Preliminary Numerical Simulation and Test Plan for Actual Drop Accident Condition

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1. Introduction

As we construct a safety case of transport cask and spent fuel, there are actual accident conditions in the life-cycle, which are beyond the regulatory hypothetical accident conditions. To ensure the safety of spent fuel transportation, it is necessary to select the accident conditions for the safety evaluation based on the analysis of accident scenarios and to perform a safety assessment under these actual accident conditions.

2. Test plan for actual accident conditions

2.1 Evaluation of actual accident conditions

Actual operation scenarios of spent fuel handling and transportation were derived by analyzing spent nuclear fuel storage facilities, transport systems and transport procedures in domestic nuclear power plants.

Among them, it was analyzed that there could be a possibility of a drop of nuclear fuel due to the shortage of the crane cables, the damage of the fuel handling device, or the operator's mistake during withdrawal, movement and loading of the fuel in the spent fuel wet storage tank.

In case of underwater fall, the maximum drop height was estimated to be about 5 m. The nuclear fuel would be damaged, but no radioactivity or radiation leakage would occur. In addition, when the cask is moved from the decontamination tank to the transportation vehicle, it is possible to cause a drop of 9.5 ~ 14 m due to the various reason described above.

One of the worst accident conditions in which the cladding of the spent nuclear fuel assemblies is damaged is dropping of cask from the high height without the impact limiter which is shock absorbing component. Therefore, it is necessary to evaluate the safety of the actual accident condition when the cask without impact limiter drops down from 15 m height.

In this study, structural integrity of cask, nuclear fuel assemblies, cladding tubes and support grids is evaluated when a transport cask without shock absorbers drops down to concrete pad at a maximum of 15 m.

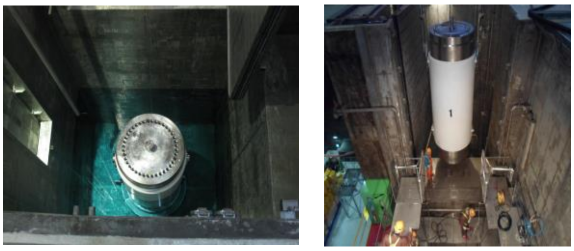


Fig. 1. Cask transportation w/o lid bolt fastening (Loading pit -> Decon. pit).

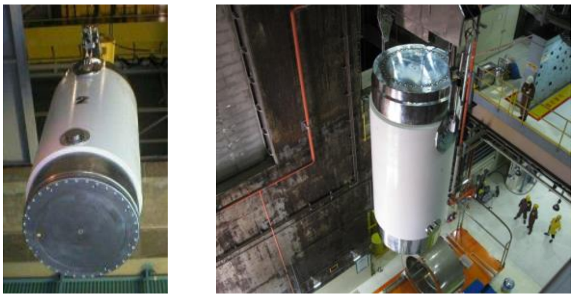


Fig. 2. Cask transportation w/o impact limiters (Decon. pit -> Truck bay).

2.2 Test plan simulating actual accident condition

To assess the actual accident conditions, KAERI will conduct a non-absorbing drop test with a drop height of 15 m. The schematic diagram of the overall drop test is shown in Fig. 3.

In order to carry out the ultimate drop impact test, we considered where to place the test. At the KAERI's safety test facility, tests have been carried out according to the IAEA Regulation SSR-6 and the Nuclear Safety Commission Act No. 2014-50, which are falling to a non-deformable rigid pad at a height of 9 m. Drop test at 15 m height is not possible at KAERI test facility.

We have also examined concrete pads installed on vacant lots, closed buildings, or factory sites, and tested after people's access control. However, significant problems such as operation of the hydraulic equipment that releases the cask in the air (440V needed), movement of structures, power supply (using generators or batteries), and coping with the unexpected weather have been found. Finally, it was decided to carry out the test by modifying and repairing a part of the facility in KAERI.

