

Extended Storage for Research and Test Reactor Spent Fuel for 2006 and Beyond

W. L. Hurt
K. M. Moore
E. L. Shaber
R. E. Mizia

October 14, 1999 – October 17, 1999

IAEA Conference on Extended Storage of
Research Reactor Fuel

This is a preprint of a paper intended for publication in journal or proceedings. Since changes may be before publication, this preprint should not be cited reproduced without permission of the author.

This document was prepared as a account of sponsored by an agency of the United States Neither the United States Government nor any thereof, or any of their employees, makes any expressed or implied, or assumes any legal liability or responsibility for any third party's use, or the results such use, of any information, apparatus, product process disclosed in this report, or represents that use by such third party would not infringe privately owned rights. The views expressed in this paper not necessarily those of the U.S. Government or sponsoring agency.

EXTENDED STORAGE FOR RESEARCH AND TEST REACTOR SPENT FUEL FOR 2006 AND BEYOND

William L. Hurt, Karen M. Moore, Eric L. Shaber, Ronald E. Mizia
Idaho National Engineering and Environmental Laboratory
Idaho Falls ID 83415

Abstract

This paper will examine issues associated with extended storage of a variety of spent nuclear fuels. Recent experiences at the Idaho National Engineering and Environmental Laboratory and Hanford sites will be described. Particular attention will be given to storage of damaged or degraded fuel. The first section will address a survey of corrosion experience regarding wet storage of spent nuclear fuel. The second section will examine issues associated with movement from wet to dry storage. This paper also examines technology development needs to support storage and ultimate disposition.

Introduction

The United States Department of Energy (DOE) manages about 2500 metric tons heavy metal (MTHM) of spent nuclear fuel (SNF). This SNF varies widely in composition and condition. Extended storage followed by direct disposal in a planned geologic repository is the preferred disposition strategy. DOE currently is planning to put all SNF into sealed storage canisters that will not be opened before shipment to the repository. Paramount to the success of this strategy is the ability to stabilize the corroded and damaged SNF and transport following storage without reopening the package.

Survey of Corrosion Experience Regarding Spent Nuclear Fuels

This section describes fuel examinations and corrosion test data from the INEEL to support the investigation on whether SNF continues pit propagation while in clean water environments. The conclusion from this effort is that fuel management decisions need to take into account that fuels with existing pits have been observed to continue pitting even while stored in clean water conditions.

Background

The United States will continue to store aluminum-clad research SNF in wet basin storage. Wet storage has been shown to cause cladding degradation from pitting¹. Pitting is an especially damaging form of corrosion since it leads to perforation and failure of the fuel plate. The characteristic feature of the process is the formation of an acidified, occluded cell where the chemistry inside the cell differs from the bulk water chemistry in the fuel storage basin.

High quality water conditions are necessary to delay pit initiation, however some SNF is already pitted by the time storage in high quality water is started. A review of corrosion

data and observations was performed to clarify the issue of whether the deleterious conditions in an existing occluded pit will be mitigated by transfer to high quality water conditions. While intuition suggests arresting of pit propagation, a period of continued pit propagation cannot be discounted based on available data². Through wall pitting of SNF cladding substantially increases the risk and cost of handling and shipping. Globally, SNF has been stored in wet basins beyond initial predictions. Ongoing degradation of the SNF affects any decisions regarding fuel movements and transfers.

The fabrication process and material specification for aluminum fuel assemblies creates a wide range of cladding morphologies. The pitting process is dependent on the fuel metallurgical condition (composition, initial heat-treated condition, resultant secondary phases, metallurgical treatment, reactor thermal exposure history, stress state). This is then affected by the storage environment. The storage conditions are defined by water quality, temperature, flow, and the possibility of formation of microbial films on the surface.

INEEL Experience with Aluminum SNF in Wet Storage

Aluminum cladding may already be damaged from reactor exposure when it is placed in wet storage. Fuel plate inspections by Beeston³ and corrosion tests by Henslee⁴ on fuel exposed in the Advanced Test Reactor (ATR) at the INEEL have shown pit initiation and propagation in the reactor and in storage with high purity water. The Beeston study measured a maximum pit corrosion rate for reactor operations of 0.24 mil/month. The causes of this pitting were identified as fuel burnup rate and surface impurities that act as pit initiation sites. The Henslee study investigated corrosion in the high purity water of the ATR fuel storage canal. It also concluded that the pitting is initiated by surface contamination. Both studies identified metal impurities such as copper and iron in the corrosion pits. A common surface impurity is iron particulate that is embedded in the surface from the fuel fabrication process. Other surface impurities can come from lubricants used in the rolling process such as molybdenum sulfides, graphite, or leaded oils. Both studies also concluded that a thermohydraulic prefilming treatment to form a stable, boehmite film in the aluminum could decrease but not eliminate pitting tendencies.

