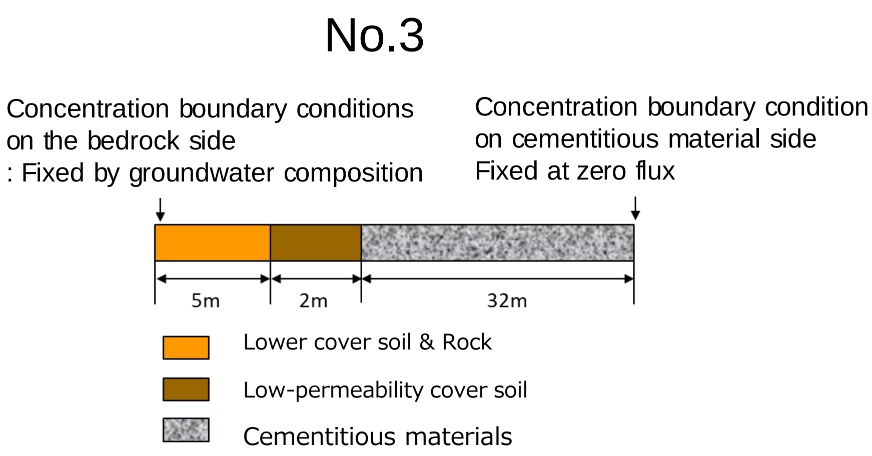


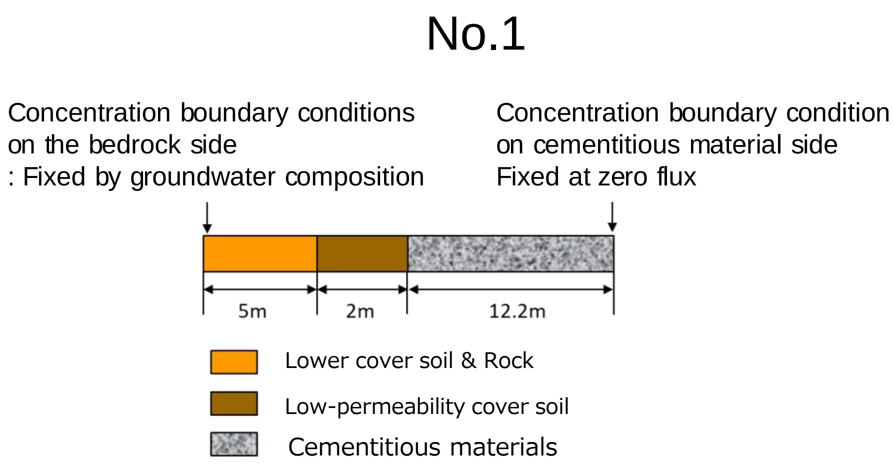


Less-likely scenario

Chemical Effects of Soil Cover

- The composition of groundwater changes due to contact with cementitious materials or soluble salts contained in the waste material buried in the No. 1 waste burial site.
- Highly alkaline groundwater can dissolve or alter the montmorillonite in the bentonite material and, gradually reducing the low permeability function.
- The migration and chemical reactions to impermeable soil cover were evaluated using the PHREEQC-TRANS (coupled chemical reactant migration analysis code).
- Transition of hydraulic conductivity of the impermeable soil lining due to chemical alteration was evaluated.





