

# Application of Logistic Simulation for Transport of SFs From Kori Site to an Assumed Interim Storage Facility

Young-Min Kim and Chang-Lak Kim\*

*Kepeco International Nuclear Graduate School, 658-91, Haemaji-ro, Seosaeng-myeon, Ulju-gun, Ulsan, Republic of Korea*

(Received December 1, 2020 / Revised December 16, 2020 / Approved January 6, 2021)

---

A paradigm shift in the government's energy policy was reflected in its declaration of early closure of old nuclear plants as well as cancellation of plans for the construction of new plants. To this end, unit 1 of Kori Nuclear Power Plant was permanently shut down and is set for decommissioning. Based on these changes, the off-site transport of spent fuels from nuclear power plants has become a critical issue. The purpose of this study is to develop an optimized method for transportation of spent fuels from Kori Nuclear Power Plant's units 1, 2, 3, and 4 to an assumed interim storage facility by simulating the scenarios using the Flexsim software, which is widely used in logistics and manufacturing applications. The results of the simulation suggest that the optimized transport methods may contribute to the development of delivery schedule of spent fuels in the near future. Furthermore, these methods can be applied to decommissioning plan of nuclear power plants.

Keywords: Kori NPP, Nuclear power plant decommissioning, Transportation of spent fuels, Logistics, Discrete event, Discrete simulation

---

\*Corresponding Author.

Chang-Lak Kim, KEPCO International Nuclear Graduate School, E-mail: [clkim@kings.ac.kr](mailto:clkim@kings.ac.kr), Tel: +82-52-712-7333

## ORCID

Young-Min Kim

<http://orcid.org/0000-0003-2466-0620>

Chang-Lak Kim

<http://orcid.org/0000-0002-6931-9541>

## 1. Introduction

A paradigm shift in the government's energy policy was reflected in its declaration of early closure of old nuclear plants as well as cancellation of plans for the construction of new plants. To this end, Kori nuclear power plant unit 1 was permanently shut-down in July 2017 and is preparing to decommission. Based on these changes, the off-site transport of spent fuels from nuclear power plants has become a critical issue. For these issues the optimized off-site transport of spent fuels that satisfy regulatory requirements and consider the current technology should be needed.

The purpose of this study is to develop an optimized method for transportation of spent fuels from Kori Nuclear Power Plant's units 1, 2, 3, and 4 to an assumed interim storage facility by simulating the scenarios using the Flexsim software version 18.1.0. This software is widely used for simulation of logistic and manufacturing industrials and this software reduces the time and cost requirements associated with physical testing by evaluating and experimenting with processes in a virtual environment. In order to prepare an optimized transport method, the several constraints were reviewed. And the assumptions for simulation were established based on the reviewed results. To conduct the simulation, firstly, scenarios in which variables were applied to the basic transport modeling were created, and secondly, the evaluation was conducted using the Flexsim software. Finally, the results obtained through simulation were compared with each other to prepare an optimized transport method.

## 2. Literature review

### 2.1 Difference of spent fuel type

There were various types of nuclear fuel assemblies loaded in units 1, 2, 3, and 4 at Kori Nuclear Power Plant such as OFA (Optimized Fuel Assembly) which was

designed by Westinghouse and ACE7 which was designed by KNF (Korea Electric Power Corporation Nuclear Fuel). As various types of nuclear fuels have been loaded, the transport cask must be able to accommodate all types of spent fuels. So this study was intended to review transport casks that satisfy this specification and apply them to basic transport modeling.

### 2.2 Handling capacity of spent fuels

The weight of spent fuel cask fully loaded with the spent fuels would be between 100 and 120 tons. To securely handle the crane at NPP sites or at an assumed interim storage facility, the capacity of the handling crane must be above 120 tons. The current crane located at the spent fuel pool could enough to transport cask with Spent Fuels (SF) except Kori unit 1. Accordingly, the simulation was performed assuming that follow-up measure such as installing the additional crane at Kori unit 1 were performed in advance.

### 2.3 Exclusive vessel

For marine transport of spent fuels, it is necessary to build an exclusive vessel that can be used for maritime transport. And the vessel must satisfy INF3 code (International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-level Radioactive Wastes on Board Ships) of IMO (the International Maritime Organization of the United Nations). Since there is no exclusive vessel dedicated for the transport of spent fuels in Korea, in this study, foreign cases applicable to the basic modeling of transport were investigated as shown in Table 1 and applied in the basic modeling.

#### 2.3.1 U.K.

In the U.K., spent fuels as well as high-level waste and MOX (Mixed Oxide) fuels have been transported by sea using exclusive vessels. In the U.K., PNTL (Pacific Nuclear Transport Limited) operates three exclusive vessels (Pacific

Table 1. Status of SF exclusive vessel

Country	Name	Built (year)	INF Level	Length (m)	No. of the shipping cask	Shipping capacity (ton)	Purpose
U.K.	Pacific Heron	2008	3	103.9	20	4,850	SF/ HLW/MOX
U.K.	Pacific Egret	2010	3	103.9	20	4,408	SF/ HLW/ MOX
U.K.	Pacific Grebe	2010	3	103.9	20	4,916	SF/HLW/MOX
Sweden	M/S Sigrid	2013	3	99.5	12	1,600	SF/ ILW
Japan	Rokuei maru	1987	3	100.0	20	3,000	SF
Japan	Kaiei maru	1985	3	100.0	12	3,000	SF

Heron, Pacific Egret, Pacific Grebe) licensed as INF3 class. Since its establishment in 1975, PNTL has transported spent fuels, high-level waste, MOX fuels, and plutonium more than 180 times [1].