In a wet storage environment with poor water quality (see Table 1) such as the INEEL CPP-603, another pit initiation mechanism may be operative as shown in Figure 1. A second phase intermetallic in a type 6061 aluminum can act as a noble, cathodic site in a corrosion reaction where the passive oxide film is breached and then aluminum metal becomes the actively corroding anodic site. The Cl⁻ ion present in the CPP 603 water will aid in the passive film breakdown. A porous hydroxide diaphragm forms over the pit forming an underlying occluded cell. The efficiency of the cathodic reaction can be increased by metal ions, especially copper, which can increase the kinetics of the oxygen reduction. The cathodic reaction at the inclusion thus causes the local pH to increase. In turn, because the oxide film is not protective in an environment of high pH the passive film degrades. While the water circulation does appear to influence the local concentration of ions at the pit, the water circulation rate in fuel storage pools is

considered stagnant at the fuel surface. Transfer of SNF with pitting or cladding breaches into a fuel pool with benign water conditions would allow continuing corrosion of the fuel though possibly at lower rates. Poor water quality with high conductivity will also tend to accelerate galvanic and crevice attack.

Table 1. Pool Water Chemistry

Parameters	ISO(Draft) ⁸	CPP-603 ²	CPP-666 ²
pH	5.5 – 6.5	5.0 – 8.5	5.5
Cl ⁻	<1ppm	Up to 800 ppm	30 ppb
Temperature	<40 ⁰ C	20 ⁰ C	20 ⁰ C
Conductivity	1-3 μS/cm	600 μS/cm	1μS/cm

The INEEL fuel storage area, CPP-666, is a modern stainless steel lined facility with nominal water chemistry as shown in Table 1. This chemistry regime equals or exceeds the recommended draft ISO parameters⁸. However, corrosion inspection of aluminum alloy 6061-T6 corrosion samples (mockup fuel cans that simulate internal corrosion from leaking fuel elements, dummy fuel cans and corrosion coupons) gave evidence of external corrosion in the basin environment. The samples were initially installed in 1988. The first corrosion inspection conducted in 1992 showed pit initiation. Some observations from subsequent inspections are:

1. The dummy fuel can that had the biofilm removed on an annual basis during can inspections showed less pitting than the remaining three dummy fuel cans with the biofilm remaining. This indicates that the biofilm and/or organisms in the biofilm are contributing to the pitting process in some way.
2. Biofilm samples taken from ATR fuel plates in the ICPP-666 fuel storage pool were cultured. All ATR fuel plates sampled showed that either bacteria and/or fungus were present after culturing with sulfate reducing bacteria being the predominant form.
3. There was no white corrosion product observed such as aluminum oxide (Al₂O₃.xH₂O) on any of the pitted samples. This corrosion product is typical for aluminum pitting. The aluminum oxide would insoluble in the high purity water found in the ICPP-666 basin. The observed pits are large enough to provide large amounts of corrosion product. The lack of such corrosion product indicates that another corrosion mechanism may be operative. There is a research program at the INEEL that is currently investigating microbiologically induced corrosion of aluminum.
4. Visual examination of corrosion coupons, prior to formation of the biofilm, shows no evidence of pit initiation. Two possible conclusions can be reached from this information. One is that there was insufficient time for pit initiation to occur. The second possibility is biofilm and microbial colonies in the biofilm act either to enhance pit initiation or act directly to cause pit initiation.

4. Biocides were not effective against organisms in the biofilm covering the 6061 aluminum samples. Thicker oxide layers on the aluminum samples showed no greater resistance to biofilm formations^{2,5}.

The conclusion is for these aluminum samples is that there is pit initiation and propagation in the high purity water in CPP-666 which may be assisted by biofilms present on the surface. Continuing fuel storage will require a well defined monitoring program that will follow the changes to the fuel cladding. Extended storage of aluminum SNF in wet storage requires fuel management decisions to take into account that SNF with existing pits has been observed to continue pitting even while stored in clean water conditions.

