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Analysis on the Spent Nuclear Fuels Streams of Back-end cycle facilities in Rep. of Korea through the Enhanced ENVI Simulator

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1. Introduction

There are interim storage, direct disposal and reprocessing as the main unit management options for SNF, and many significant discussions have been made on finding the most suitable spent fuel management plan in Korea. The Korean Public Engagement Commission on Spent Nuclear Fuel Management (PEBCOS), the Korean version of the Public and Stakeholder Engagement (PSE) for SNF management, submitted to the government a final recommendation on spent fuel management in June 2015 as a result of twenty months of learning and communication since October 2013 [1]. Accordingly, the government has confirmed in the 6th Atomic Energy Committee held in July that sites should be selected by the end of 2028 through scientific and democratic methods and the research on spent nuclear fuel pyro-processing (Pyro) should be continued [2].

At present, direct disposal is mainly selected internationally, but considering the uncertainty of the energy market, it is also important to develop alternative technologies besides direct disposal. To support the development of any feasible alternatives, the transparent economic evaluation of spent nuclear fuel management measures should also be done. In the spent nuclear fuel management project, it is necessary to analyze the amount and the economic efficiency of spent nuclear fuel considering the long-term uncertainty because it takes from decades to hundreds of years for the storage business to store spent fuel. The time period to successfully accomplish this back-end fuel cycle tasks is quite long compared with the average lifetime of reactor operation. In that sense, to properly manage the safety and financial arrangement for the back-end fuel cycle requires the precise integrated approach. Therefore, it is important to assess all the probable options and then successfully identify the optimal comprehensive options for each country from a long-term perspective [3][4].

In order to properly manage spent nuclear fuel, it is needed to develop the System Prioritization Method (SPM) for the entire back-end fuel cycle options. In this paper the SPM software ENVI is fully developed for the SPM and applied to analysis the SNF streams of back-end cycle facilities according to potential scenarios.

2. Revision of ENVI Simulator and Development of the Transportation Logic on the of SNF

2.1 Revision of the ENVI Simulator

The ENVI program is based on GoldSim [5], a generic simulation package developed by GoldSim Technology Group LLC. It was originally developed by Korea Atomic Energy Research Institute [6]. The ENVI program can deal with all activities related to spent nuclear fuel management in a streamlined manner from the original nuclear cycle to the final disposal. The ENVI program is useful to determine the spent nuclear fuel management plan to allow policy decision makers to evaluate the system dynamics factors such as the capacity of AR/AFR options and to predict the appropriate time required for incremental facility capacity additions and the required site gross area.

As shown in Fig. 1, the enhanced ENVI program can set up the simulation period artificially and it is possible to simulate the distributions of spent nuclear fuel by choosing the facilities according to various scenarios. In this study, initial conditions were set to simulate spent nuclear fuel distributions of 120 years period from 1978 to 2098.

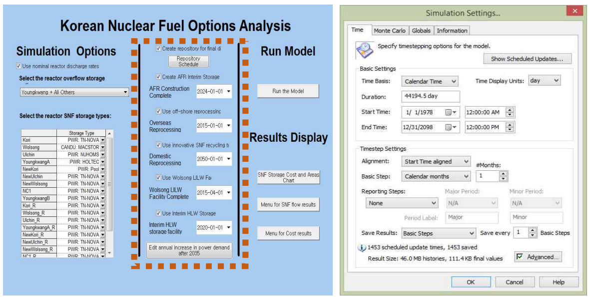

Fig. 1 GUI of ENVI Program and Simulation Setting

2.2 Logic Development on SNF Transportation Prioritization

To analyze the spent nuclear fuel stream in Rep. of Korea, we set up the basic applicable back-end cycle facilities' scenario that shown in Fig. 2. Spent nuclear fuel will be stored in nuclear reactors (AR) such as storage pools or in-plant dry storage facilities or in additional on-site and off-shore storage facilities (AFR).

At present, the AR storage facility utilizes only a pool per NPPs site, which is a wet storage facility or a dry storage according to reactor type. Therefore the program was developed by using a single ARPOOL CODE to store spent fuel in the same site in one pool group. In this way, the storage size of the AR storage facility is set at each nuclear power plant, and the saturation year of each AR storage facility is predicted using this. When the AR storage facility is saturated, spent fuel stored in the AR will be transported to the AFR storage facility, or the reprocessing/recycling facility, or the final repository after a certain period of cooling time.