### 2.3.2 Sweden

In Sweden, SKB (Swedish Nuclear Fuel & Waste Management Co.) is in charge of the maritime transport of spent fuels and radioactive waste. Since 1982, the M/S Sigyn transport vessel, which can simultaneously transport spent fuels as well as low- and intermediate-level wastes, had been used until her retirement in 2013. Sigrid transport ships have been used to transport spent fuels and the intermediate and low-level radioactive wastes since 2012 [2].

### 2.3.3 Japan

Nuclear power plants and nuclear cycle facilities in Japan are mainly located in coastal areas and spent fuels and low- and intermediate-level radioactive wastes have been transporting through maritime transport. In September 2017, the Kansai Electric Power Company of Japan used the PNTL's Pacific Heron and Pacific Egret to receive MOX fuels from AREVA in France for reprocessing [3].

## 2.4 Transport cask

Currently, various types of casks for spent fuel trans-

port are developed and commercialized. Since transport cask is not commercialized for off-site transport of spent fuels in Korea, in this study, foreign cases applicable to the basic modeling of transport were investigated and applied to the basic modeling.

### 2.4.1 HI-STAR

HI-STAR 100 developed by Holtec was licensed as a cask for transport and storage of spent fuels. It consists of a metal multi-purpose canister (MPC) and an overpack with an impact limiting device. The HI-STAR system is designed to be equipped with various types of canisters. The canister designs include MPC-24 to load 24 PWR spent fuels, MPC-32 to load 32 PWR spent fuels, and MPC-68, which can load 68 BWR spent fuels. The cask body is carbon steel and has NS-4-FR as a neutron shielding. The canister consists of a nuclear fuel basket, spacer, base plate, canister shell, lid, close ring, etc. The material uses stainless steel as a structural material, boral ( $B_4C+Al$ ) as a neutron absorber, and the lid is welded to the outer shell to maintain the seal. The containment method is designed with double containment structure in which the canister loaded inside the cask and the lid of the cask body has containment [4].

### 2.4.2 NAC-STC

NAC-STC was developed by Nuclear Assurance Corporation (NAC) in the United States and was first licensed for transport and storage in the United States. The cask can

store 26 PWR spent fuels. The NAC system is a transport compatible dry storage system that uses a stainless steel transportable storage canister (TSC) stored within the central cavity of a vertical concrete cask (VCC). The shape of the cask is a multilayered cylindrical form that casts lead as a gamma-ray shielding between the inner and intermediate shells of stainless steel. The upper and lower parts of the cask forged stainless steel, and the intermediate and outer shells used NSA4-FR from Bisco as neutron shielding [5, 6].

**2.4.3 KORAD 21 & DSS21/24**

Korea Radioactive Waste Agency (KORAD) has applied for license application of the KORAD-21 transport cask that can carry 21 SF using the canister method. The spent fuel casks developed by Doosan Heavy Industries & Construction used a metal overpack with reinforced structural safety with a canister method. The transport cask is capable of transporting 21 SF using TC21 (Transport Cask) and 24 SF using TC24, respectively. This cask is based on the design approved by U.S. NRC through a technology partnership with NAC [7].

**3. Simulation**

In this study, simulations were conducted using the Flexsim software 18.0.1 version which is widely used for simulation in the manufacturing and logistic industrials. And this software provides many powerful modules and easy-to-use 3D graphic modeling for discrete and continuous simulation. A discrete method was used for the spent fuel transport simulation.

**3.1 Basic assumptions**

**3.1.1 Limiting SF quantity**

The quantity of spent fuel transport from Kori Nuclear Power Plant units 1, 2, 3, and 4 was assumed to be

Table 2. Estimated Amount of SF at Kori site [8]

Unit	Estimated total storage	
	FA (s)	Ton (U)
Kori 1	495	177
Kori 2	1,118	434
Kori 3	2,481	1,033
Kori 4	2,479	1,031
Total	6,573	2,675

6,573 assemblies (2,675 Ut) as shown in Table 2, according to the final report of Public Engagement on Spent Fuel Management Committee in 2015 [8].

**3.1.2 Location of interim storage**

The location of the interim storage facility was assumed in this study to be located near one of the nuclear power plants taking into account the followings:

- Nuclear Safety and Security Commission Notice No. 2017-58 (December 26, 2017), “Compliance with technical standards on the location of interim storage facility for spent fuels” [9]
- Interim storage facility is assumed to be adjacent to existing nuclear power plants to minimize transport distance and to take advantage of exists harbor infrastructural of NPPs.

The location of the interim storage facility considered in this study has no practical meaning and is used only to assess the transport schedule.