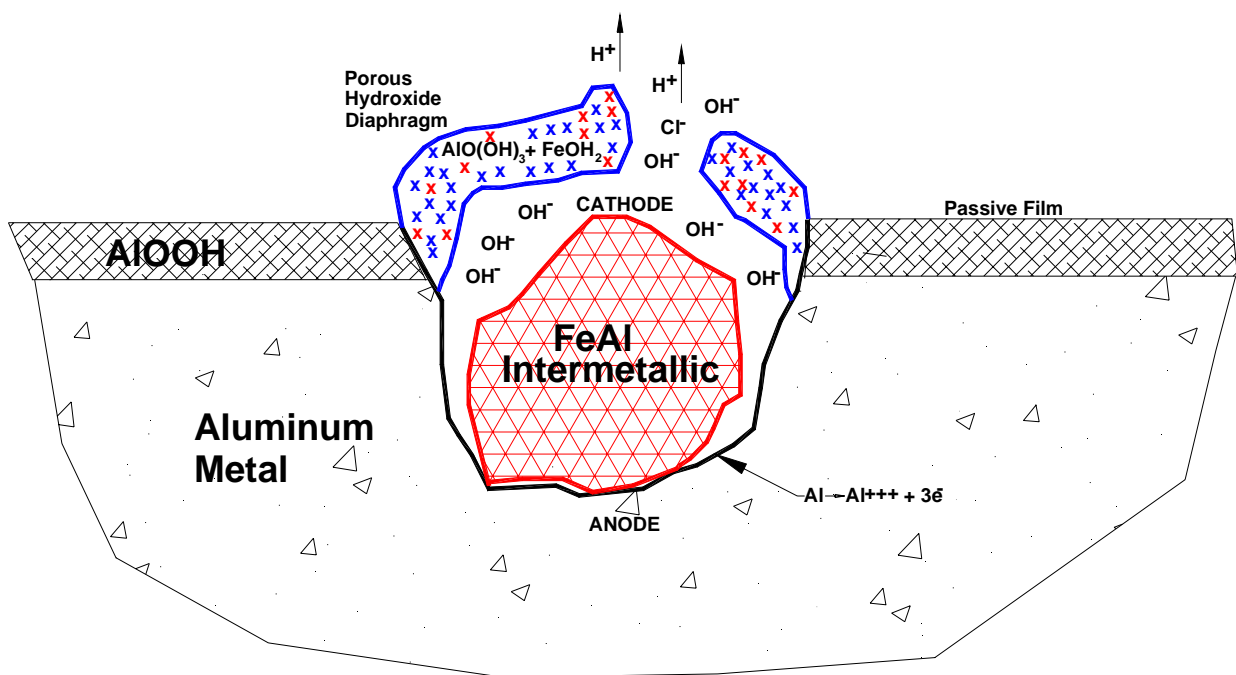


Figure 1⁶ Aluminum Pitting Morphology

The INEEL is currently in the middle of a research program to measure pit propagation on previously pitted corrosion coupons. These aluminum coupons will be dried and placed in dry storage. Pit depth measurement will be taken over 20 years⁷.

Stainless Steel and Zircalloy Cladding in Wet Storage

Stainless steel corrosion coupons have been exposed in ICPP-666 since 1994 with extremely low corrosion rates and no pitting. It is believed that zircalloy clad SNF can be stored indefinitely in clean water. It is recommended that a monitoring program for these fuels be continued.

Draft ISO “Standard Guidelines for Corrosion Protection of Research Reactor Aluminum Clad Spent Nuclear Fuel in Interim Wet Storage”

The wet basin corrosion studies at the Savannah River Site¹ observed that aluminum cladding corrosion was mitigated by improvements in water quality. This observation is reflected in the Draft ISO Standard⁸.

The following comments are offered on the draft standard.

- The water chemistry guidelines accurately give a best practice recommendation for all fuels.
- The ISO standard could better serve the needs of the international community if it were a general purpose standard for all wet basins. Best practices for specific fuel types such as aluminum could be given in addenda.
- The standard should address storage of previously damaged fuel from reactor operations in high quality water. All fuel should be inspected before placement in wet storage to determine if there is any damage and if the fuel needs to be repackaged.
- While canning fuels may be necessary, putting sealed cans in wet storage creates another set of problems. Sealed cans have leaked creating localized water chemistry conditions that cannot be easily monitored.
- The experience of the INEEL with pit initiation and propagation in high quality water should be reconciled.

Aluminum SNF in Dry Storage

The pits formed in wet storage may or may not continue to propagate in dry storage. Two criteria must be met for continued pit propagation after drying. The first requirement is the presence of a bulk aqueous phase present in the pit. The only way for this to occur after drying is by capillary condensation of moisture delivered in the vapor phase. This is a necessary but not sufficient condition for continued pit propagation. The second essential requirement is that the pits are deep enough to enable local separation of anode and cathode within the same pit. This depth is necessary because an acidic electrolyte containing a high chloride content is required at the anode site in order to create the pit chemistry necessary to sustain pit propagation. The cathodic site usually becomes more alkaline due to production of hydroxyl ions resulting from water and oxygen reduction. This will be a determining factor assuming high enough relative humidity to enable moisture condensation⁹.

Another feature of drying previously corroded Al-clad SNF is that all chloride ions will already be entrapped on surfaces local to the pit, and will be unlikely to be removed by drying. Moreover, Cl⁻ can not migrate into the pit from the external environment during vapor phase exposure because an external aqueous phase is lacking. High chloride contents existing in pits already formed during wet storage will likely be available for re-

hydration (assuming that drying doesn't induce a phase change in the compound containing the chloride ions). The anode-cathode separation condition helps the pit to meet the criterion for an acidic chemistry that enables continued pit propagation. The entrapped local chemical composition that is available for re-hydration provides the source of chloride.⁷

Dry Storage of Spent Nuclear Fuel

The United States is actively pursuing dry storage of spent nuclear fuel as a solution to wet storage capacity issues and a method to arrest aqueous corrosion processes. Dry storage has been accomplished using one of three basic types of systems designed to meet SNF containment, confinement, and retrievability criteria¹⁰:

- Underground storage cells – Holds the SNF in a lined underground container, typically arranged with a shielded lid or plug for worker protection.
- Surface storage casks – Holds the SNF in a shielded cask arranged in a controlled area or storage pad.
- Surface Storage Vault Facility – Holds the SNF in a storage array within a remotely operated facility designed to contain radionuclide releases.