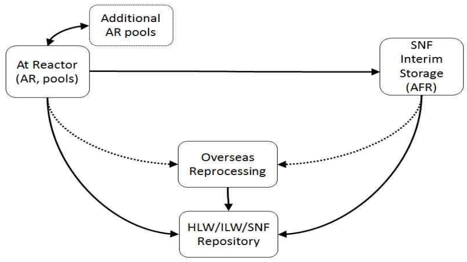

Fig. 2 Applicable Basic Scenario of Back-end Cycle Facilities in ROK

We assumed that the spent nuclear fuel will be transported two years before the saturation point by setting the actual saturation year to two years before the total storage capacity is fully saturated. The logic to determine the priorities of AR storage facilities for the spent nuclear fuel to be transported is as follows;

(1) *The spent nuclear fuel stored in the AR storage facility which has reached the actual saturation year is transported first.*
(2) *In principle, spent nuclear fuel with the longest cooling period should be transferred at this time.*
(3) *The amount of spent fuel transported at this time shall be determined in advance according to the shipping capacity, the annual amount of reprocessing / recycling facilities, and so on.*
(4) *If there is no AR storage facility that has reached the actual saturation year, spent fuel transport starts from the AR storage facility with the highest inventory of spent nuclear fuel.*

In this study, the saturation of AR storage facility was occurred in some NPPs site before the start of operation of AFR storage facilities. To calculate the amounts of overflowed SNF, we added the additional AR as shown in Fig. 2.

The logic from AR pools and AFR storage facility to ship to the repository is as follows. The shipping block amount is 667 MTU/year.

(1) *The first shipping priority is the overflowed AR facility for this particular option assuming that have six months of spent nuclear fuel ready to be shipped*
(2) *If there is not six months ready for shipping at the AR facility, then the dead fuel stored ready to be decommissioned and urgent fuel that is fully cooled/shutdown for 2 years from the reactor pool facilities are examined as possible source*
(3) *The next priority is any additional cooled fuel which exists an AFR facility*
(4) *The last possible source is any reactor pool with sufficiently-aged spent fuel*

Based on the above logic, the spent fuel transportation plan was decided from the AR/AFR storage facility to AFR or final repository facilities.

3. Introduction Analysis on the Spent Nuclear Fuels Streams Using ENVI Simulator

3.1 Analysis on the amounts and time of SNF overflow at reactor pool

When an AR pool overflows, the overflow goes to the logical additional AR pool of each site, assuming that AFR operation has not started as specified. Through the ENVI simulation, the amounts of overflow AR pool were estimated as shown in Fig. 3. Simulation results illustrates the AR facilities is overflowed since 2023. Before the introduction of AFR facilities in 2030, the overflow of SNF were occurred at 4 NPP sites (Kori(Code #1, 126 MTU), Ulchin(Code #3, 477 MTU), Youngkwang(Code #4, 718 MTU), NewWolsong(Code #7, 76 MTU)) and the total overflow SNF were calculated as about 1,397 MTU.

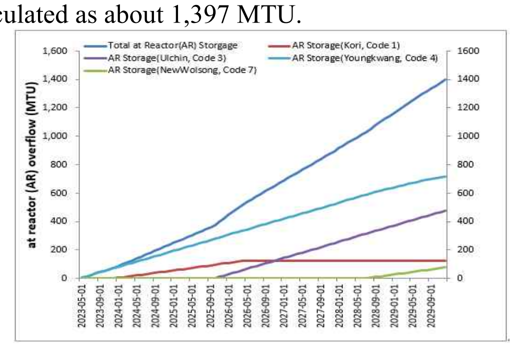

Fig. 3 Overflowed Spent Nuclear Fuel AR Pools

It indicates that the AFR storage facility should be introduced in accordance with the saturation point of the AR storage facility by 2023. If the AFR is not applicable at the appropriate time, and the overseas reprocessing can be applied as an option to earn the time until the AFR storage facility is introduced.

In 2023, the first overflow was occurred at Youngkwang NPPs site. By 2030, the insufficient capacity of SNF pool was corresponded to about 718 MTU. Based on these results, the expansion of AR pool capacity or transportation of SNF to AR pool of other NPP site should be considered at above 4 NPPs sites. In the case of Korea, the short-term storage facility recommended by the Korean Public Engagement Commission on Spent Nuclear Fuel Management (PEBCOS) should be required. Of course, in order to apply overseas reprocessing, there are various issues such as the preparation of requirements for abroad transportation of nuclear materials and the permission for transportation means.