**3.1.3 Sailing time**

To assume the sailing time, the distance from the Kori site to an assumed interim storage facility was divided by the average speed. The average speed of ship operation was assumed to be 10 knots (18.52 km·h<sup>-1</sup>). For accurate distance measurement, an ocean distance measurement system provided by the Korea Hydrographic and Oceanographic

Table 3. Assumed sailing time

Route	Distance	Estimated Time	Assumed date
Kori → Wolsong	70 km	4 hour	0.5 day
Kori → Hanul	252 km	14 hour	1 day
Kori → Hanbit	869 km	46 hour	2 day

Table 4. Operation day of SF transport [12]

Categories	Operation	Assumed day (day per cask)
Site operation	Loading SF to canister	3.5
	Loading canisters with SF to transport casks & cask closure	0.5
Inland Transport	Loading/unloading casks onto a vessel	0.5
	Inland transport within site (or interim facility)	0.5
Maritime Transport	Loading/unloading casks onto a vessel	0.5
	Maritime transport	Applicable to Table 3
Interim storage facility operation	Storing the canister with SF	3
	Decontamination and inspection of transport cask	2

Agency was used [10]. In consideration of safety, distance measurement avoided metropolitan ports such as Ulsan Port on the route from Kori to Wolsong or Hanul. On the route from Kori to Hanbit, the distance was measured by sailing outside of Jeju Island.

### 3.1.4 Shipping capacity

For transport modeling, it was necessary to assume the shipping capacity of the spent fuel ship. As a result of reviewing the shipping capacity of the exclusive vessel in use in foreign countries, it was possible to ship at least 12 casks from a maximum of 20 casks depending on the ship. As there was no exclusive vessel for transporting spent fuels in Korea, the operation history of Cheong Jeong Nuri which transport the low- and intermediate-level wastes was reviewed for assuming the shipping capacity. The vessel

was designed to carry up to 9,000 drums per year, however, most of the time its performance was less than half [11]. Based in this case, the shipping capacity was assumed to be 10 casks more conservatively.

### 3.1.5 Basic transport order

It was assumed that the basic transport model was a multi-transport method. Trailer transport was conducted within the NPP site or an assumed interim storage facility. Vessel transport was used outside the NPP site or an assumed interim storage facility. The basic transport order was as follows:

- The empty casks are returned to the site.
- The spent fuels are loaded onto a trailer at the site and then moved to the port within the site.
- The spent fuels are loaded onto an exclusive vessel

Table 5. Scenario creation

Scenario	Variable			
	Location of interim storage	No. of vessel	No. of cask	No. of trailer
1	Kori	-	5	1
2	Kori	-	5	2
3	Kori	-	10	1
4	Kori	-	10	2
5	Kori	-	20	1
6	Kori	-	20	2
7	Wolsong	1	5	2
8	Wolsong	1	5	4
9	Wolsong	1	10	2
10	Wolsong	1	10	4
11	Wolsong	1	20	2
12	Wolsong	1	20	4
13	Wolsong	2	5	2
14	Wolsong	2	5	4
15	Wolsong	2	10	2
16	Wolsong	2	10	4
17	Wolsong	2	20	2
18	Wolsong	2	20	4
19	Hanul	1	5	2
20	Hanul	1	5	4
21	Hanul	1	10	2
22	Hanul	1	10	4
23	Hanul	1	20	2
24	Hanul	1	20	4
25	Hanul	2	5	2
26	Hanul	2	5	4
27	Hanul	2	10	2
28	Hanul	2	10	4
29	Hanul	2	20	2
30	Hanul	2	20	4
31	Hanbit	1	5	2
32	Hanbit	1	5	4
33	Hanbit	1	10	2
34	Hanbit	1	10	4
35	Hanbit	1	20	2
36	Hanbit	1	20	4

Scenario	Variable			
	Location of interim storage	No. of vessel	No. of cask	No. of trailer
37	Hanbit	2	5	2
38	Hanbit	2	5	4
39	Hanbit	2	10	2
40	Hanbit	2	10	4
41	Hanbit	2	20	2
42	Hanbit	2	20	4