Typically, the dry storage environment is much more benign than an aqueous storage environment. However, several technical and operational considerations are involved with successful emplacement and retention of SNF in a dry storage system. Some United States experience and selection criteria with dry storage of spent fuel is provided in the following sections.

Factors in Selecting a Dry Storage System

SNF age, burnup, cladding condition, and storage history should be considered in selection of dry storage systems. The age and burnup of the fuel determine the decay heat that a storage system is required to manage. Typically, commercial SNF is retained in wet storage for a minimum of 5 years to reduce decay heat to acceptable levels for storage. Cladding condition, damage, and corrosion must be considered if the SNF was stored under water for an extended time. Intact-clad SNF can readily be stored in sealed storage casks or underground cells but damaged SNF may require vented storage in a HEPA-filtered surface facility to prevent pressure buildup from radiolytic gases and fission products.

The local climate, soil, and groundwater also enter the decision of which system to use. Underground cell storage is well suited to dry arid climates without a high water table. Both types of surface storage systems are suitable for wet climates where groundwater may tend to flood an underground system. Cask storage systems, however, are exposed to the local atmosphere and may be inappropriate for coastal areas where mists may contain high chloride concentrations. The United States continues to use underground systems but is not considering construction of new systems because of previous problems with moisture ingress.

Making the determination of which type of storage is best for a specific type of SNF can be difficult due to the number of technical considerations involved. Work is in progress to generate standards to help SNF custodians select appropriate storage mediums for specific SNF types. The selection logic¹¹ shown graphically in Figure 2 is designed to help determine if sealed dry storage systems are feasible. However, prior to finalization of a dryness standard, each of the technical constraints involved must be considered separately.

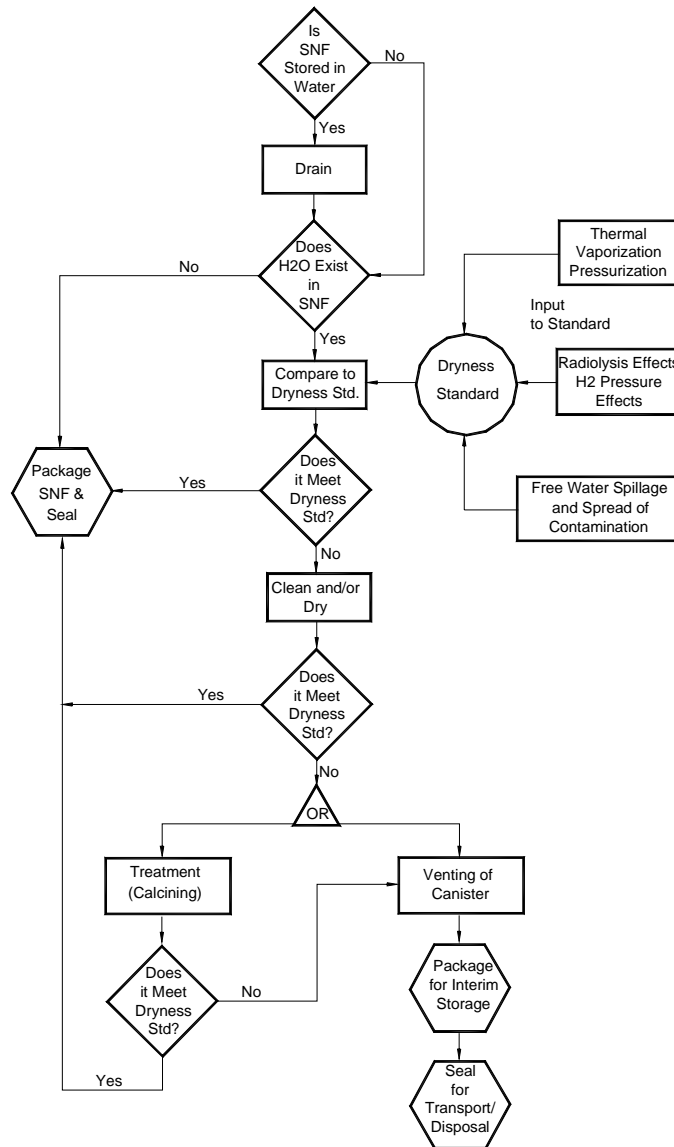


Figure 2: Dry Storage Decision Logic

Technical Considerations in Moving from Wet to Dry Storage

The following technical issues have been considered when moving SNF into dry storage.

