U.S. EXPERIENCE WITH DRY CASK STORAGE
A REGULATOR'S PERSPECTIVE

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Introduction

In the late 1970's and early 1980's, the need for alternative storage in the United States (US) began to grow when spent fuel pools (SFPs) at many nuclear reactors began to fill up with stored nuclear spent fuel. Utilities began looking at options such as dry cask storage for increasing spent fuel storage capacity. Figure 1 shows the nuclear spent fuel storage pool capacity as a function of time.

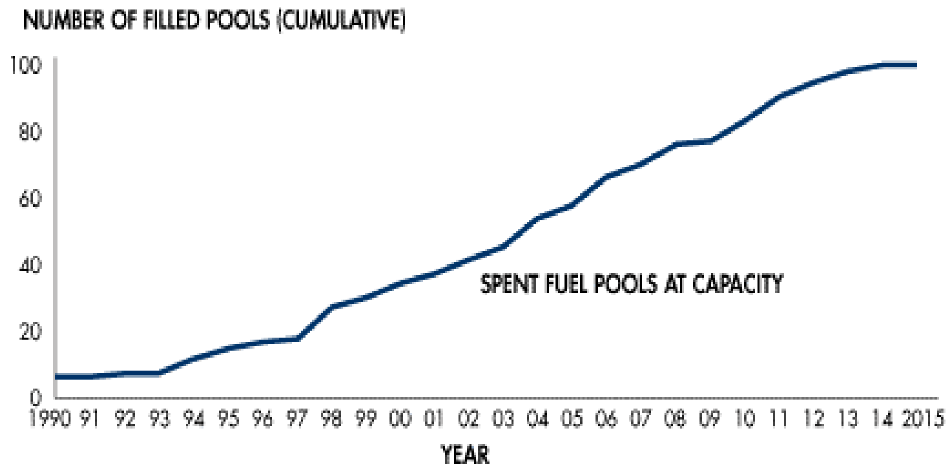
This paper discusses the regulatory framework that permits spent fuel licensees to store fuel in dry storage facilities and the US licensing processes used to certify dry spent fuel storage casks and facilities. It also provides an overview of the technical requirements for evaluating the safety of dry cask storage systems and facilities. The US experience and safety record of dry cask storage are also discussed in this paper. The technical issues and staff guidance associated with the storage of high burnup and failed spent fuel are also described.

Licensing Framework

Most US nuclear power plant SFPs were not originally designed to have a storage capacity for all the spent fuel generated by their reactors. Utilities originally planned for spent fuel to remain in the SFPs for a few years after discharge, and then to be sent to a reprocessing facility. However, the US Government declared a moratorium on reprocessing in 1977. Although the ban was later lifted, reprocessing was not recommended as a feasible option. Consequently, utilities expanded the storage capacity of their SFPs by using high-density storage racks. This has been only a short-term solution and many utilities have reached, or will soon reach, their SFP storage capacity.

Nuclear power reactor utilities plan to ship their spent fuel in the future to a geologic repository operated by the U.S. Government. The Nuclear Waste Policy Act of 1982, as amended (NWPA) required the US Department of Energy (DOE) to begin accepting spent fuel for permanent disposal in 1998. However, the federal repository still remains in the planning stages, and did not accept spent fuel in 1998. Until DOE receives spent fuel for disposal, utilities will continue to rely on independent spent fuel storage installations (ISFSIs) technology as a means for expanding their spent fuel storage capacity on an interim basis.

Figure 1. Spent Fuel Storage Pool Capacity



Note: All operating nuclear power reactors are storing used fuel under NRC license in spent fuel pools. Some operating nuclear reactors are using dry cask storage. Information is based on loss of full-core reserve in the spent fuel pools.

Source: Energy Resources International and DOE/RW-0431 – Revision 1

In addition to prescribing the laws for developing plans for disposal of spent fuel in a geologic repository, the NWPA directed the DOE to work with utilities and develop dry cask storage technologies to safely store spent fuel in a dry mode[1]. Section 218(a) of the NWPA includes the following directive: "The Secretary [of DOE] shall establish a demonstration program in cooperation with the private sector, for the dry storage of spent nuclear fuel at civilian nuclear power reactor sites, with the objective of establishing one or more technologies that the [Nuclear Regulatory] Commission may, by rule, approve for use at the sites of civilian nuclear power reactors without, to the maximum extent practicable, the need for additional site specific approvals by the Commission."

As directed in the NWPA and as established by a NRC final rule for 10 CFR Part 72[2], the requirements for licensing dry casks storage systems under site-specific and general licenses were codified. In 1986, the Surry Nuclear Power Plant became the first utility in the US to obtain a license to store spent nuclear fuel at a site-specific ISFSI using the 10 CFR Part 72 license requirements. In 1993, Palisades Nuclear Power Plant became the first utility to use the general licensing provisions of 10 CFR Part 72.

Options for Licensing Dry Storage Systems in the United States

There are two options for licensing dry cask storage technologies in the US in accordance with 10 CFR Part 72. This section describes the site-specific and general licensing processes and the NRC inspection and oversight programs.

Site-Specific Licenses

In November 1980, regulations for dry cask storage under 10 CFR Part 72[3] were promulgated to permit the storage of spent fuel outside of reactor spent fuel pools in either at-reactor sites or away-from-reactor sites. From 1980 through 1990, the NRC only issued site-specific ISFSI licenses in accordance with the 1980 10 CFR Part 72 final rule[3].

Most current site-specific ISFSIs are owned and operated by operating power reactor license holders. However, facilities owned by non-reactor entities may also apply for a site-specific license to store spent fuel. An approved site-specific ISFSI could be located offsite from a nuclear power plant, and could possibly accept fuel from more than one nuclear power plant. An example of this type of facility is the Private Fuel Storage Facility which is currently under licensing review by the NRC.