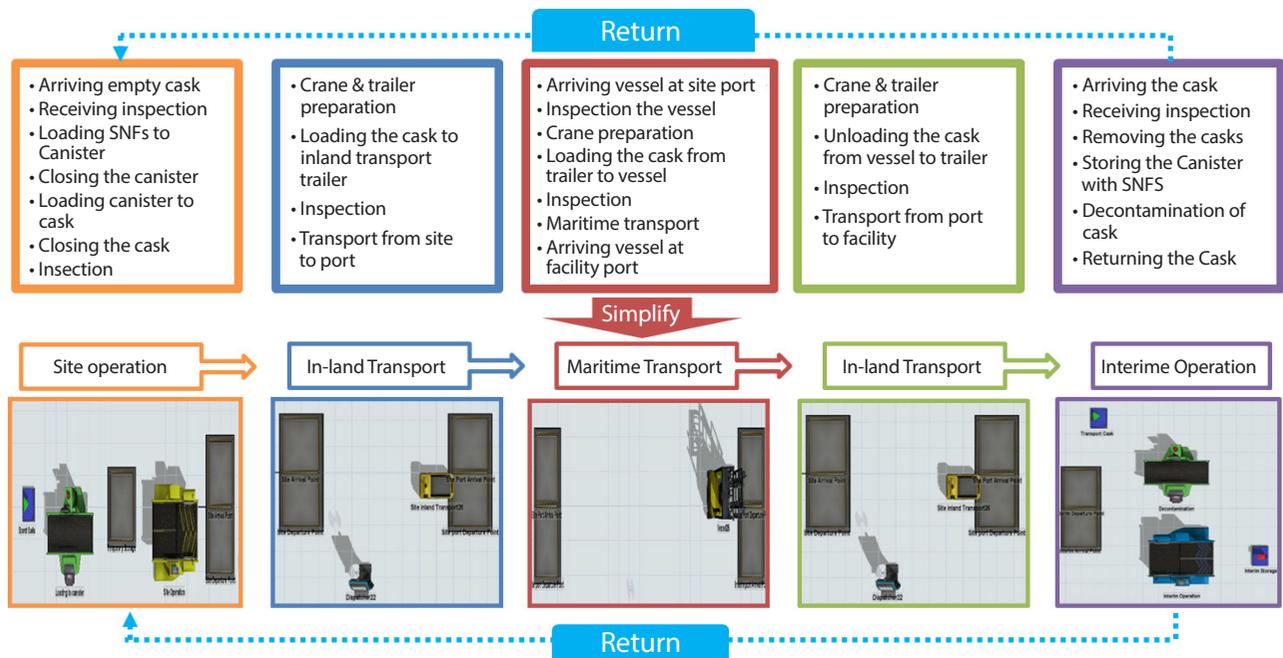


Fig. 1. Simplification of task for simulation.

and move from the site to the port of the assumed interim storage facility.

- The spent fuels are loaded onto a trailer at the port and then moved to the interim storage facility.

### 3.1.6 Operation time

The operation time should be assumed for evaluating the data of each scenario. For the assumption of the operation

time of the cask, the handling procedures were referred from Holtec’s HI-STAR 100 cask system.

### 3.2 Scenarios creation

In order to prepare the transport scenario, the main variables affecting the scenario were derived as follows:

- Interim storage facility location: Near Kori or Wolsong

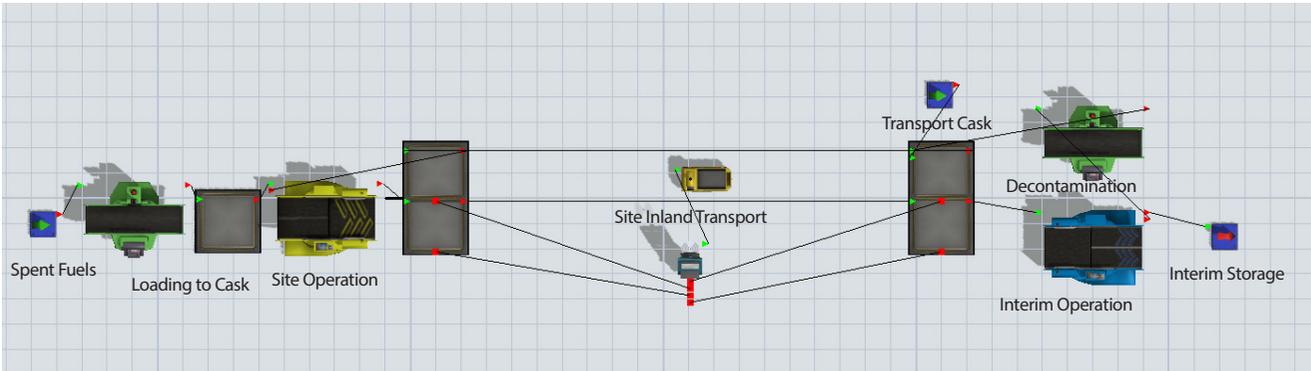


Fig. 2. Simulation model from Kori site to an assumed interim storage facility near the Kori site.

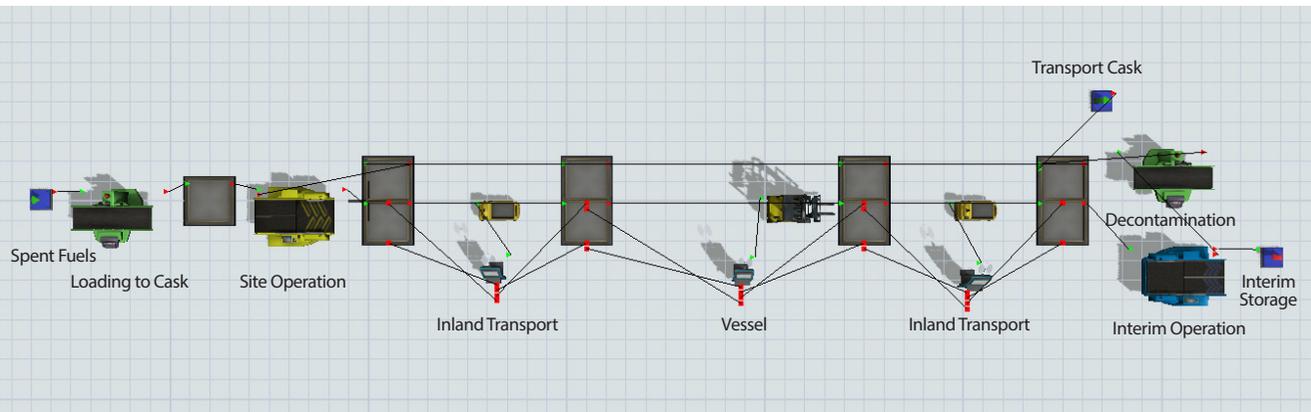


Fig. 3. Simulation model from Kori site to an assumed interim storage facility near the Wolsong site.

