PRELIMINARY STUDY OF PRE-CLOSURE SAFETY ASSESSMENT IN THE NUMO SAFETY CASE

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Abstract

The methodology of assessment for pre-closure safety has been developed as a part of NUMO safety case. The ongoing update of the safety case for co-disposal of HLW and TRU waste in Japan will include a more extensive assessment of pre-closure safety than has been carried out in the past. The pre-closure safety case aims to assure both radiological and conventional safety. Radiological safety for public and workers requires radiation shielding and radionuclide containment within the disposal facilities in case of operational perturbations. Radiation control and facility design are based on guidelines applied for other nuclear facilities. Within the radiation-controlled zones, most operations will be remote-handled or will involve appropriate shielding, avoiding any significant dose to workers. For conventional safety for workers, the working environment will be maintained to ensure worker comfort and safety during normal operation. After identifying the evaluation scenarios that take into account the progress of abnormal situation, an impact analysis is conducted to evaluate the damage to waste packages and/or workers. In the evaluation of the abnormal state, the relationship between the abnormal state that may occur at the geological disposal facility and the potential countermeasures are schematized by taking the same approach as the event tree analysis method.

1. Introduction

NUMO has developed a generic safety case for geological disposal in Japan. This safety case presents technical evidence to support the feasibility and safety of geological disposal, which will encourage stakeholder confidence in the safe implementation of geological disposal and will provide the basic structure for a safety case which will be applicable to any potential site. The target range of the safety case is not only after closure of the repository but also the pre-closure period.

In the previous generic safety studies[1, 2], the feasibility of geological disposal in Japan of vitrified high-level waste (HLW) and various types waste from reprocessing of spent fuel and from mixed-oxide (MOX) fuel fabrication (termed "TRU waste" in Japan) was demonstrated, focusing on long-term post-closure safety but not discussing operational safety in detail.

NUMO has been developing the key technologies required for the safe implementation of the geological disposal project and published a comprehensive technical report[3] in 2011. The target range of the safety case is not only after closure of the repository but also the pre-closure period.

Based on the design of the disposal facility and the procedures for construction and operation, etc., a Hazard Database is established to allow transparent scenario development for the pre-closure safety assessment. It is important to discuss how operational safety can be secured in the disposal facility. The present study was, therefore, undertaken in order to demonstrate the prospect of ensuring safety.

During the period for construction and operation, the state of the disposal facility is classified into the normal state and the abnormal state. The normal state is defined as the state of the facility assumed as normal operation in the design. A state that deviates from planned operation due to abnormal events such as internal fire, equipment failure or loss of power is defined as an abnormal state.

In the evaluation of the abnormal state, the relationship between the abnormal state which can occur in the geological disposal facility and potential countermeasures is schematized using the event tree analysis method. These results are compiled into the Hazard Database for operational safety. After identifying the evaluation scenarios based on the Hazard Database, an impact analysis is conducted to evaluate the damage to waste packages and/or workers.

The pre-closure safety assessment aims to assure both radiological and non-radiological protection of the public and workers. This paper describes the key aspects of safety case concerned with the assessment of pre-closure safety.

2. Operational procedures and design of the geological disposal facility

Specified radioactive waste final disposal plan[4] requires disposal of 40,000 vitrified waste packages and 19,000 m^3 of TRU waste. NUMO plans to design a geological repository in accordance with this disposal plan. The repository design consists of the various surface facilities and an underground repository.

As shown in Fig. 1, the operational processes for geological disposal can be consisted of seven processes. These images illustrate the seven processes for HLW. The processes for TRU waste are almost the same as for HLW.

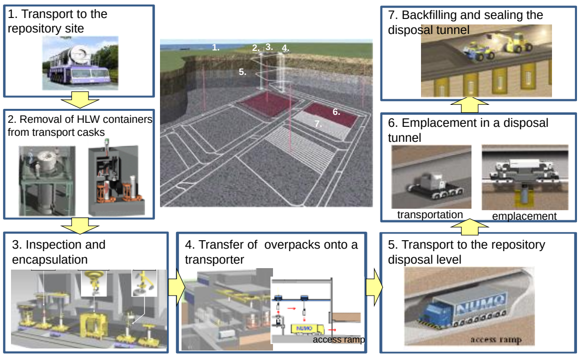

Fig. 1. Operational processes for HLW waste

The underground facilities consist of an access ramp and connecting tunnels for transporting the waste from the surface facilities to the underground facilities, disposal tunnels for emplacing the waste and shafts for ventilation, drainage, transportation of excavated rocks and workers.

3. Concept of ensuring operational safety

Radiological protection of the public and conventional safety for workers during the period for construction and operation of the repository are discussed. During the period for construction and operation of the disposal facility, the public and workers are protected from radiation by maintaining the functions "containment" and "radiation shielding" for the radioactive waste in the transport container and the surface facility. In addition, conventional safety for workers will also be implemented.

Radiological protection is planned according to the Reactor Regulation Act and guidelines for other nuclear facilities[6, 7].

On the other hand, conventional safety for workers is based on the Industrial Safety and Health Act. The measures for ensuring operational safety are thus implemented based on the measures for existing atomic energy facilities and infrastructure such as road tunnels, mines or underground power plants.

Fig. 2 shows schematically the conceptual flow of event sequences and safety measures based on the defense in depth concept[8].

Firstly, "Measures to prevent the occurrence of an abnormal state" are applied to prevent the occurrence of an abnormal state of the facility or wastes due to external hazards such as natural events, anthropogenic events and equipment failure. This is the first protection step.

The second protection step includes measures for preventing the escalation of the abnormal state. In the event of failure or incorrect operation during construction and operation, it is necessary to detect the abnormal state at an early stage, remedy it, or take measures to prevent progression to an accident state. "Measures to prevent progression of the abnormal state", such as the use of incombustible materials and flame-retardant materials, duplication of lines, etc., are prepared for abnormal states such as fire, overpack dropping or loss of power.

Furthermore, if the abnormal state exceeds the assumed magnitude, it may be that "measures to prevent the progression of the abnormal state" will become invalid. In this case, in order to prevent the abnormal state from progressing to an accident situation involving release of radiation by keeping the abnormal state within the design basis and the robustness of the facility and the waste, it is necessary to take measures such as emergency fire extinguishing facilities and limitation of lifting height of the overpack. This is the third protection.

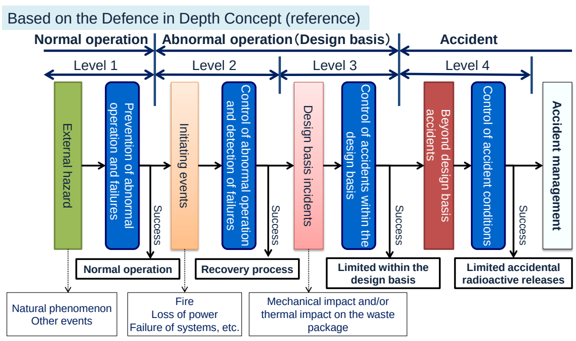

Fig. 2. Conceptual flow of event sequences and safety measures[5]

The Hazard Database for operational safety was constructed to protect the public and workers from radiation and to ensure conventional safety for the period for construction and operation of the geological disposal facility[5]. The process of development and justification of scenarios are provided in chapter 4.

4. Scenario development for pre-closure safety

This chapter illustrates how to construct the Hazard Database for the period of construction and operation. In the evaluation of abnormal situations, the Hazard Database for operational safety was constructed to allow transparent scenario development for pre-closure safety and to promote protection of the public and workers from radiation and ensure conventional safety for workers.

In the evaluation of the abnormal state, the relationship between an abnormal state which can occur in the geological disposal facility and the potential countermeasures is schematized using the event tree analysis method. These results are compiled into the Hazard Database for operational safety.

In constructing the Hazard Database for operational safety, we proceeded with consideration of international safety standards[9, 10].

The development processes for event identification and event evaluation are shown in Fig. 3.

Five steps are set within this scope of work.

Hazard Database development is included in the scope of STEP 4. The contents of each step are presented in section 4.1 to 4.5.

Finally, based on the results of the Hazard Database development, evaluation scenarios relating to mechanical and thermal impacts are constructed and the effects of these impacts are evaluated by analysis.