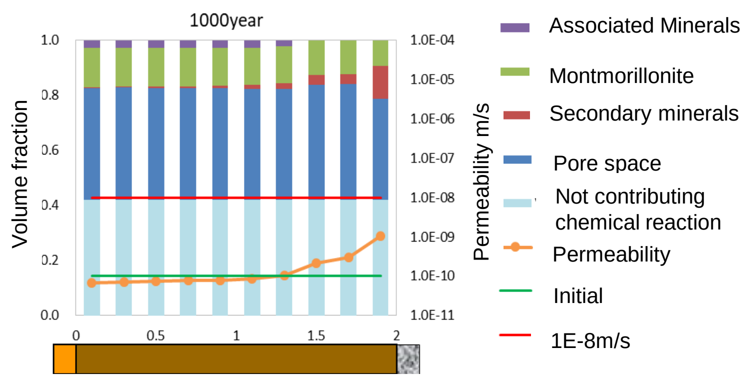
Model & boundary conditions

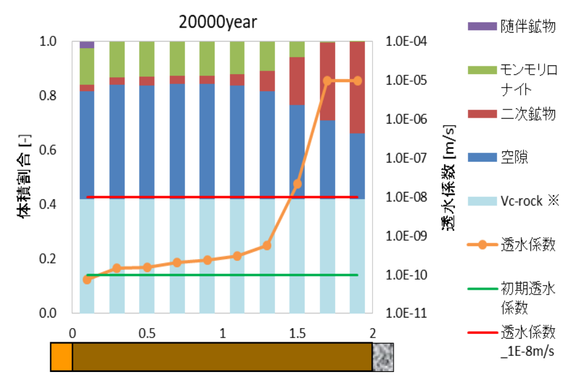
Chemical Effects of Soil Cover

- Permeability coefficients for dose assessment of impermeable soil cover considering long-term chemical effects are set based on the following values after 1,000 years.
- The lower soil cover placed around the impermeable soil cover should not change the hydraulic conductivity due to chemical effects, because the montmorillonite in the impermeable soil cover will remain even after chemical effects.

No. 3

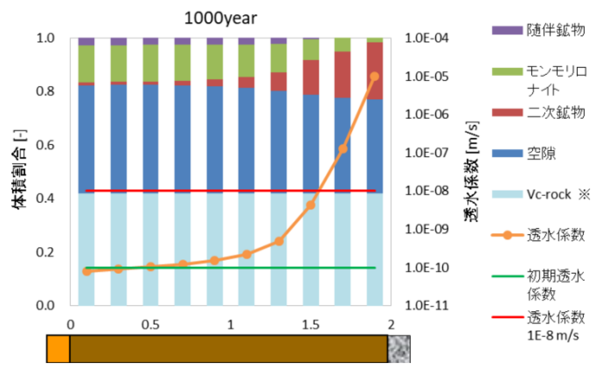
	No.3 [m/s]	
	Likely scenario	Less-likely scenario
0 year	1.00×10^{-10}	1.00×10^{-10}
1,000 year	1.01×10^{-10}	1.02×10^{-10}

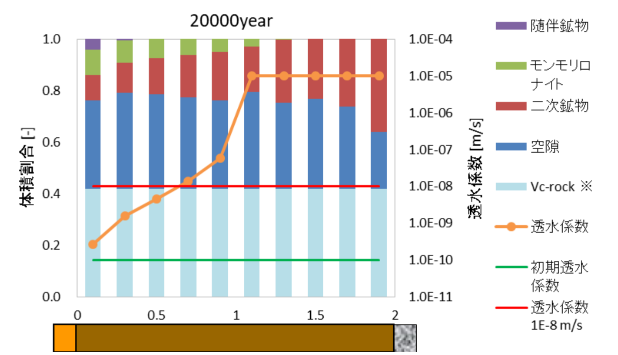




No. 1

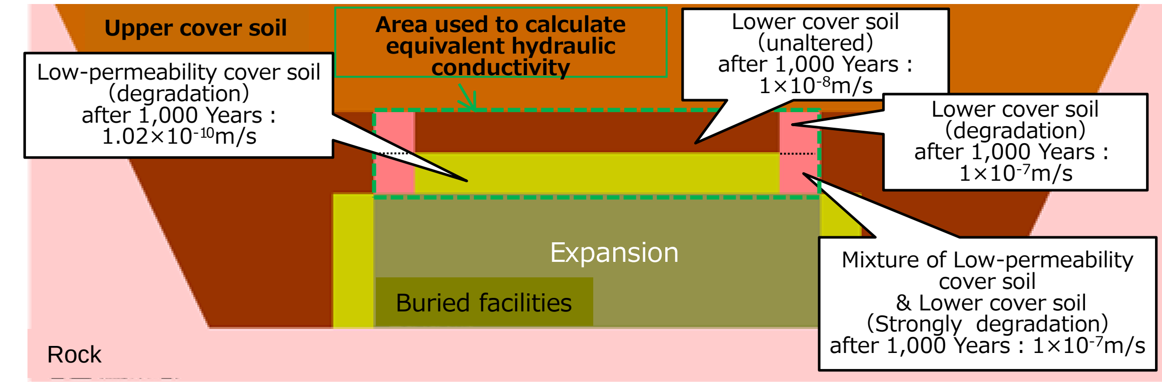
	No, 1 [m/s]	
	Likely scenario	Less-likely scenario
0 year	1.00×10^{-10}	1.00×10^{-10}
1,000 year	1.42×10^{-10}	1.84×10^{-10}



