▣ PAPER ▣

DEVELOPMENT OF A COMPUTER PROGRAM FOR AN ANALYSIS OF THE LOGISTICS AND TRANSPORTATION COSTS OF THE PWR SPENT FUELS IN KOREA

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It is expected that a substantial amount of spent fuels will be transported from the four nuclear power plant (NPP) sites in Korea to a hypothetical centralized interim storage facility or a final repository in the near future. The cost for the transportation is proportional to the amount of spent fuels. In this paper, a cost estimation program is developed based on the conceptual design of a transportation system and a logistics analysis. Using the developed computer program, named as CASK, the minimum capacity of a centralized interim storage facility (CISF) and the transportation cost for PWR spent fuels are calculated. The PWR spent fuels are transported from 4 NPP sites to a final repository (FR) via the CISF. Since NPP sites and the CISF are located along the coast, a sea-transportation is considered and a road-transportation is considered between the CISF and the FR. The result shows that the minimum capacity of the interim storage facility is 15,000 MTU.

Keywords : Spent Fuel Transportation, Logistics Analysis, Cost Estimation, CASK, Repository, Interim Storage

1. INTRODUCTION

It is expected that the temporary storage capacity at the nuclear power plants will be exhausted with spent fuels within 8 years in Korea [1]. Thus, if an interim storage facility away from a nuclear power plant (NPP) site is constructed, a substantial amount of spent fuels should be transported by sea or by land depending on the location of the facility. It is necessary to estimate the transportation cost as accurately as possible in order to reduce the burden for the future generations.

A cost estimation for the transportation of spent fuels might cover a wide range of scopes. However, Korea Atomic Energy Research Institute (KAERI) has proposed a simple cost estimation model for a transportation of the spent fuels from the Younggwang site (YG site) to a hypothetical Final repository (FR) via a Centralized Interim Storage Facility (CISF) located adjacent to the repository [2].

It is defined that the transportation cost covers the money needed for the transportation of spent fuels from the main gates of each NPP site to the main gates of the final encapsulation building of the final repository. All the handling equipments needed at the NPP site are assumed to be prepared at the site. However, the long-term milestone for the management of the spent fuels is not decided yet. Thus, various potential transportation scenarios will be compared in view of the economy and technology. To review the various potential transportation scenarios simply, the CASK program was developed. The CASK program supports “Cost detail” Excel spread sheet to upgrade transportation unit costs because the transportation unit costs would be change frequently. Thus, through the result from the co-research by KAERI and TN International in 2007 [3], the overnight transportation unit cost was defined.

In this paper, the total amount of the spent fuel inventories, from 20 OPR-1000 PWR reactors under the assumption of a 40-year lifespan and 4 APR-1400 PWR reactors under the assumption of a 60-year lifespan, are defined. Since NPP sites, CISF, and FR are located along

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the coast of the Korean Peninsula, mostly a see-transportation of the spent fuel is considered. That is, the spent fuels will be transported from the NPP sites to the CISF by ship and from the CISF to the FR by truck. The FR is assumed to be located close the CISF and will begin to operate in 2066 for the PWR spent fuels. Regarding the transportation means, road trailers are assumed to be used between the CISF and the FR. They are composed of a tractor and an 8 or 9 axle trailer, on which a transportation frame is mounted. Only one cask will be loaded per trailer. Depending on the annual disposal rates at the FR, the annual transportation rates and unit transportation cost are determined.

2. PWR SPENT FUEL

16 PWR and 4 CANDU nuclear plants are currently operating in Korea. According to the 3rd Basic plan for Long-term Electricity Supply and Demand (2006~2020) [4], 4 OPR-1000 nuclear plants and 4 APR-1400 nuclear plants will be constructed by 2016. The temporary storage capacity in each NPP site was expanded already or will be expanded to hold the spent fuels generated til 2016. Table 1 shows the capacity of each NPP site.

Since the discharge rate of the spent fuels from a PWR in nearly constant, it is quite simple to estimate the amount of spent fuels in the future. The total amount of spent fuels is estimated as 22,500 MTU from 24 PWR NPPs [5]. Figure 1 shows the CASK input form for the selection of the NPP lifespan.

Annual average discharged model:

$$C_f^{site} = \sum_{j=1}^{m}\left(C_c^j + \sum_{i=1}^{n} D_{avg}^j + L_c^j\right)\ [MtU]$$

Where,

C_f^{site}: The total amount of spent fuels discharged from the f NPP site

m : The number of NPPs in the f site

C_c^j : The real cumulative spent fuels in unit j until 2003

L_c^j : The total amount of nuclear fuels in the core of unit j

D_{avg}^k : The annual average discharge rate for unit j

n : The years between 2004 and the decommissioning year of unit j.

