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Standard Guide for Drying of Spent Nuclear Fuel[1]

This standard is issued under the fixed designation C1553; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide discusses three steps in preparing spent nuclear fuel (SNF) for placement in a sealed dry storage system: (*1*) evaluating the needs for drying the SNF after removal from a water storage pool and prior to placement in dry storage, (*2*) drying the SNF, and (*3*) demonstrating that adequate dryness has been achieved.

1.1.1 The scope of SNF includes nuclear fuel of any design (fuel core, clad materials, and geometric configuration) discharged from power reactors and research reactors and its condition as impacted by reactor operation, handling, and water storage.

1.1.2 The guide addresses drying methods and their limitations when applied to the drying of SNF that has been stored in water pools. The guide discusses sources and forms of water that may remain in the SNF, the container, or both after the drying process has been completed. It also discusses the important and potential effects of the drying process and any residual water on fuel integrity and container materials during the dry storage period. The effects of residual water are discussed mechanistically as a function of the container thermal and radiological environment to provide guidance on situations that may require extraordinary drying methods, specialized handling, or other treatments.

1.1.3 The basic issues in drying are: (*1*) to determine how dry the SNF must be in order to prevent problems with fuel retrievability, container pressurization, or container corrosion during storage, handling, and transfer, and (*2*) to demonstrate that adequate dryness has been achieved. Achieving adequate dryness may be straightforward for intact commercial fuel but complex for any SNF where the cladding is breached prior to or during placement and storage at the spent fuel pools. Challenges in achieving adequate dryness may also result from the presence of sludge, CRUD, and any other hydrated compounds. These may be transferred with the SNF to the storage container and may hold water and resist drying.

1.1.4 Units are given in both SI and non-SI units as is industry standard. In some cases, mathematical equivalents are given in parentheses.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.3 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C859 Terminology Relating to Nuclear Materials

C1174 Guide for Evaluation of Long-Term Behavior of Materials Used in Engineered Barrier Systems (EBS) for Geological Disposal of High-Level Radioactive Waste

C1562 Guide for Evaluation of Materials Used in Extended Service of Interim Spent Nuclear Fuel Dry Storage Systems

2.2 *ANSI/ANS Standards:*[3]

ANSI/ANS 8.1-1998 Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors

ANSI/ANS-8.7-1998 Nuclear Criticality Safety in the Storage of Fissile Materials

ANSI/ANS-57.9 American National Standard Design Criteria for Independent Spent Fuel Storage Installation (Dry Type)

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[1] This guide is under the jurisdiction of ASTM Committee C26 on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee C26.13 on Spent Fuel and High Level Waste.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

2.3 *Government Documents:*[4] The U.S. government documents listed in 2.3 or referenced in this standard guide are included as examples of local regulations and regulatory guidance that, depending on the location of the dry storage site, may be applicable. Users of this standard should adhere to the applicable regulatory documents and regulations and should consider applicable regulatory guidance.

Title 10 on Energy, Code of Federal Regulations, Part 60, 10 CFR 60, U.S. Code of Federal Regulations, Disposal of High Level radioactive Wastes in Geologic Repositories

Title 10 on Energy, Code of Federal Regulations, Part 63, 10 CFR 63, U.S. Code of Federal Regulations, Disposal of High-Level Radioactive Wastes in Geologic Repository at Yucca Mountain, Nevada

Title 10 on Energy, Code of Federal Regulations, Part 71, 10 CFR 71, U.S. Code of Federal Regulations, Packaging and Transport of Radioactive Materials

Title 10 on Energy, Code of Federal Regulations, Part 72, 10 CFR 72, U.S. Code of Federal Regulations, Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste

Title 10 on Energy, Code of Federal Regulations, Part 961, 10 CFR 961 U.S. Code of Federal Regulations, Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste SFST-IST-1, Damaged Fuel

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide but not defined herein, refer to Terminology C859 or Practice C1174.

3.2 *Definitions of Terms Specific to This Standard*—Various terms are used internationally for the broad set of definitions related to failed fuel (ref. IAEA Nuclear Energy Series, No NF-T-3.6). In this drying guide, only two fuel conditions that can impact drying behavior are considered (*1*) intact or non-breached fuel; and (*2*) breached or failed fuel.

