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Preliminary Safety Evaluation Framework for a PWR Spent Nuclear Fuel Dry Storage

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1. Introduction

Spent nuclear fuel (SNF) generated from domestic pressurized water reactors (PWRs) has been stored in onsite At-Reactor (AR) storage facilities. Due to the limited existing SNF storage capacity, however, onsite Away-From-Reactor (AFR) storage has been considered as an attractive alternative [1]. In this regard, staffs in KINS (Korea Institute of Nuclear Safety) have investigated to establish a preliminary safety evaluation framework for a hypothetical AFR PWR-SNF storage facility. At first, a reference fuel storage system was assumed based upon public domain information on commercial PWR-SNF storage casks. And then, potential safety cases for the reference storage system were analyzed and standard evaluation procedures for major safety factors were established. Finally, preliminary evaluations were performed for a few representative scenarios which may affect the safety functions of the reference storage system.

2. Reference Storage System

It is assumed that the PWR-SNF should be stored in the existing AR storage pool for a sufficient time after discharge from the reactor core. After heat-generation rate and radioactivity due to short-lived radionuclides are sufficiently reduced for handling, the SNF is moved to a new AFR dry storage facility and stored for a few decades. The types of commercially available PWR-SNF dry storage systems can be categorized into (1) vault, (2) silo, and (3) cask storage systems. In this study, the cask storage system, which has been safely used in other countries, was selected as an option for storing sufficiently cooled- and decayed- PWR-SNF.

In order to derive a reference design concept, we have collected public domain information on the SNF dry storage systems used in Canada (CANSTOR), Germany (CASTOR), Japan (Concrete Cask), the United States (NAC-UMS, VSC-24, HISTORM-100, etc.) [1,2]. As the result, the major structures, systems, and components (SSCs) of the hypothetical reference storage system were brought up as shown in Figure 1.

The fuel elements to be stored can be categorized into fuel rods, burnable poison rods, and other internals. Major structures are concrete pads on which storage casks are laid, storage buildings which may house arrays of storage casks, and fabrication buildings in which some components can be fabricated onsite. Furthermore, office buildings and access control buildings may be constructed close to the storage area, and the storage area is usually surrounded by fences. In some cases the storage casks are operated without storage buildings, though, concrete foundation, walls, ceilings, and air-cooling structures of the storage buildings should be taken into account. In addition, major systems and components of the cask storage systems can be categorized into the followings: systems for fuel management (fuel storage systems, cask handling system, and onsite transfer systems), monitoring systems (radiation control systems and I&C systems), and other supporting systems.

The SSCs listed in Figure 1 should not be understood as exclusive. That is, some SSCs can be either optional or mandatory in a specific storage system.

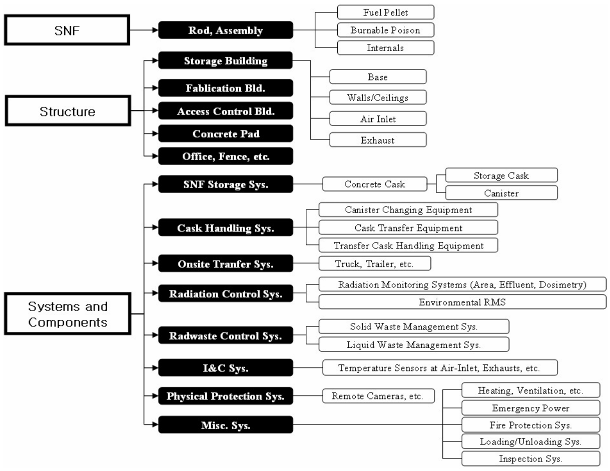

Figure 1. Major SSCs of the reference AFR PWR-SNF storage system

3. Safety Cases and Safety Evaluation Procedure

In this section, a series of safety cases for the reference AFR PWR-SNF storage system are analyzed and described. In addition, standard safety evaluation procedures for verifying representative safety factors are discussed and a sample stepwise evaluation procedure is illustrated.

3.1 Generic Safety Cases

In order to establish generic safety cases for the reference SNF storage system, potential accident and/or abnormal event scenarios should be analyzed [2]. That is, root-causes, possible initiating events, and potential impacts due to the events were investigated and the major components of concern under the situation were identified. These analyses were performed for each management step (i.e. handling, storage, etc.) of SNF. The events/accidents were derived based on the possible deterioration of major safety functions (i.e. shielding, confinement, heat-removal, criticality, etc.) of the SNF storage system. Table 1 shows a part of generic safety case taking into account of potential impact to the shielding safety function during the storage period of casks.