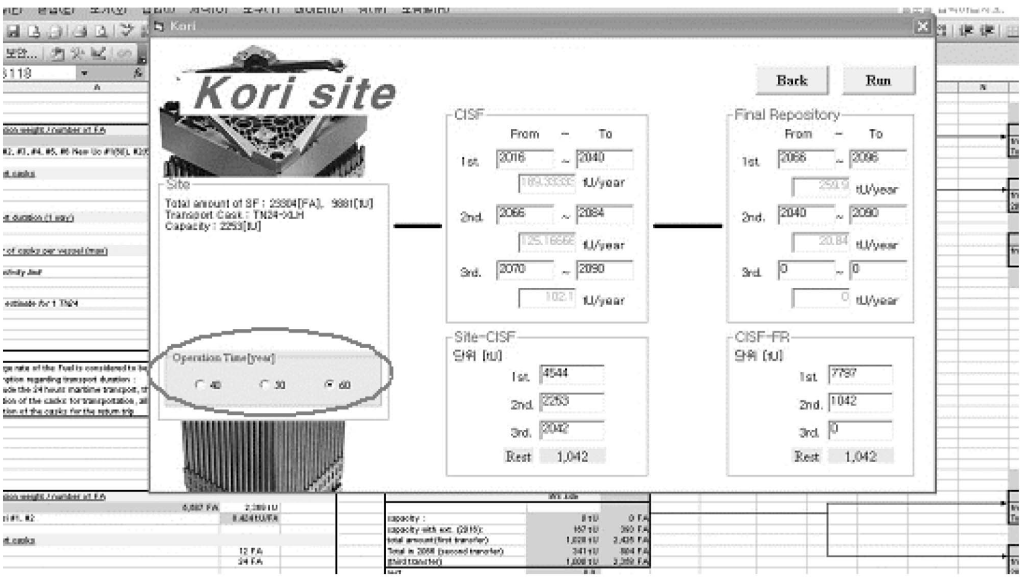

Fig. 1. Life-time selection of the NPPs.

Table 1. The temporary storage capacity in the NPP sites in 2006.

Site Name	Current Capacity of Storage	Storage Amount of spent fuels	Expansion Capacity of storage	Total Capacity of Storage	Storage possible year
Kori	2,253	1,562	0	2,253	2016
Yonggwang	2,218	1,357	466	2,684	2016
Ulchin	1,642	1,054	685	2,327	2016
Wolsong	5,980	4,697	3,175	9,155	2016

3. TRANSPORTATION OF PWR SPENT FUEL

3.1 Mode and Route

Since the NPP sites, CISF, and FR are assumed to be located along the coast of the peninsula, mostly a see transportation of the spent fuels is considered in the CASK. The spent fuels are transported by truck or trailer from the CISF to the FR.

Based on the transportation mode, more detailed analysis was carried out to determine the sea route. The INF-2 or INF-3 transportation ship with a velocity of 13 to 15 knots is considered in the study. The distance from the YG site to the CISF is determined by using a sea distance analysis program that NORI (National Oceanographic Research Institute) supplies on the web. Figure 2 shows an example of a sea route distance analysis along the western coast of the Korean peninsula. A restricted area for the oil-tanker was considered in determining the sea route. The sea route from the YG site to the CISF was determined in the same way. The total distance is about 750 km.

Finally, a distance of 30 km from the CISF to the FR was assumed since nothing about the location of the facilities is fixed.

3.2 Casks

The result, from the KAERI study [6], shows that the TN24XLH transportation cask is to be selected for the transportation of the PWR spent fuels from the YG site. The main components of the TN24XLH cask include a cylindrical body, a fuel basket, a primary lid and a secondary lid, two shock absorbing covers, and an anti-crash cover for a storage. The cask is designed to meet the IAEA B Type packaging requirements. As a consequence, its compliance with the IAEA routine, normal and accidental transport requirements is ensured.

3.3 Transportation Means

For the sea transportation from the NPP site to the interim storage facility, two types of ships are considered, i.e., INF-2 and INF-3. Since the INF-2 ship can carry irradiated fuel or high-level radioactive waste with an activity less than 2 x 10^6 TBq, the number of transported casks is determined depending on the activity level. INF-3 ship has no limitation on the radioactivity level. The cost is estimated based on the lease of a ship.

Road trailers are assumed for the road transportation of the spent fuels from the CISF to the FR. The road trailers consist of a tractor and a trailer. The overall length of a trailer is 24 m. The cost for a bridge or a tunnel is not included in the transportation cost.