3.2.1 *breached spent fuel rod, or failed fuel, n*—spent fuel rod with cladding defects that permit the release of gas from the interior of the fuel rod; a breached spent fuel rod may be such that the cladding defects are sufficient to permit the release of fuel particulate; water could enter a breached spent fuel rod of any severity, and thus may adversely impact the ability to dry the fuel to remove this water.

3.2.2 *CRUD, n—in nuclear waste management*, deposits on fuel surfaces from corrosion products that circulate in the reactor coolant.

3.2.2.1 *Discussion*—Compositions of the deposits reflect materials exposed to coolant and activation products formed during irradiation.

3.2.2.2 *Discussion*—The term CRUD was originally an acronym for "Chalk River Unidentified Deposits."

3.2.3 *disposal, n—in nuclear waste management*, the emplacement of radioactive materials and wastes in a geologic repository with the intent of leaving them there permanently.

3.2.4 *getter, n—in nuclear waste management*, a material (typically a solid) used to chemically react with certain gases (for example, H_2, O_2, H_2O vapor) to form a solid compound of low vapor pressure.

3.2.4.1 *Discussion*—Some fuel rod designs include an internal getter to remove residual hydrogen/moisture from the internal rod atmosphere.

3.2.5 *independent spent fuel storage installation (ISFSI), n*—a system designed and constructed for the interim storage of spent nuclear fuel and other radioactive materials associated with spent fuel storage.

3.2.6 *intact SNF, n*—any fuel that can fulfill all fuel-specific and system-related functions, and that is not breached. Note that all intact SNF is undamaged, but not all undamaged SNF is intact, since in most situations, breached spent fuel rods that are not grossly breached will be considered undamaged.

3.2.7 *packaging, or SNF storage container, n—in nuclear waste management*, an assembly of components used to ensure compliance with the applicable requirements for independent storage of spent nuclear fuel and high-level radioactive waste or for transportation of radioactive materials.

3.2.8 *repository, geologic repository, n—in nuclear waste management*, a disposal site, a permanent location for radioactive wastes.

3.2.9 *spent nuclear fuel (SNF), n*—nuclear fuel that has been irradiated in a nuclear reactor and contains fission products, activation products, actinides, and unreacted fissionable fuel.

3.2.10 *sludge, n—in nuclear waste management*, a slurry or sediment containing nuclear waste materials; a residue, generally radioactive, that has usually been formed from processing operations, corrosion, or other similar reactions.

3.2.11 *waste container, n—in nuclear waste management*, the waste form and any containers, shielding, packing, and other materials immediately surrounding an individual waste container.

3.2.12 *water, n—in drying of spent nuclear fuel*, refers to the various forms of H_2O present in the fuel storage container. It is the total amount of moisture (specified by weight, volume, or number of moles) present in a container as a combination of vapor, free or unbound liquid H_2O, physisorbed H_2O, chemisorbed H_2O, and ice. The following specific terms for water are used in this guide:

3.2.12.1 *chemisorbed water, n*—water that is bound to other species by forces whose energy levels approximate those of a chemical bond.

3.2.12.2 *physisorbed water (adsorbed water), n*—water that is physically bound (as an adsorbate, typically by weak forces) to internal or external surfaces of solid material; the binding energy of the first monolayer of water on oxides (for example, ZrO_2) is strong with reduced binding energy of successive monolayers.

[4] The Code of Federal Regulations is available from U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., NW, Washington, DC 20401-0001, http://www.access.gpo.gov.

3.2.12.3 *trapped water, n*—unbound water that is physically trapped or contained by surrounding matrix, blocked vent pores, cavities, or by the nearby formations of solids that prevent or slow the escape of water from the waste package.

3.2.12.4 *unbound/free water, n*—water, in the solid, liquid, or vapor state, that is not physically or chemically bound to another species.

4. Significance and Use

4.1 Drying of the SNF and fuel cavity of the SNF container and its internals is needed to prepare for sealed dry storage, transportation, or permanent disposal at a repository. This guide provides technical information for use in determining the forms of water that need to be considered when choosing a drying process. This guide provides information to aid in (*a*) selecting a drying system, (*b*) selecting a drying method, and (*c*) demonstrating that adequate dryness was achieved (see Annex A2).