A site-specific ISFSI must meet several licensing requirements which are similar to those of a nuclear power plant reactor license. The applicant must submit to the NRC a license application to store spent fuel which contains a safety analysis report (SAR), an environmental report (ER), and an emergency plan (EP). The following list identifies the kind of information that is needed by NRC staff to conduct and complete its review:

- Siting evaluation factors - the site characteristics (including external natural and manmade events) that may directly affect the safety or the environmental impact of the ISFSI;

- General site and storage cask design criteria - the design, fabrication, construction, testing, maintenance, and performance requirements for structures, systems, and components important to safety;

- Quality assurance - the planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service as applied to the site and cask design, purchase, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair, modification, and decommissioning;

- Physical protection - the detailed plans for ISFSI security; and

- Personnel training - the programs for training, proficiency testing, and certification of ISFSI personnel who operate equipment or implement controls important to safety.

The NRC reviews the license application and completes an evaluation of potential environmental impacts of the ISFSI in accordance with the National Environmental Policy Act of 1969 (NEPA). The evaluation of potential impacts of the proposed and reasonable alternative actions is documented in either an environmental assessment (EA) or a more extensive environmental impact statement (EIS). After completing its safety review and resolving comments, the NRC issues a safety evaluation report (SER) and the final EA or EIS, and makes a decision about issuing the license. The SER documents the staff's evaluation of the SAR and assesses the technical adequacy of the dry cask storage system, the site, or other facilities that will be used. Under the site-specific licensing process, the public may request a hearing on the site-specific license.

A license may be granted for a site-specific ISFSI for a period of up to 20 years.

General Licenses

In accordance with the NWPA, the NRC revised 10 CFR Part 72 in July 1990[2] to license acceptable dry cask storage system designs and preclude the need for additional site-specific reviews which were already licensed by NRC under an operating reactor license. The basis for revising 10 CFR 72 was that existing reactor sites already met most 10 CFR Part 72 licensing criteria (i.e., physical protection, environmental impact statements, emergency planning) under the terms in the reactor license. The revision to the regulation allows nuclear power plants with a reactor operating license to store spent fuel in a dry cask storage system with a certificate of compliance for the dry storage system. A certificate of compliance is obtained from the NRC once the staff has conducted a safety review using the general license criteria of the July 1990 revision of 10 CFR 72. The general licensee may only store spent fuel that it is authorized to possess under its power reactor license.

Before using a general license, the licensee must perform written safety evaluations which establishes that the conditions of the certificate of compliance have been met, that the cask storage pads and areas have been adequately designed, and that the criteria for radioactive materials in effluents and direct radiation have been met in accordance with 10 CFR Part 72. These conditions entail verification that the reactor site parameters, such as extreme temperatures, seismic design criteria and wind velocities, are enveloped by the dry casks storage system design bases. The licensee must also develop operating procedures and training modules, a preoperational testing and training exercise plan, plans for protection from radiological sabotage and emergencies, and ISFSI surveillance requirements.

Once the cask application is received by the NRC, the application is made available for public inspection. The NRC staff reviews the SAR, prepares a draft SER, and a draft certificate of compliance, and publishes a notice of proposed rulemaking to amend 10 CFR Part 72 to add the cask model to the list of approved casks. All documents relied upon for the proposed rulemaking are made publicly available, and public comments are received by the NRC for a period of time. After reviewing the public comments, the NRC prepares the final SER, and certificate of compliance.

The certificate of compliance obtained under a general license is valid for 20 years.

Inspection and Oversight Programs

The NRC's safety oversight program for spent fuel storage is designed to assure compliance with the regulations and rules to: protect public health and safety, protect the environment, and the common defense and security. The oversight program includes inspections and assessments of licensee and vendor activities with a focus on minimizing risk to public health and safety. NRC inspects to verify regulations are met and storage casks are built in accordance with approved designs. This helps ensure that licensees provide safe interim storage of spent reactor fuel.

The NRC periodically inspects the design, fabrication, and use of dry cask storage by sending inspectors to licensee and cask vendor facilities. The inspectors examine whether licensees and vendors are performing activities in accordance with radiation safety requirements, licensing and certificate of compliance requirements, quality assurance program commitments. Inspectors also inspect physical programs. Findings are documented in publicly available reports.

Inspections can result in negative findings and this can lead to enforcement actions. NRC enforces its regulations by issuing violations and possibly civil penalties, and can in extreme cases result in shut down or termination of operation. These NRC sanctions may include notices of violation, monetary fines, or orders to modify, suspend, or revoke a license or require specific actions.

Technical Requirements for Licensing Dry Cask Storage Systems

To assure licensed storage cask designs meet NRC regulations and are accident resistant, the staff conducts comprehensive technical reviews of the cask and facility designs. Typically, the NRC staff reviews the following aspects of the cask and facility designs for routine operations and under accident conditions: structural robustness (including thermal and materials considerations), adequacy of shielding components, maintenance of subcriticality, and adequacy of the confinement boundary. NRC requires applicants to analyze the cask design for all external man-made and natural events, including fire, flood, tornado and tornado missiles (such as automobiles), earthquake, cask drop, loss of shielding, heat up, and damage from accidents at nearby sites. The staff's review of the safety basis requires applicants and licensees to: perform stringent tests and analyses of the casks, develop quality assurance programs to ensure that the casks and facilities are robust, and develop physical security programs.

To assist the NRC staff with their reviews, the Spent Fuel Project Office (SFPO) developed several Standard Review Plans (SRPs), one for reviewing spent fuel dry storage facilities applications (for site-specific licenses) and one for reviewing storage cask designs (for generally licensed casks). The SRPs provide guidance to the staff when reviewing applications for license approval, amendment, or renewal. The SRPs contain the regulatory requirements, staff positions, references to applicable national and other industry standards and codes, acceptance criteria, guidance on preparation of the SER, and other guidance. In conjunction with the SRPs, SFPO has developed several Interim

Staff Guidance (ISG) documents. These ISGs were developed to address emerging issues for which interim guidance was needed. The last section of this paper discusses ISG documents on two technical spent fuel issues.

Status of Dry Cask Storage in the United States

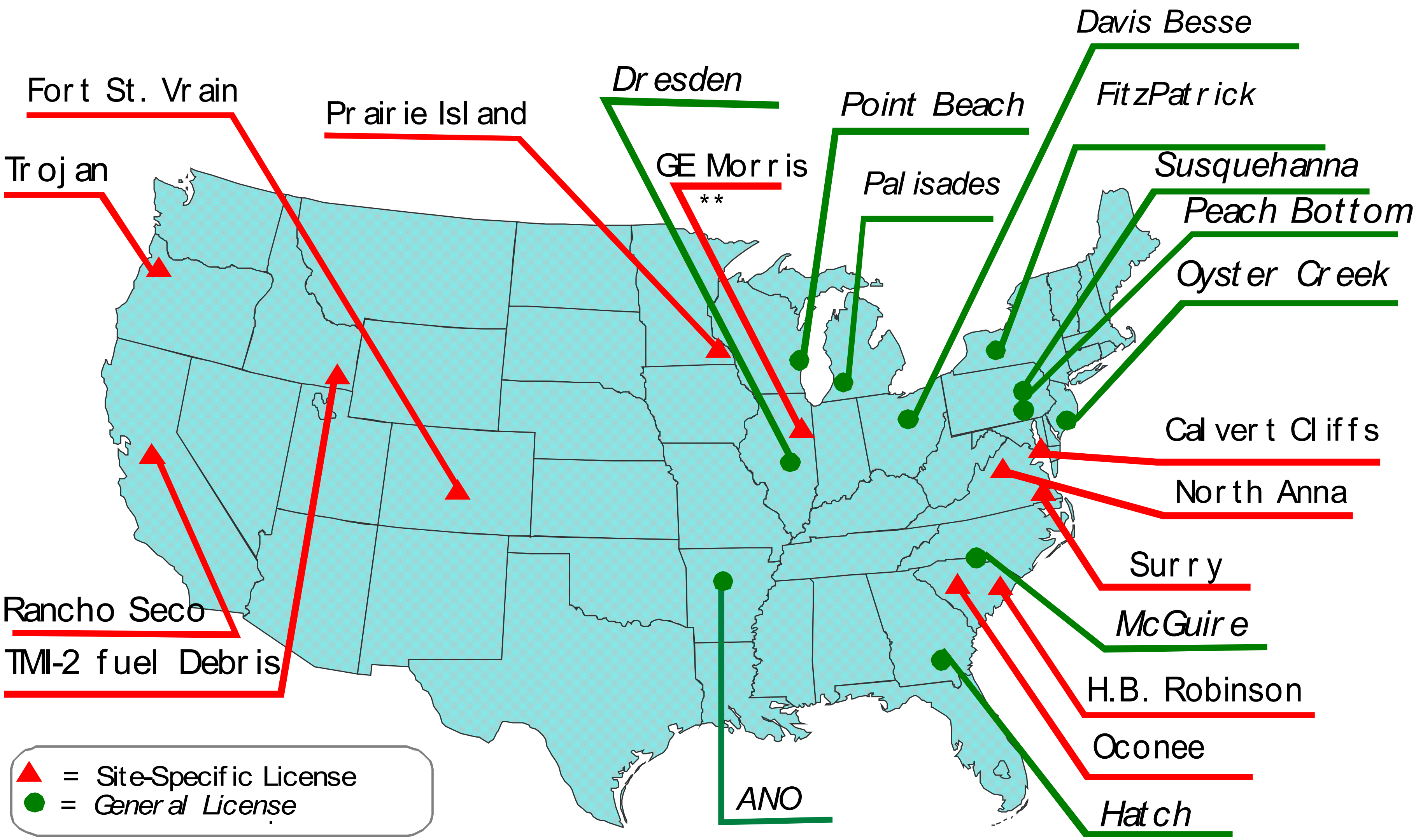
About 117,000 spent fuel assemblies, containing approximately 42,540 tons of spent fuel from nuclear power plants, are currently in storage in the US[4]. Of these, about 97% (or 113,500 assemblies) are stored at nuclear power plants, and approximately 3% (or 3,500 assemblies) are stored at away-from-reactor storage facilities, such as the General Electric plant in Morris, IL. The vast majority of the total number of assemblies is stored in SFPs at the reactor with less than 10% of the total inventory stored in dry casks as the present time. However, there is an increasing demand to store spent fuel in dry storage casks.

Currently, there are 22 operating ISFSIs (11 site-specific licenses and 11 general licenses) in the US as shown in Figure 2. Figure 3 shows ISFSI sites that may be licensed or operational in the near future. Four general dry cask designs have been approved for use in licensed ISFSIs: vertical metal storage casks, vertical concrete-shielded metal storage casks, horizontal metal canisters housed in concrete modules, and concrete storage vaults. A total of 19 dry casks storage system designs, made by seven different vendors, have been approved or certified by the NRC over the last 20 years. Only one non-SFP wet storage systems has been licensed by the NRC to date.

Of the 19 certified dry storage cask systems, there are 12 commonly used dry storage-only cask designs. Some characteristics of these 12 systems are provided in Table 1. As shown in the table, these storage casks can accommodate between 21 and 40 pressurized water reactor (PWR) or up to 68 boiling water reactor (BWR) spent fuel assemblies. The maximum approved initial enrichment and burnup of the PWR and BWR assemblies are 5.0% uranium-235 and 45 GWd/MTU, respectively. Two of the casks (i.e., the FuelSolutions and Hi-Storm casks) are licensed to store PWR spent fuel assemblies having burnups of 60 GWd/MTU or higher.

In addition to the storage casks described above, there are four dual-purpose cask systems (i.e., cask systems designed for both storage and transportation operations) licensed by the NRC. Dual-purpose cask systems typically utilize a canister that confines the spent fuel. The canister is used for both storage and transportation operations. Individual storage and transportation overpacks are placed around the canister to provide shielding. As shown in Table 2, the dual-purpose casks can accommodate between 21 and 36 PWR or between 52 and 68 BWR spent fuel assemblies. For most of the dual-purpose casks, the maximum approved initial enrichment and burnup of the PWR and BWR assemblies

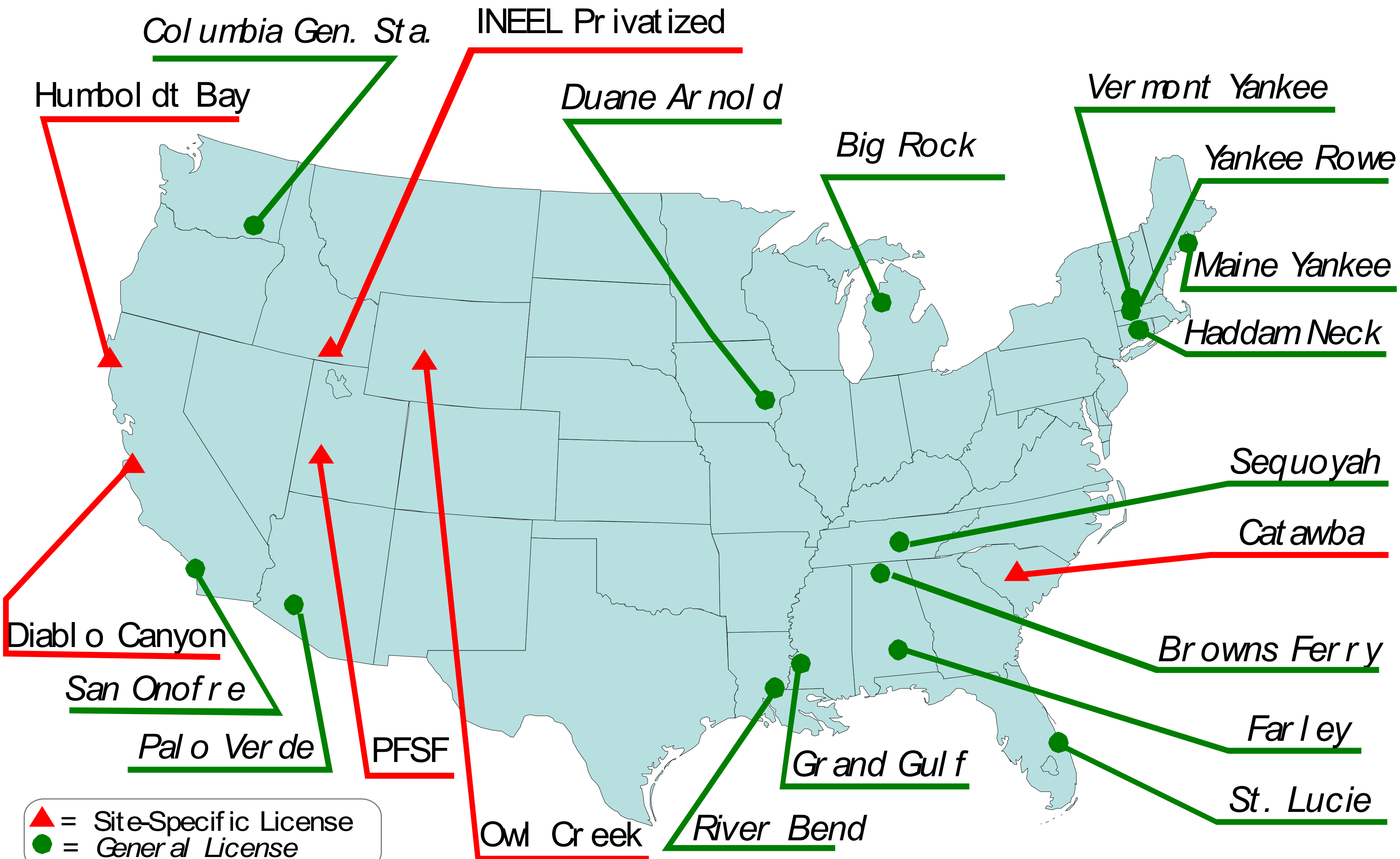
Figure 2. Operating ISFSIs



** GE Morris uses wet storage

Information as of May 15, 2002

Figure 3. Potential Near-Term, New ISFSIs



Information as of May 15, 2002

Table 1. Characteristics of Most Commonly Used Spent Fuel Storage Casks

Cask Model Number	Cask Description	Confinement Closure	Spent Fuel No. Assemblies and Type	Max. Init. Enrichm't, % U-235	Max. Burnup (GWd/MgU)
CASTOR V/21 (Certificate #1000)	vertical metal cask on concrete pad	bolted	21-PWR	3.0	40
NAC-S/T (Certificate #1002)	vertical metal cask on concrete pad	bolted	26-PWR	3.5	35
NAC-C28 S/T (Certificate #1003)	vertical metal cask; can also contains 56 consolidated FA's	bolted	28-PWR	3.5	35
Std.NUHOMS-24P (Certificate #1004)	horizontal concrete storage module w/ canisters of fuel	welded	24-PWR	4.5	47
Std. NUHOMS-52B (Certificate #1004)	horizontal concrete storage module w/ canisters of fuel	welded	52-BWR	4.0	35
TN-24 (Certificate #1005)	vertical metal cask	bolted	24-PWR	3.5	35
VSC-24 (Certificate #1007)	vertical concrete overpack w/ canister of fuel	welded	24-PWR	4.2	51.8
Hi-Storm 100 (Certificate #1014)	vertical concrete cask w/ canister of fuel	welded	24-PWR or 68-BWR	4.6 (PWR), 5.0 (BWR)	44.1 (PWR), 39.2 (BWR)
TN-32 (Certificate #1021)	vertical metal cask	bolted	32-PWR	4.05	45
NAC-I28 S/T (Site-specific license only; Certificate #SNM-2501)	vertical metal cask	bolted	28-PWR	1.9	35
TN-40 (Site specific license only; Certificate #SNM-2506)	vertical metal cask	bolted	40-PWR	3.85	45
FuelSolutions (Certificate #1026)	vertical metal/concrete overpack w/ canister of fuel	welded	21-PWR 64-BWR	5 (PWR), 4.1 (BWR)	60 (PWR), 60 (BWR)

Table 2. Characteristics of Spent Fuel Dual-Purpose Casks

Cask Model Number	System Description	Confinement Closure	Spent Fuel No. of Assemblies and Type	Max. Init. Enrichm't, % U-235	Max. Burnup (GWd/MgU)
Hi-Star 100	dual-purpose canister w/ single metal overpack for transportation and storage	welded	24-PWR or 68-BWR	4.6 (PWR), 5.0 (BWR)	44.1 (PWR), 39.2 (BWR)
TN-68	single metal cask for transportation and storage	bolted	68-BWR	3.7	40
NAC-MPC (storage only)	dual-purpose canister w/ metal/concrete overpack	welded	26 PWR or 36-PWR	4.94	36.0
NAC-STC (transport only)	uses same dual-purpose canister as for NAC-MPC w/ metal overpack	bolted	26-PWR or 36-PWR	4.94	45.0
NAC-UMS (storage)	dual-purpose canister w/ metal/concrete overpack	welded	24-PWR or 56-BWR	4.2 (PWR), 4.0 (BWR)	45 (PWR), 45 (BWR)
NAC-UMS (transport)	uses same dual-purpose canister as for NAC-UMS w/ metal overpack	bolted	24-PWR or 56-BWR	4.2 (PWR), 3.75 (BWR)	45 (PWR), 40 (BWR)

are 5.0% uranium-235 and 45 GWd/MTU, respectively. However, one dual-purpose cask (i.e., the NAC-UMS cask) is in the process of being licensed to store PWR spent fuel assemblies having burnups up to 50 GWd/MTU.

From an operational perspective, there have been no incidents that have resulted in a reduction of safety to the worker, members of the public, or the environment. Minor design changes to the casks have been required at the cask fabricator sites to facilitate shop-specific practices and equipment operations. Changes to operating procedures at the nuclear power plants have also been required to permit loading spent fuel and transferring the loaded cask using plant-specific operating equipment and established procedures. Dry cask storage loading operations have not gone without operational incidents. For example, the following types of non-safety related storage cask degradation have been observed.

- Several low pressure alarms, which monitor the cask internal pressure, were activated over six months for three of the same type of cask. The problem was attributed to faulty and/or loose pressure switches which were replaced at the ISFSI storage pad with pressure switches manufactured by different vendors.

- Corrosion of metallic outer lid seals (which are not part of the containment boundary) on multiple storage cask lids at one site was observed during a routine inspection. All of the casks were transferred to the spent fuel pool and their lids were removed. Examinations of the seals revealed that galvanic corrosion between the aluminum seal and the stainless steel cask body created small thru-wall holes in the seal. The defective seals were replaced, the lids were re-secured onto the casks, and the casks were returned to the ISFSI pad. No corrosion of the inner containment seal (which is part of the containment boundary) was observed, and there was no leakage detected past the inner seal.

- Several casks at one site were observed to have loose cask lid bolts. The casks were returned to the spent fuel pool for examination. During the examinations, it was determined that many of the bolts were inadequately tightened. Even though the bolts were loose, the inner seals were intact.

- At one ISFSI, a crane’s load cell failed after completing the installation of a rear impact limiter on a spent fuel shipping cask. A combination of a less than adequate safety factor, a material defect, cyclic loading (horizontal and vertical), or a combination of these factors over a period of time may have caused the mechanical failure of the load cell.

Overall, NRC’s programs for certifying and safeguarding spent fuel storage casks and independent spent fuel storage installations have also led to an outstanding safety record. Over the last 20 years, there have been no radiation releases which have impacted the public from the 300 storage casks at 22 licensed ISFSIs. Also, no radioactive contamination has occurred from the 22 licensed ISFSIs; and, there have been no known or suspected attempts to sabotage spent fuel casks or ISFSIs.

Probablistic risk assessments (PRA) and other studies will help risk inform 10 CFR Part 72 regulations, review processes, and inspection programs in the future. For example, NRC staff is conducting a PRA study to assess the risks of spent fuel storage under normal, off-normal and accident conditions. The PRA analysis is also design specific (i.e., it uses a Holtec Hi-Storm storage cask) but could be applied more generically. Preliminary results from the PRA analysis show that: (1) the individual probability of prompt fatality (within 1 mile) is 0 for cask accidents (i.e., threshold dose needed for prompt fatality is not achieved), and (2) the individual probability of latent cancer fatality (within 10 miles) is about a factor of 400 lower than for reactor accidents. A draft of the dry cask storage PRA is expected to be completed in June 2002.

Spent Fuel Integrity Issues

High Burnup Fuel

In order to improve nuclear reactor utilization in the US, nuclear power plant utilities have had to operate the plants with fuel that is licensed for extended burnup. In the US, the NRC has licensed fuel burnup limits up to 62 GWd/MTU since the early 1990's. As shown in Figure 4 and Figure 5, the number of PWR and BWR spent fuel assemblies with burnups greater than 45 GWd/MTU (i.e., high burnup fuel) will exceed the number of spent fuel assemblies with burnup lower than that by 2002. Additionally, in 2005, the burnup level will exceed 45 GWD/MTU for about 80% of the PWR and BWR spent fuel discharged from SPFs. An analysis of industry's current and projected spent fuel inventories[5] shows a number of plants will need to place HBF into dry storage casks by 2004. By about 2006, the utilities will need additional flexibility to load HBF and fuel with cooler, lower burnup to meet the thermal limits on the currently designed casks. If some utilities are not able to preferentially load the HBF with the lower burnup fuel, they may be unable to place fuel into dry cask storage unless new cask designs can be licensed for HBF only.

As the burnup level of the fuel increases beyond 45 GWd/MTU during reactor operation, the thickness of the oxide layer on the exterior of Zircaloy cladding increases at a faster rate than at lower burnup levels. Under certain reactor conditions, this increase in the oxide thickness has been shown to cause localized degradation of the cladding material. Additionally, as burnup levels increase, the cladding absorbs more hydrogen which affects the rate of material deformation and, depending on the environmental conditions of the cladding, can affect the mode of ultimate cladding failure.

With regard to the storage of spent fuel, creep rupture is considered to be the dominant cladding failure mechanism under normal operations of dry cask storage.