The scenario we want to simulate is to drop cask without impact limiter onto a concrete pad, which represent the second floor of a building. Therefore, we will construct the concrete pad laid over the ground through reinforcement work on the empty space of test facility in Fig. 4. The protecting structure will be installed to prevent accidents caused by the rebound of the transport cask after the impact. We decided to use a portable heavy car crane to lift the cask to a height of 15 m and to drop it. It is expected that a lot of budget will be required for the series of works such as modifying of test facility, performing drop test, and restoration of facility after test.

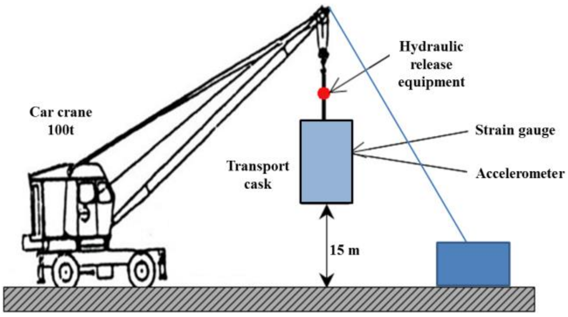


Fig. 3. Conceptual schematic drawing for test.

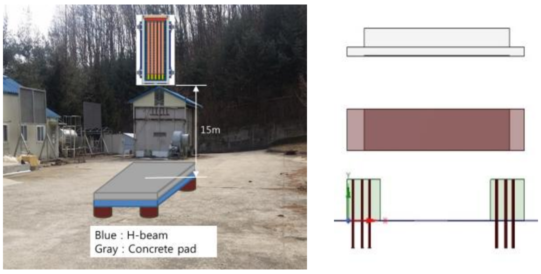


Fig. 4. Conceptual drawing of concrete pad.

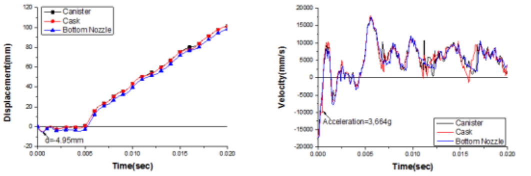
2.3 Preliminary numerical simulation

Displacement and velocity history of cask, canisters, and bottom nozzle of the fuel assembly after a 15 m fall are shown in Fig. 5. In Fig. 5(a), the displacement history of each component showed that the concrete pads were compressed to a maximum of 4.95 mm after impact, and that the cask was rebounded upward after about 5 ms. In Fig. 5(b), the speed of the cask was rapidly reduced during 1 ms at the beginning. The maximum deceleration was about 3,664 g.

Generally, a deceleration is about 100 to 300 g, and contact holding time is about 10 to 25 ms, when the impact limiter is assembled into a cask. However, the impact energy is hardly absorbed in this actual accident condition such as the drop of high height and without impact limiter.

The plastic deformation of the canister occurred from the bottom to the middle height, which resulted in the expansion of the diameter. As a result of the expansion of the canister, the outer wall of the canister has come into contact with the inner wall of the cask.

In other words, since the contact area after the drop occurred widely from the bottom of the canister to the middle height, it is estimated impossible to recover the canister from the cask after the actual drop accident condition of 15 m height.



(a) Displacement (b) Velocity

Fig. 5. Displacement and velocity time history.

The average axial stress acting on the bolt was 1,615 MPa and the average shear stress was calculated to be 231 MPa. The allowable tensile stress and allowable shear stress of the bolts applied in this analysis are 557 MPa and 334 MPa, respectively. Therefore, stress evaluation for multiple loads was performed, and as a result, all bolts were evaluated to be damaged.

3. Conclusions

The actual accident conditions beyond regulatory accident conditions were evaluated. Among them, preliminary structural integrity evaluation was carried out for the actual drop accident condition in which the transport cask without impact limiter drops at a maximum of 15 m. As a result, it was estimated that all the cladding, supporting guide tube, bottom nozzle and lower support grid in the spent fuel assembly were damaged and all the bolts in the cask lid were also damaged. For the further evaluation, KAERI will perform the test to simulate the drop condition with 15 m height and without impact limiter.