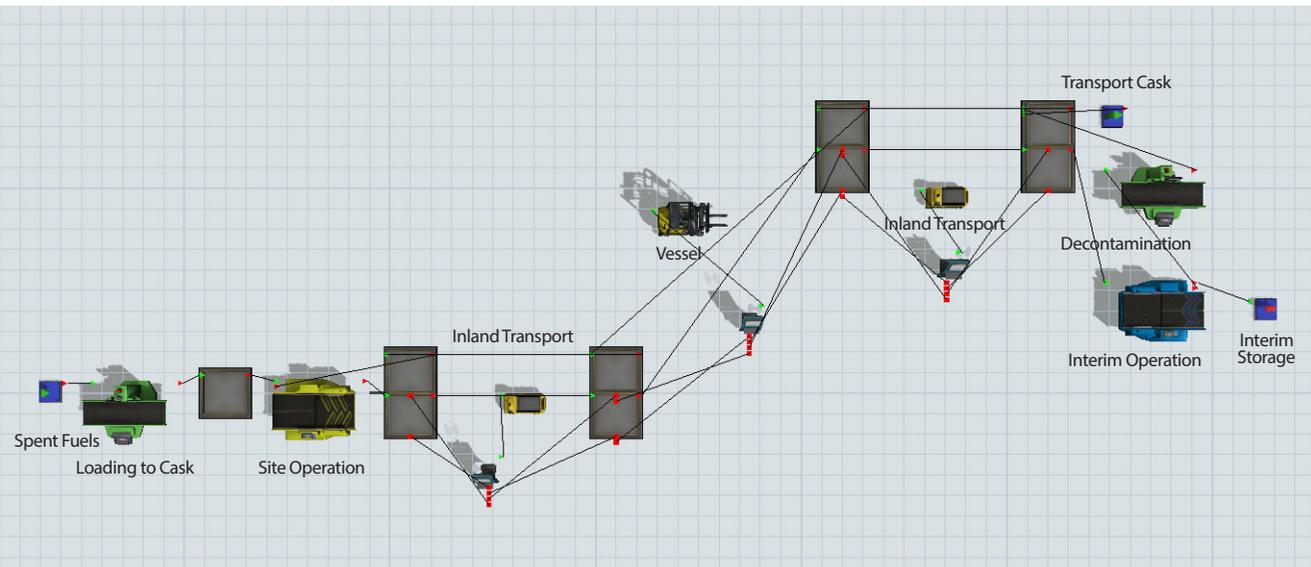


Fig. 4. Simulation model from Kori site to an assumed interim storage facility near the Hanul site.

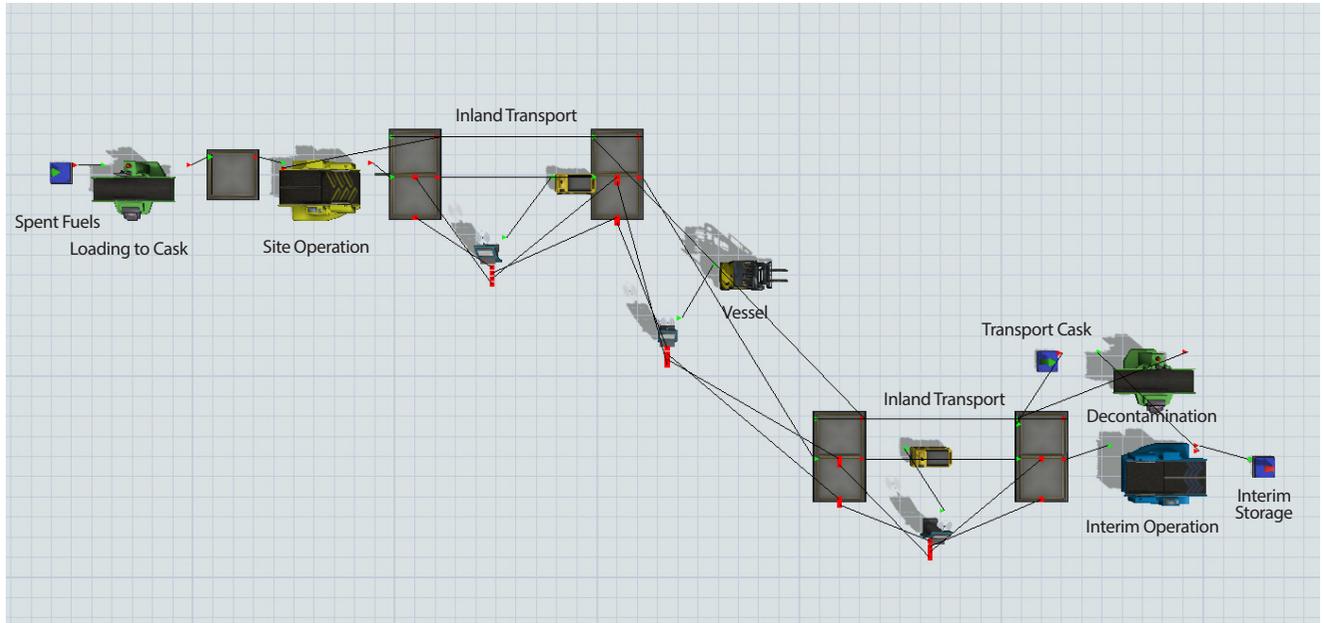


Fig. 5. Simulation model from Kori site to an assumed interim storage facility near the Hanbit site.

or Hanul or Hanbit site

- Number of transport casks: 5, 10, 20
- Number of the vessel: 1 or 2
- Number of the trailer: 1 to 4

There were total of 42 scenarios that can be created according to the main variables. However, if there was an interim storage facility near the Kori site, maritime transport was not required. So these scenarios were excluded.