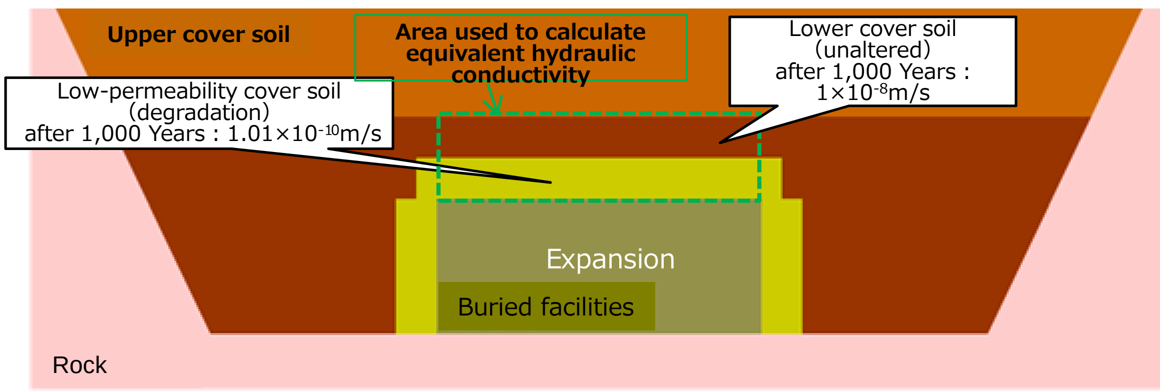


Condition setting of permeability of soil cover (mechanical and chemical influences)

The hydraulic conductivity of the entire soil cover used to calculate the flow rate through the facility is calculated assuming that the soil cover on top of the buried facility is subjected to mechanical and chemical influences.



Example of estimated changes in condition and calculation of equivalent hydraulic conductivity (No.3、Less-likely scenario)



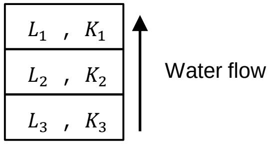
Example of estimated changes in condition and calculation of equivalent hydraulic conductivity (No.3、Likely scenario)

(Composite formula in vertical series direction)

$$K = \frac{\sum L_i}{\sum (L_i / K_i)}$$

L_i: Thickness of the i-th layer of soil cover [m]

K_i : Permeability of the i-th layer [m/s]

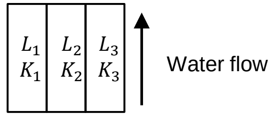


(Vertical parallel direction composite equation)

$$K = \frac{\sum (K_i \times L_i)}{\sum L_i}$$

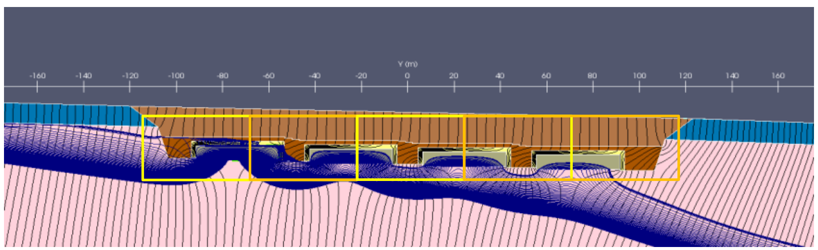
L_i : Thickness of the i-th layer of soil cover [m]