Also, if the introduction of the AFR facility has been delayed, the AR pools can be overflowed additionally. Through the simulation using this ENVI code, it is possible to evaluate the timing of introduction of AFR storage facilities

3.2 Analysis on the Shipment to Repository from the AR/AFR facility

In this ENVI model, the repository can receive shipments given specified construction date. In the ENVI model, the time for the construction of the required final disposal repository can be specified as needed. In this simulation, the final disposal site is planned to be completed at least around 2053. Through the developed SNF transportation logic(AR/AFR -> repository) described above, the cumulative amount of spent nuclear fuel at the final disposal facility is shown in Fig. 4 (from AR) and Fig. 5(from AFR).

According to transportation priority and the shipping block amount(667MTU/year) of final repository, SNF of Sin-Kori(#5), Sin-Ulchin(#7) that are in operation are transported first as shown in Fig. 4. These SNF transportations of NPP in operation are stopped according to the termination of NPP in 2080(#5) and 2082(#7) respectively.

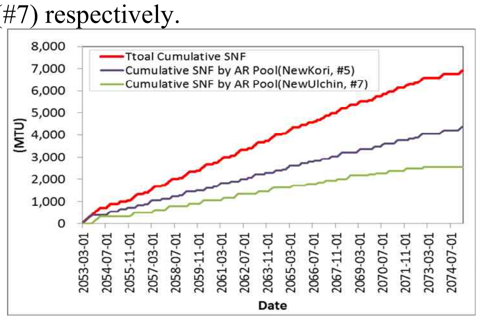

Fig. 4 Cumulative Spent Nuclear Fuel Arrivals From At Reactor to Repository

If there is not six months ready for shipping at the AR facility of NPP in operation, then the dead fuel stored ready to be decommissioned and urgent fuel that is fully cooled/shutdown for 2 years from the license terminated NPPs are transported. According to license termination of Kori(#1, 2025), Wolsong(#2, 2039), Ulchin(#3, 2045), YoungKwang(#4, 2042), Sin-Wolsong(#6, 2053) NPPs, the fully cooled SNF are transported to final repository.

Fig. 5 shows the amounts of SNF transportation from AFR facility to final repository facility. According to the transportation logic, SNF transport from the AR takes precedence and transport from the AFR to the final repository begin around 2065. The simulation results show that the cumulative SNF of 13,530 MTU will continue to be transported until 2090, when final transport occurs.

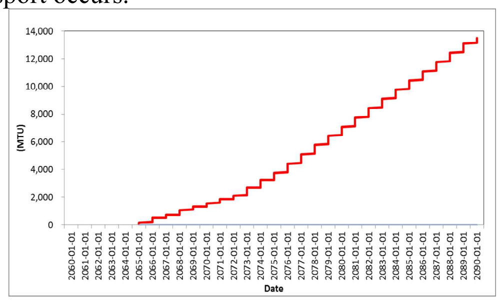

Fig. 5 Cumulative Spent Nuclear Fuel Arrivals From AFR Facility to Repository

According to 667 MTU/year shipping block amount, all spent fuel for the AR / AFR was expected to be transported to the final repository by 2135. If reprocessing/recycling technology is not applied in Korea, it is expected that the total 55,045 MTU cumulative amount of SNF generated in Korea should be disposed at the final repository. Therefore the capacity of final repository facility should 55,045 MTU at least.

4. Conclusions

In this study, improved ENVI simulator was used to analyze the spent nuclear fuel cycle in Korea. Through the simulation, it is estimated that about 55,045 MTU of spent fuel will be generated by 2087 from the 32 nuclear power plants without extension of life or power upgrade.

In order to set up a spent nuclear fuel management plan, the variety of policy-making factors must be considered. In this regard, the ENVI simulator is developed to meet the demand for estimating SNF arising and to evaluate the appropriate operating and management for the AFR facility and the final disposal repository according to the introduction time of such facilities and the yearly expansion period. The timing of SNF transport among unit management option as a policy-making factor can be evaluated by ENVI program.

The ENVI simulator was upgraded to meet the domestic situation for spent nuclear fuel and spent nuclear fuel movement priorities. The ENVI simulator through this study can be utilized to calculate the total fuel quantity; the amount managed by the facility, the construction, operation and, and eventually can be used to select the optimal scenario through comparative analysis.

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