# SCIENTIFIC BASIS FOR NATIONWIDE SCREENING OF GEOLOGICAL DISPOSAL SITES IN JAPAN

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**Key words**; geological disposal, site selection process, nationwide screening

**Abstract**

In Japan, the legal system (Final Disposal Act) was established for geological disposal of high level radioactive waste in 2000, which specifies three steps of siting process as literature survey, preliminary investigation and detail investigation to be conducted by the Nuclear Waste Management Organization of Japan (NUMO). Although NUMO has been promoting the siting process by a volunteering approach, no volunteer so far has appeared and selection of geological disposal sites in Japan has not advanced significantly over 15 years. Taking such situation into consideration, the government reinforced measures for achieving solutions and promoting geological disposal in the "Strategic Energy Plan" published in April 2014. In association with the reinforcement, a new process for selecting repository sites, which is the nationwide screening by the government before initiating legally defined siting process, has been added by the revision of the Basic Policy in May 2015. The nationwide screening is aiming at deepen public understanding of geological disposal.

## 1. Introduction

Discussion for the nationwide screening for stepping into the literature survey was initiated in December 2014 at Geological Disposal Technology Working Group (Technology WG), which is a geological disposal advisory committee for the Ministry of Economy, Trade and Industry (METI). Technology WG developed requirements and criteria for the screening, and summarized them in the report which was published in April 2017 (Technology WG, 2017). In July 28, 2017, METI published "Nationwide Map of "Scientific Features" relevant for Geological Disposal" (METI, 2017(http://www.enecho.meti.go.jp/category/electricity_and_gas/nuclear/rw/kagakutekitokuseimap/maps/kagakutekitokuseimap.pdf (in Japanese)), which was drawn up based on the report.

NUMO has been developing the nationwide information base on the geological environment to be utilized for its siting process by reflecting the state-of-the-art knowledge. The information base contributed to the discussion at Technology WG.

This paper presents the scientific and technical basis for identification of requirements and criteria for nationwide screening by Technology WG.

## 2. The Map for the nationwide screening

The nationwide screening by "Nationwide Map of "Scientific Features" relevant for Geological Disposal" does not directly indicate specific areas which have suitable scientific features for developing a geological repository. Stepwise investigation and careful evaluation of candidate sites according to the Final Disposal Act are essential for selecting a final repository site; this takes into account various other important factors that are not taken into account in the Map. Publication of the Map is the first step on a long way toward completion of geological disposal.

Areas in the Map are classified by four features "Assumed to be unfavorable from the viewpoint of long-term stability of the deep geological environment", "Assumed to be unfavorable from the viewpoint of the risk of future inadvertent human intrusion", "Assumed to be favorable" and "Assumed to be preferable also from the viewpoint of safe waste transportation". The requirements and criteria by Technology WG which are applied to identify the feature of nationwide areas in Japan are shown in **Table 1**. The applicability of the criteria to the four features is shown in **Fig. 1**.

## 3. Scientific and technical basis for developing the requirements and criteria

### 3.1 Basic approach

Technology WG discussed the requirements and criteria from the viewpoints of 1) geological environment characteristics and their long-term stability favorable to geological disposal; 2) safety of construction and operation of facilities; and 3) safety and security of waste transportation.

Reliable literatures or data, which cover nationwide areas and are widely available, are selected for developing the requirements and criteria. In the case when there does not exist available nationwide data directly used for a criterion, the corresponding requirement is not considered or alternative criterion is applied if this alternative is relevant to the corresponding requirement and nationwide data is available.

For coastal areas which include islands and under seabed, a special study group (Study Group) was organized to discuss their distinctive features from the view points above mentioned. These features include favorable characteristics for geological disposal, which are 1) very low driving force for groundwater flow and mass transport is highly expected and 2) low uplift rate is observed many places. It is also pointed out for coastal areas that special attention should be paid to long-term hydraulic and geochemical changes associated with sea-level changes. The Study Group concluded that development of repository at coastal areas is generally feasible based on the existing technology although R&Ds are required further to provide geological environment data and demonstrate investigation techniques specific to these areas (Study Group, 2016).

NUMO information base for nationwide geological environments based on open literature was used for the discussion at Technology WG to provide clear evidence and arguments for development of requirements and criteria. The discussion at Technology WG were widely opened to ask comments, and to be reviewed by technical experts in the relevant academic societies and OECD NEA international review team (NEA, 2016). The review comments were then discussed at Technology WG further to modify the requirements and criteria if needed.