4. TRANSPORTATION SCENARIO

The first transfer between the NPPs (Except Wolsong site (WS site) – the first PWR spent fuel is discharged in 2012) and the CISF will start in 2016 and the FR will start in 2066 [6]. The shipping scenario between the NPP sites and the CISF is composed of 2 steps: 2016-2065 and 2066-2095.

To minimize the capacity of the CISF, the number of transportations between the NPP sites and the CISF should be kept as low as possible until the FR begins to operate. During the transfer between the NPPs and the CISF, the accumulative amount of the spent fuels in the NPPs has to

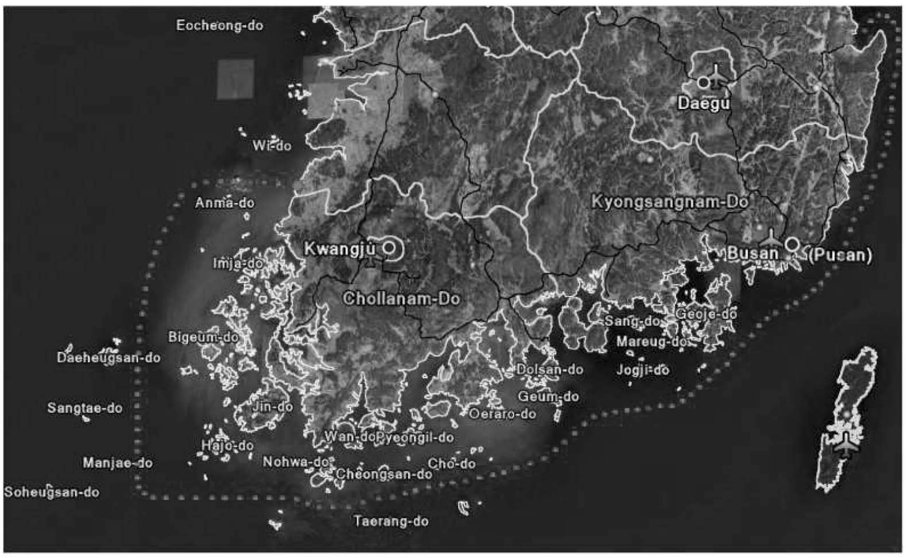

Fig. 2. Sea route determined for this study.

Table 2. Transportation logistics for the preliminary analysis.

Site Name	Peak amount of spent fuels at NPP	1st (NPP-CISF) Transportation (2016-2065)	2nd (NPP-CISF) Transportation (2066-2095)	1st (CISF-FR) Transportation (2066-2095)
Kori	2033 year 2241.8 MtU	5,544 MtU	2,253 MtU	7,797 MtU
Yonggwang	2043 year 2649.6 MtU	3,500 MtU	1,443 MtU	4,943 MtU
Ulchin	2046 year 2241.2 MtU	5,838 MtU	2,327 MtU	8,165 MtU
Wolsong	-	0 MtU	1,629 MtU	1,629 MtU

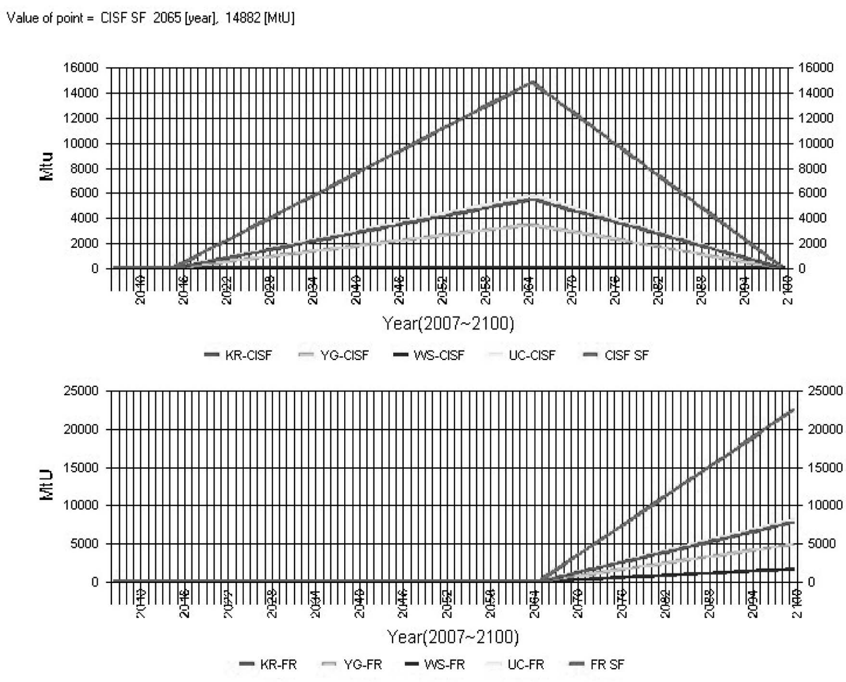

Fig. 3. The total cumulative amount of spent fuels per year at the interim storage facility and the final repository.