1. Drying and disposition of bound water
2. Effects of hydrogen gas pressure
3. Removal of decay heat
4. Cleaning and removal of sludge
5. Radiation damage to packaging materials
6. Fission product interactions
7. Monitoring of the Storage Environment

1. Drying and Disposition of Bound Water

If a sealed package is to be used to hold the SNF in dry storage, particular care must be taken to ensure that the fuel is dry. For intact, high burnup, commercial SNF, drying may be accomplished simply by moving the fuel out of the wet storage environment and allowing any residual water to flash to steam and escape the system before sealing the dry storage package.

With research reactor SNF and other SNF with low decay heat, specific systems must be employed to dry the fuel. Systems used for drying vary in size and complexity but most drying units currently being designed or in operation in the United States externally heat an SNF package while the SNF in the package is held in a vacuum. The internal vacuum reduces the boiling point of the water. External heat is required to improve mass transfer and prevent the formation of ice in the package during the drying cycle. The adequacy of drying for the package is typically measured by sealing the package from the vacuum system and measuring the pressure increase as a function of time at constant temperature.

Drying cycles will vary considerably based on variations in the SNF to be dried. SNF with intact cladding which just requires the removal of free water is typically dried rapidly using vacuum and moderate heating^{12,13}. If the SNF cladding is badly damaged with an exposed fuel oxide matrix (inert fuel compound) drying cycles will typically involve an extended time at relatively high temperatures to try to get most of the water out of cracks, crevices, and internal surfaces of the cladding. The TMI core debris drying system is a good example of this type of drying unit¹⁴. In the case of metallic fuels, the drying is complicated by the pyrophoric nature of uranium hydride and uranium metal. Uranium metal SNF such as Hanford's N-Reactor fuel, with badly damaged cladding and exposed core metal, may require multiple extended drying cycles using relatively low temperatures and intermediate gas purges¹⁵. The purge gas may be used to prevent or quench pyrophoric reactions, or it may contain a partial pressure of oxygen to facilitate

the controlled oxidation of uranium hydrides to obtain a stable, SNF compound for storage. Drying of badly damaged uranium metal fuel may be difficult to complete safely and may require considerable characterization, analysis and testing.

With the possible exception of intact SNF, drying processes are typically not able to remove all water from the SNF. Entrapment of water within sludges, fuel matrix structures, and within cracks and crevices in fuel cladding makes complete drying very difficult.

Drying processes also have little to no effect on the bound water in the SNF system. Bound water is potentially an issue because radiolysis reactions may decompose the bound water, releasing hydrogen into sealed storage containers. Radiolysis effects have been calculated and estimated¹⁶, but very few actual measurements have been made. In metal fuels, complex uranyl hydrates form during aqueous corrosion processes. Some of these hydrates decompose at temperatures as low as 200°C but some are stable to temperatures above 900°C¹⁷. Likewise, aluminum cladding will form hydrated oxides during irradiation and/or water storage that retain bound water. Below ~ 80°C, aluminum tends to form tri-hydrated oxides. These tri-hydrates decompose to a mono-hydrate form around 100°C, but Al does not give up all its bound water until temperatures exceed 340°C¹⁸. The Savannah River Site is currently testing aluminum clad SNF to determine whether or not radiolysis is a significant mechanism for releasing bound water¹⁹, but the studies are not yet complete.

2. Effects of Hydrogen Gas Pressure

With incomplete drying, the dissociation of water molecules by radiolysis or oxidation processes within sealed SNF containers will result in the release of hydrogen gas in the package. Hydrogen is also a fission product and will be released in small quantities from the fuel matrix unless cladding is completely intact. Hydrogen will react with uranium metal in an anoxic environment and will diffuse into almost every metal at a rate dependent on the structure and the characteristics of the protective surface oxide film. High neutron radiation is expected to increase the diffusion rate of hydrogen in materials by formation of vacancies in the surface oxide and metal lattice²⁰. Neutron radiation is present in SNF both from the decay of fission products and from the spontaneous fission of Pu isotopes in the fuel. Hydrogen tends to concentrate in metals at locations where there is irregular surface finish and residual stress. Because of this tendency, hydrogen damage is of greatest concern at welded joints in SNF packages.

Hydrogen charging of stainless steel packaging materials at high temperatures and high pressures results in the accumulation of enough hydrogen in the metal structure to promote embrittlement of the material when subjected to strain at relatively slow rates²¹. However, deformation at high strain rates (accidental drops or impacts) shows much less effect from hydrogen content. Unfortunately, very little work has been done on the accumulation of hydrogen in stainless steels from low pressure and temperature, long-term exposure to hydrogen gas.