**Table 1**, The requirements and criteria for classification of areas corresponding to specific features (METI, 2017)

| Relevant events and processes | Consequence or impact required to be precluded | Criteria |
|---|---|---|
| Volcanic/igneous activity | Magma intrusion affecting physical isolation | **Vicinity of volcanoes:** Within an area of 15 km from the center of individual Quaternary volcanoes (or the caldera rim if this is greater) |
| Fault movement | Fault movement affecting containment | **Vicinity of active faults:** Within the fracture zone around an active fault, the width of which is about 1/100 of the fault length |
| Uplift/erosion | Uplift/erosion affecting physical isolation | **Significant uplift/erosion:** Net erosion greater than 300 m / 100,000 years; in coastal areas, accounting for sea-level change, uplift rate greater than 90 m / 100,000 years. |
| Geothermal activity | Geothermal activity affecting containment | **High geothermal gradient:** Geothermal gradient greater than about 15°C/100 m |
| Volcanic thermal fluids and deep-seated fluids | Intrusion of exotic groundwater affecting containment | **Presence of hydrothermal water or other deep-seated groundwater:** Groundwater with pH less than 4.8 |
| Unconsolidated geological formations | Geotechnical instability affecting safe construction | **Location in unconsolidated geological formations:** Geological formations younger than Middle Pleistocene as cover to a depth of greater than 300 m |
| Volcanic eruption | Volcanic eruption affecting safe operation | **Susceptibility to distant impacts from volcanic eruptions:** Traces of Holocene pyroclastic flows or associated pyroclastic rocks. |
| Mineral resources | Future inadvertent human intrusion | **Existence of mineral resources:** Known oil, gas and coal fields, metal ores. |

- Criteria to identify preferable features

| Relevant events and processes | Requirements for preferring | Criteria |
|---|---|---|
| Transportation | Safe waste transportation in terms of radiation exposure and nuclear security | **Relatively short distance from coastline** (including sub-seabed and islands): Within about 20 km from coastline |

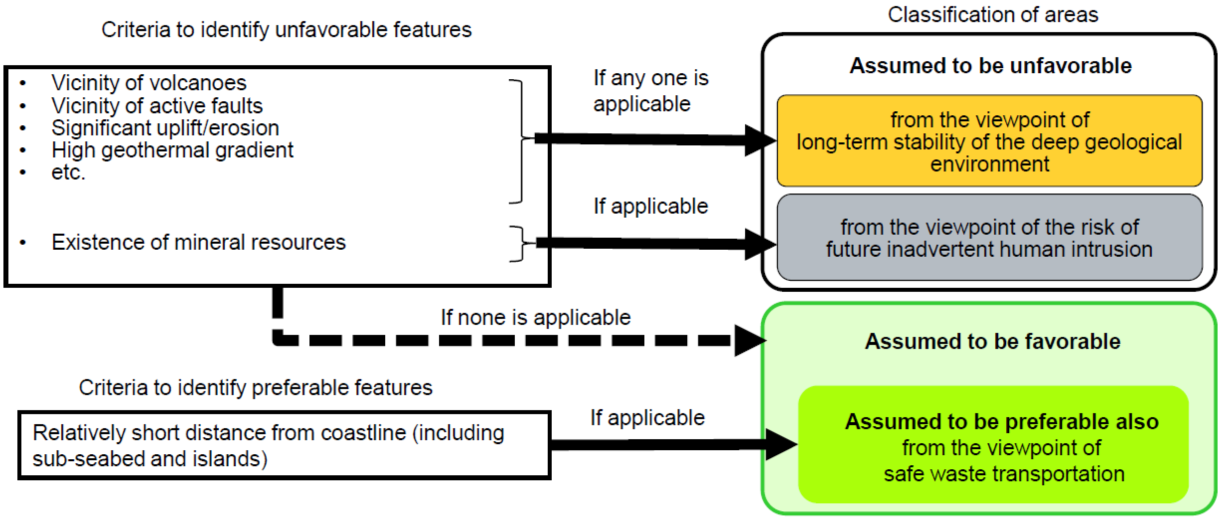


**Fig. 1**, Relationship between the criteria and classification of areas (METI, 2017)

### 3.2 Long-term stability of favorable geological environments

#### 3.2.1 Requirements and criteria for THMC conditions

Preferable Thermal, Hydrological Mechanical and Chemical (THMC) conditions for geological disposal, from the viewpoint of containment safety function, characteristics and properties of geological environment are identified as follows; "low ambient rock temperature" for restricting temperatures in the Engineered Barrier System (EBS), "small rock deformation" for the mechanical stability of the EBS, "slow groundwater movement" mainly for the natural barrier function and "Neither high nor low groundwater pH", "reducing groundwater" and "low dissolved inorganic carbon in groundwater" for preventing or restricting dissolution or migration of radionuclides from the EBS (**Table 2**).