Figure 4

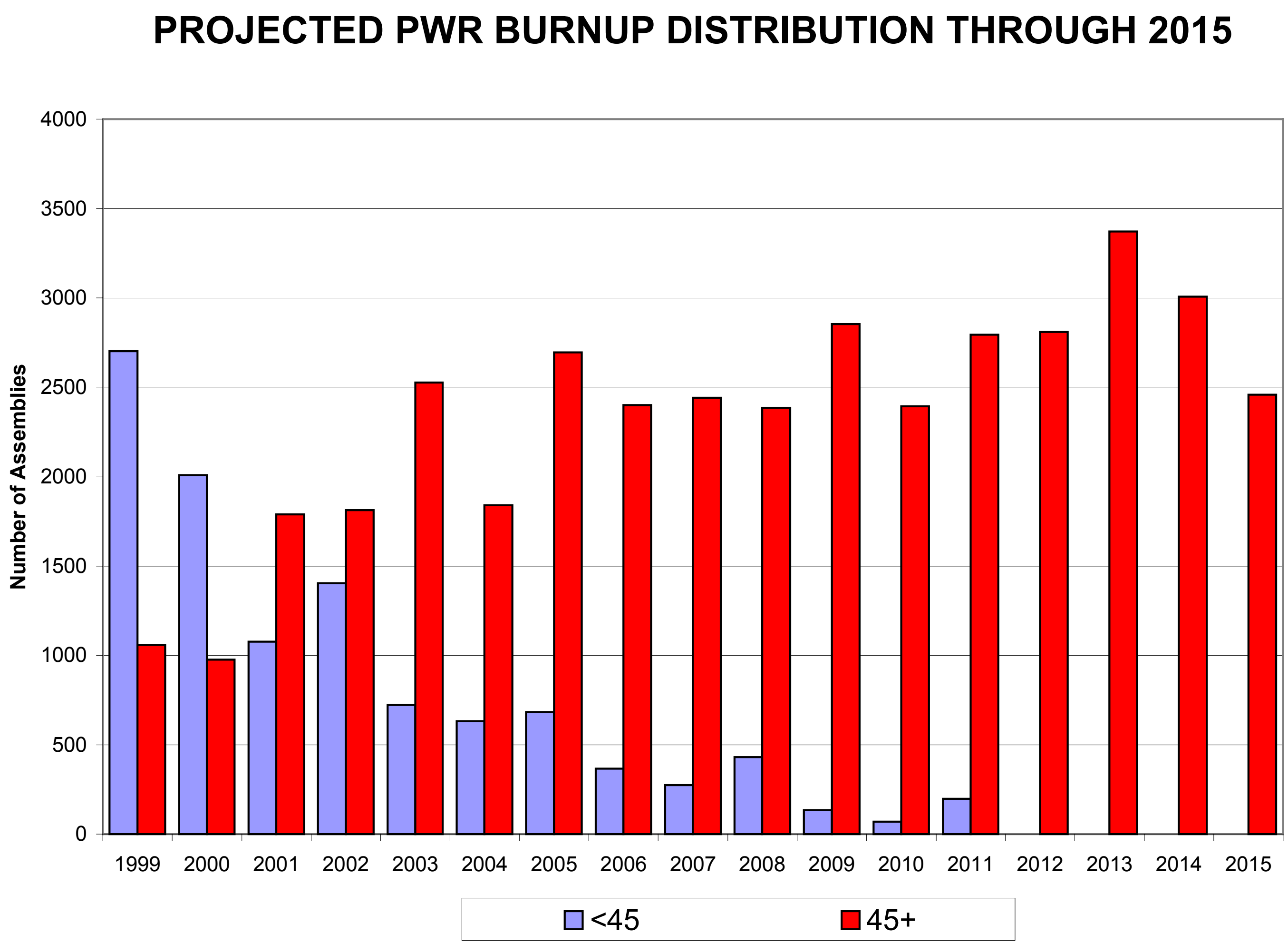


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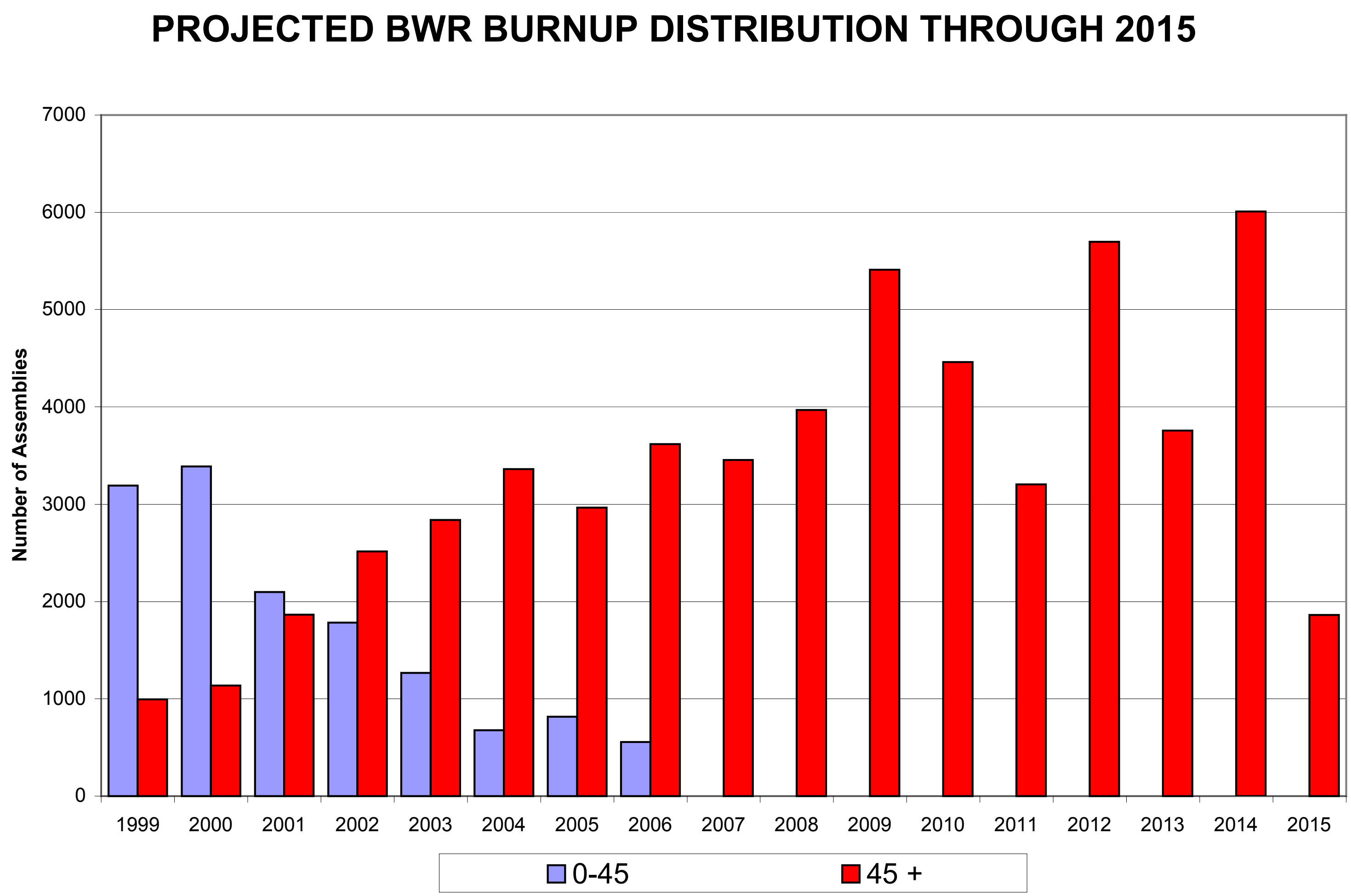
Figure 5



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Accordingly, cladding temperature limits are controlled over the license period to retain the fuel and fission product gases inside the cladding. The CSFM methodology developed by the Pacific Northwest National laboratory has historically and typically used to calculate the initial cladding temperature limits that would assure only a small percentage (0.5%) of cladding breaches[6] over a 20 year license period. Using this methodology, maximum allowable cladding temperature at the beginning of dry storage are typically below 380 ºC (716 ºF) for a 5-year cooled Zircaloy-clad fuel assembly and 340 ºC (612 ºF) for a 10-year cooled Zircaloy-clad fuel.

For high burnup fuel, the NRC staff believed that it was necessary to further control the conditions of the fuel in order to have assurance that high burnup fuel will be maintained in the as-analyzed condition under all conditions. Therefore, in May 2000, the staff issued more stringent guidelines for evaluating the integrity of the cladding. Specifically, the staff may approve license applications for the storage of high burnup fuel provided that the applicants can demonstrate that the cladding will be protected from degradation which could lead to gross rupture and that the storage system is designed to allow ready retrieval of the spent fuel from the storage system. If such a demonstration cannot be performed, high burnup fuel assemblies should be enclosed by approved baskets to confine the fuel so that potential degradation of the fuel during storage will not pose problems with respect to redistribution of material during storage or subsequent transportation. Such an enclosure would also maintain subcriticality based on optimum moderation conditions and no potential for buckling and failure of fuel rods, grid spacers, and end fittings under accident conditions.

