THE REQUIREMENTS FOR CANNING FOREIGN RESEARCH REACTOR SPENT NUCLEAR FUEL

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SUMMARY

In accordance with the *Record of Decision on a Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel* (DOE, 1996a), the U.S. Department of Energy (DOE) is implementing a 13-year program under which DOE accepts foreign research reactor spent nuclear fuel (SNF) containing uranium that was enriched in the United States, and whose export was licensed by the Atomic Energy Commission (before 1972) or the Nuclear Regulatory Commission (after 1972). The SNF is of varying age and condition. The transportation to and storage of the SNF at the DOE's receiving sites may require special packaging for some of this spent research reactor fuel.

In response to a number of issues associated with the transportation of damaged fuel, the DOE has developed packaging criteria for transportation and storage of research reactor spent nuclear fuel and defined "failed" for those purposes. The criteria incorporate a clear understanding of the unique characteristics of research reactor fuel, as well as the technical and regulatory issues associated with safe storage and transport.

Introduction

Beginning in the 1950s, as part of the "Atoms for Peace" program, the United States provided nuclear technology to foreign nations for peaceful applications in exchange for their promise to forego development of nuclear weapons. A major element of this program was the provision of research reactor technology and the highly enriched uranium (HEU) needed in the early years to fuel the research reactors. In the past, after irradiation in the research reactor, the spent nuclear fuel was returned to the United States so that the United States maintained control over disposition of the HEU that it provided to other nations. The United States accepted foreign research reactor spent nuclear fuel until the "Off-Site Fuels Policy" expired in 1988 for HEU fuel and 1992 for low enriched uranium (LEU) fuel.

On May 13, 1996, the U.S. Department of Energy issued a *Record of Decision on Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel* (DOE, 1996a). The goal of the long-term policy is to recover enriched uranium exported from the United States, while giving foreign research reactor (FRR) operators sufficient time to develop their own long-term solutions for storage and disposal of spent fuel. The spent nuclear fuel (SNF) accepted by the U.S. DOE under the policy must be out of the research reactors by May 13, 2006 and returned to the U.S. by May 12, 2009.

Forty-one countries are eligible for shipment of their SNF. The total inventory of eligible fuel contains approximately 17,000 Materials Testing Reactor (MTR)-type SNF assemblies and approximately 5,000 Training, Research, Isotope, General Atomic (TRIGA)-type SNF elements. The SNF will be packaged in shipping casks at the site of origin and transported to one of two DOE receiving sites. For MTR-type fuel, the receiving site will be the Savannah River Site (SRS) in Aiken, South Carolina. For TRIGA fuel, the receiving site will be the Idaho National Engineering and Environmental Laboratory (INEEL). All SNF will be transported dry in U.S. Nuclear Regulatory Commission (NRC) licensed or Department of Transportation (DOT) certified casks. The MTR fuel will be initially stored under water at existing wet storage facilities at SRS. The TRIGA fuel will be stored dry upon receipt at the INEEL Irradiated Fuel Storage Facility.

Much of the FRR spent fuel which will be accepted by the DOE has been stored for long periods of time (10 to 30 years) in facilities not designed for long-term storage. The deterioration of some of the spent fuel in storage required that the DOE develop acceptance criteria for the transportation and storage of the spent fuel, especially in light of the numbers of assemblies to be accepted under the new policy. In response, the two receiving sites, INEEL and SRS, developed interim criteria for packaging spent nuclear fuel based on the statements in the *Environmental Impact Statement (EIS) on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel* (DOE, 1996b).

As the first site to receive spent nuclear fuel under the new acceptance policy, SRS directed its operating contractor, the Westinghouse Savannah River Company (WSRC), to develop inspection and acceptance criteria.

The Environmental Impact Statement

The EIS defines "failed" SNF broadly, and does not differentiate how that term should be interpreted for purposes of transportation or storage. In fact, some SNF that is technically "failed" for purposes of reactor operation may pose no (or very little) risk of fission product release and, therefore, may be transported and stored safely without any additional packaging. The glossary defined "failed fuel" as "SNF whose external cladding has cracked, pitted, corroded, or potentially allows the leakage of radioactive material." The EIS also states in an appendix that addresses storage issues that:

> "Since only mechanically sound spent nuclear fuel elements are shipped, no radioactive releases are expected during transit. To ensure no such releases, the spent fuel elements are checked prior to shipment to identify and separate any damaged fuel elements. The damaged fuel elements are then encapsulated and prepared for shipment." (DOE, 1996b)

As drafted, the definition of "failed fuel" could be interpreted to require encapsulation of any spent fuel whose external cladding, in any way, "has cracked, pitted, corroded or potentially allows the leakage of radioactive material." Such an overbroad interpretation could lead to the encapsulation of spent fuel that would otherwise not be required for either transportation or storage, as was the case in the development of the WSRC criteria.

The Preliminary Criteria

In response to the absence of clear regulatory guidance or technical standards for canning MTR-type fuel which has material conditions such as through-clad pitting, the WSRC undertook an effort to develop standards by which MTR-type spent fuel would be judged for purposes of canning prior to transport. The effort focused strongly on potential canning requirements for interim storage because transport issues were felt to be DOE or NRC cask-related issues.

The original SRS storage criteria was based on having no exposed fuel meat from any form of cladding penetration on a fuel plate. In response to DOE's request for SRS fuel receipt criteria for acceptance of aluminum-based foreign research reactor spent nuclear fuel, WSRC informed DOE on December 31, 1996 that studies showed that corrosion nodules on the surface of a fuel plate would not penetrate the clad unless the diameter of the nodule exceeded approximately 1/8 inch diameter. The WSRC criteria recommended that any fuel assembly that did not meet this criteria be considered failed and be encapsulated prior to direct storage at SRS. Radionuclide sampling (sip test) was added to build a technical database to support future decisions on encapsulation, shipping requirements, and storage at SRS. Although the WSRC-recommended criteria were not formally approved by the DOE, they became the conservative basis until an official DOE fuel acceptance criteria could be issued.

In early 1997 conservative criteria were applied to Italian, Spanish, German, and Swiss fuel. Several fuel assemblies did not meet the acceptance criteria as a result of nodules greater than 1/4 inch, leading to the assumption of through-clad pitting. Can design requirements were identified and some cans were fabricated. One of the assemblies identified as failing the WSRC criteria was a CIEMAT-owned MTR fuel assembly in storage at Dounreay. The assembly was found to have several corrosion nodules greater than 1/4 inch on fuel plates. Even though the cask owner, the shipper, and relevant competent authorities agreed that the assembly could be shipped within all transportation requirements, DOE decided that, in light of the only existing criteria, they could not accept the "failed" fuel assembly unless it was canned. News of the characterization of the assembly as "failed" because of the corrosion nodules spread quickly and initiated an intense effort by DOE to address this issue.

Technical Considerations of Research Reactor Fuel Characteristics

The situation in Dounreay and the recognition that the interim canning criteria being used could have a large impact on transport costs and storage with no health or safety benefits concerned DOE. As a result, it was deemed appropriate to clarify the criteria for transportation and storage of research reactor SNF, including what constitutes "failed" SNF for those purposes. The clarification was needed because the nuclear industry normally interprets reactor failed fuel as fuel which is no longer acceptable for use in the reactor. However, fuel that is no longer suitable for use in a reactor may be perfectly acceptable for safe transportation and storage. Hence, the use of the word "failed" in the context of an operational failure.

Reactor failed fuel assemblies are typically identified during reactor operation when off-gas activities increase above normal levels, usually as a result of leakage of radioactive materials from a damaged element(s). There are several techniques available to identify an individual "leaking" assembly, and usually it is removed from the reactor and placed into the spent fuel pool. After removal of a "leaking" MTR assembly or TRIGA element from the reactor, the leakage of radioactive materials normally stops. The assembly or element no longer leaks because the fission product release mechanism resulting from the heat and fission created during criticality is no longer present.

Because the accepted definition of reactor failed fuel applies to the performance of fuel during reactor operation and implies release of fission products during reactor operation, reactor failed fuel was deemed an inappropriate term to use for the present considerations of transportation and storage. A more appropriate approach to the problem would be to define "acceptability" with respect to SNF behavior under the environmental conditions present during transportation and storage. The definition of "acceptability" depends principally on three factors: (1) fuel condition, (2) transportation (per DOT and NRC regulations), and (3) receipt and storage at SRS or INEEL.

Research Reactor Fuel Characteristics Which Influence Breached Cladding Performance

An MTR fuel assembly has an UAl_x-Al, U_3O_8 -Al, or U_3Si_2-Al fuel matrix that is clad with an aluminum alloy. TRIGA fuel consists of a U-ZrH_x fuel matrix that is clad with either aluminum or stainless steel (in some cases, Incoloy). The design of the fuel matrix strongly influences fission product release if the cladding is breached. In the case of the MTR fuel, the fissile material is tightly bound in the aluminum fuel matrix and, hence, the fission products are "captured" in this metal (aluminum) fuel matrix. With this type of design, perforation of the cladding, the result of mechanical damage or localized corrosion such as pitting, has little effect on the release of fission products outside of reactor operations. Recent inspections of cladding damaged MTR fuel in Brazil that had been in wet storage for over 20 years, has shown that the release rate of fission products is very low. Release rates on the order of 10 ηCi (10×10^{-9} Ci) per hour per 0.5 square inch of exposed fuel were measured.

The findings in Brazil agree with the data gathered at the SRS which show that the behavior of the UAl_x-Al, U_3O_3-Al, or U_3Si_2-Al fuel "meat" used for the MTR fuel is such that the corrosion rates are extremely low, less than 0.001 inch (25 microns) per year in water with good chemical control against corrosion. The very low corrosion rate of the fuel meat exposed to water actually approaches that of the aluminum cladding itself. In a dry environment there is essentially no corrosion (Sindelar, 1997). Because transportation of the SNF to Savannah River will take place in a dry condition, it is expected that fission product release rates during transportation will be virtually zero and, essentially, unmeasurable.

TRIGA fuel has a design that physically resembles that of commercial light water reactor (LWR) fuel, but there is a very significant difference in the metallurgical properties of the two types. TRIGA fuel consists of a stack of three 6-inch cylindrical slugs of U-ZrH_x clad with either an aluminum alloy or stainless steel. In the case of aluminum cladding, a breach of the cladding can result in accelerated corrosion of the cladding due to the galvanic couple between the fuel and the clad. In the case of stainless steel cladding, this type of galvanic coupling and accelerated corrosion damage is not observed. However, in either case the fuel matrix material is protected by the formation of a very tough and almost impermeable ZrO_2 layer that forms on the surface of the fuel matrix that is in contact with the water. Thus, for the TRIGA fuel, the fissile material (and, hence, the fission products) are unlikely to escape from the fuel matrix. This results in a very low release rate of fission products. Data on TRIGA fuel fission product release have been obtained at up to 800°C, and measurable fission product release did not occur until the temperature reached 350°C, at which the overall fractional release gaseous fission products was only 10^{-5}, virtually negligible (Richards, 1977 and Mathews, 1997). Release of non-gaseous fission products would be even less.

Given that the corrosion rates (hence, activity release rates) are very low for research reactor fuel, acceptance criteria that assume corrosion-related activity release will be a controlling mechanism would not be particularly relevant. Additionally, encapsulation may be detrimental to proper management of SNF that has cladding perforations due to corrosion or mechanical damage. Whether at INEEL or SRS, SNF received in a canned condition will be uncanned prior to storage so that the operating contractor at these sites can observe the real condition of the fuel. In the case of SNF shipped to Savannah River, corrosion rates of perforated fuel are better controlled by maintaining proper pool chemistry than by placing fuel in another container. Because the condition of canned fuel cannot be visually ascertained, the degradation rate of canned fuel, in fact, would be unknown. In addition, the chemical environment inside a sealed can cannot be easily determined or controlled. In the case of TRIGA fuel, which will be shipped and stored dry, the only reason for canning defected fuel would be to prevent volatile fission products from being released during shipping. However, as discussed above, volatile fission products are not released by the TRIGA fuel matrix until attainment of temperatures well above those associated with typical and accidental transport conditions and storage operations.

When the issue is structural damage, there are significant differences between MTR and TRIGA fuel. In either case it is very important that the SNF be able to be manipulated (picked up, moved, etc.) without danger of loss of structural integrity, i.e., the SNF will not fall apart during handling and shipping. Criticality control configuration is also an important issue. The MTR fuel elements maintain excellent structural integrity, even with many small cladding breaches. However, in the case of the aluminum clad TRIGA fuel, a number of fuel pins with minimal visible corrosion have actually broken apart. Hence, TRIGA fuel that has broken or otherwise lost its structural integrity needs to be transported in baskets that allow for easy handling and containment of the fuel within configurations analyzed in the safety analyses. The transportation of TRIGA fuel and similar LWR fuel slugs, in damaged structural configurations, has already been accomplished using baskets of 250-mesh screen. A minor modification of these baskets for a particular cask type may be necessary but it is not an obstacle or safety issue.

