Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

A Review on Sabotage against Transportation of Spent Nuclear Fuel

Sungyeol Choi [a*], Jihwan Lim [a]

[a]*Department of Nuclear Engineering, Ulsan National Institute of Science and Technology, 50 UNIST-gil, UNIST, Ulsan, 44919, Republic of Korea*
[*]*Corresponding author: chois@unist.ac.kr*

1. Introduction

To ensure the security of spent fuel storage and transportation, in recent years, many researchers have assessed sabotage attacks against spent nuclear fuel during storage and transportation. A brief review published in 2006 in the U. S. National Academies Press explains scenarios of terrorist attacks on spent fuel storage with the concept of risk, but this study covers scenarios roughly as either air or ground attacks without details [1]. The U. S. Nuclear Regulatory Commission published a report on risk assessment of spent nuclear fuel transportation in 2014. This report assesses the risk of routine transportation including cask response to an impact or fire accidents [2]. In addition, we have still found the non-negligible difference among the studies for scenarios, approaches, and data. In order to evaluate attack cases on the same basis and reflect more realistic situations, at this moment, it is worthwhile to thoroughly review and analyze the existing studies and to suggest further development directions. In Section 2, we compare scenarios of terror attacks against spent fuel storage and transportation. Section 3 compares target scenarios, capabilities, and limitations of assessment methods. In addition, we collect and compare modeling data used for previous studies to analyze gaps and uncertainties in the existing studies.

2. Scenarios of Terror Attacks

With the presence of any potentially dangerous material, it is important to anticipate the possibility of malicious attack or theft. For radioactive materials such as spent fuel, security threats fall into two general categories: sabotage and theft. In the former, the intent is to damage shielding and potentially disperse radioactive material, therefore exposing the environment and population to radiation. The latter involves stealing the material for future use in a radiological dispersal device or a potential nuclear device. Inter alia, it is possible to imagine a wide range of terrorist attacks against spent fuel transportation.

2.1 Air-based attacks

The September 11, 2001 attacks demonstrated that terrorists are capable of successfully attacking fixed infrastructure with large civilian jetliners. Assaults by such large aircraft could impart enormous energy impulses to spent fuel storage facilities. This kind of scenarios in published literature range from attack with a small aircraft loaded with explosives or attack with a hijacked commercial aircraft through to the use of weapons from the air. Additionally, attacks with aircraft carrying large fuel loads could produce fires that would greatly complicate rescue and recovery efforts.

2.2 Ground-based attacks

A 1987 study for NRC analyzed historical truck and rail accident data to predict radiological risk from ground-based sabotage attack. The report concluded that few of the accidents studied would have released radioactivity if spent fuel had been involved; most accidents involved energy-absorbing targets such as other vehicles, insufficient velocity to damage shipping casks, little or no fire, or other mitigating factors. No documented accident was found in the NRC study that would have caused extensive cask or spent fuel damage, but it was estimated that such damage would occur in about one in 100,000 truck accidents and one in 10,000 rail accidents. The Sandia researchers also calculated from the experimental data that an attack on a truck cask carrying three spent fuel assemblies would release a maximum of 34 grams of reparable irradiated fuel.

2.3 Maritime attacks

Some analysts suggest that there is a threat from terrorist attacks on Liquefied Natural Gas (LNG) or Liquefied Petroleum Gas LPG or tanker ships passing coastal facilities. Two main terrorist attack scenarios have been postulated: A terrorist attack on a tanker, leading to an explosion, the blast from which would cause structural damage to a facility. A terrorist attack leading to release of a cloud of inflammable gas, which could then explode as it passed over the nuclear facility.

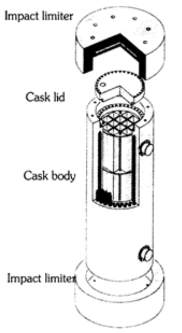
3. Methods and Results

The risk of transporting highly radioactive spent fuel from nuclear power plants to a central storage site or permanent underground repository is a major factor in the current nuclear waste debate. Also, transport activities will take place between the central interim storage facility and the final repository which will start its operation by the year 2065. Therefore, the safe and economical logistics for the transport of these spent fuels have to be determined by considering their transport risks and security measures.

3.1Transportation Cask

In recent years, ROK has developed a new type of cask, the KN-18. The KN-12, as the name suggests, can hold 12 pressurized water reactor (PWR) spent fuel assemblies while the KN-18 can hold 18 PWR spent fuel assemblies. Both of these casks are capable of transferring the spent fuel assemblies in wet or dry conditions. This report will focus on the KN-12 cask as there are already 3 sets manufactured for the Hanul and Ulchin nuclear power plants. According to Korea Hydro and Nuclear Power's Central Research Institute in 2013, 4 KN-18 casks were still being fabricated.

At the time of writing, it is unsure whether or not these casks have been put into commercial use and if so which NPPs they were allocated to. Thus, it is more practical to focus on the KN-12, considering that it has been in use longer and more information is known about it. As the KN-12 is already in use for on-site transportation, ROK has developed various accompanying technologies to aid in the transport of the cask— such as a transport trailer, cask lifting device, cask lid handling tool, and a dedicated on-site transport process. With these technologies in place, it would be easier to implement inter-NPP transfers with the KN-12 cask as opposed to the KN-18.



Package type: B(U)F

Transport capacity: 12 PWR spent nuclear fuels

Design basis fuel
- Fuel type : W.H 14x14, 16x16, 17x17
- Max. burn-up : 50,000 MWD/MTU
- Max. enrichment : 5.0 wt.%
- Min. cooling time : 7 years

Figure 4. The Design of the KN-12 Cask

The KN-12 is compliant with various international and domestic regulations that include: the IAEA's Safety Standards Series No.ST-1, US 10 CFR Part 71 for a Type B(U)F package, IAEA's Regulations for the Safe Transport of Radioactive Material, Korea Ministry of Science and Technology's Notice No. 2001-23, and the Korea Atomic Energy Act.

However, we will briefly summarize KN-12 cask's security features, showing it is fit for both land and maritime transport as recommended in this paper's inter-NPP SNF transport route. In order to be considered a type B package, a cask must be designed so that it is resistant to leakage of radioactive materials in certain accident scenarios. These hypothetical accident scenarios include a 9 meter free drop, puncture, thermal fire accident (30 minutes in a fire at around 800℃), 200 meter water immersion, and 1.5 times Maximum Normal Operation Pressure (MNOP) internal pressure. The testing also include normal conditions endured during transportation such as—performance in hot environments, in cold environments, under increased external pressure (140MPa), under minimum external pressure (24.5kPa), under vibration and shock, and under a 0.3m free drop. [3]

The Nuclear Environment Technology Institute evaluated the KN-12's safety features that included thermal and structural performances and radiation shielding. The results that they yielded confirmed that the KN-12 is suitable for transportation and provides "containment, radiation shielding, structural integrity, criticality control and passive heat removal for both normal transport and hypothetical accident conditions." In their findings, the radiation shielding features of the cask was able to limit the gamma and neutron dose rates to less than 2 mSV/h on the surface and to less than 0.1 mSv/h at 2m from the outer surface of the cask under normal transport conditions. In terms of heat management, the group subjected the cask to 30 minutes of fire and analyzed the safety components of the cask to see if their temperatures rose past the maximum safe operating temperatures. The findings indicated that none of the safety related cask parts surpassed their maximum safe operating temperatures when subjected to the fire expect for the moderator rods and the moderator plate.

3.2 Transportation Vessel

At the time of writing, it seems that information on the Hanjin Cheong Jeong Nuri, the ship used to transport LILW in ROK, is extremely limited and details about the safety features are currently vague at best. The following is a general overview of the safety features provided by the Korea Radioactive Waste Agency (KORAD);

1 Double Hull and Double Engines
2 Automatic radar plotting aid, Racon, satellite communication equipment and weather information system
3 Fire protection system and emergency power supply equipment (for 36 hours)
4 Radiation monitoring and radiation shielding

Since the specific safety features for the Hanjin Cheong Jeong Nuri have not been disclosed to the public, it is assumed that it has the capacity of an INF-1 ship as it is used to handle LILW. If this is true, then this report recommends that a new ship be built to comply with the regulations stipulated in the international code aforementioned for an INF-3 ship.