The staff has prescribed the following acceptance criteria that applicants must meet in order to store high burnup fuel in dry casks.

A high burnup fuel assembly containing Zircaloy clad fuel may be treated as intact if both of the following conditions are met:

A1. No more than 1% of the rods in an assembly have peak cladding oxide thicknesses greater than 80 micrometers; and

A2. No more than 3% of the rods in an assembly have peak cladding oxide thicknesses greater than 70 micrometers.

A high burnup fuel assembly should be treated as potentially damaged fuel if either of the following conditions is met:

B1. The fuel assembly does not meet both criteria A1 and A2; or

B2. The fuel assembly contains fuel rods with oxide that has become detached or spalled from the cladding.

The 1% and 3% numbers are consistent with the percentages of fuel rod failures assumed to be available for release to the environment in the confinement analyses for normal conditions of storage and transportation, respectively. This assumption is for safety analysis purposes only, and relates to assumptions for thermal analysis, containment performance, and cask unloading operations.

In terms of lessons learned by the NRC staff over the last two years, the criteria described above have resulted in an increased burden to the licensees without a significant enhancement in safety. Specifically, the licensees are required to take measurements of the cladding oxide thickness and/or conduct special computer analyses for any high burnup fuel that needed to be loaded into dry cask storage to demonstrate compliance with this guidance. The guidance led cask vendors to develop new creep models and required them to use 1% as the creep strain limit over the 20 year storage period. The licensees are allowed to store Zircaloy-clad high burnup fuel using the justification contained in the ISG. However, if a licensee wants to store fuel clad with advanced alloys (such as Zirlo, M5, etc.), additional justification of and data for the creep behavior and mechanical properties in the SAR are required.

The NRC is continuing to develop a better understanding of the characteristics of high burnup fuel and will continue to evaluate the behavior of that fuel under the expected storage and transportation conditions. There are several research programs being conducted by the NRC to address the technical issues associated with the storage of high burnup fuel. The NRC's Office of Nuclear Regulatory Research (RES), in collaboration with the Electric Power Research Institute and several nuclear industry participants, is conducting a research program to characterize the metallurgical condition, mechanical properties, creep behavior, fracture toughness, and radiological source terms of high burnup fuel. RES is also organizing a cask demonstration program for high burnup fuel that would include fuel inspections and tests following several years of dry cask storage. NRC staff is re-evaluating the methods for controlling degradation of the fuel cladding under all conditions of dry cask storage by conducting independent analyses. Though NRC is conducting this work, it continues to seek input from the nuclear industry to develop additional data, analyses, and methods to support the safe storage and transportation of high burnup fuel. Through NRC and the nuclear industry's efforts, it is expected that the criteria for the storage and transportation of high burnup fuel, as described above, can be modified when sufficient technical information becomes available.

The staff will issue a revision to the current ISG on high burnup fuel in mid-2002. It is expected that with the new guidance in place licensees will be able to store all spent fuel in dry cask storage systems regardless of burnup levels, the type of fuel cladding (e.g., Zircaloy-4, Zircaloy-2, Zirlo, M-5, etc.), or the amount of cladding oxidation. Additionally, the new guidance may consider a different methodology for determining temperature limits to control degradation of the cladding, one that is based preventing hydride reorientation from embrittling the cladding.

Failed Fuel

There is no definition of damaged fuel in NRC's storage regulations. In 1998, the staff formalized the definition for damaged fuel by developing guidance to assure subcriticality during off-normal and accident conditions of storage in accordance with 10 CFR 72.

In the SAR, the applicant must specify if damaged, or failed, fuel is to be stored at an ISFSI in a dry storage cask. In accordance with the 1998 staff guidance, damaged fuel is defined as spent nuclear fuel with known or suspected cladding defects greater than a hairline crack or a pinhole leak. Presently, damaged fuel must be canned prior to being loaded into a storage cask. As proof that the fuel is undamaged, or intact, the applicant, at a minimum, is required to review the fuel records and verify that the fuel was undamaged. For fuel assemblies where reactor records are not available, the applicant should perform suitable tests to provide reasonable assurance that the fuel is undamaged, or that damaged fuel loaded in a storage cask is canned.

The purpose of canning damaged fuel is to confine large fuel particles to a known, subcritical volume during off-normal and accident conditions, and to facilitate handling and retrievability. Canning damaged fuel facilitates retrieval operations by minimizing doses to the workers and facilitates analytical calculations to demonstrate nuclear criticality safety, adequate heat removal, sufficient shielding, etc.

The staff anticipates that the majority of the spent fuel inventory placed in dry cask storage facilities will have intact, undamaged cladding. However, from a lessons learned perspective, there will be a small percentage of fuel rods that will have defects ranging from small pinholes, to axial splits, to larger fuel pellet-size openings, to parts/portions of rods due to the various reactor water chemistries and operating conditions. Additionally, damaged fuel assemblies could have missing or relocated grid spacers and related hardware.

To account for all of these variations of damaged fuel without increasing the burden on licensees, the NRC staff is revising its guidance on damaged fuel. The staff is considering expanding the definition of damaged fuel and developing a protocol for classifying damaged fuel. An engineering analysis may be used to justify that damaged fuel with greater than a hairline crack or pinhole leak can be safely stored and retrieved without being placed in a separate can prior to being loaded into a dry cask. From a practical standpoint, this new guidance would minimize the amount of fuel that would need to be canned.

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