Waste Management Study for the Disposition of Spent Uranium-Metal Fuel from the Democratic People's Republic of Korea (DPRK)

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ABSTRACT

AECL is completing a study commissioned by the Korean Peninsula Energy Development Organization (KEDO) to examine options for the disposition of spent uranium-metal fuel currently being stored in the Democratic People's Republic of Korea (DPRK). Key to the acceptability of this spent-fuel type for disposal in a future high-level waste repository is an understanding of its current condition and continued monitoring for evidence of stability or deterioration. Technical feasibility of several waste management options is discussed and several recommendations are made for the storage conditions of the spent fuel over the next few decades.

1. Introduction

Canada's expertise in nuclear fuel waste management is being called upon to help solve problems halfway around the world. Although the success of CANDU reactors in the Korean Peninsula is well-known, another project involving the Democratic People's Republic of Korea (DPRK, or North Korea) has had a lower profile. The multinational Korean Peninsula Energy Development Organization (KEDO) was formed in 1995 to assist the DPRK in meeting its energy requirements. The KEDO members, including USA, Japan, Republic of Korea, EURATOM, Argentina, Australia, Canada, Chile, Finland, Indonesia and New Zealand, plus a dozen non-member contributing states, are planning to provide the DPRK with two light-water power reactors, as well as heavy oil for heating until the reactors are commissioned. In exchange, the DPRK has agreed to terminate its domestic program for the development of nuclear energy. This program was based on graphite-moderated reactors, one of which had already operated for several years.

An immediate concern was the deterioration of 50 tonnes of spent fuel from the 5 MWe reactor at Nyongbyon (Jones et al. 1998). The DPRK agreed that they would not reprocess it and would eventually ship it out of the country. In the interim, the USA is taking the lead to ensure the safe management of this spent fuel. The first priority has been to stabilize and package the spent fuel in a way that protects it from further corrosion and deterioration. The USA has contracted a fuel-management company to take part in this activity and the International Atomic Energy Agency (IAEA) has arranged to apply safeguards to the packaged fuel. KEDO has also contracted several organizations to carry out studies relating to the storage and eventual disposition of the spent DPRK fuel. AECL has been requested to study the option of direct geological disposal and to prepare a long-term maintenance plan for the spent fuel. The overall objective of the AECL study is to recommend a maintenance and monitoring plan for the spent DPRK fuel that recognizes the potential interim storage period involved and takes into account information that will likely be needed for its transportation and eventual conditioning and disposal. This paper summarizes the results of the study to date.

The spent DPRK fuel consists of ~8000 rods of natural uranium metal, each 61 cm long including end fittings. The fuel was irradiated to low burnup, discharged in 1994, and stored under water. During wet storage, much of the magnesium alloy cladding corroded away. Therefore, the prevention of additional corrosion was of immediate concern. The spent-fuel rods have now been dried and sealed in storage canisters with pressurized argon (including 2% oxygen to minimize corrosion). The canisters have been placed in racks under water in the original spent-fuel pool at Nyongbyon. The spent fuel may remain there for a decade or more, until plans are finalized for its disposition. The option of eventually sending it to a functioning high-level-waste (HLW) repository in another country is attractive, but faces many technical and political hurdles. We deal only with the technical issues in our study.

2. Disposition Options

2.1 Description of Options

There are several disposition options for the spent fuel, each with its own technical, safety and economic ramifications. For the purposes of the discussion, the final destination of the spent fuel is assumed to be in a foreign, operating repository constructed for disposal of high-level wastes originating in that nation. The spent fuel could be directly disposed, or it could be reprocessed and the resulting wastes disposed as high-level waste (HLW) in glass form and low and intermediate level waste (LILW) in solid forms. The repository is assumed to be in either crystalline, sedimentary or volcanic rock and could be located in the geographical region in which the spent fuel is presently located or elsewhere. As an example only, the spent fuel may be co-disposed with spent LWR fuel in the planned Yucca Mountain repository in the USA. In any case, the 50 Mg of spent DPRK fuel rods or the derived reprocessing wastes are a very small increment to any planned repository, because most repository designs are based on fuel waste inventories of thousands to tens of thousands of Mg U.

For all disposition options, the condition of the spent DPRK fuel in the present storage canisters is assumed to be continually monitored throughout the interim storage period in the DPRK. In addition, it is assumed that the monitoring program will confirm that no further degradation has occurred. The methods of assuring this are discussed below. Knowledge of the condition of the spent fuel and the storage canisters will be undoubtedly critical for securing approval to transport the spent fuel to either a reprocessing or a direct-disposal facility.

In the case of the direct disposal option (Option 1), the spent-fuel storage canisters are assumed to be shipped from DPRK to the disposal facility, with the possibility that interim dry storage of the canisters may be necessary for some years until the disposal facility is ready. At the disposal facility, two options are available for packaging the spent fuel into disposal containers. In both cases, the container licensed for disposal of spent fuel in the repository will be used for the disposal of the spent DPRK fuel. This is necessary because the cost is prohibitive for design, development and licensing of a special container for a very small quantity of DPRK fuel.

In the first packaging option (Option 1a), the spent-fuel rods remain in the storage canisters and the canisters are loaded into a disposal container. The number of canisters in a container is determined by the internal diameter and height of the licensed disposal container. These dimensions are currently unknown but are assumed to be similar to the preliminary published concept design studies for spent LWR fuels (e.g., SKB 1992; USDOE 1998). In the second packaging option (Option 1b), the spent-fuel rods are unloaded from the storage canisters, placed in a basket (i.e., an array of tubes of appropriate diameter) and the baskets loaded into the disposal container. There would be several baskets per container, given the short length of the fuel rods relative to the size of a spent LWR fuel disposal container. Option 1b would be expected to achieve a higher fuel-rod packing density than Option 1a.

In the case of the fuel reprocessing option (Option 2), the spent-fuel storage canisters are assumed to be shipped (see below) from the DPRK to a commercial reprocessing facility. The resulting reprocessing wastes (i.e., HLW glass and solidified LILW) are then shipped to their respective disposal sites. At the HLW repository, the HLW glass canister is packaged in the licensed disposal container. Note that only the container licensed for disposal of vitrified HLW is assumed to be used for the disposal of the DPRK fuel waste at that site. The LILW are shipped to a licensed LILW repository.

2.2 Qualification for Transport and Disposition

The present storage mode for the spent DPRK fuel is designed to ensure that no further degradation of the fuel occurs. The prevention of further degradation is required to ensure that eventually the spent fuel can be safely dispositioned by a program involving its shipment to a waste management facility for direct disposal or reprocessing. The objective of monitoring under the present storage condition is to measure parameters that directly or indirectly confirm that:

- the spent fuel has not experienced any further degradation; and
- any degradation of the storage canisters is sufficiently limited that approval for transportation will be possible.

Properly performed, with mitigation measures implemented where necessary, the monitoring program will ensure that the spent fuel storage canisters can be shipped without any need for repackaging prior to shipment.

The condition of the spent DPRK fuel upon receipt of the canisters at an interim storage, reprocessing or disposal facility is important, in that their condition forms the basis for developing criteria for safe handling during any subsequent operations, particularly the operations that involve removal of the fuel from the canisters. The condition of the spent fuel is also important for disposition Option 1a, wherein the canisters are to be overpacked for disposal without unloading, as there will be criteria for acceptance of both the canisters and spent fuel for disposal. At a minimum, the spent fuel within the canisters must be demonstrably dry to some established dryness criterion prior to overpacking.

For acceptance of the spent fuel at a reprocessing facility, we expect that the condition of the fuel may be a less significant issue, because wet shipment (i.e., filling the storage canisters with water prior to shipping) can be used to avoid any potential difficulties associated with dry shipment and receipt of hydrided and potentially pyrophoric fuel. The spent fuel will likely be unloaded and reprocessed relatively soon after receipt at the reprocessing site. The complexity of spent-fuel handling and fuel handling issues may be less for the reprocessing case than for Option 1b (i.e., spent-fuel rods removed from the storage canisters). Option 1a (i.e., spent-fuel rods remain in the storage canisters), in contrast, would involve no direct handling of the spent fuel, thus the degree to which the fuel might have further degraded during storage and transport appears to be a less important issue. Nonetheless, an effective monitoring program appears essential to ensure that all disposition options remain open. The approach to monitoring is discussed in detail in the final section.

2.3 Transportation of the Spent DPRK Fuel

Significant differences may exist between the two disposition options in the area of transportation of the spent DPRK fuel. The location of the repository that may ultimately accept the spent fuel or vitrified waste therefrom is unknown. It may be located in south-east Asia or, for a variety of reasons, may be in Europe or the United States but speculation on what would be the final location is unproductive. However, the locations of the two civilian reprocessing facilities capable of dealing with the spent DPRK fuel are known (Sellafield, UK and Marcoule, France) and no new reprocessing facilities are likely to be constructed in the interim. It is reasonable to conclude that shipment to one of these European reprocessing facilities will be necessary, followed by shipment of the solidified wastes to the final HLW and LILW repositories.

The licensed container for spent fuel disposal in the repository is assumed to be adopted as the overpack for the spent DPRK fuel (or vitrified waste therefrom). The facilities for final encapsulation may be at the disposal site, which is the approach being taken in US and Canadian conceptual designs (USDOE 1998, Johnson et al. 1994); or encapsulation may be at a centralized spent fuel storage site as in the Swedish disposal concept (SKB 1992). In the former case, no further shipping of the spent fuel is required, whereas in the latter case, final disposal containers are to be shipped to the repository. Based on the above discussion, the reprocessing option is likely to involve greater transport distances and more transport steps than the option of direct disposal. Because the routes and distances are unknown, our analysis of transport issues and costs is generic, focusing on transport to a port by road, followed by transport by sea to a reprocessing/disposal facility.

The canisters containing the spent DPRK fuel rods are designed to be shipped in an existing approved cask, which can hold five canisters. Shipping the entire fuel inventory contained in 400 canisters requires 80 cask loadings. Since only a few such casks are available, leasing them over an extended time period is required. A specially-outfitted ship needs to be chartered for several years to move the spent fuel, whether it goes to a reprocessing facility or directly to a repository. The cask lease cost represents the largest single contribution to the overall cost of transportation.

2.4 Quantities of Waste

The packaging of the spent DPRK fuel into containers for direct disposal will result in 25 to 40 disposal containers, depending on the available design of a licensed disposal container for spent LWR fuel assemblies. The small amount of ILW produced (fuel end fittings removed to simplify encapsulation in Option 1b), if any, is ignored for costing purposes.

For the reprocessing case, we have attempted to summarize the quantities of various waste types produced from the reprocessing of ~50 Mg of spent DPRK fuel. The estimates are based on studies undertaken during preparation of AECL's Environmental Impact Statement for the Disposal of Canada's Nuclear Fuel Waste. We presented a comparison between the volumes of waste arising from direct disposal of CANDU fuel compared to those from reprocessing of the same fuel (Johnson et al. 1994). These data are based on many European and American studies. The data derived for the case of reprocessing spent CANDU fuel have been used to derive estimates for quantities of wastes from spent DPRK fuel by adjusting for the differences in burnup of the two fuels (185 MWh/kg U for CANDU fuel vs. 29 MWh/kg U for DPRK fuel). The results indicate that the quantity of HLW glass resulting from vitrification of the waste requires only one HLW disposal container. However, the additional quantities of ILW (i.e., 10-15 m^3 of bituminized waste along with cemented fuel sheath) and LLW are significant.

An additional item not commonly noted in evaluations of wastes arising from reprocessing is the presence of volatile fission and activation products released during the fuel dissolution process. In particular, ^{14}C, ^{129}I, ^{36}Cl and ^{85}Kr are all present in off-gases from reprocessing and may or may not be captured for solidification and final disposal. Note that the first three of these radionuclides are frequently shown to be among the principal dose contributors for disposal of spent fuel (SKB 1992, Wikjord et al. 1996). The conditions of the reprocessing contract for the spent fuel are expected to specify return of the HLW to the country of origin (or country which is accepting the waste), but the LILW is expected to be disposed by the reprocessing plant operator.

3. Technical Issues and Cost

The main technical issue is the assurance of the acceptability of the spent fuel at a repository sometime in the future. The radionuclide inventory and decay heat of the spent fuel have been estimated and these are found to be very low relative to commercial power reactor fuel because of the low burnup of the spent DPRK fuel. A simple safety case for deep geological disposal of the spent fuel was prepared, based on evaluating the release of the most important radionuclides, under conservative corrosion assumptions. The results are similar to those for spent PWR and CANDU fuels for most radionuclides. Since the levels of impurities in the spent DPRK fuel and sheath are not known, conservative estimates for these are used. Eventual availability of information on impurities or measurement of actual ^{14}C and ^{36}Cl inventories in the spent fuel may permit significant reductions in the predicted dose consequences for these radionuclides in planning for its disposal.

Long-lived disposal containers are required to protect the spent fuel from groundwater after emplacement. Container designs compatible with several countries' concepts for HLW disposal have been proposed. This allows handling of the containers by the repository staff with few or no modifications required to the standard equipment. The currently planned disposal containers are about 4.5 m high with a diameter of about 1 m. They would then be emplaced in galleries in the repository, under the same conditions as the other spent LWR fuel containers.

The preliminary cost estimate for disposal is based on a costing study by the Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD) based on data from the fuel waste management programs of several nations (NEA 1993). We selected the costs from Sweden, Canada and the US because these costs were readily useable. The option to dispose of the spent fuel without transferring it from its current canisters to larger containers is somewhat less costly than the option to reduce volume by repackaging. Relative to reprocessing, either option for direct disposal of the spent fuel is again somewhat less costly.

4. Monitoring

Monitoring the condition of the spent DPRK fuel while it is stored in canisters under water is important to ensure that it remains in adequate condition for eventual geological disposal. However, monitoring is hampered by limited access to the fuel. Direct indications of the fuel integrity are impossible without opening the canisters, so indirect measurements are required. A few leaking canisters have already been identified by the release of gas bubbles in the pool at Nyongbyon. The presence of significant quantities of water in a canister can be ultrasonically determined. The rate and types of corrosion reactions which might be taking place in the spent fuel are affected by the ambient temperature and by the atmosphere inside the canister. Reduction and control of the pool water temperature is recommended as a means of limiting reaction rate. Analysis of the cover gas in the spent-fuel canisters can provide much information about the condition of the spent fuel. A monitoring and maintenance plan is proposed, based on technical and administrative feasibility of measurements.

A key indirect indication of corrosion can be obtained by measuring several parameters of the gas composition, in particular the moisture, oxygen and hydrogen content. The original fill gas was dry, so the presence of moisture is an indication of a leaking canister or incomplete drying of the spent fuel. The original oxygen concentration of 2% (in argon) decreases only if corrosion processes take place. These processes can generate hydrogen gas, which is easier to detect than a slight drop in oxygen concentration. Other gases whose detection may be of interest are krypton and xenon, fission products which are liberated if there is continuing corrosion of spent fuel.

A gas sampling plan should include repeated measurements on the same canisters according to a fixed schedule (e.g., annually). If no changes are noted, the frequency of sampling can be decreased. The proportion of canisters sampled can also begin at a reasonably high value such as 10% to obtain meaningful statistics and then be decreased if little or no oxygen consumption or hydrogen generation is occurring and little or no moisture is detected. It may be possible to affix gas sampling lines to some of the canisters in the top level of the rack without having to move the canisters. This simplifies the subsequent sampling activities. Analytical sensors specific to water vapour and other common gases are available at relatively low cost, so that performing a total gas analysis by mass spectrometry is not required. This keeps both instrumentation and training costs low. Canisters found to contain water vapour or hydrogen or decreased levels of oxygen should be re-dried and have their cover gas replenished. Subsequently, they should be inspected more frequently.

There is a timing issue which affects the monitoring program in the long term; namely, the possibility that the spent fuel must be moved before a repository is ready. If after several years, the effort or cost to monitor the spent fuel in its current location is judged too great or if the current storage mode is to continue for decades, transfer of the fuel to a surface dry store may be more effective. Dry storage as an intermediate-term option is attractive relative to pool storage because of its relatively low cost. Moisture ingress is also less likely and safeguards containment/surveillance methods are well-established for this storage mode. To load the dry-storage modules, a shielded flask is positioned above the pool. The spent-fuel canisters are lifted up into the flask and transferred to concrete containers, each of which can hold several canisters. At AECL's Whiteshell Laboratories, this intermediate storage option has been used for spent CANDU, WR-1 carbide and experimental fuels (Wasywich et al. 1995).

5. Conclusion

This study shows that the irradiated uranium-metal fuel from the Nyongbyon research centre in DPRK can be dealt with in ways similar to those planned for spent fuel from other reactors. Technical issues are manageable and several options exist for disposition, including reprocessing or direct disposal in a high-level waste repository. The direct disposal option is estimated to be least costly.

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