### 3.3 Simulation model

For the simulating model, all of tasks for the spent fuel transport was described. And then the tasks was categorized by task step such as site operation, in-land transport within the site, maritime transport, in-land transport within the facility, interim operation. The categorized tasks were modeled as shown in Fig. 1.

#### 3.3.1 Simulation model for scenario 1 to 6

According to the location of interim storage, each scenario had the main simulation model. Fig. 2 showed the

main simulation model for Scenarios 1 to 6 in aerial view. The only differences among these scenarios were variables such as the number of trailers and transport casks.

#### 3.3.2 Simulation model for scenario 7 to 18

Scenarios 7 to 18 were simulated that an assumed interim storage facility for spent fuel was located near the Wolsong site. The major difference was the application of maritime transport. It also meant the loading or unloading operation from trailer to vessel (or vessel to a trailer) was additionally needed. Fig. 3 showed the main simulation model for Scenarios 7 to 18 in aerial view. Each scenario also had different variables such as the number of trailers and transport casks.

#### 3.3.3 Simulation model for scenario 19 to 30

Scenarios 19 to 30 were simulated that an interim storage facility for spent fuel was located near the Hanul site. Without sailing time, the main simulation was the same as previous scenarios. Fig. 4 showed the main simulation model for Scenarios 19 to 30 in aerial view.

Table 6. Results of scenario 1 to 6

Operation	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Variable	5 casks, 1 trailer	5 casks, 2 trailers	10 casks, 1 trailer	10 casks, 2 trailers	20 casks, 1 trailer	20 casks, 2 trailers
Total duration (day)	990	990	990	990	990	990
Utilization of transport (%)						
Trailer	94	57	95	58	97	58
Avg. waiting time (day)						
At Site	4.25	8.90	12.70	13.48	24.31	29.86
At facility	0.74	1.05	2.94	1.18	12.51	1.85

### 3.3.4 Simulation model for scenario 31 to 42

Scenarios 31 to 42 were simulated that an interim storage facility for spent fuel is located near the Hanbit site. It also had the same simulation model with previous scenarios except for the sailing time. Fig. 5 showed the main simulation model for these scenarios.

## 4. Results

### 4.1 Scenario 1 to 6

In the case of scenarios 1 to 6, the major variables were the location of interim storage facilities near the Kori site, the number of transport casks, and the number of trailers. As the interim storage facility was located near the Kori site, it was assumed that only inland transport using trailers required without maritime transport. It meant that the additional loading or unloading working days could be reduced.

As a result of the simulation, the results for each scenario were derived as shown in Table 6. The duration of all scenarios was calculated the same. This meant that each variable did not affect the results of each scenario and the transport was not a critical path in the process. In addition, the results showed that increasing the number of trailers resulted in an

increase in the number of trailers, but rather an increase in waiting times. When comparing the overall results, the case of scenario 1 using 5 casks and 1 trailer was calculated as the most optimized transport method among scenario 1 to 6.

### 4.2 Scenario 7 to 18

In the case of scenarios 7, to 18, the major variable was the location of interim storage facilities near the Wolsong site, number of the vessel, number of casks, and number of trailers. As a result of the simulation, the results for each scenario were derived as shown in Table 7.

From the perspective of total duration, scenarios 12 and 18 had the shortest durations. The common point of the two scenarios was the case that the number of transport cask was 20 and 4 trailers were used, and these results showed that the total duration can be shortened as the number of available casks and trailers increases regardless of the number of ships. From a trailer perspective, the trailer utilization rate was calculated lower when using 4 trailers than when using 2 trailers. However, in terms of the total duration, it was confirmed that the case of using four trailers had a significant positive effect on the duration shortening as the waiting time could be reduced. From the perspective of vessel

Table 7. Results of Scenario 7 to 18

Operation	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	#17	#18
Variable												
-Vessel	1	1	1	1	1	1	2	2	2	2	2	2
-Cask	5	5	10	10	20	20	5	5	10	10	20	20
-Trailer	2	4	2	4	2	4	2	4	2	4	2	4
Total duration (day)	2,602	2,184	2,510	1,894	1,554	1,051	2,432	2,015	2,367	1,751	1,481	1,037
Utilization of transport (%)												
Trailer at site	39	23	42	27	68	50	21	25	22	29	72	51
Vessel	29	28	24	32	40	58	14	17	13	18	22	31
Trailer at facility	42	25	45	29	74	54	45	27	48	32	78	54
Avg. Waiting time (day)												
At Site	4.1	2.3	8.56	4.22	10.27	4.44	4.0	2.2	8.56	4.22	10.26	6.16
At facility	3.6	3.6	8.27	7.27	10.93	8.24	3.5	3.5	8.27	7.27	10.92	7.60