Cask vendors under contract to DOE to provide transportation service to the Foreign Research Reactor Spent Nuclear Fuel Acceptance Program were asked to supply information related to the design of their particular cask(s), the status of each cask license and/or certificate of compliance (COC), and any cask requirements applicable to transportation of SNF with cladding penetrations or other damage. In all cases, the transportation of SNF with perforated cladding was within the cask safety analyses. While cask representatives indicated that some form of additional cask certification would be required, none believed that there would be any difficulty in obtaining the required certification.

The controlling SNF storage issue for wet storage is the ability of the pool cleanup systems to maintain water activity below authorized limits. SRS has evaluated the capability of the basins [Receiving Basin for Offsite Fuels (RBOF) and L Area Spent Fuel Storage Basin] to cope with SNF that has defects that are greater than those which simply make the fuel unacceptable for use in a reactor (Sindelar, 1997). Release rate calculations, based on a breached clad reference fuel assembly containing a bounding fission product inventory, were compared to actual measured fission product release rates from a corroded (with cladding penetration) Brazilian MTR fuel element for verification. Calculations were made of activity buildups in both RBOF and L Area basins assuming that approximately 10% (1,500 assemblies) of all of the SNF that will be received is perforated, that all of the perforated SNF has damage and release rates similar to the Brazilian fuel, and that these have fission product inventories equivalent to the referenced fuel assembly. During normal operation of either basin the increase in activity from the perforated SNF is of no consequence. For the situation in which the pool cleanup system fails, the activity buildup in either pool is very slow, allowing months to years of time to correct the situation without concern for exceeding pool water quality/release limits (Sindelar, 1997).

Based on the data presented and discussions with SRS personnel, it was concluded that wet storage of corroded (with cladding penetration) MTR fuel should not be the basis for determining if canning (in a sealed container) should be required. In fact, as discussed above, there are good reasons for not canning cladding-perforated SNF. The most important of these is that chemistry control (pH, conductivity) is the primary variable in controlling corrosion that would lead to fission product release. SNF stored in sealed cans does not allow adequate chemistry control.

The Final Acceptance Criteria

Criteria for accepting fuel in an "as is" condition for transportation and storage are considered jointly. Transportation criteria might, in certain cases, be less stringent than storage criteria at a given facility given the temporary duration of transport and the robustness of the transport package. Unless there is a specific reason why these two criteria should be different, however, shipping across various states should be done under as stringent conditions as storage in any given state facility.

Based upon the foregoing reasons, spent nuclear fuel that does not comply with all of the following criteria will be considered "failed" for the transportation/storage functions and will require special handling prior to being transported to and stored in a DOE facility.

- Transportation must comply with all shipping cask license and/or certificate of compliance conditions.
- SNF must be structurally sound, i.e., not change shape with handling.
- SNF must not be bent or deformed such that the SNF cannot be positioned in the cask.

Fuel whose history and origin cannot be traced must be adequately packaged with regard to shipping to meet the necessary criticality prevention criteria for unknowns. Under suspect conditions, the shipper and the eventual receiver (INEEL or SRS) may require that the shipping facility do testing (under procedures approved by the receiving facility) to prove the nature of the fuel.

The final acceptance criteria is based on verifying the structural integrity of the SNF and insuring that SNF that has been damaged with respect to this criteria is suitably packaged for shipment and handling. As has been discussed above, corrosion related fission product release is not significant except as it may affect basin water cleanup at SRS; however, even in this case, the expected (and verified) rates of fission product releases are so low as to make a limitation based on this criterion unnecessary. It is clear that structural integrity is the key issue.

Accordingly, a set of MTR acceptance criteria based on an assurance of structural integrity for handling and criticality control and a check (or verification based on site records) of expected fission product release in wet storage is appropriate.

For the case of TRIGA fuel, additional requirements related to the special nature of the design are appropriate since experience has shown that there are certain external "indicators" of potential internal degradation that would lead to structural instability and resultant breakage during handling. TRIGA fuel that is damaged to the extent that handling could result in breakage of the fuel assembly must be placed in a suitable basket for shipping. The exact container design will need to be defined for each cask and fuel type (the 250-mesh screen enclosure would appear to be applicable to most situations). The decision to package TRIGA to ensure safe handling will be based on a series of lifting tests, inspections, and measurements.

CONCLUSION

The spent nuclear fuel acceptance criteria developed by DOE addresses the issues of transporting damaged fuel. The criteria recognize the characteristics of research reactor fuel and properly distinguish between fuel conditions under reactor operation versus transport conditions.

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