The THMC conditions should however evaluated comprehensively by taking into account interactions between each conditions at a specific site, which needs detailed characterizations through site specific investigations. These conditions were therefore not applied for the Map as requirements and criteria.

#### 3.2.2 Requirements and criteria for disruptive natural events and process

Natural disruptive events and processes that significantly affect the long-term safety of a geological disposal system were identified at Technology WG, for which requirements and criteria were discussed for providing the Map.

As a result, the relevant events and processes with their consequence/impact on safety function of containment and isolation in this regard are 1) volcanic/igneous activity, 2) fault movement, 3) uplift/erosion, 4) geothermal activity, and 5) volcanic thermal fluids and deep-seated fluids (see **Table 1**). The scientific basis to provide criteria for these events and processes are summarized in the following sections.

#### 3.2.2.1 Volcanic/igneous activity

The locations where volcanic activity occurred in the Japanese archipelago during the Late Miocene to the Pliocene are limited to distinct regions, only within the East Japan Volcanic Belt and the West Japan Volcanic Belt; changes in the location of volcanism during the past hundreds of thousands of years occurred within some volcanic regions, including expansion, shrinkage or movement of active volcanic regions. However, there has been no prominent shift in the location of volcanic fronts on the scale of the island arc.

A volcanic front has also developed in Hokkaido. In southwest Japan, a volcanic front has not clearly developed in the region extending from San'in to north Kyushu (**Fig.2**).

The individual volcanic bodies of each Quaternary volcano are distributed within 15 km from a representative location of the volcano in all but some exceptional cases (**Fig.3**).

As a nationwide documentation, "Volcanoes of Japan (3rd Edition)" (Geological Survey of Japan, AIST, 2013) was used for the basis to define the center of each volcano identified available.

#### 3.2.2.2 Fault movement

Fault movement reaching the repository would break the repository and damage the barrier performance. In addition, fault has fracture zone (damage zone) that has high fracture density, in which has potential to cause water conducting. Active faults in vicinity of disposal sites are thus to be avoided. In Japan, same tendency of earthquakes and fault movements of known active faults have continued approximately past several 100,000 years (JNC, 2000a). From this reason, it can be considered that present tendency of active fault movements will continue for future about 100,000 years (JNC, 2000a).

In addition, some papers are shown relationships between the length of existing faults and the width of crush zones (e.g. about 1/350 to 1/150 of fault length (Ogata and Honsho, 1981)).

As a nationwide documentation, "Active Fault Database of Japan" (website of Geological Survey of Japan, AIST) was used for the basis to define the location and length of active fault.

#### 3.2.2.3 Uplift/erosion

The mode and rate of crustal movement that have been stable since the Middle Pleistocene will quite likely

**Table 2,** Favorable geological environment characteristics for geological disposal (NEA, 2016)

| | Favourable characteristics and properties of the geological environment in terms of the EBS | Favourable characteristics and properties of the geological environment in terms of the natural barriers |
|---|---|---|
| Thermal environment | Low ambient rock temperature | - |
| Mechanical regime | Small rock deformation | - |
| Hydrological regime | - | Slow groundwater movement |
| Geochemical environment | Neither high nor low groundwater pH<br>Reducing groundwater<br>Low dissolved inorganic carbon in groundwater | Neither high nor low groundwater pH<br>Reducing groundwater |

Source : Technology WG (2014), Table 1

remain unchanged for future at least about 100,000 years or so (Umeda et al., 2013). The present understanding is, therefore, that the current mode and rate of crustal movement will very likely continue for the next hundred thousand years or so.

Particularly in coastal areas, it is necessary to take into account that sea-level changes which the maximum sea-level drop of 150 m during a glacial stage erosion rate (Clark et al., 2009).

"Japanese Island-arc and Geosphere Stability" (Committee for Geosphere Stability Research, 2011) was selected to use for the criteria because it shows average uplift rates of recent 100,000 years as approximately