4.2 The considerations affecting drying processes include:

4.2.1 Water remaining on and in commercial, research, and production reactor spent nuclear fuels after removal from wet storage may become an issue when the fuel is sealed in a dry storage system or transport cask. The movement to a dry storage environment typically results in an increase in fuel temperature, which may be sufficient to cause the release of water from the fuel. The water release coupled with the temperature increase in a sealed container may result in container pressurization, corrosion of fuel or assembly structures, or both, that could affect retrieval of the fuel, and container corrosion.

4.2.2 Removal of the water associated with the SNF may be accomplished by a variety of technologies including heating, imposing a vacuum over the system, flushing the system with dry gases, and combinations of these and other similar processes.

4.2.3 Water removal processes are time, temperature, and pressure-dependent. Residual water in some form(s) should be anticipated.

4.2.4 Drying processes may not readily remove the water that was retained in porous materials, capillaries, sludge, CRUD, physical features that retain water and as thin wetted surface films. Water trapped within breached SNF may be especially difficult to remove.

4.2.5 Drying processes may be even less successful in removing bound water from the SNF and associated materials because removal of bound water will only occur when the threshold energy required to break the specific water-material bonds is applied to the system. For spent nuclear fuel this threshold energy may come from the combination of thermal input from decay heat, externally applied heat, or from the ionizing radiation itself.

4.2.6 The adequacy of a drying procedure may be evaluated by measuring the response of the system after the drying operation is completed. For example, if a vacuum drying technology is used for water removal, a specific vacuum could be applied to the system, the vacuum pumps turned off, and the time dependence of pressure rebound measured. The rebound response could then be associated with the residual water, especially unbound water, in the system.

4.2.7 Residual water associated with the SNF, CRUD, and sludge inside a sealed package may become available to react with the internal environment, the fuel, and the package materials under dry storage conditions.

4.2.8 Thermal gradients within the container evolve with time, and as a result water vapor will tend to migrate to the cooler portions of the package. Water may condense in these areas. Condensed water will tend to migrate to the physically lower positions under gravity such as the container bottom.

4.2.9 Radiolytic decomposition of hydrated and other water-containing compounds may release moisture, oxygen and hydrogen to the container.

4.2.10 Extended time at temperature, coupled with the presence of ionizing radiation, may provide the energy necessary to release bound or trapped water to the container.

5. Considerations in Drying

5.1 An effective approach to drying SNF will depend on fuel type, fuel condition, fuel basket design, and associated materials (such as the neutron absorber in the basket). There is no single correct or even preferred approach. Intact commercial fuel may be dried by one approach, SNF with breached fuel rods by another approach, and research and production reactor fuels by yet another approach. Furthermore, the variables that must be considered in selecting a drying approach for one fuel type may differ significantly from those that are important for another fuel type. For example, hydride behavior should be considered in fuel systems clad with zirconium-based alloys but is not important to aluminum or stainless steel clad SNF. An effective drying approach will minimize the potential for damage of the fuel during the drying operation and subsequent dry storage. Ref. (**1**) provides additional information regarding vacuum drying.

5.1.1 Some forms of fuel degradation, such as cladding pinholes or cracks, may form before or during the dry storage period without violating design or licensing requirements. However, damage such as small cladding cracks or pinholes formed during the dry storage period could cause the fuel to be reclassified as failed fuel for disposal. Fuel is classified at the time of loading, so the drying process should be chosen to balance the risks caused by the presence of water in the container and the risks incurred by removing the water.

5.2 Thermal cycling during drying of commercial light water reactor SNF may affect the hydride morphology in the cladding (**2**). Heating the SNF during a drying operation may dissolve precipitated hydrides, and subsequent cooling may result in hydride reprecipitation. The hydride orientation and therefore the properties of the fuel cladding may be affected by the dissolution-reprecipitation process.

5.3 Research reactor and other non-commercial SNF that is not treated or reprocessed may be stored in sealed canisters within regulated dry storage systems. Such dry storage canisters may be expected to contain the SNF through interim storage, transport, and repository packaging.

5.4 The following objectives of drying processes are common to most fuels and containers: