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North Korea's Corroding Fuel

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The roughly 8,000 irradiated or "spent" fuel rods recently discharged from the North Korean 25 megawatt (thermal) reactor are difficult to store safely under the conditions in the spent fuel ponds near the reactor. The magnesium alloy jacket, or "cladding," around the fuel elements is corroding. If the corrosion creates holes in the cladding, radionuclides may be released. In addition, the uranium metal underneath the cladding may begin to corrode, possibly creating uranium hydride which can spontaneously ignite in air.

Unless the storage conditions are improved, North Korea may use the risk posed by the corrosion as an argument for reprocessing this fuel, a violation of its June 1994 pledge to the United States to freeze its nuclear program. North Korea, however, can take several steps to slow dramatically the rate of corrosion. Using available techniques, it can extend safe storage times by months or even years.

INTRODUCTION

The United States and other Western governments have insisted that North Korea not reprocess irradiated fuel from its small gas-graphite reactor. The United States wants the North to send the fuel to another country for storage or reprocessing. Because this type of fuel is difficult to store safely, North Korea may find it difficult to avoid reprocessing, even if it did not want to separate plutonium. Reprocessing of these rods would violate North Korea's June 1994 pledge to freeze its nuclear program.

The irradiated or spent "magnox" fuel rods discharged from North Korea's 5-megawatt (electric) reactor this summer cannot be stored safely for long under the current conditions in the ponds near the reactor. The magnesium metal alloy jacket or "cladding" around the uranium metal fuel is corroding, and radionuclides in the uranium fuel may escape into the environment. In addition, the underlying uranium metal fuel will corrode. Under certain conditions, the uranium metal can ignite spontaneously if exposed to air, possibly causing a serious radiation accident.

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So far, North Korea appears to have done little to slow the corrosion of the fuel cladding, or even to clean the water adequately to allow visual inspection of the fuel to check for cladding corrosion. The United States and other Western governments have offered the North help in slowing the corrosion of the cladding. Western assistance could extend the wet storage arrangement by many months or even several years, but work must begin soon.

Western nations have found that under optimal water storage conditions, the type of fuel used by North Korea can be stored in spent fuel ponds for up to two years. (Storage up to five years is possible with the use of special canisters placed in the spent fuel ponds.) Since the North's fuel has been in the ponds under poor conditions since May or June, such long storage times might not be possible with this fuel even if clean up began immediately. But it still might be possible to extend fuel storage in the ponds up to one year, or several years if special cannisters are utilized.

As of late September 1994, the North had refused all Western assistance, saying that it can handle the situation itself. Although no dramatic degradation of the cladding is evident so far, the North still does not appear to apply the range of methods necessary to ensure safe, long-term storage.

Although the fuel currently in the ponds could be dried off and placed in dry stores, this technique is complicated, unproven, and time-consuming. This approach might also be beyond North Korea's capabilities to do safely without extensive Western assistance.

North Korea has a small dry storage area for damaged fuel elements, but this area is not maintained adequately to prevent continued corrosion and the possibility of a serious fire. In well-maintained dry facilities, spent fuel which has never been placed in water can be stored for a decade or more without significant corrosion or risk of fire.

SITUATION IN NORTH KOREA

In May and June, the North discharged about 8,000 spent fuel rods (about 50 metric tons of fuel) from the 5-megawatt (electric) reactor. The fuel rod itself is a cylinder of natural uranium metal encased in a magnesium alloy cladding that contains trace quantities of zirconium. Each rod is about 50 centimeters in length and about 3.0 centimeters in diameter (including the cladding). The rod is surrounded by fins, bracers, and other structures to support the rod in the reactor fuel channel.

Upon discharge, according to Western experts, the reactor operators placed the 8,000 rods in about 200 metal baskets, each containing about forty rods. Each basket was put in a concrete cask and transferred by trolley from the reactor hall through a 50-meter tunnel to the spent fuel storage building. This building contains an inspection bay, two connected spent fuel ponds, and a dry storage area.

In the inspection or decontamination bay, operators inspected the fuel rods in each basket for any damage. If the rods appeared intact, a crane placed the basket in one of two connected spent fuel ponds, each about 7.5 meters deep. Because few rods had failed, nearly all the rods were placed in the spent fuel ponds in baskets stacked up to three high.

If a fuel rod in a basket appeared damaged, the entire basket was sent to the dry storage area. In total, about 300 rods were placed in dry storage. There they joined another 300 damaged rods unloaded from the reactor between 1989 and the time of the most recent fuel unloading.

Because visual inspection procedures are not believed capable of detecting all damaged fuel, some fuel sent to the spent fuel pond could be damaged and vulnerable to accelerated corrosion.

Spent Fuel Ponds

It appears that North Korea waits a few months for short-lived elements, such as iodine-131, to decay and then the fuel is sent for reprocessing. However, the current conditions in the spent fuel ponds does not bode well for continued safe storage, and the North has implemented little technology to slow corrosion of the cladding.

The actual rate of corrosion of the fuel in the ponds is unknown. The IAEA has reported that, based on its inspectors' observations, the water is often opaque and dirty, and the ponds do not have adequate filtering or purification systems. A video of North Korean nuclear facilities made public by the IAEA in 1992 shows the spent fuel ponds green with algae.

More important, the IAEA has said that the North does not conduct detailed chemical analyses of the water in its ponds. Nor do they control the level of certain impurities, particularly chlorides and sulfates, that can greatly accelerate cladding corrosion. If the water contains excessive concentrations of these impurities, the cladding might corrode significantly within a few months. To reduce the level of these impurities, Western magnox spent fuel ponds use demineralized water.

Dry Storage Area

The dry storage area is also inadequate, especially as it holds damaged fuel elements and it is located too close to the ponds. An IAEA official described it as "moist." The moisture in the air can corrode both the cladding and the uranium metal fuel itself. Sometimes, the corrosion of the uranium metal can lead to the spontaneous combustion of the fuel at ambient temperatures, particularly if anyone disturbs the fuel. In addition, the gamma radiation emitted by the spent fuel in dry storage poses a risk to anyone in the pond area, complicating inspections and pond cleanup.

RISKS FROM CORROSION

Both the magnesium and uranium metal are vulnerable to corrosion when exposed to water or moist air.[1] Corrosion could allow large quantities of radioactive materials to leak into the pools and eventually into the air or nearby groundwater, The primary reaction is oxidation, involving water and the subsequent release of hydrogen. Excess hydrogen can react with bare uranium metal, forming uranium hydride, a brownish-black or brownish-gray powder that burns spontaneously in air at room temperature.

Cladding Corrosion

There are two basic types of corrosion of the magnesium alloy cladding—general superficial corrosion and localized, or pitting, corrosion. In North Korea, localized corrosion is the more serious concern because the possible presence of impurities in the water could significantly accelerate the rate of this type of corrosion compared to general corrosion rates.

General corrosion depends on the temperature and the pH level of the water in the pool. Ideally, the water should be chilled to about 15°C and kept alkaline with a pH level of 11.5 to 12. In contrast, the North's pond water was reportedly at about 30°C and had a pH of about 11 this summer.

Localized corrosion begins in cracks, crevices, or scratches in the cladding. Poor handling of the spent fuel during discharge can produce many sites where pitting can occur. Pitting corrosion is accelerated in the presence of sulfate and chlorine ions, and carbon depositions on the fuel.

Once corrosion creates holes in the cladding, soluble radioactive elements will leach out and diffuse throughout the spent fuel pond and migrate to the surface. The most immediate concern is cesium-137, which emits penetrating gamma rays that pose a risk to anyone near the ponds.

Uranium Corrosion and Hydride Formation

Once exposed, uranium metal will react with water to form uranium oxide and hydrogen. Although a uranium oxide layer could be expected to seal the metal and prevent further corrosion, the main type of oxide that forms on uranium metal, namely uranium dioxide, does not act as a seal. As the oxide layer builds up, it tends to crack exposing bare metal to further corrosion.

Hydrogen from the oxidation process or elsewhere will react with bare metal to form uranium hydride. Often, the hydride powder is coated with an oxide layer that can prevent its spontaneous combustion. But if the oxide layer is disturbed, such as can occur during fuel handling, the hydride will glow and spark, and possibly ignite the surrounding uranium metal, leading to the release of the radioactivity in the spent fuel element.

Conditions that favor high uranium hydride concentrations are high relative humidity, lack of free oxygen, and high hydrogen concentrations. These conditions can exist inside a failed fuel rod in a spent fuel pond, where water may penetrate through a small hole in the cladding and the hydrogen resulting from the oxidation of the uranium cannot diffuse out of the cladding effectively.

BUYING TIME: SLOWING DOWN THE CORROSION OF THE SPENT FUEL

Given the condition of the North Korean storage facility, the Western priority has been to ensure that the spent fuel is safely stored in the spent fuel ponds and the dry storage area for many months and perhaps years. Methods to accomplish this goal have been proven in France and Britain, which have extensive experience storing their own magnesium-clad fuel.

Spent Fuel Ponds

Controlling the corrosion of the cladding requires rigorous and continual control of the pond water conditions. Even relatively small variations from the recommended conditions can significantly accelerate corrosion. Fortunately, the implementation of the appropriate controls can be accomplished quickly.

Improving the Water Chemistry

The fuel storage life in the ponds can be extended for several months by purifying the water, raising the pH level, and lowering the concentrations of particular ions, especially chlorides and sulfates. Since much of the fuel has already been stored for several months, these steps need to be carried out as soon as possible if they are to be effective.

According to recent Western analyses, the following steps can extend the fuel storage life many months, perhaps for a year:

- ♦ Use only demineralized water in the pond to improve the visibility of the water and reduce impurity concentrations in the water. Chlorine ion concentrations should be below 0.5 grams per cubic meter, sulfate concentrations below 0.2 grams per cubic meter, and carbonate ions below three kilograms per cubic meter. The demineralized water should continuously be replaced (at least 10 percent per day) to maintain water purity and keep the deleterious ions below specified concentrations.
- ♦ Raise the pH level at least to 11.5 and maintain it at this level by adding pure sodium hydroxide ions;
- ♦ Regularly measure and record the pH level, chlorine and sulfate ion concentrations, and other impurities in the water;
- ♦ Maintain the water temperature at 15°C by portable water chillers to improve water clarity, retard algae growth, and reduce the magnesium corrosion rate;
- ♦ If possible, remove any magnox corrosion product sludge which may have settled to the bottom of the pool.

Special Magnox Fuel Canisters

The corrosion rate could be reduced further, permitting wet storage for up to five years by raising the pH level around the fuel to 13, and maintaining total chlorine and sulphate levels below 0.5 grams per cubic meter. However, a pH cannot be achieved in the ponds because the pH level is lowered too much by dissolved carbon dioxide from the atmosphere.

As a solution, Britain has developed the Magnox Fuel Canister, which when loaded into a spent fuel pond can maintain a pH of 13 around the fuel in the canister. The canister works by isolating the water in the canister from the pond water by a gas space under the canister's loose fitting lid. The lid is loose-fitting to ensure that hydrogen produced during any residual corrosion of the cladding or uranium does not build up to unacceptable levels.

The gas space above the water in the canister is called "ullage." Initially, nitrogen is injected into the space, but it is replaced over time by hydrogen from the continued corrosion of the fuel cladding. Oxygen from the water also gradually diffuses, some combining with the hydrogen. The British have found that the gas space can be maintained for up to five years before it must be replenished.

Each Magnox canister has a mass of about one metric ton, and can hold several hundred fuel rods; the exact number depends on the rod's outer structures. These canisters are stacked up to three high in a spent fuel pond. Drawbacks are that they have an elaborate design and require special handling equipment to establish the ullage and place the container in the spent fuel ponds.

Radioactive Clean-Up

The West should supply North Korea with portable equipment to clean up radioactive contamination, particularly radioactive cesium, from the pond water. This would reduce exposure to workers and inspectors, lower the probability of environmental contamination, and prevent large-scale contamination of the spent fuel pond and associated equipment.

Dry Storage Area

Although this area contains a relatively small number of fuel elements, it poses a significant fire hazard from corroded or damaged fuel. Some options suggested by Western experts include drying the air, or flooding the area and treating it as another spent fuel pond.

DISPOSAL OF THE SPENT FUEL

The main long-term option for disposing the spent fuel is reprocessing, preferably outside of North Korea. Another option is to transfer the intact fuel to dry storage after drying off the fuel stored in water. This latter option, however, has never been proven.

Transportation to an Overseas Reprocessor

U.S. and British officials have said that the fuel could be removed from North Korea in six to nine months. Transportation casks for this type of fuel are plentiful, safe and nearby. Japan, for example, has been transporting a similar type of fuel from its Tokai gas-graphite reactor to a British reprocessing plant for many years.

British makes a cask that weighs 60 metric tons, and contains water with a pH greater than 11.5, and the French make a cask that weighs about 50 metric tons. These casks can hold up to about five metric tons of undamaged fuel, although they might not be able to hold this amount of North Korean fuel. The list of potential reprocessors includes Britain, France, Russia, and China. It is unclear what would become of the separated plutonium and waste.

The crane over the storage pools at the Yongbyon spent fuel storage ponds can reportedly hold only up to 35 metric tons. Either a new crane would have to be supplied, or lighter casks secured.

Prior to shipment, the fuel would need to be inspected to determine if it was damaged, since a cask should not contain too many damaged fuel elements that could overly contaminate the cask water. In any case, special precautions need to be taken to ensure that any damaged fuel did not come into contact with air.

Going from Wet to Dry Storage

Another option is to take the wet spent fuel, dry it off, and place it in a dry air storage facility. The British have proven that storage of magnesium clad fuel in dry air is safe and delays the need for reprocessing for many years, perhaps decades.[2] However, this approach has been used only with fuel that has never been wet.

Because of the potential of dry storage, the British have studied the process of drying fuel stored in wet spent fuel ponds and placing it in dry stores since 1978. A British nuclear industry study of this process with British magnox fuel concluded that going from wet to dry storage is feasible, but expensive and difficult.[3] This study recommended the procedure only if absolutely necessary.

This study envisioned few difficulties in drying off fuel with intact cladding and transferring it to dry storage. But fuel with defective cladding is riskier to dry because water leaks through small holes in the cladding and uranium hydride forms.

Because of the likelihood of missing some damaged fuel rods during fuel inspection, this study concluded that each element would need to be treated in the same way.[4] The study envisioned that each element would be individually dried at elevated temperatures in a tightly fitting drying tube in a specially designed facility. The heated air would also oxidize uranium hydride on the fuel, a necessary step for extended safe storage. Air, however, might not reach all the uranium hydride underneath the cladding since hydrogen can migrate a significant distance from where it was formed before forming uranium hydride. As a result, the fuel would require careful handling to avoid breaking the fuel and exposing any hydride to air.

If uranium hydride inadvertently ignited the fuel during the drying process, the fire would occur in an isolated and contained environment where the amount of air could be restricted until the fire was extinguished.

CONCLUSION

North Korea so far has not taken steps to extend storage times of its fuel or moved the fuel to another country. Because of the technical discussions between North Korea and the United States, North Korean officials know the methods that would permit safe, long-term storage. As of late September, it remained unclear whether North Korea will implement these steps.

NOTES AND REFERENCES

1. For a review of magnesium cladding corrosion problems see "Appendix 2: The Storage of Magnox Fuel—CEGB Experience and Research," in The CEGB [Central Electricity Generating Board] / SSEB [/South of Scotland Electricity Board] Response to Recommendation 17 in the Environment Committee's Report on Radioactive Waste, November 1986. See also chapter 7 on uranium in C.R. Tipton (editor) Reactor Handbook, Volume I: Materials (New York: Interscience Publishers, Inc., 1960).

2. A.H. Speller, E.O. Maxwell, and R.J. Pearce, "The Long-Term Dry Storage of Irradiated Magnox Fuel," in Proceedings of BNES Conference on Gas-Cooled Reactors Today, held in Bristol, Britain, September 1982, volume 4, pp. 25–30. Air is preferred over inert gases because corrosion rates of uranium and magnesium in air are acceptably low, and moist air is a more benign medium in regard to uranium hydride suppression than moist nitrogen or argon, two common inert gases. The oxygen in the air inhibits the formation of uranium hydrides.

3. See, for example, The CEGB/SSEB Response to Recommendation 17 in the Environment Committee's Report on Radioactive Waste, Volume 1,November 1986. The Environment Committee of the British Parliament asked the nuclear electricity utilities to study the feasibility of using only dry stores for Magnox fuel prior to geological disposal with no reprocessing. This assessment included a study of the process of drying off Magnox fuel once it had been stored in a cooling pond.

4. Ibid, p. 17; and National Nuclear Corporation, Dry Storage of Magnox Fuel: A Design Concept Document, report no. C6996/DCD/001, issue B (Risley, Warrington, Cheshire: National Nuclear Corporation, September 1986).