be kept at less than the temporary storage capacity. That is, the temporary storage capacity is exhausted with spent fuels by 2065 (The capacity of the temporary storage for PWR spent fuels, in the WS site, is not considered). The transfer between the WS site and the CISF will start in 2066. Table 2 shows the transportation scenario. And the minimum capacity of the interim storage facility is 14,882 MtU in 2065. Figure 3 shows the result of the analysis.

5. COST DETAIL

10 TN-24XLH casks will be necessary to perform the maritime route, and 2 TN-24 for the road part. One TN-24 XLH cask costs $5 Millions, meaning that the required investment for the whole fleet (for INF-2 scenario) would be up to $60 Millions, and considering the lifespan of a cask, two fleets are considered in the study. Also, based on a truck lifespan of 20 years, 3 sets of vehicles are included in the cost estimation for a road transportation vehicle. Cask transportation needs special accessories at the handling interfaces between sea and road. A yoke is required in order to handle a cask.

Table 3 shows the number of ship journeys and return road trips per year with the TN-24, KN-18, and KN-12 casks. A ship with onboard cranes could be chosen. The

Table 3. Summary of the ship journeys and truck trips per year.

Type of Cask	NPP Site	Transportation Step	Ship Journeys / year		Truck trip / year (CISF-FR)
			INF-2	INF-3	
TN-24	KORI	1st	3	1	26
		2nd	2	1	
	YG	1st	2	1	17
		2nd	1	1	
	UC	1st	3	1	27
		2nd	2	1	
	WS	1st	-	-	6
		2nd	2	1	
KN-18	KORI	1st	3	1	35
		2nd	2	1	
	YG	1st	2	1	22
		2nd	1	1	
	UC	1st	3	1	36
		2nd	2	1	
	WS	1st	-	-	8
		2nd	2	1	
KN-12	KORI	1st	3	1	52
		2nd	2	1	
	YG	1st	2	1	33
		2nd	1	1	
	UC	1st	3	1	54
		2nd	2	1	
	WS	1st	-	-	11
		2nd	2	1	

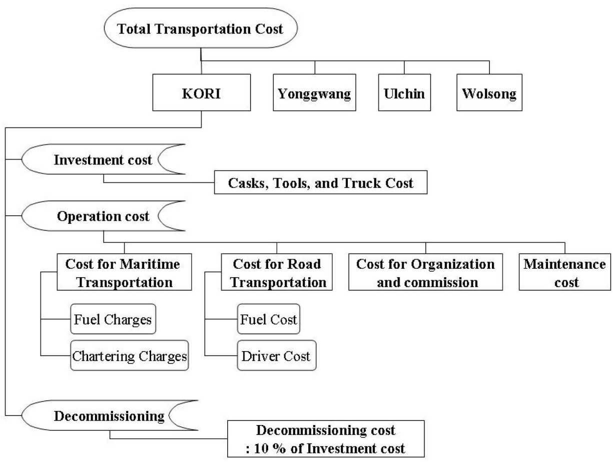

Fig. 4. Construction process of the Transportation cost in CASK.

ship costs include a chartering cost, trip cost, fuel cost, and so on. In this study, a total of 11 staffs are included for a transport organization and commissioning. The labor cost is only determined based on the Korean situation for this study. The transportation costs with the TN-24, KN-18, and KN-12 casks are summarized in Table 4. As shown in Table 4, the transportation cost with TN-24 is cheaper than the others although the price of the TN-24 cask is higher than the others, because of the number of truck trips. The Transportation cost of each NPP site with the TN-24 casks is summarized in Table 5. It is assumed that the decommissioning cost is around 10 % of the investment cost. Figure 4 shows the construction process for the transportation cost in the CASK. However, only one transportation ship will be required for the sea-transportation and it means only one set of transportation casks is required for all of the NPP sites for 40 years. Table 6 shows the grand total transportation cost and Figure 5 shows the transportation cash flow with the TN-24 casks. As shown in Table 6 and Figure 5, the total transportation cost is 1,160 M$.

Table 4. Summary of the transportation costs with the TN-24, KN-18, and KN-12 casks.

