Annals of Nuclear Energy 38 (2011) 976–981

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Cost comparisons of wet and dry interim storage facilities for PWR spent nuclear fuel in Korea

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ARTICLE INFO

Article history:
Received 20 September 2010
Received in revised form 29 December 2010
Accepted 8 January 2011

Keywords:
Spent nuclear fuel
Cost assessment
Wet storage
Dry storage
Interim storage
Sensitivity analysis

ABSTRACT

As a part of an effort to determine the ideal storage solution for pressurized water reactor (PWR) spent nuclear fuel, a cost assessment was performed to better quantify the competitiveness of several storage types. Several storage solutions were chosen for comparison, including three dry storage concepts and a wet storage concept. The net present value (NPV) and the levelized unit cost (LUC) of each solution were calculated, taking into consideration established scenarios and facility size. Wet storage was calculated to be the most expensive solution for a 1700 MTU facility, and metal cask storage marked the highest cost for a 5000 MTU facility. Sensitivity analyses on discount rate, metal cask price, operation and maintenance cost, and facility size revealed that the system price is the most decisive factor affecting competitiveness among the storage types.

1. Introduction

Korea Radioactive Waste Management Corporation (KRMC), which is responsible for radioactive waste management in Korea, is leading a project to develop an indigenous dry storage system for PWR spent nuclear fuel. It is expected that the spent fuel pools at some of nuclear power plants will be saturated from 2016; therefore, the dry storage system is one of the most practical alternatives to solve the imminent problem. While the development of a storage system for spent nuclear fuel is technically feasible, there remain other challenges, which complicate the selection of a storage solution. When deciding on a particular waste management system, many factors must be considered including, technical experience, economics, licensability, and public acceptance. Even though the priority of these factors can be different from a standpoint of experts or stakeholders, the underlying economics of storage is a factor that is difficult to ignore for any interested party. Under this context, the main objective of this study is to suggest reasonable cost comparison data to be used in the decision-making process.

While cost comparisons of different storage options have been conducted previously, it is difficult to infer information by comparing different studies because of discrepancies in various factors, such as facility size, storage scenarios, evaluated items, location of facility, time of evaluation, and price level. Electric Power Research Institute (EPRI) conducted cost estimations for an interim storage facility, but these were limited to outdated on-site storage options (McCartney and Cairns, 1984) and away-from-reactor (AFR) interim storage options using concrete casks (Kessler, 2009). The Central Research Institute of Electric Power Industry (CRIEPI) in Japan analyzed the cost of pool and cask storage options (Nagano, 2003); however, it was also limited to an AFR interim storage facility. In Korea, unfortunately, location of interim storage facility, size, and opening target year have not yet been determined. Consequently, cost analyses on these variables and alternatives are also needed.

To estimate the cost for an interim storage facility, the step or status of a project should first be defined. Along with the maturity of a project, the status of a project can be characterized as being in the conceptual design phase, basic design phase, or detailed design phase. As the stages progress, better information and improved accuracy usually come at a greater expense (Lee and Lovasic, 2009). Because the status of our project is in the first phase for conceptual designing of indigenous storage system, the primary concern of this study is to demonstrate a priority in cost efficiency among various storage types, not to calculate the actual project cost. To produce the more objective results, parametric methods to deduce the unknown cost elements and quotations from manufacturers to acquire realistic storage system prices were complementarily used in cost assessment process.

The first step in the cost analysis was to provide a clear boundary of the study; a ground rule for cost estimation was established characterizing the size of the facility, loading/unloading scenarios,

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doi:10.1016/j.anucene.2011.01.015

cost elements, and escalation factors. Based on the ground rule, the net present value (NPV) and the levelized unit cost (LUC) were calculated for each storage type, depending on the time frames, such as construction period, loading period, storage period, and unloading period. It is important to not only calculate both the NPV and LUC but also to show the effect of cost factors on competitiveness for each storage type; therefore, the sensitivity analysis on discount rate, metal cask price, operation and maintenance (O&M) cost of metal cask, and facility size was also performed. These items were selected for analysis because the discount rate is an indicator of time-dependent cash flow, metal cask price is a decisive factor determining the competitiveness with other storage types, and O&M cost of metal cask storage is a well-known advantage over other dry storage solutions. Additionally, facility size is a factor that can distinguish the competitiveness of wet storage over dry storage types.

2. Ground rule

Several factors needed to be taken into consideration when determining an estimated cost, including generated spent nuclear fuel characteristics, storage scenarios, the size of the interim facility, cost items, and the escalation factor. The size of the interim storage facility can be inferred from the expected amount of spent nuclear fuel. At the end of 2008, a total of 11,121 PWR spent nuclear fuel assemblies had been stored at nuclear power plants in Korea. Analysis of the generated spent fuel showed that 85.2% of the total number of fuel assemblies, 9471, was less than $4.5^{w}/_{o}$ in initial enrichment and had a burn-up factor of 45,000 MWD/MTU. Though 9471 assemblies correspond to 4262 MTU, considering the margin for uncertainties, 5000 MTU was fixed as the capacity of the first stage of AFR facility. This was done because it is foreseeable that an interim storage facility will be constructed by a gradual step-by-step approach. Since there are three PWR sites in Korea, 1700 MTU was chosen as the capacity of the first stage of at-reactor (AR) facility by evenly distributing the 5000 MTU which was drawn from the capacity of AFR facility.

In order to determine a relationship between the value of time and monetary value, it was necessary to define the life cycle of an interim storage facility. The life cycle consisted of the construction period, the loading period, the storage period, and the unloading period as shown in Fig. 1. It was assumed that operation of the facility begins in 2017, devoting 3 years towards the facility construction, which was assumed to begin in 2014. The life cycle periods and cost items associated with each period were determined by Kessler (2009) and Lee and Lovasic (2009), respectively. Costs for administration buildings, O&M buildings, a canister transfer building, a wet storage building, shipping casks, shipping vessels, trailers, monitoring systems and a security fence were considered to be the cost items of construction period. During the loading period, it was assumed that 5000 MTU (1700 MTU for AR storage) of spent fuel is transferred and loaded into interim storage facility for 10 years from 2017. In case of dry storage, costs for the manufacturing and installation of the storage system, as well as the construction of a concrete pad, associated labor cost, transportation fee, and O&M cost were included as cost items for loading period. Following the loading period, the storage period lasts for 40 years from 2027. It was assumed that pure management action to be performed during this period; therefore, only labor cost and O&M cost were considered for this period. As the final phase, a 10-year unloading period was allotted for the unloading of spent fuel and its transportation to final repository or reprocessing facility. All labor cost, O&M cost, the costs of decontamination and decommissioning, and transportation fee were included as cost items for unloading period.

To perform these calculations using reference data, it was necessary that all costs were adjusted for inflation. Although several sources can be used as an escalation factor, such as consumer price index (CPI), and building construction cost data (BCCD), CPI was applied to the generate escalation factor because of its availability and accuracy. Fig. 2 shows the CPIs (US DOL, 2010) and escalation factors used in this study. The other assumptions for cost estimation were as follows:

(a) Cost estimations are to be performed for wet storage, metal cask, concrete module and concrete cask types.
(b) Spent fuel is loaded at a rate of 500 MTU/year for an AFR facility and 170 MTU/year for an AR facility.
(c) The capacity of a dual-purpose canister is assumed to be 24 PWR assemblies and it can be commonly used with shipping casks, concrete modules, and concrete casks.
(d) Social cost, contingency cost and costs for siting and land preparation were not considered.

3. Cost assessment procedure

Prior to compiling a total cost assessment, unit costs for individual items should be decided. In the case of wet storage, each cost item was drawn from reference data using a parametric method. Raw cost data were extracted from several reports, such as IAEA (1994), KOPEC (1994), McCartney and Cairns (1984), and a few others. Because each cost datum is based on different capacity and year, a parametric approach was used to find out of the unit cost for the interested year and the facility's capacity. For example, Fig. 3 shows the curve generation of capacity vs. wet storage capital cost, where each capital cost had been extracted from the previously mentioned references and then escalated to January 2010 dollars.

Using the generated curve, capital cost at the interested capacity could be determined. Other cost items, such as O&M cost and transportation cost, were drawn in the same manner. In the dry storage solution, canister cost, metal cask cost, concrete module cost, concrete cask cost, and construction cost for the concrete pad, concrete pavement, and security fence were estimated directly by vendors. In estimating the decommissioning and decontamination (D&D) cost, it was assumed that D&D cost would be 10% of the capital cost and costs for canisters, casks, and construction costs for concrete pads and concrete pavement. Table 1 shows the estimated prices of canisters and casks (or modules). Estimated prices were compared with reference price (JAI, 2003) to check for accuracy and reliability. As shown in Table 1, the estimated prices were similar to the reference cost data; therefore, the estimated price was considered as a reasonable price to use in this cost analysis.

Fig. 1. Life cycle of the interim storage facility.