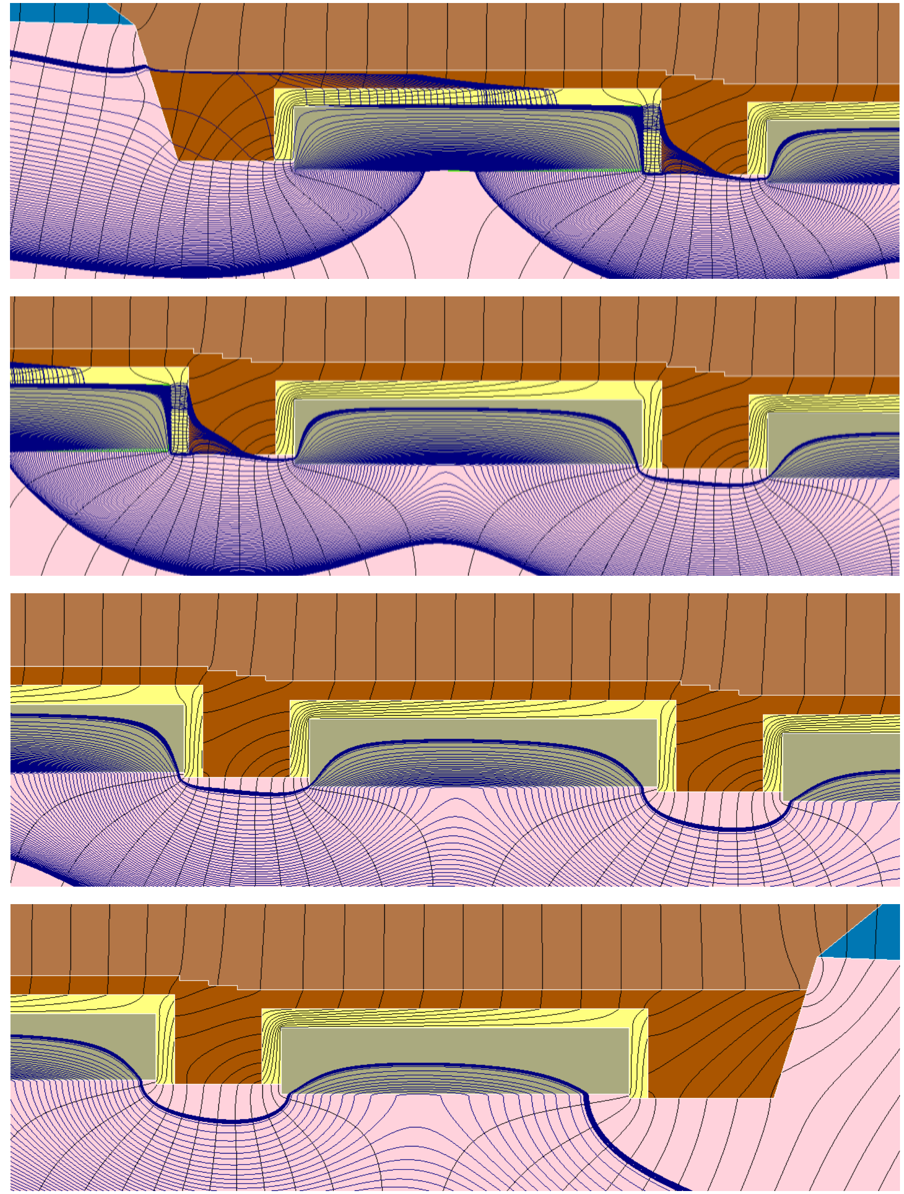
K_i : Permeability of the i-th layer [m/s]



	Equivalent hydraulic conductivity	
	Less-likely scenario	Likely scenario
No.3	1.5×10^{-8}	2.0×10^{-10}
No.1	3.0×10^{-9}	2.5×10^{-9}
No.2	1.5×10^{-8}	2.0×10^{-10}