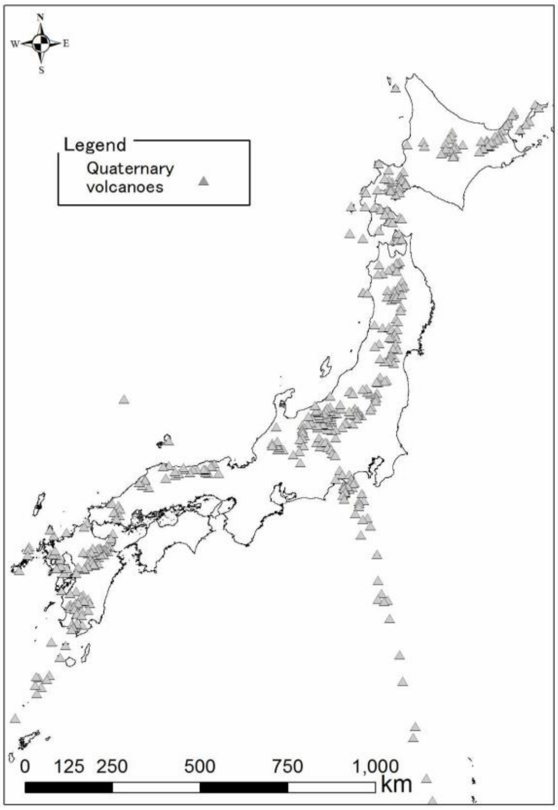


**Fig. 2**, Distribution of Quaternary volcanoes and volcanic front in Japan (Based on Geological Survey of Japan, AIST, 2013))

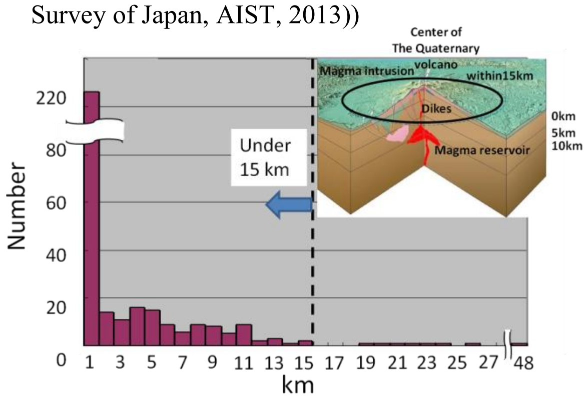


**Fig. 3**, Maximum distance and frequency between the center of Quaternary volcanoes and individual volcanic bodies (Based on Committee for catalog of Quaternary volcanoes in Japan, 1999 and NUMO, 2004 )

20km×20km square areas based on the investigations of sea terraces and river terraces.

However, the legend of the literature designates areas where the recent uplift rate exceeds 300m/100,000 years as 'uplift amounting to >90m during the last 100,000 years', hence the recent uplift rate exceeds past 300m/100,000 years couldn't be settled as the criteria. On the other hand, in coastal areas, the largest estimation of Quaternary sea level fall is 150m below the current level from mainly the investigations about oxygen isotopes of ice sheet or fissile (e.g. Huybrechts, 2000). This figure could account for an eroded thickness of 150m of overburden. Take this into consideration, coastal areas where designated as 'uplift amounting to >90m during the last 100,000 years' is likely to excess erosion of 300 m in next 100,000 years.

#### 3.2.2.4 Geothermal activity

If ground temperature exceeds 130°C for 10,000 years or exceeds 170°C for 10,000 years, montmorillonite in buffer would be altered by 50% and performance of the buffer will be reduced (JNC, 2000b). On the other hand, JNC (2000b) shows that montmorillonite alteration which losses ability of the buffer would not be caused in the temperature of under 100°C from many references.

Considering the repository size (6~10km$^2$), the maximum occupied area of the waste in the repository is 86.6m$^2$ (JNC, 2000b). From thermal analysis, rising in temperature of the buffer in the occupancy is approximately 40°C not depends on rocks or waste emplacement style (JNC, 2000b). Assuming the shallowest depth of 300m and surface temperature of 15°C, geothermal gradient of greater than 15°C /100m may lead to the excess 100°C of the buffer temperature.

As a nationwide database, "Geothermal potential Map in Japan" (in Japanese) (Geological Survey of Japan, AIST, 2009) was used for applying the criteria.

#### 3.2.2.5 Volcanic thermal fluids and deep-seated fluids

Existence of low pH groundwater, which derives from volcanic thermal fluids or deep-seated water, would accelerate dissolution of the waste (ex. Wicks et al., 1982, Inagaki et al., 2012). In addition, carbonate concentration higher than 0.5mol/dm$^3$, which derives from deep seated water, would cause passivation and local corrosion of overpack due to the passivation (Taniguchi et al., 1999).

However, there is none nationwide literature or data in which show existence of hydrothermal convection/deep seated water. For this reason, groundwater with pH less than 4.8 that is actual acid region in which has no $HCO3^-$ (Noda and Takahashi, 1992), or carbonate concentration higher than 0.5mol/dm$^3$ are considered as the criteria instead of.

As a nationwide database, same database for geothermal activity was used for applying the criteria.