Uranium metal exposed to hydrogen in the absence of oxygen will form uranium hydride. UH_3 is brittle at temperatures below about 100°C^{22} and may cause the metal to disintegrate into a powder if the fuel is stressed or jarred. UH_3 is quite reactive and the powder can be expected to ignite if exposed to air at room temperature. Therefore, formation of uranium hydride during dry storage may result in a safety issue for any re-packaging operations after the storage period.

Zirconium fuel cladding may also form hydrides when exposed to hydrogen at temperatures above 240°C^{23} . The actual rate of formation of the hydride is dependent on the quality of the surface oxide present. Zirconium hydride is not as reactive as the pure metal but does embrittle the metal. The formation of significant ZrH_2 needs to be prevented to ensure that SNF can be successfully retrieved at the end of the storage period.

5. *Removal of Decay Heat*

Decay heating of SNF is the result of the spontaneous breakdown of fission byproducts (isotopes) resulting from irradiation of the fuel. Each fission product formed will decay by formation of a chain of isotopes, each with a specific lifetime and energy. Water storage of SNF has been used traditionally to ensure that the decay heat from the fuel could be adequately removed. As discussed previously, decay heat can be beneficial to assist in drying the fuel during the transfer to dry storage.

Dry storage systems employed for containing SNF must be capable of removing the decay heat from the system as fast as it is generated to prevent the fuel from exceeding design temperatures. It is generally agreed that the fuel should not reach temperatures which would allow substantial creep (typically about $\frac{1}{2}$ the melting temperature of the alloy) or temperatures that would cause structural changes in the cladding. Also, if hydrogen is expected to be present in a sealed package, excessive heat could result in severe degradation of Zirconium cladding.

Surface storage facilities in the United States use both forced and natural circulation ventilation to control the fuel temperature. Storage casks may be purchased with cooling fins to aid in heat removal. Vault systems are generally vented to stacks to enhance convection cooling.

Studies are now in progress to determine realistic lifetimes for SNF in dry storage at elevated temperatures through evaluation of commercial SNF in dry storage casks located at the INEEL. These fuels have been in storage for since 1986. The results of such studies will be formalized in an American Society for Testing Materials (ASTM) standard for dry storage life extension²⁴.

4. *Cleaning and Removal of Sludge*

Sludge or “crud” removal from SNF prior to dry storage is one method of minimizing the potential problems with SNF drying. It also minimizes the issues with internal corrosion of dry storage containers during the dry storage period.

Sludge may contain a variety of elements depending on their source. Windblown clays, salts, and sands are common in storage basins, as are metal compounds from corrosion of fuel cladding and piping within the primary loop of the reactor. Damage to SNF during irradiation or in wet storage may allow the addition of uranium compounds and a variety of fission products to the sludge.

Sludge that collects in the bottom of dry storage containers prior to SNF drying operations can be highly corrosive. Drying operations are typically insufficient to fully remove all water from the sludge, but may reduce the total water content resulting in concentration of metals and corrosive ions. This concentration of corrosive species results in a local reduction in the pH and the high probability of forming a pitting and/or crevice corrosion cell²⁵. If the sludge concentrates near a stressed portion of the container (typically around welds) and the sludge contains corrosive salts, especially chlorides, intergranular stress corrosion cracking can also be expected.

Sludge removal can be performed using a number of techniques but high-pressure water washing is probably the most common. This is the technique proposed for the Hanford N reactor fuel

5. *Radiation Damage to Packaging Materials*

Spent nuclear fuels emit high levels of radiation. Although such radiation is generally thought to be inadequate to significantly degrade stainless steel SNF canning materials, it would have a profound effect on plastics, and other hydrocarbon-based materials. The use of plastics or other hydrocarbons are not recommended inside SNF packages because of the potential decomposition of the material and release of hydrogen.

Gasket materials for sealing SNF packages are a primary radiation damage concern. If organic base gasket materials are used, the packages should have a planned gasket replacement cycle to prevent unwanted release of radionuclides to the environment. Inorganic gasket materials such as soft copper, silver, and graphite are typically better suited for SNF storage service.

6. *Fission Product Interactions*

The chemical interaction of fission products other than hydrogen within SNF dry storage packages has been studied²⁶. The potential for damage to packaging materials from fission product interactions is minimal because of the tortuous path involved for the fission products to collect in sufficient quantities to be of concern.

The potential interaction of low melting point, reactive metals with fuel cladding and container materials was determined possible for badly damaged SNF stored in sealed systems at elevated temperatures. The fission products, cesium and rubidium are common in SNF. At elevated temperatures (28.5°C for Cs and 38.9°C for Rb) these metals melt and, depending on the state of the fuel matrix and cladding, can become mobile within the fuel and sealed package. Because they are highly reactive, they will immediately react with any available oxygen and with a number of other fission products. However, it has been shown mathematically that there is more Cs and Rb than can be reacted inside a typical sealed SNF container. Residual liquid Cs and Rb are strong liquid metal embrittlement agents for both Zr fuel cladding and most container materials. The actual damage of fuel cladding and/or containers will depend on the quality of the surface oxides (ZrO_2 and CrO_2) that normally protect the materials from attack. This degradation mechanism has been studied in nuclear fuels and has historically been termed “pellet-clad interaction.” It was found to cause fuel failure when the Zr oxide surface was disrupted in an inert environment by pellet abrasion allowing the Cs and/or Rb to attack the Zr and crack the cladding.

7. *Monitoring of Dry Storage Systems*

Current U.S. NRC regulations¹⁰ for dry storage require that the SNF “*have the capability for continuous monitoring in a manner such that the licensee will be able to determine when corrective action needs to be taken to maintain safe storage conditions.*” For sealed dry storage systems, this requirement is typically viewed as the need to verify the internal pressure of sealed storage units. However, in vented storage systems or storage units where the potential for container and/or SNF corrosion is significant, monitoring for fission gases may also be appropriate. Indications of increased levels of fission gas in underground storage cells or above storage vaults indicates that the canister and/or fuel cladding has breached allowing release of the gas, or that existing corrosive conditions in the system have increased in magnitude exposing more fuel matrix material.

For dry storage of potentially reactive SNF such as Hanford N-Reactor metallic fuels, the combination of pressure, temperature, and gas composition monitoring is prudent²⁷ on a sample of dry storage units to verify the adequacy of drying operations and benchmark calculated storage conditions with actual full size units.

United States Experience in Dry Storage

Dry storage systems have been employed for many years in the United States, both within Department of Energy Laboratories and at commercial nuclear sites. All of the major types of storage systems are currently in use but U.S. experience with dry storage has not all been positive.

Most commercial SNF dry storage has been accomplished using surface casks. These units perform well in most environments and appear to provide relatively trouble-free

service. The storage design life without re-licensing, however, was set by the Nuclear Regulatory Commission at 20 years. Several commercial storage systems are nearing this regulatory design life and will require re-packaging unless license renewals are granted. Surface cask storage (also called modular storage) is also being used by the Department of Energy at Hanford and the Idaho National Engineering and Environmental Laboratory (INEEL) to store a variety of research reactor and commercial type fuels with varying levels of SNF cladding integrity. Such systems are generally more cost effective because of the lower capital cost and minimal facilities infrastructures involved.

Surface storage vault facilities are being used at Hanford and the INEEL to store a wide variety of research reactor fuel materials. These vented and HEPA-filtered storage systems are well suited for research reactor SNF that may have been damaged, tested beyond normal limits, or is otherwise problematic. Specific SNF characterization and analyses are typically performed on SNF in wet storage before moving it to these dry storage vaults to ensure that the SNF will not degrade the dry storage system². Gas cooled reactor fuels (graphite block fuels) from the Fort St. Vrain reactor have also been stored in a dry surface vault facility for many years with no significant problems.

Underground storage cells are currently in use at the INEEL, Oak Ridge, and a few commercially owned research facilities. However, this type of dry storage is typically being phased out because of the difficulties involved in keeping the storage cells dry while still retaining the capability to monitor the SNF condition. Underground corrosion processes from rain, snow, and groundwater have led to high maintenance costs and water intrusion problems. Cells used for low decay heat fuels are also plagued with breathing in moist air from the external environment and having the water condense on SNF containers whose temperature is below the dew point during some part of the day or during some seasons of the year.

Summary

Storage of aluminum clad fuel in wet basins is achievable with continued monitoring. Because pitting has been detected in basins with high water quality, one cannot assure indefinite storage. Pit propagation in aluminum fuel after moving from wet to dry is being investigated. Initial results are expected in FY 2000.

Dry storage systems can be used safely and effectively to manage SNF for extended times. Appropriate, fuel-specific processes are required to condition the fuel at the time the fuel is transferred from wet storage and placed into the dry storage environment. Dry storage lifetime is determined by both the internal and external environments involved.

