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Standard Guide for Pyrophoricity/Combustibility Testing in Support of Pyrophoricity Analyses of Metallic Uranium Spent Nuclear Fuel[1]

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1. Scope

1.1 This guide covers testing protocols for testing the pyrophoricity/combustibility characteristics of metallic uranium-based spent nuclear fuel (SNF). The testing will provide basic data for input into more detailed computer codes or analyses of thermal, chemical, and mechanical SNF responses. These analyses would support the engineered barrier system (EBS) design bases and safety assessment of extended interim storage facilities and final disposal in a geologic repository. The testing also could provide data related to licensing requirements for the design and operation of a monitored retrievable storage facility (MRS) or independent spent fuel storage installation (ISFSI).

1.2 This guide describes testing of metallic uranium and metallic uranium-based SNF in support of transportation (in accordance with the requirements of 10CFR71), interim storage (in accordance with the requirements of 10CFR72), and geologic repository disposal (in accordance with the requirements of 10CFR60/63). The testing described herein is designed to provide basic data related to the evaluation of the pyrophoricity/combustibility characteristics of containers or waste packages containing metallic uranium SNF in support of safety analyses (SAR), or performance assessments (PA) of transport, storage, or disposal systems, or a combination thereof.

1.3 Spent nuclear fuel that is not reprocessed must be emplaced in secure temporary interim storage as a step towards its final disposal in a geologic repository. In the United States, SNF, from both civilian commercial power reactors and defense nuclear materials production reactors, will be sent to interim storage, and subsequently, to deep geologic disposal. U.S. commercial SNF comes predominantly from light water reactors (LWRs) and is uranium dioxide-based, whereas U.S. Department of Energy (DOE) owned defense reactor SNF is in several different chemical forms, but predominantly (approximately 80 % by weight of uranium) consists of metallic uranium.

1.4 Knowledge of the pyrophoricity/combustibility characteristics of the SNF is required to support licensing activities for extended interim storage and ultimate disposition in a geologic repository. These activities could include interim storage configuration safety analyses, conditioning treatment development, preclosure design basis event (DBE) analyses of the repository controlled area, and postclosure performance assessment of the EBS.

1.5 Metallic uranium fuels are clad, generally with zirconium, aluminum, stainless steel, or magnesium alloy, to prevent corrosion of the fuel and to contain fission products. If the cladding is damaged and the metallic SNF is stored in water the consequent corrosion and swelling of the exposed uranium enhances the chemical reactivity of the SNF by further rupturing the cladding and creating uranium hydride particulates and/or inclusions in the uranium metal matrix. The condition of the metallic SNF will affect its behavior in transport, interim storage or repository emplacement, or both, and therefore, influence the engineering decisions in designing the pathway to disposal.

1.6 Zircaloy[2] spent fuel cladding has occasionally demonstrated pyrophoric behavior. This behavior often occurred on cladding pieces or particulate residues left after the chemical dissolution of metallic uranium or uranium dioxide during fuel reprocessing of commercial spent fuel and/or extraction of plutonium from defense reactor spent fuel. Although it is generally believed that zirconium is not as intrinsically prone to pyrophoric behavior as uranium or plutonium, it has in the past ignited after being sensitized during the chemical extraction process. Although this guide primarily addresses the

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[2] Zircaloy, the term, and any of its instances are a trademark of Westinghouse Electric Company. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

pyrophoricity of the metallic uranium component of the spent fuel, some of the general principles involved could also apply to zirconium alloy spent fuel cladding.

1.7 The interpretation of the test data depends on the characteristics of the sample tested and/or the usage to which the test results are put. For example, usage could include simple comparison of the relative ignition temperature of different sample configurations or as inputs to more complex computer simulations of spontaneous ignition. The type and the size of the SNF sample must be chosen carefully and accounted for in the usage of the data. The use of the data obtained by the testing described herein may require that samples be used which mimic the condition of the SNF at times far into the future, for example, the repository postcontainment period. This guide does not specifically address methods for ′aging' samples for this purpose. The section in Practice C 1174 concerning the accelerated testing of waste package materials is recommended for guidance on this subject.