Type of Cask	NPP Site	Transportation Cost [M$]	
		INF-2	INF-3
TN-24	KORI	415.7	661.0
	YG	371.6	661.0
	UC	415.7	661.0
	WS	230.8	399.8
KN-18	KORI	443.7	721.5
	YG	399.6	721.4
	UC	443.7	721.5
	WS	246.8	436.2
KN-12	KORI	476.9	792.3
	YG	432.9	792.3
	UC	476.9	792.3
	WS	262.0	471.0

Table 5. Transportation costs of each NPP site with the TN-24 casks.

NPP Site		Transportation Cost [M$]	
		INF-2	INF-3
KORI	Investment	136.5	220.9
	Operation	265.6	418.1
	Decommissioning	13.6	22.1
	Sub Total	415.7	661.0
YG	Investment	136.5	220.9
	Operation	221.5	418.0
	Decommissioning	13.6	22.1
	Sub Total	371.6	661.0
UC	Investment	136.5	220.9
	Operation	265.6	418.1
	Decommissioning	13.6	22.1
	Sub Total	415.7	661.0
WS	Investment	128.7	220.9
	Operation	89.3	156.8
	Decommissioning	12.9	22.1
	Sub Total	230.8	399.8

6. CONCLUSION AND DISCUSSION

The CASK program has been developed to estimate transportation costs. CASK provides 40 years, 50 years, and 60 years lifespans for NPPs and 3 steps of the transportation between NPP sites and the FR via the CISF. By using the CASK, various transportation scenarios could be analyzed and compared economically. The results of the preliminary analysis, in this study, show that the minimum capacity of the interim storage facility is approximately 15,000 MTU

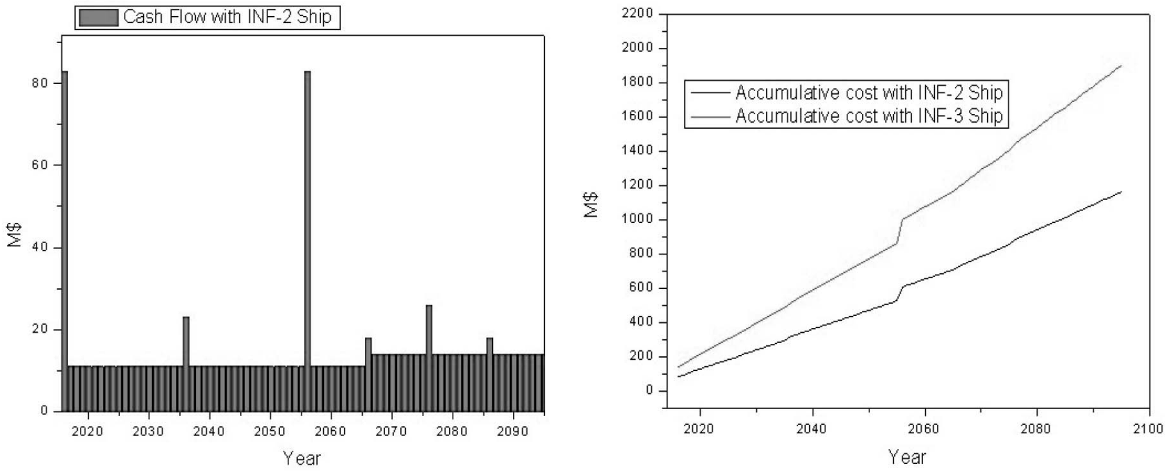

Fig. 5. Cash Flow for the transportation cost with the TN-24 casks.

Table 6. Total transportation cost with the TN-24 casks.

	INF-2	INF-3
KR	314.8	480.6
YG	270.7	480.5
UC	344.0	539.4
WS	109.9	178.9
Total	1160,3	1,900.3

and the transportation costs is 1,160 [M$]. Since the cost for the transportation casks is very high and the lifespan of the casks is 40 years, it is recommended that the operation time should be set within 80 years.

To reduce the transportation cost with the same operation time, a reduction of the cost for the transportation casks and the transportation ship is required. The results show that a selection of the TN-24 cask and the INF-2 ship is appropriate to reduce the total transportation cost. However, considering the risk cost for the sea-transportation between a NPP site and the CISF, selection of the INF-3 ship for a sea-transportation will need to be reviewed again.

Although an insurance cost and a depreciation cost were not considered because of an uncertainty, the economical efficiency regarding various transportation scenarios was analyzed by using the CASK in this study. Therefore, the analysis for the transportation and logistics costs will be estimated again in the future.

Finally, it is expected that the CASK program could become a part of the cost estimation tools which are under development at KAERI. And this program will be a very useful tool for the establishment of a transportation scenario and cost in Korean situations. Also CASK will be able to contribute to a transportation policy making process in Korea.

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