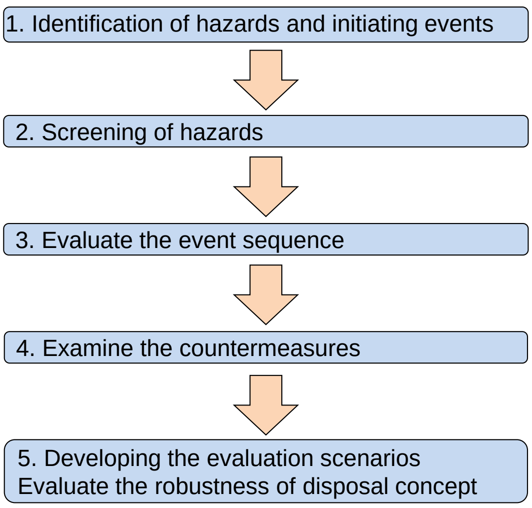

Fig. 3. The process of development and justification of scenarios[5]

The relationship between abnormal conditions that may occur in the geological disposal facility and the safety measures taken against them is schematized using the event tree analysis method. The details are described in section 4.1 to 4.4.

The summary of these results represents the Hazard Database for operational safety. It is displayed in the database in the form of an event tree and is linked with hazard datasheets showing the details of the progress of each event.

4.1 Identification of hazards and initiating events

The guideline for similar facility, “Regulations and guides for waste management facilities“, is used as a reference, and the external hazards that may cause the abnormal state of facility or abnormal situation of the wastes are identified. And the hazards are identified from relevant laws and regulations in Japan shown in Table 1.

Table 1. Relevant laws and regulations in Japan

Relevant laws and regulations in Japan
Regulations on the location, structure and equipment standards for waste management facilities
Disaster Countermeasures Basic Act
Industrial Health and Safety Act (second and third editions)
Regulations for Enforcement of the Mine Safety Act

First of all, natural events and other events that are the cause of the hazard are extracted based on relevant laws and regulations as shown in Table 1.

According to the guidelines for waste management facilities, all events are classified into natural events and other events.

The events listed in the regulations for similar facilities have different causes and effects, affecting the facilities and/or wastes. This makes it difficult to organize the hazards.

For this reason, the extracted hazards were first classified into causes and effects. With this arrangement, it is possible to avoid complicating the work of organizing the events causing the abnormal state in the next step. Also, all the events are reviewed and the relationship between cause and effect may be revised in the next step, as may some of the classifications.

For natural events 11 events such as earthquake, tsunami, floods, wind, tornado, rain, snow, lightning, volcanic influence, biological event and forest fire were identified.

For other events 13 events such as ballistic fragment, dam collapse, explosion, fire in neighboring installations, toxic gas, ship collision, electromagnetic interference, illegal intruders, carry on of the explosive and harmful material, cyberterrorism, mine inundation, ground pressure, and terrestrial heat were identified.

In this way, 11 natural events and 13 other events were extracted, totaling 24 events. Also, because pre-closure safety is required to ensure both radiation protection and conventional safety, the effects of events on radiological safety and conventional safety for workers were arranged separately.

After this identification, ballistic fragments (for example aircraft crash, etc.), dam collapse, fire in neighboring installations and ship collision were excluded at present. It is difficult to consider these events at the current stage because whether the facility will be affected by these events depends on the location, topography and surrounding environment at a specific site to be selected in the future. Other external events (e.g. criticality events, decay heat, direct release of radiation, etc.) are excluded because they are evaluated to be less frequent or are considered in other event sequence analyses.

4.2 Screening of hazards

The natural events and other events are taken as the starting-point and the event sequences that might affect the facilities, waste and workers are identified. The initiating events of an abnormal state in the disposal facility are identified. As a typical example, Fig. 4 shows the result of an event sequence analysis due to an earthquake.

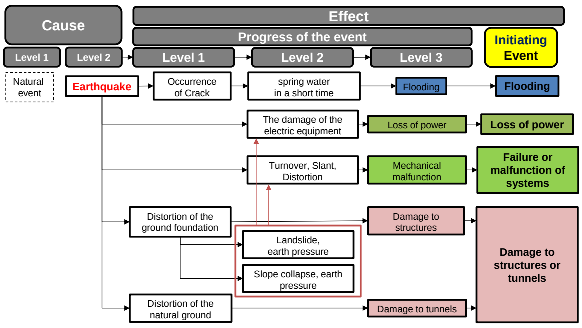

Fig. 4. Event sequence analysis due to earthquake[5]

As shown in Fig. 4, when an earthquake is the initiating event, progression will eventually lead to flooding, loss of power, failure or malfunctioning of systems and damage to structures or tunnels. Event sequence analyses were organized for all events in the same way.

In arranging these event sequences, if all combinations were to be considered the combinations would be too numerous to allow clear arrangement. Events which cannot be reasonably explained are also included in the initiating events to be considered. For this reason, we organized these event developments in the following way.

We investigated the types of natural disasters worldwide in the past, the occurrence situation and the number of occurrences of each.

By comparing with the accident in the past, it is possible to screen out the events which are not plausible or low frequency of occurrence.

Also, in judging whether these could be an initiating event or not, we organized them based on whether or not they should be considered for the geological disposal facility. By proceeding in this way, it was possible to extract event sequences to be considered from among the many combinations of events.

Natural events and other events listed in Tables 2 and 3 were arranged in the same way for each.

As a result, for radiological protection all hazards can be organized into six initiating events. Taking the conventional safety for workers into account, a poor working environment should be added as a seventh initiating event as shown in Table 2.

Table 2. Initiating events affecting to the disposal facility

Initiating events
1. Fire
2. Explosion
3. Flooding
4. Loss of power
5. Failure or malfunctioning of systems
6. Damage to structures or tunnels
7. Poor working environment

4.3 Event tree analysis for event sequences

In the evaluation of the abnormal state, the relationship between the abnormal state and potential countermeasures are schematized using the event tree analysis method, with the initiating event specified in the previous section as the starting-point.

As a typical example, Fig. 5 shows the result of an event tree analysis for failure or malfunctioning of systems leading to dropping of the overpack. This figure shows the analysis results for progression of the initiating event caused by the machine failures, malfunctioning and human error, etc. assumed in the surface facilities. As a result, events that impact on the overpack are arranged in four cases and the preventive measures are indicated in the next chapter.

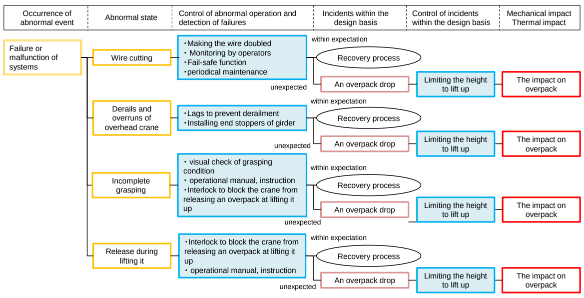

Fig. 5. Result of event tree analysis for dropping of the overpack[5]

Through the analysis of event sequences, "hazard datasheets" that show the details of the event sequence are developed. "Hazard datasheets" show not only the details of the progression but also the measures to be taken against the events.

The hazard datasheet also describes incident cases, relevant laws and regulations for related facilities and other facilities as reference information.

Every initiating event was analyzed for each operational process. Identified initiating events were treated as the starting-point, every situation which is generated by considering all combination of initiating events and operational processes were analyzed with Event Tree Analysis method. In this case, the operational processes was grouped into three processes in the surface facilities, access ramp and underground facilities and analyzed in the same way.

As a result, 54 events that have mechanical or thermal effects on the overpack and waste packages were identified; 48 events that affect workers and others during the operational period were also identified. In the construction period of the underground facility, there were 52 events affecting people such as workers.

4.4 Measures against abnormal situations

Event sequences are analyzed and the measures to be taken in the case of these abnormal events are also examined. Measures are classified into three stages: "Measures to prevent occurrence of the abnormal state", "Measures to prevent progression of the abnormal state" and "Mitigation measures" based on the defense in depth concept[8].

The purposes of these measures are as follows:

・To prevent abnormal operation and failures

・To control abnormal operation and detection of failures

・To control incidents within the design basis by mitigating the thermal or mechanical impact.

These safety measures are also included in hazard datasheets.

4.5 Numerical analysis for dropping of the overpack

After identifying the evaluation scenarios based on the Hazard Database development, an impact analysis is conducted to evaluate the damage to waste packages and/or workers.

In the surface facility, overpacks are shipped to the transport vehicle which transfers them through the access tunnel. In this process, it was assumed that overpack would fall due to the failure of lifting equipment.

For example, to evaluate the consequences of the dropping impact on the overpack, Fig. 6 indicates the evaluation model of a finite element analysis which assumes a maximum drop height of 9 m. The evaluation focused on the possibility of cracks penetrating the overpack.

For the purpose of conducting more precise evaluation, analysis is performed with an analysis model reflecting the following items.

- Modeling the parts of lid of overpack and welds of it in order to consider the shearing force and stress concentration at the welded part in the case of collision.
- Modeling the vitrified waste and waste canister inside the overpack in order to consider the behavior such as a bounce behavior inside the overpack in the case of collision.
- Simulating the collision against concrete floors in order to consider the effect of impact mitigation.

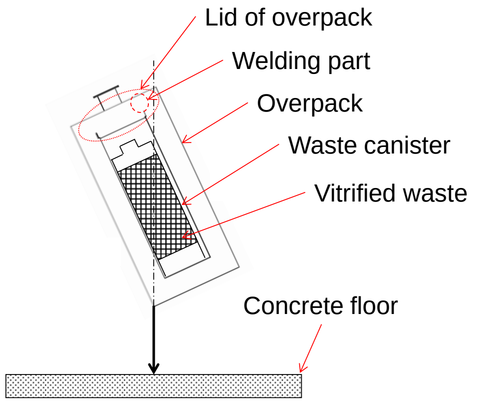

Fig. 6. Analysis model for evaluating the dropping impact on the overpack

LS-DYNA Ver.8.0.0., which is general-purpose structural analysis software, was used for this analysis.

The possibility of cracks penetrating the overpack is judged by comparing the equivalent plastic strain and breaking strain of the overpack material. In the judgment, the penetrating cracks were judged to occur when the region where the equivalent plastic strain exceeded the fracture strain of the material was connected from surface to the inside of overpack.

The analysis results indicated that the area where the equivalent strain exceeds the strain limit of the carbon steel is generated only at the region surrounding the impact point, but did not reach the inside of the overpack as shown in Fig. 7.

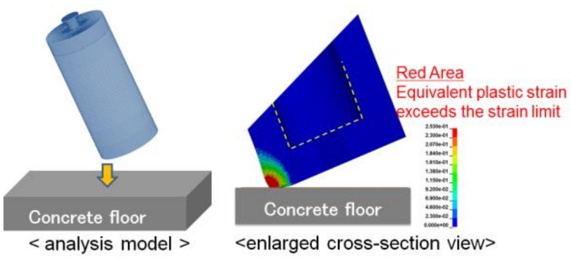

Fig. 7. Result of the analysis in case of dropping of overpacks

In addition, the waste canister resulted in maintaining structural integrity. There was no influence on welded part of an overpack due to the jumping up of the vitrified waste and no influence on the upper part of the canister.

This scenario is assuming the case of dropping from a lifted height of 9 m, the height expected for the time of actual handling. Therefore, it is unlikely to result in through crack in case of dropping of overpacks.

5. CONCLUSIONS

A methodology for assessment that demonstrates the prospect of ensuring pre-closure safety has been developed in the NUMO safety case. The safety case for the period of pre-closure includes both radiological and conventional safety.

NUMO has also constructed a Hazard Database for operational safety during the period for construction and operation of the geological repository. The Hazard Database is established to allow transparent scenario development for the pre-closure safety assessment.

In the evaluation of the abnormal state, the relationship between the abnormal state which can occur in the geological disposal facility and the potential countermeasures is schematized using the event tree analysis method. These results are compiled into the Hazard Database for operational safety.

The compiled Hazard Database for operational safety will be continuously updated in the future and the comprehensiveness for assessing the pre-closure safety will be improved.

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