Table 8. Result of Scenario 19 to 30

Operation	#19	#20	#21	#22	#23	#24	#25	#26	#27	#28	#29	#30
Variable												
-Vessel	1	1	1	1	1	1	2	2	2	2	2	2
-Cask	5	5	10	10	20	20	5	5	10	10	20	20
-Trailer	2	4	2	4	2	4	2	4	2	4	2	4
Total duration (day)	2,765	2,347	2,537	1,920	1,568	1,078	2,592	2,174	2,394	1,777	1,495	1,038
Utilization of transport (%)												
Trailer at site	37	21	41	27	68	48	39	23	44	29	71	50
Vessel	28	33	25	33	42	59	19	23	14	19	25	34
Trailer at facility	40	23	44	29	73	52	42	25	47	31	77	54
Avg. Waiting time (day)												
At Site	4.1	2.3	8.6	4.2	10.3	4.4	4.0	2.2	8.6	4.2	10.3	5.9
At facility	3.6	3.6	8.3	7.3	10.9	8.5	3.5	3.5	8.3	7.3	10.9	7.6

Table 9. Results of Scenario 31 to 42

Operation	#31	#32	#33	#34	#35	#36	#37	#38	#39	#40	#41	#42
Variable												
-Vessel	1	1	1	1	1	1	2	2	2	2	2	2
-Cask	5	5	10	10	20	20	5	5	10	10	20	20
-Trailer	2	4	2	4	2	4	2	4	2	4	2	4
Total duration (day)	2,770	2,352	2,592	1,974	1,534	1,130	2,599	2,181	2,448	1,830	1,477	1,073
Utilization of transport (%)												
Trailer at site	36	21	40	26	69	46	39	23	43	28	72	49
Vessel	28	33	26	34	48	62	19	23	16	22	33	40
Trailer at facility	40	23	43	28	75	50	42	25	46	30	78	53
Avg. Waiting time (day)												
At Site	4.1	2.3	8.6	4.2	9.9	4.4	4.0	2.2	8.6	4.2	9.7	4.6
At facility	3.6	3.6	8.3	7.3	10.4	8.9	3.5	3.5	8.3	7.3	8.9	8.5

utilization, the utilization rate was relatively high using one vessel. This confirmed that it was much more efficient and economical to use one vessel regardless of the change in the number of trailers and the number of transport casks. When comparing the overall results, the case of scenario 12, which uses one vessel and four trailers with 20 transport casks, was calculated as the most optimized transport method.

### 4.3 Scenario 19 to 30

In the case of scenarios 19 to 30, the major factors were the location of interim storage facilities near the Hanul site, number of the vessel, number of casks, and number of trailers. As a result of the simulation, the results for each scenario were derived as shown in Table 8.

From the perspective of total duration, scenarios 24 and 30 had the shortest durations. The common point of the two scenarios was the case that the number of transport cask was 20 and 4 trailers were used, and these results showed that

the total duration can be shortened as the number of available casks and trailers increases regardless of the number of ships. From a trailer perspective, the trailer utilization rate was calculated lower when using 4 trailers than when using 2 trailers. However, in terms of the total duration, it was confirmed that the case of using four trailers had a significant positive effect on the duration shortening as the waiting time could be reduced. From the perspective of vessel utilization, the utilization rate was relatively high using one vessel. This confirmed that it was much more efficient and economical to use one vessel regardless of the change in the number of trailers and the number of transport casks. When comparing the overall results, the case of scenario 24, which uses one vessel and four trailers with 20 transport casks, was calculated as the most optimized transport method.

### 4.4 Scenario 31 to 42

In the case of scenarios 31 to 42, the major factors were the location of interim storage facilities near the Hanbit site

number of the vessel, number of casks, and number of trailers. As a result of the simulation, the results for each scenario were derived as shown in Table 9.

From the perspective of total duration, scenarios 40 and 42 had the shortest durations. The common point of the two scenarios was the case that the number of transport cask was 20 and 4 trailers were used, and these results showed that the total duration can be shortened as the number of available casks and trailers increases regardless of the number of ships. From a trailer perspective, the trailer utilization rate was calculated lower when using 4 trailers than when using 2 trailers. However, in terms of the total duration, it was confirmed that the case of using four trailers had a significant positive effect on the duration shortening as the waiting time could be reduced. From the perspective of vessel utilization, the utilization rate was relatively high using one vessel. This confirmed that it was much more efficient and economical to use one vessel regardless of the change in the number of trailers and the number of transport casks. When comparing the overall results, the case of scenario 36, which uses one vessel and four trailers with 20 transport casks, was calculated as the most optimized transport method.

## 5. Conclusions

Process and schedule review should be preceded in advance to plan the transportation of spent fuels which stored at Kori NPP. Accordingly, the transportation modeling using Flexism software were carried out. So, the variables were selected to prepare the most optimized spent fuel transport plan, and each scenario was created by considering the number of selected variables in several cases. For scenario evaluation, an objective assessment was made using Flexsim software, which is widely used in logistics and manufacturing.

As a result of, four optimized transport method of spent fuels generated from Kori Nuclear Power Plant Units 1–4

were assessed. First, if an assumed interim storage facility was located near the Kori nuclear power plant, it could be transported within 990 days using 10 transport casks and one trailer. Second, if an assumed interim storage facility was located near the Wolsong nuclear power plant, it could be transported within 1,051 days using one ship, four trailers and 20 transport casks. Third, if an assumed interim storage facility was located near the Hanul nuclear power plant, it could be transported within 1,078 days using one ship, four trailers and 20 transport casks. Finally, an assumed interim storage facility was located near the Hanbit Nuclear Power Plant, it could be transported within 1,130 days using one ship, four trailers and 20 transport casks.

Since unexpected accidents during transport were excluded, the prevention plan should be considered and applied such as the addition of trailer and cask for accident prevention. The location of interim storage facility will be decided transparently in the near future. Then, the transportation research result would be more accurate. In addition, if the economic analysis is additionally performed on the derived results, it can be applied effectively in preparing the decommissioning project.

## Acknowledgement

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP Project No. 20204010600130) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea.

## REFERENCES

- [1] Pacific Nuclear Transport Ltd., “PNTL Vessel Information.” PNTL. Accessed Nov. 1 2020. Available from: <https://www.pntl.co.uk/our-fleet>.
- [2] Swedish Nuclear Fuel and Waste Management Co., “SKB Vessel Information.” SKB. Accessed Nov. 1 2020.

- Available from: <https://www.skbc.com/our-operations/transport-by-sea/>.
- [3] Nuclear Fuel Transport Co., “NFT Vessel Information.” N.F.T Co., Ltd. Accessed Nov. 1 2020. Available from: <https://www.nft.co.jp/english/business/vessels.html>.
- [4] Holtec International. October 11 2010. “Safety Analysis Report on HI-STAR 100 Cask System.” U.S. NRC. Accessed Nov. 1 2020. Available from: <https://www.nrc.gov/docs/ML1028/ML102871079.pdf>.
- [5] NAC International, October 1998. “NAC-MPC Safety Analysis Report.” U.S. NRC. Accessed Nov. 1 2020. Available from: <https://www.nrc.gov/docs/ML0800/ML080020416.pdf>.
- [6] Korea Atomic Energy Research Institute. Final Report on the Analysis for the Off-Site Transport Plan of Spent Fuel, Korea Atomic Energy Research Institute Technical Report, 24, KAERI/CR-320/2008 (2008).
- [7] Doosan Heavy Industries & Construction Nuclear BG/ Safety Equipment Design Team. September 14 2018. “Current Status of Cask Business and Technology Development/Introduction of the Manufacturing Process.” Doosan Heavy Industries & Construction. Accessed Nov. 1 2020. Available from: [http://www.ndira.re.kr/\\_ADM/bbs/bbs\\_download.php?download=1&filename=bbs\\_file&file\\_idx=2&bbs\\_data=aWR4PTQwOSZzdGFyZFBhZ2U9Jmxc3RObz04JnRhYmxlPWRoX2Jic19kYXRhJmNvZGU9bm90aWNlJnNlYXJjaF9pdGVtPSZzZWZyY2hfb3JkZXI9](http://www.ndira.re.kr/_ADM/bbs/bbs_download.php?download=1&filename=bbs_file&file_idx=2&bbs_data=aWR4PTQwOSZzdGFyZFBhZ2U9Jmxc3RObz04JnRhYmxlPWRoX2Jic19kYXRhJmNvZGU9bm90aWNlJnNlYXJjaF9pdGVtPSZzZWZyY2hfb3JkZXI9).
- [8] Spent Fuel Public Debate Committee in Korea. June 11 2015. “Recommendations on the Management of Spent Fuel.” Spent Fuel Public Debate Committee. Accessed Nov. 1 2020. Available from: [http://fissilematerials.org/blog/A%20report%20of%20PECOS%20recommendations\\_20150611.PDF](http://fissilematerials.org/blog/A%20report%20of%20PECOS%20recommendations_20150611.PDF).
- [9] Nuclear Safety and Security Commission. December 26 2017. “Compliance with Technical Standards on the Location of Interim Storage Facilities for Spent Fuel.” Nuclear Safety and Security Commission. Accessed Nov. 1 2020. Available from: <https://www.law.go.kr/%ED%96%89%EC%A0%95%EA%B7%9C%EC%B9%99%EC%82%AC%EC%9A%A9%ED%9B%84%ED%95%B5%EC%97%B0%EB%A3%8C%EC%A4%91%EA%B0%84%EC%A0%80%EC%9E%A5%EC%8B%9C%EC%84%A4%EC%9D%98%EC%9C%84%EC%B9%98%EC%97%90%EA%B4%80%ED%95%9C%EA%B8%B0%EC%88%A0%EA%B8%B0%EC%A4%80/>.
- [10] Korea Hydrographic and Oceanographic Agency. “Ocean Distance Measurement System.” KHOA. Accessed Nov. 1 2020. Available from: <http://www.khoa.go.kr/kcom/cnt/selectContentsPagedo?cntId=31307000>.
- [11] The National Assembly of Korea, “Parliamentary Inspection of the Government Offices 2017.” Skenews. Accessed Nov. 1 2020. Available from: <http://www.skenews.kr/news/articleView.html?idxno=11836>.
- [12] R. Springman. “Multi-Purpose Canisters for Long-Term Interim Storage.” International Atomic Energy Agency. Accessed Nov. 1 2020. Available from: <http://www-pub.iaea.org/iaemeetings/cn226p/Session5/ID-147Springman.pdfpub>.