Groundwater Flow Analysis



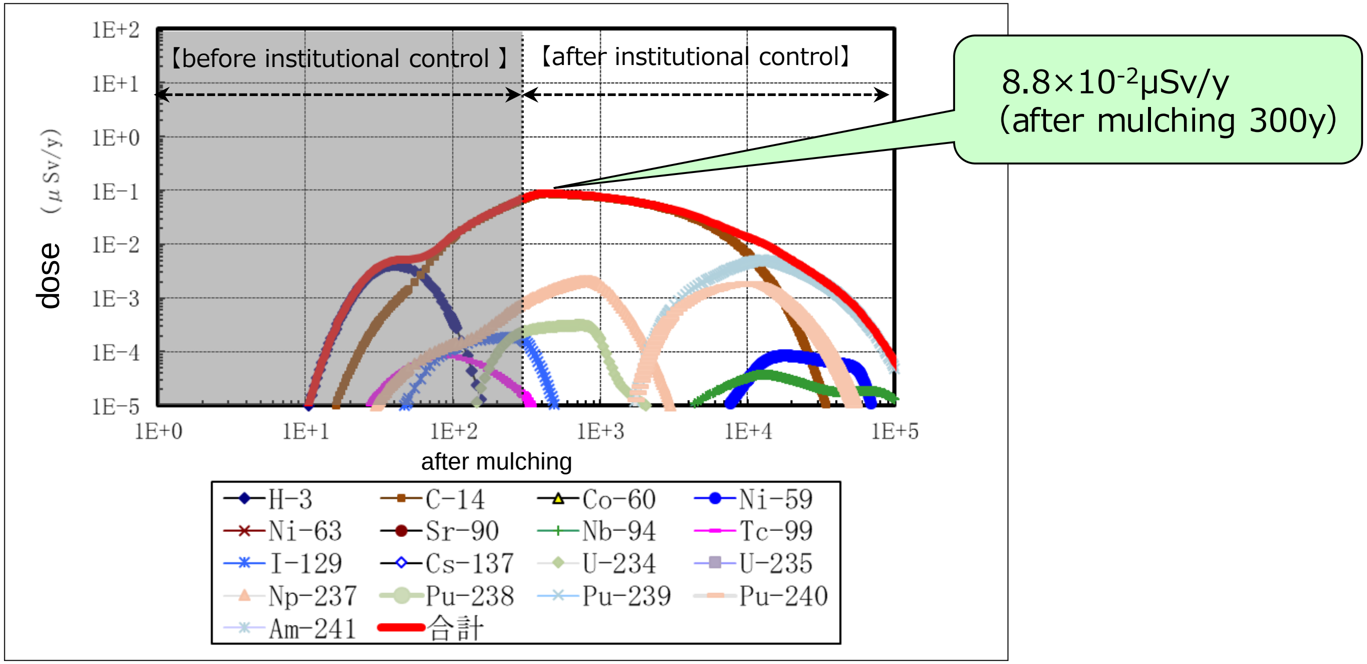


Setting of living environment conditions (setting of individuals to be evaluated)

- The individuals shall be those who live in and around the site or in the general lifestyle currently recognized in Japan, and shall be adults who represent the population that is exposed to relatively high exposure.
- In the likely scenario, the individuals to be evaluated are assumed to be residents.
- In the less-likely scenario, the individuals to be evaluated all of the following.

target group	Lifestyle
Fishermen	The target population is people who live in the landfill site, and it is assumed that marine products to which radioactive materials are transferred are consumed at home in a conservative manner. Other products are assumed to be consumed from general marketed foods.
Agricultural workers	It is assumed that agricultural products to which radioactive materials are transferred will be consumed by the residents of the waste burial sites for their own consumption on a conservative basis, and that other food products distributed in general markets will be consumed by the residents. In the case of water use, rice cultivation using stream water containing radioactive materials for irrigation is assumed.
Livestock Industry Workers	The target population is the people who live in the waste burial sites, and it is assumed that livestock products to which radioactive materials are transferred are consumed by them for their own consumption in a conservative manner. However, exposure due to ingestion of livestock products to which radioactive materials are transferred is not assumed.
Construction workers	The target population is assumed to be people who live in the waste burial ground and consume food products distributed in the general market. It is also assumed that construction workers will be working on the contaminated land.
resident	The target population is assumed to consume agricultural products produced in home gardens and food products distributed to the market.

Safety Assessment Results



Safety Assessment Results No.3 facility (Likely scenario : inhabitants)

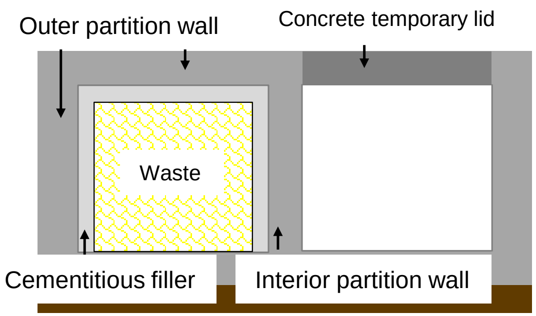
Safety Assessment Results

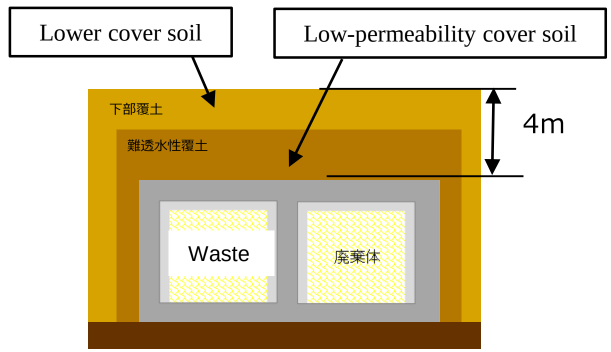
dose		No.1 (μSv/y)	No.2 (μSv/y)	No.3 (μSv/y)	splendid (μSv/y)	Criteria
Less-likely scenario	fisherman *1	3.3	4.0	3.8	11	300μSv/y
Likely scenario	inhabitants	0.20	0.18	0.088	0.46	10μSv/y
Human intrusion	Construction worker	5.9	5.8	2.5		1000μSv/y (1mSv/y)
	inhabitants	42	31	16		

*1 : individuals to be evaluated for the highest dose

Shielding

Period	~ Completion of soil covering	Period	Completion of soil covering ～
Shielding material	burial equipment	Shielding material	Covering soil





Assessment results of radiation exposure to the public

	No.1+No.2+No3 (μSv/y)	
	～ Completion of soil covering	Completion of soil covering ～
external exposure	23	1.0×10^{-4} ※

※ result of Lower cover soil surface