2. Referenced Documents

2.1 *ASTM Standards:* [3]

C 1174 Practice for Prediction of the Long-Term Behavior of Materials, Including Waste Forms, Used in Engineered Barrier Systems (EBS) for Geological Disposal of High-Level Radioactive Waste

C 1431 Guide for Corrosion Testing of Aluminum-Based Spent Nuclear Fuel in Support of Repository Disposal

G 86 Test Method for Determining Ignition Sensitivity of Materials to Mechanical Impact in Ambient Liquid Oxygen and Pressurized Liquid and Gaseous Oxygen Environments

2.2 *CFR Documents:*[4]

10CFR60, US Code of Federal Regulations Title 10, Part 60, Disposal of High Level Radioactive Wastes in a Geologic Repository

10CFR63, US Code of Federal Regulations Title 10, Part 63, Disposal of High Level Radioactive Wastes in Geologic Repositories at Yucca Mountain, Nevada

10CFR72, US Code of Federal Regulations Title 10, Part 72, Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste

10CFR71, US Code of Federal Regulations Title 10, Part 71, Packaging and Transport of Radioactive Materials

40CFR191, US Code of Federal Regulations Title 40 Part 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes

40CFR197, Code of Federal Regulations Title 40, Part 197. 2005 Protection of Environment: Public Health and Environmental Radiation Standards for Yucca Mountain, Nevada

3. Terminology

3.1 *Definitions*—Terms used in this guide are as defined in Practice C 1174 or, if not defined therein as per their common usage, except where defined specifically for this guide as described as follows.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *attribute test*, *n*—a test conducted to provide material properties that are required as input to behavior models, but that are not themselves responses to the environment.

3.2.2 *characterization test*, *n*—in high-level radioactive waste management, any test conducted principally to furnish information for a mechanistic understanding of alteration.

3.2.3 *combustible*, *adj*—capable of burning or undergoing rapid chemical oxidation.

3.2.4 *design bases*, *n*—that information that identifies the specific functions to be performed by a structure, system, or component of a facility and the specific values or ranges of values chosen for controlling parameters as reference bounds for design (see 10CFR72).

3.2.5 *design basis event (DBE)*, *n*—(*1*) those natural and human-induced events that are expected to occur one or more times before permanent closure of the geologic repository operations area (referred to as Category 1 events); and (*2*) other natural and man-induced events that have at least one chance in 10,000 of occuring before permanent closure of the geologic repository (referred to as Category 2 events) (see 10CFR60).

3.2.6 *ignite*, *v*—to cause to burn and reach a state of rapid oxidation, which is maintained without requiring an external heat source.

3.2.7 *interim storage facility*, *n*—a facility for the storage of spent nuclear fuel for 20 years or longer, and which meets the intent of the requirements of an independent spent fuel storage installation (ISFSI) or a monitored retrievable storage facility (MRS) as described in 10CFR72.

3.2.8 *performance assessment (PA)*, *n*—an analysis that identifies the processes and events that might affect the disposal system; examines the effects of these processes and events on the performance of the disposal system; and, estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates shall be incorporated into an overall probability distribution of cumulative release to the extent practicable (see 40CFR191.12).

3.2.9 *pyrophoric*, *adj*—capable of igniting spontaneously under temperature, chemical, or physical/mechanical conditions specific to the storage, handling, or transportation environment.

3.2.10 *safety analysis*, *n*—in high-level radioactive waste management, an analysis whose purpose is to determine the risk to the public health and safety associated with the reception, handling, treatment, packaging, storage, retrieval, transportation, or disposal of spent fuel or high-level waste. (see also Guide C 1431)

3.2.11 *service condition test*, *n*—a test of a material conducted under conditions in which the values of the independent variables characterizing the service environment are in the range expected in actual service.

[3] 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.

[4] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, http://www.dodssp.daps.mil.

3.2.12 *sibling sample*, *n*—one of two or more test samples that are nearly indistinguishable with respect to their chemical and physical properties.

3.2.13 *spent nuclear fuel*, *n*—nuclear fuel that has been irradiated in, and removed from a nuclear reactor.

3.2.14 *waste form*, *n*—the radioactive waste materials and any encapsulating or stabilizing matrix (see 10CFR63.2).

3.2.15 *waste package*, *n*—the waste form and any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container (see 10CFR63.2).

4. Significance and Use

4.1 Disposition of SNF will involve isolation from the accessible environment, placement in a safe and environmentally-sound extended interim storage facility (ISFSI or MRS), and preparation for final disposal in a geologic repository. Disposition will be further complicated in the case of metallic uranium-based SNF if it is damaged/corroded.

4.2 Metallic uranium-based SNF has some unique physical and chemical characteristics, which must be considered in the design, safety analysis, and performance assessment of the planned U.S. geologic repository, that is, those of a reactive metal in a corroded condition. The metallic uranium SNF could be pyrophoric, or combustible, and determination of these characteristics is necessary for the development of EBS design bases and the safety and performance assessment analyses associated with those designs. In particular, repository preclosure design basis event (DBE) analyses and post-containment performance assessment analyses could require pyrophoricity/combustibility data.

4.3 The U.S. Nuclear Regulatory Commission (NRC) has licensing authority over the transportation in the public domain, and the repository emplacement, or interim dry storage, or both, in an ISFSI or MRS, of spent nuclear fuel and high level radioactive waste under the requirements set forth in 10 CFR Parts 71, 60/63, and 72, respectively. These requirements specifically include the following limitations:

4.3.1 10CFR60.135 requires that the waste form be in a solid form and that the waste package be free from significant amounts of liquid, powder, or particulate matter and not contain explosive, pyrophoric, or chemically reactive materials in an amount that could compromise the ability of the underground facility to contribute to waste isolation or the ability of the geologic repository to satisfy the performance objectives. It also requires that all combustible radioactive wastes shall be reduced to a noncombustible form unless it can be demonstrated that a fire involving the waste packages containing combustibles will not compromise the integrity of other waste packages, adversely affect any structures, systems, or components important to safety, or compromise the ability of the underground facility to contribute to waste isolation. The pyrophoricity constraint concerns the systems level performance of the repository, that is, the capability of the underground facility to meet performance requirements, whereas, the waste form combustibility constraint concerns EBS component performance, that is, the effect of waste form combustion on other individual waste packages. A combustible waste form thus does not necessarily mean a pyrophoric waste package. The repository system performance assessment, however, must demonstrate that the assumed combustion of combustible waste forms in their waste packages will not adversely affect other (noncombustible-containing) waste packages, and ignition either will not occur or, if it does occur, will not adversely affect overall repository performance.

4.3.2 Section 43 of Part 71 (packaging and transport) requires that a package must be made of materials and construction, which assure that there will be no significant chemical, galvanic, or other reaction among the packaging components, or between the packaging components and package contents, including possible reaction from inleakage of water to the maximum feasible extent.

4.3.3 Section 122 of Part 72 (interim storage) requires that components important to safety must be designed so that they can continue to perform their safety functions effectively under credible fire and explosion exposure conditions. Noncombustible and heat-resistant materials must be used whenever practical throughout the ISFSI or MRS.

4.4 The metallic uranium SNF characterization activities described in this guide apply to the assessment of such issues as geologic repository disposal waste form combustibility under normal repository (post-closure) environment conditions. They also address waste package pyrophoricity under preclosure DBE or off-normal conditions, interim storage off-normal event consequence analyses, and public domain transportation safety analyses.

4.5 Zirconium spent fuel cladding has also displayed pyrophoric behavior in the past. Pyrophoricity/ignition of zirconium has commonly been associated with cladding pieces and residues resulting from reprocessing operations. These cladding pieces and residues—left after the chemical dissolution of metallic uranium and/or uranium dioxide fuel element cores during fuel reprocessing or extraction of plutonium—have on occasion spontaneously ignited. Although it is generally believed that zirconium is not as intrinsically prone to pyrophoric behavior as uranium or plutonium **(16)** it has in the past spontaneously ignited after being sensitized by the chemical extraction of uranium, **(17)** as a result of an electrical spark or severe physical trauma,**(10)** or as the result of being wetted while fully exposed to air in a storage bin.**(16)** As with uranium metal, zirconium hydride inclusions form in the metal as a byproduct of corrosion and these hydride inclusions are believed to enhance the potential for pyrophoric behavior. Although this guide is focused on the pyrophoric behavior of the uranium in metallic uranium spent fuel, some of the general principles involved could also apply to zirconium spent fuel cladding.

5. Information Needs Related to Pyrophoricity for Interim Storage, Transport, and Disposal

5.1 SSNF characterization and/or accelerated testing should focus on those information needs most pertinent to the SNF form and disposition pathway chosen. The disposal pathway could include continued wet storage in the reactor spent fuel pool,, interim dry storage (per 10CFR72, receipt (per 40CFR197) and emplacement (per 10 CFR60 and 10CFR63) in a geologic repository, and the transport (per 10CFR71) involved in these steps. This guide addresses certain information