Table 1. Events, causes, and potential impacts which may affect the shielding safety function of SNF storage casks

<table>
<tr><th>Causes</th><th colspan="2">Initiating Events</th><th>Components of Concern</th><th>Impacts</th></tr>
<tr><td rowspan="2">External Force</td><td colspan="2">Earthquake</td><td rowspan="9">Cask, Canister</td><td rowspan="9">Deformation, Rupture</td></tr>
<tr><td colspan="2">Missiles</td></tr>
<tr><td rowspan="2">External Heating</td><td colspan="2">Fire (Onsite)</td></tr>
<tr><td colspan="2">Fire (Offsite)</td></tr>
<tr><td rowspan="4">Heating Inside Canister</td><td rowspan="2">Plugging of Air-Inlet</td><td>Cask</td></tr>
<tr><td>Building</td></tr>
<tr><td rowspan="2">Plugging of Air-Exhaust</td><td>Cask</td></tr>
<tr><td>Building</td></tr>
<tr><td>Corrosion</td><td colspan="2">Aging</td></tr>
<tr><td rowspan="7">External Force</td><td colspan="2">Earthquake</td><td rowspan="7">Building</td><td rowspan="7">Damage, Degradation</td></tr>
<tr><td colspan="2">Missiles</td></tr>
<tr><td colspan="2">Typhoon</td></tr>
<tr><td colspan="2">Tsunami</td></tr>
<tr><td colspan="2">Flood</td></tr>
<tr><td colspan="2">Explosion (Offsite)</td></tr>
<tr><td colspan="2">Land Slide</td></tr>
<tr><td rowspan="2">External Heating</td><td colspan="2">Fire (Onsite)</td><td rowspan="3">Cask, Canister, Building</td><td rowspan="3">Concrete Composition Change</td></tr>
<tr><td colspan="2">Fire (Offsite)</td></tr>
<tr><td>Aging</td><td colspan="2">Aging</td></tr>
</table>

3.2 Standard Safety Evaluation Procedure

In this study, a set of standard safety evaluation procedures was developed for safety reviewers to verify major safety functions of the proposed SNF storage system. As an example, Figure 2 shows the preliminary evaluation procedure to determine the shielding design of the storage system is sufficient to meet the regulatory requirements and criteria.

It should be noted that shielding design of arrays of multiple casks as well as a single storage cask is to be verified in the safety review process.

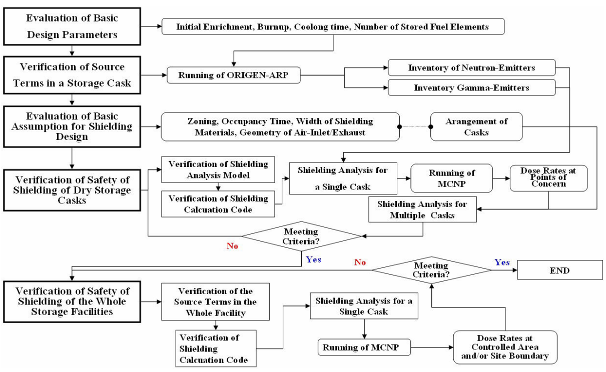

Figure 2. Standard safety evaluation procedure for verifying shielding safety function of the reference AFR PWR-SNF storage system

3.3 Preliminary Evaluations

In order to determine the applicability of the draft evaluation framework proposed so far, preliminary safety evaluations were performed for a few safety cases such as fire during onsite transport, flood, lightning, wind, missile, and so forth. Figure 3 shows a hypothetical situation of a cask when the site is flooded.

Based upon a series of assumptions and Bernoulli's equation, it turns out that the cask can be moved by the water flow when the flow rate exceeds 8.6 m/s. Accordingly, the acceptance of the cask design for the flooding condition can be determined by use of site-specific historical records of meteorology [3].

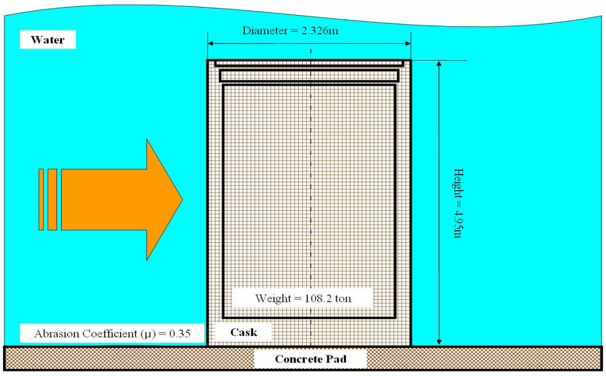

Figure 3. Hypothetical situation of a storage cask under flooding event

4. Conclusion

In preparation for the potential licensing application of an AFR PWR-SNF storage system, a set of preliminary framework for safety evaluation was established. It is believed that the reference fuel storage system, generic safety cases, and standard safety evaluation procedure would give safety reviewers some insights into how to plan and what should be taken into consideration in the regulatory review of newly proposed SNF storage system. However, the framework proposed in this paper is still under development and it will be finalized by the end of 2006.

REFERENCES

[1] J. H. Cheong, et al., Development of Safety Evaluation Method for Dry Storage of Spent Nuclear Fuel : I. Investigation of Current Status, KINS/RR-197, 2003.

[2] Nuclear Safety Research Association, Safety Design and Assessment Methodology for Canister-Type Spent Nuclear Fuel Storage Facility Adopting Concrete Cask Storage Method, 2002.

[3] J. H. Cheong, et al., Safety Evaluation Methodology for Dry Storage Facility of CANDU Spent Nuclear Fuel, KINS/RR-319, 2005.