Study on operational safety issues in the Japanese disposal concept

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Introduction

In Japan, vitrified high-level radioactive waste (HLW) and certain types of low-level radioactive waste that results from the reprocessing of spent fuel and classified as TRU waste will be disposed of in deep geological formations.

NUMO aims to ensure the safety of local residents and workers during the operational phase and after repository closure and will therefore establish a safety case for the geological disposal programme at the end of each stage of the stepwise siting process. Although the Japanese programme is still in the stage before initiation of the siting process, updating the generic (non-site-specific) safety case is required for building confidence among stakeholders. This study focuses on operational safety issues for the Japanese HLW disposal concept.

Operational procedures

The following operational procedures after the construction of the underground facility are addressed in this study. This study focuses mainly on the operational phase, with the exception of the transport of the waste from the reprocessing facility to the repository.

In the surface facilities:

- inspection of the waste forms;
- packaging of the waste forms, e.g. into a metal overpack in case of HLW;
- transport of the overpack to the entrance of the access shaft/ramp.

In the underground facility:

- transport of the overpack in the access shaft/ramp (shaft and ramp are the alternatives for accessing the underground facility);
- emplacing the overpack in the disposal tunnel/pit;
- backfilling the remaining voids and the disposal tunnels;
- closing the access ramp and access and ventilation shafts.

Operational activities will start in a disposal panel once construction is complete; construction of the next panel will be carried out simultaneously with operations in existing panels (NUMO, 2011a).

Requirements for ensuring operational safety

Operational safety is aimed at the radiological and non-radiological protection of local residents and workers (NUMO, 2011a).

The requirements applying to radiological protection during the implementation of geological disposal are similar to those for operation in other nuclear facilities. The containment of radionuclides is ensured by the design of the facility and packaging, for example stainless steel canisters for vitrified waste and metal overpacks, and exhaust air filtering. Radiation shielding can be provided by e.g. thick concrete walls. Controlling radiation exposure to workers is also an essential component of radiological protection.

The requirements for non-radiological protection are similar to those in conventional civil engineering and mining projects. It is necessary to maintain an appropriate working environment, for example temperature and relative humidity in tunnels, and to secure evacuation routes.

Safety measures for preventing incident situations

The safety measures for preventing incident situations in the surface facilities, such as the waste inspection facility, are similar to those in other nuclear facilities, while those for the underground facility are specific to geological disposal. Incident situations are addressed based on an event-tree analysis as follows:

- dropping the waste form/overpack during handling (surface/underground);
- loss of electric power (surface/underground);
- fire (surface/underground);
- collision of transporter vehicle or deposition machine with tunnel wall (underground);
- damage to buildings (surface);
- rock fall (underground);
- explosion (surface/underground);
- flooding of tunnels (underground);
- flooding of the surface facilities (surface).

Various engineering measures will be designed based on the defence-in-depth principle to prevent the above incident situations.

For example, dropping the metal overpack during deposition in a disposal pit can be considered. This might be due to overloading of the suspension wire, probably as a result of seismic motion, or a fault in the handling device. To prevent dropping of the metal overpack, a double wire should be used for suspension or fail proof machinery should be used for the handling device. Periodic maintenance is also important. Moreover, the maximum height from the pit bottom to the deposition machine should be restricted to prevent damage to the overpack if the above measures fail.

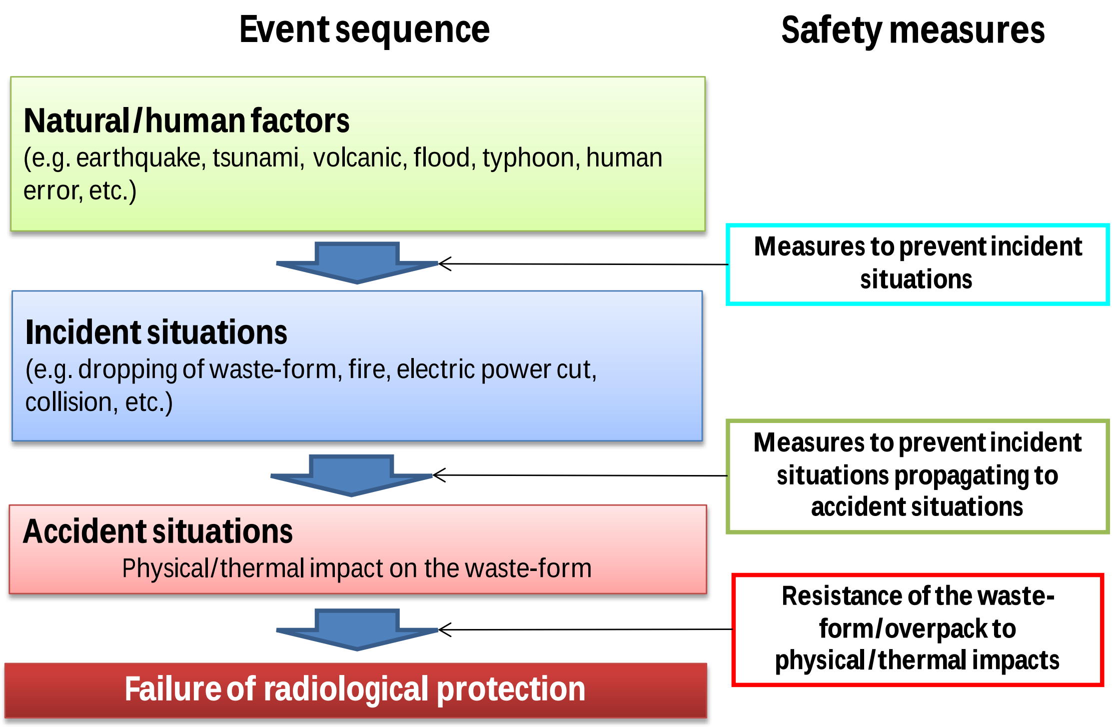
The overpack will be transported with a transporter vehicle along the access ramp (NUMO, 2011a). If the vehicle goes out of control, e.g. due to brake failure, it could be accelerated by the slope of the ramp and finally collide into a wall and/or another obstacle. To prevent this scenario, the vehicle will be equipped with an interlock device and periodic maintenance will be necessary. For the situation where the vehicle goes completely out of control, a speed-reducing run-out should be placed at a corner of the ramp. The vehicle should be equipped with impact reducing structures such as shock absorbers.

As another example, electric power may fail due to an explosion during construction of the facility in sedimentary rock. It is assumed in this case that methane gas is escaping from the surrounding rocks. During normal operation, the ventilation system can remove methane gas and the gas concentration can be monitored. If the ventilation stops for a longer period of time due to loss of electric power, the concentration of methane gas in the tunnel may increase. In this situation, the gas monitoring equipment would not function and the risk of a methane gas explosion might increase. To counter this risk, an explosion-proof design should be used e.g. for the excavation machine. In addition, if methane gas flows from the construction area to the waste deposition area, a gas explosion could occur in the deposition area. To prevent this, the ventilation system should be separated between the construction and deposition areas.

It is also possible that an earthquake could damage the tunnels, resulting in rock falling onto the waste deposition machine. Rock support will be installed as a measure for preventing rock fall. The resistance of underground tunnels to seismic wave motion has been confirmed by numerical analysis (NUMO, 2011b). As the acceleration of seismic waves underground is smaller than at the surface and the rock pressure on the tunnel wall is sufficiently high, the tunnel wall will not be damaged.

Although the measures for preventing other incidents are not mentioned here, they will be considered in the safety design of the facilities. Figure 1 illustrates the event sequence and safety measures mentioned above.

Figure 1: Schematic illustration of event sequence and safety measures



Resistance of the metal overpack to physical impacts in accident situations

Incidents can be prevented by multiple safety measures as mentioned above. Here, it is assumed that all the measures fail, resulting in an accident situation. If the metal overpack cracks due to an incident, radionuclides could be leached. In order to confirm the resistance of the metal overpack to physical impacts, numerical simulations are performed based on conservative assumptions. This study considers incidents associated with an accidental impact on the metal canister in the underground facility as follows:

- *Case I:* Dropping the overpack onto the bottom of the disposal pit during deposition.
- *Case II:* Collision of the transporter vehicle with the tunnel wall in the access ramp.
- *Case III:* Collision of the overpack with the tunnel wall due to methane gas explosion.
- *Case IV:* Rock fall on the deposition machine due to damage to the tunnel wall.

It is assumed that the overpack is damaged by crack penetration through the outer to the inner surface of overpack when the equivalent plastic strain on the overpack exceeds the strain limit of carbon steel (JIS SF340A) of 0.24.

Figure 2(a) shows the results of dropping the overpack onto the bottom of the disposal pit from a height of 5 m. The bottom of the pit was assumed to be a barely deformable solid for the conservative calculation. This calculation shows that a corner of the overpack was deformed, but crack penetration does not occur. It has been confirmed that there is no crack penetration when the overpack falls from a height less than 50 m.

For the second case, the collision of the overpack with the tunnel wall in the access ramp has also been simulated (NUMO, 2011a). In this calculation, it is assumed that the transporter vehicle is out of control on the access ramp, reaches a speed of 35 km/h and collides with the tunnel wall. Although the transport container and vehicle may reduce the impact of the collision during actual incidents, it is assumed here for the conservative calculation that the overpack is unprotected and collides directly with the wall. However, the equivalent plastic strain was a maximum of 0.046 at the surface and crack penetration did not occur (NUMO, 2011a).

Figure 2(b) shows the result for the collision of the overpack with the tunnel wall following a methane gas explosion. In this calculation, it is assumed that methane gas flows from the construction area to the deposition tunnel, explodes and the blast blows over the overpack being deposited. The overpack flies through the air with a maximum speed of 72 km/h and collides with the tunnel wall. This calculation also shows that a corner of overpack was deformed, but that crack penetration does not occur.

Figure 2(c) shows the result of a rock fall onto the overpack. In this calculation, the rock mass with a cubic form of 5 m ´ 5 m ´ 5 m (around 200 tonnes) falls directly from a height of three metres onto the unprotected overpack for the conservative calculation. However, only slight damage was observed on the surface of overpack, while brittle deformation of the rock occurs.

The overpack is thus highly resistant to physical impact and no accidents will occur.

Recovery from accident situations

The numerical calculation of the physical impacts on the overpack showed no leaching of radionuclides during accident situations. To maintain a sustainable disposal programme, techniques for recovering from incidents should be prepared. Figure 3 shows a schematic illustration of the procedure for recovery from rock fall (Case IV above). The rock fragments can be removed by the existing machines and the damaged roof will be reinforced. After removing the deposition machine, the overpack can be removed, for example by overcoring of the bentonite buffer. To reduce the radiation exposure of workers, these machines should be remotely handled. These techniques should be developed before starting operation.

Figure 2: Distribution of equivalent plastic strain on the cross-section of the overpack after incidents

Red areas indicate strain exceeding the limit; arrows indicate the direction of the stress

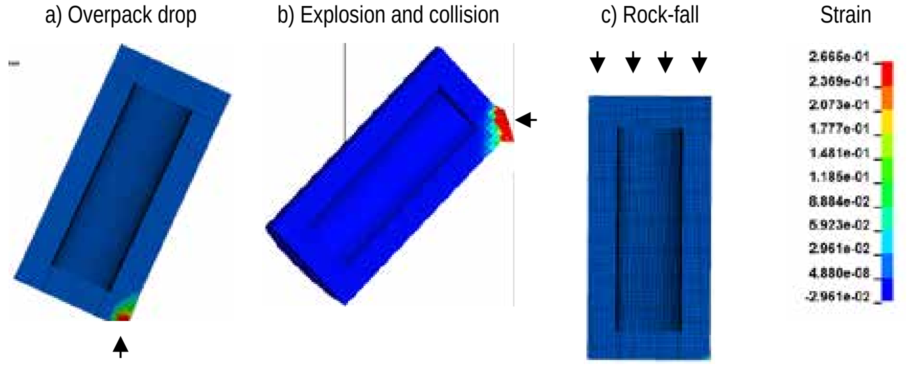
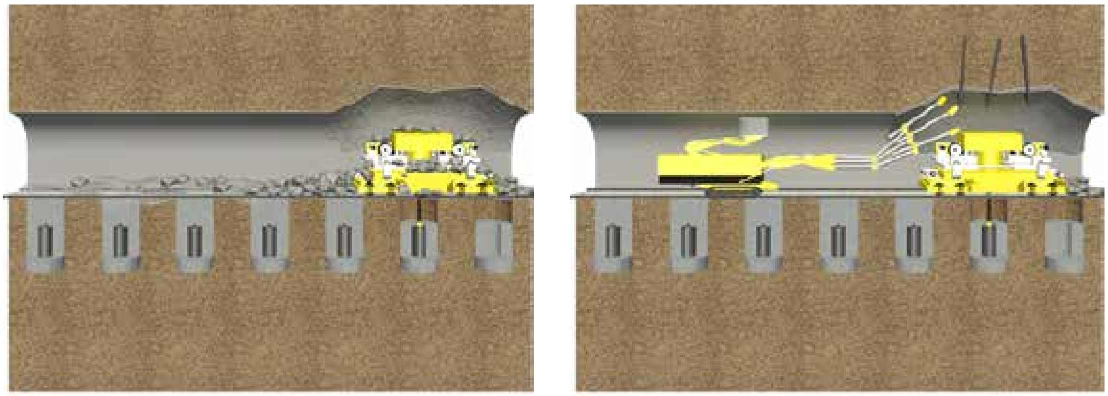


Figure 3: Conceptual view of the recovery technique from a rock fall incident during the deposition of an overpack into the disposal pit

Left – rock fall incident during the deposition process
Right – removing the rock and reinforcing the damaged roof



Conclusions

The operational safety of the Japanese disposal concept can be assured by applying requirements similar to those for other nuclear facilities and conventional civil engineering projects. To prevent incidents, safety measures can be designed based on the defence-in-depth principle. The metal overpack has a high resistance to physical impacts resulting from incident scenarios. Although the risk of radionuclide leaching is negligible, remotely controlled recovery techniques should be developed before starting operation.

References

Nuclear Waste Management Organization of Japan (NUMO) (2011a), *Safety of the Geological Disposal Project 2010: Safe Geological Disposal Based on Reliable Technology*, NUMO-TR-11-01, Tokyo, Japan (in Japanese).

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