References

-
- ¹ James P. Howell, Durability of Aluminum-Clad Spent Nuclear Fuels in Wet Basin Storage, Paper 128, Corrosion 96, NACE International, Houston Texas
- ² R. J. Guenther, A. B. Johnson, A. L. Lund, E. R. Gilbert, et al. "Initial Evaluation of Dry Storage Issues for Spent Nuclear Fuels in Wet Storage at the Idaho Chemical Processing Plant", INEL-96-0140, Lockheed Martin Idaho Technologies Co, Idaho Falls, ID 83415, July 1996
- ³ Beeston, J. M., Miller, L. G., Brown, K. R., McGinty, D. M., "ELAF Failed Fuel Plate Examination" EGG-SE-6696, EG & G Idaho, Inc. Idaho Falls, ID 83415, October 1984
- ⁴ Henslee, S. P., "ATR Fuel Element Pitting" PR-T-80-030, EG&G Idaho, Inc., Idaho Falls, ID 83415, April 1980
- ⁵ Dirk, W.J., Letter 05Dirk97, Lockheed Martin Idaho Technologies Co., Idaho Falls, ID 83415, March 1997
- ⁶ Shaber, E. L., "Micro-Pitting of 6061-0 Aluminum Fuel Plates During Hydroxide Coating" INEL EDF-730, INEEL February 1998
- ⁷ Mizia, R.E., "Test Plan: Corrosion Testing/Characterization for Aluminum Clad Spent Nuclear Fuel in the Irradiated Fuel Storage Facility" DOE/SNF/REP-037, INEEL 1999
- ⁸ Draft Standard Guidelines for Corrosion Protection of Research Reactor Aluminum-Clad Spent Nuclear Fuel in Interim Wet Storage, International Standards Organization, ISO/TCXXX/SC REV. 6, March 1999
- ⁹ J. T. Scully, Letter 09/27/99 to K. Moore, University of Virginia, Charlotte, VA
- ¹⁰ 10 CFR 72, Subpart F, Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High Level Radioactive Waste, General Design Criteria.
- ¹¹ Lessing, P. A., Standard Guide for Dryness in Canisters Containing DOE Spent Nuclear Fuels, U. S. Department of Energy Environmental Management, Spent Fuel Management Office, DOE/SNF/G-003, Rev. 0, May 1999
- ¹² Housley, G., CPP – 603 IFSF Fuel Canning Station P & ID, Lockheed Martin Idaho Technologies Co., drawing 448561, March 1996
- ¹³ Christenson, A., CPP – 603 IFSF Fuel Canning Station TRIGA fuel Drying Procedure, Lockheed Martin Idaho Technologies Co., INTEC TPR P3.3-G9
- ¹⁴ Thompson, H. E., Heated Vacuum Drying System Documentation for Design, Operation, and Maintenance, INEEL ISS Facility Project, Newport News Shipbuilding NNS No. 1000-Q-017, Contract to Lockheed Martin Idaho Technologies C95-180247
- ¹⁵ Pajunen A. L., Cold Vacuum Drying Process Technical Manual, HNF-SD- SNF-TM-001, Rev. 0, SGN Eurisys Services Corporation, Richland, WA
- ¹⁶ Pajunen, A. L., Evaluation of Radiolytic Gas Generation from Water Dissociation in a Multicanister Overpack, HNF-SD-SNF-CN-006, Rev. 0A, SGN Eurisys Services Corporation, Richland, WA
- ¹⁷ Lessing, P. A., Effects of Water in Canisters Containing DOE Spent Nuclear Fuels, U.S. Department of Energy Environmental Management, Spent Fuel Management Office, DOE/SNF/REP-017, Rev. 0, October 1998

-
- ¹⁸ Wefers, K., and Misra, C., Oxides and Hydroxides of Aluminum, AlCOA Laboratories, 1987
- ¹⁹ Lam, P. S., Sindelar, L. L., and Peacock, H. B. Jr., Vapor Corrosion of Aluminum Cladding Alloys and Aluminum-Uranium Fuel Materials in Storage Environments (U), Savannah River Technology Center, Strategic Materials Technology Department, Westinghouse Savannah River, Co., Savannah River Site, WSRC-TR-97-0120.
- ²⁰ Anno, J. N., Notes on Radiation Effects on Materials, University of Cincinnati and Research Dynamics Incorporated, Hemisphere Publishing Corporation, New York, NY., 1984.
- ²¹ Mizia, R. E., Hydrogen Damage in DOE SNF in Standard Canisters, U.S. Department of Energy Environmental Management, Spent Fuel Management Office, DOE/SNF/REP-019, Rev. 0, September 1998.
- ²² Powell, G. L., Internal Hydrogen Embrittlement in Uranium Alloys, Metallurgical Technology of Uranium and Uranium Alloys, ASM International Symposium, May 1981
- ²³ Lustman, B., and Kerze, F. Jr., The Metallurgy of Zirconium, McGraw-Hill Book Co. Inc. 1955.
- ²⁴ Interrante, C., Guide for Evaluation of Materials Used in Extended Service of Interim Spent Nuclear Fuel Dry Storage Systems, American Society for Testing Materials, Light Water Reactor SNF Task Group C.26.13.
- ²⁵ Dexter, S. C., Localized Corrosion, Metals Handbook, Ninth Edition, Volume 13, Corrosion, ASM International, Metals Park, OH., 1987.
- ²⁶ Anderson, P. A., Sensitivity Analysis – Interaction of DOE SNF and Packaging Materials, U.S. Department of Energy Environmental Management, Spent Fuel Management Office, DOE/SNF/REP-020, Rev. 0, September 1998.
- ²⁷ Sexton, R. A., MCO Monitoring Activity Description, U.S. Department of Energy Contract DE-AC06-96RL13200 with DE&S Hanford, Inc., Richland, WA, HNF-3312, Rev. 1.