Table I. INF-3 ships of various countries

	HJ Cheongjeongnuri	M/S Sigyn (Sweden)*	Pacific Sandpiper (United Kingdom)	Pacific Heron (United Kingdom)
Length (m)	78.6	90.33	104	104
Width (m)	15.8	18	16	17
Deadweight (t)	1,356	2000	3,775	4,916
Displacement (t)	2,600		7,725	9,667
Engine	2 Diesel engines, each with 1632hp	2 Diesel engines each with 1568hp**	2 Diesel engines, each with 1900hp	2 Diesel engines, each with 3600hp
Max. Velocity	12 knot	12.5 knot		
Max. Capacity	190 flasks/ 1,520 LILW drums	10 casks	24 casks	20 casks

From the limited information on the Hanjin Cheong Jeong Nuri, it would appear that if a new ship were to be built for SNF transport it would have to have a bigger capacity to hold the transport casks for SNF (for which we've chosen the CASTOR KN-12 developed by Korea Atomic Energy Research Institute and Korea Hydro and Nuclear Power) as opposed to LILW drums which are smaller in size and lighter in weight. It is assumed that ROK has the capabilities of building a new INF-3 ship based on the features of the Hanjin Cheong Jeong Nuri. When compared with INF-3 ships (*see Table. 1*) from other countries, the Hanjin Cheong Jeong Nuri is not far behind their capabilities. Thus, the modifications that will be needed for an INF-3 are not drastic, considering the size of the M/S Sigyn.

KORAD has stated that Hanjin Cheong Jeong Nuri has radiation monitoring and radiation shielding but must ensure that these systems are calibrated to accommodate the radiation levels for the transport casks used. A device to handle a KN-12 cask should also be installed on the ship to ensure that the cask is handled in accordance with Korean national law on the loading and unloading of nuclear materials (the Korea Atomic Energy Act). Perhaps a modified version of the already existing cask lifting device should be installed.

3.3 Transpiration path dependent analysis

Considering a waste material in the Korea, spent fuel will remain dangerously radioactive for thousands of years. Unless spent fuel is to be kept permanently at reactor sites, it will have to be transported elsewhere for long-term storage and disposal with a prospect that has generated considerable controversy along potential transportation routes. The U.S. Department of Energy is also considering a broad range of alternatives for the future configuration of radioactive waste management at its network of facilities. Because the transportation of radioactive waste is an integral component of the management alternatives being considered, the estimated human health risks associated with both routine and accident transportation conditions must be assessed to allow a complete appraisal of the alternatives.

One important lesson from the DOE repository program is that critical transportation requirements, such as mainline rail access and interstate highway access, must be addressed in the earliest phases of site selection for storage and disposal facilities. Direct rail access to the national rail network is highly desirable in siting a geologic repository or centralized storage facility. Without direct rail access, delivery of SNF and HLW to a national facility would require either tens of thousands of cross-country over-weight truck (OWT) shipments or many thousands of heavy-haul truck (HHT) shipments from an intermodal transfer facility. [4]

3.4 Comments on Garnering Public Support for Implementation

The implementation of the policies outlined in this paper should not be difficult, considering that the factors that were taken into consideration were based on minimizing the contact citizens would have in the whole process. A maritime route was chosen because it could completely bypass civilian residences, and the routes that were proposed were chartered to be as far as land as possible while keeping the time it took to travel short. In order to avoid accidents on sea, maritime traffic was also examined. The government should communicate these factors to the public to let them know that the factors taken into consideration for chartering the maritime routes prioritized the safety of the people and that the technologies utilized have been tested to ensure that risk of radioactive leakage accidents are reduced.

4. Conclusions

The risk of transporting highly radioactive spent fuel from nuclear power plants to a central storage site or permanent underground repository is a major factor in the current nuclear waste debate. According to the long term management strategy for spent fuels in Korea, they will be transported from the spent fuel pools in each nuclear power plant to the central interim storage facility. The government should not be the only ones contributing to this dialogue. This dialogue that needs to happen should work both ways, with the government presenting their information and statistics and the public relaying their concerns for the government to review. Considering that the government has made some blunders in the past regarding nuclear safety, perhaps it should consider organizing a task force of scientists to independently analyze the maritime route, vessel, security measures, and transport casks and present these to the public.

REFERENCES

[1] Louis J.Lanzerotti et al., Chapter 2. Terrorist Attacks on Spent Fuel Storage, Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report, National Academies Press, 2006.
[2] John R. Cook, Spent Fuel Transportation Risk Assessment, NUREG-2125, U.S. Nuclear Regulatory Commission, 2014.
[3] Chung, S., Baeg, C., Choi, B., Lee, H., & Kim, J. Operational Experiences of On-Site Transport of Spent Nuclear Fuels in Korea. Proceedings from 14th International Symposium on the Packaging and Transportation of Radioactive Materials. Berlin, Germany: PATRAM, 2004.
[4] DOE, Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada, DOE/EIS-0250, February 2002.