### 3.2.3 Requirements and criteria for human intrusion

Existences of mineral resources of current or potential economic values are in potential conflict with the repository. After closure and the potential loss of knowledge and memory about the repository, resource exploration or mining activities might cause an inadvertent human intrusion into the repository. This would cause a loss of containment function of the repository.

For nationwide screening of areas with the use of hydrothermal convection, hot springs and groundwater as resources, into difficult to set a uniform criteria about the importance as natural resources. In addition, groundwater in the depth of less than 300m is normally used as water resources. As a result, only the mineral mines which are registered by the mining law and have some quantity were defined as a requirement to be excluded.

Since there is none of nationwide literature or data satisfying the requirement, only fields of oil or gas showed in Geological Survey of Japan (1976), coal showed in Geological Survey of Japan (1973), and metal deposits showed in Naito (2017) were used for applying the criteria.

### 3.3 Requirements and criteria for engineering feasibility and safety

Examples of technical bases for identifying the criteria to them are as follows.

#### 3.3.1 Construction of facilities

For the safety of the underground facilities, it is important to provide safe condition for workers when constructing shafts and disposal galleries. Since there is already much experience in similar construction works such as tunnel excavation et al, and the Japan Society of Civil Engineers presents a general concept and guidelines for the assurance of safe work. These guideline indicated the specific risk factors to be considered: unconsolidated geological formation, swelling rock, rock bursts, high ground temperature and hot springs, harmful gas emissions, flooding, and mud eruptions. There have been developed a range of engineering countermeasures for individual factors which can be applied flexibly, depending on the specific conditions. It is thus generally inappropriate to set criteria for these factors applied for nationwide screening.

If there is unconsolidated geological formation deep underground, however, it is highly likely to collapse during tunnel excavation because such formation is not self-supporting, it is desirable to avoid the formation to ensure working safes. Specifically, there is no nationwide database directly showing the existence of unconsolidated sediments at depths of 300 m or more. Instead, the fact that the geological formations younger than the Middle Pleistocene are often unconsolidated (e.g. Yorita et al., 2009) was used as an alternative criteria (see **Table 1**).

For this criteria, nationwide documentation "Three-dimensional Model on the Boundary Depth and Thickness of Sediments for Estimation of Groundwater Storage in the Japanese Islands –first edition" (Koshigai and Marui, 2012), which summarized the geological ages and distribution of geological formations, was applied as available scientific basis.

#### 3.3.2 Facility operation

The surface facilities include directly handling radioactive waste, such as the plant encapsulating vitrified wastes into overpacks. These facilities are required to assure safety operation, in order to minimize the risk of radiation exposure resulting even at the accident. Since there exist already similar facilities to handle and store storing high-level radioactive waste, it was decided to consider prevention of damage by collapse of the ground, earthquakes, tsunami and external impacts, by reference to appropriate regulation criteria.

As these issues can be assessed only based on detailed information obtained through field investigations at individual sites, it is considered inappropriate to generally set criteria for nationwide screening.

However, it is desirable to avoid any area where there is a possibility of an impact by volcanic eruptions (e.g. pyroclastic flows) (see **Table 1**) that cannot be handled during operational period. For this purpose, nationwide database, "Seamless Digital Geological Map of Japan (1/200,000)" (website of Geological Survey of Japan, AIST) was identified for applying the criteria.

### 3.4. Safe transportation and security

As the Japanese archipelago extends over 1,000 km from north to south, consideration of the requirements in terms of safe transportation for long-distance is needed. Assuming restrictions set by the current legal system for transportation of radioactive materials, marine transportation is considered to be more preferable method for long distance transportation than land transportation by railway or vehicle in terms of expected radiological risk and security.

Even for long-distance marine transportation, land transportation is needed from the nearest harbor to the final disposal facilities. In that case, it is considered appropriate to set a requirement of sufficiently short distance from a harbor to identify "preferable area". This requirement should be considered both safety (public exposure) and nuclear security (short transportation time, etc.), when assuming the restrictions in the current legal system and also limitations of transportation infrastructure (restrictions on the gradient, need for constructing dedicated roads, etc.).

As an indication for the requirements, it is considered appropriate to apply to areas within about 20 km from the coast, based on past experience of land transportation of vitrified waste over about 10 km.

## 4. Conclusions

In July 28, 2017, METI published "Nationwide Map of "Scientific Features" relevant for Geological Disposal", which was drawn up applying the requirements and criteria to identify features of areas nationwide provided by Technology WG. Scientific and technical bases for the requirements and criteria for the Map were provided by NUMO.

Publication of the Map is the first step on a long way toward completion of geological disposal. NUMO will continue to hold public dialogues to ensure a deeper public understanding of geological disposal by utilizing the Map.

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