Proceedings of the 17th International Symposium on the
Packaging and Transportation of Radioactive Material
PATRAM 2013
August 18-23, 2013, San Francisco, CA, USA

Design Approaches for Transportation of High Burnup Used Fuel

Peter Shih, Director of Design Engineering Group
Transnuclear, Inc., 7135 Minstrel Way Suite 300, Columbia MD 21045, USA
Email: peter.shih@areva.com

ABSTRACT

The approaches for handling high burnup used (HBU) fuels in the USA are, for the most part; at the reactor site (wet storage) and/or dry storage at ISFSI. Both of these storage options are considered as “interim” awaiting eventual recycling or disposal. These HBU fuels eventually need to be “transported” from the reactor site. The HBU fuels stored at reactor site (wet storage) and/or dry storage at ISFSI is licensed to meet the 10CFR Part 50 [1] and 10CFR Part 72 [2], respectively.

Transportation regulations (10CFR Part 71) [3] have several requirements that are different than those for storage. Additionally, compliance requirements to transportation regulations have evolved over the time period that the used fuels have been in storage. Design analysis methods and computer codes have undergone significant changes over time. The current accepted practices and regulatory expectations have also evolved and are different than they were when these systems were designed and licensed for storage.

This paper first will discuss the issues associated with HBU fuel including:

1. Potential for degradation of fuel cladding
2. Uncertainty associated with HBU fuel properties
3. Large radiation source terms

Then this paper will examines some of the challenges and the regulatory compliance requirements for 10CFR Part 71 and how they affect the transportation licensing of HBU fuels:

1. Review the current regulatory requirements, guidance and issues related to transportation of HBU fuels
2. Develop an understanding on some important issues associated with licensing the transportation package with high burnup contents
3. Present perspective on the need for regulatory guidance to resolve emerging issues
4. Present some design approaches for transport licensing of HBU fuels

INTRODUCTION

In the United States of America (USA) and rest of the world, nuclear power plants are using higher performance fuel designs to increase efficiency and reduce fuel cycle costs. This is resulting in fuel with increased U-235 initial enrichments that can support higher burnups up to 70,000 MWD/MTU. These high burnup used (HBU) fuels (greater than 45,000 MWD/MTU and up to 70,000 MWD/MTU) following irradiation in reactor get discharged in the spent fuel pool. Utilities have currently very few options to manage these HBU fuels. The typical options considered and employed are as follows:

1. Use spent fuel pool to store fuels in wet storage depending on the capacity of the spent fuel pool and/or the availability of other options described below
2. Use an appropriately licensed dry storage system to store fuels on-site in dry storage
3. Use an appropriately licensed transportation package to transport these fuels to an interim storage facility, repository, or recycling facility as available

ISSUES ASSOCIATED WITH HBU FUELS

1. Potential for Degradation of Fuel Cladding

The HBU fuels have experienced significantly higher neutron and gamma fluence during irradiation which results in higher potential for cladding degradation compared to fuels with burnups lower than 45,000 MWD/MTU. In addition, for HBU fuels that have been in storage over time, there is also a potential for further degradation of fuel cladding.

2. Uncertainty Associated with HBU Fuel Properties

Some of the important HBU fuel properties are yield strength, tensile strength, modulus of elasticity, creep, hydride reorientation, and ductile-to-brittle transition temperature (DBTT). Testing results from different organizations has shown some of the followings:

- Unirradiated and HBU cladding behave differently
- Different cladding material, including different Zirconium alloys behave differently
- Self-limiting creep in HBU fuels
- Existence of a DBTT below which the cladding becomes brittle
- Hydride reorientation affects DBTT
- DBTT depends on reorientation stress, hydride content, storage history and material composition

3. Large Radiation Source Terms

HBU fuels have significantly higher neutron and gamma source strengths which also result in higher decay heat compared to fuels with burnups lower than 45,000 MWD/MTU. These characteristics have significant impact on the design of the transportation packages that can be used for transporting these HBU fuels.

KEY REGULATORY REQUIREMENTS FOR HBU FUELS

The governing regulatory requirements for the transportation of HBU fuels are based on 10CFR 71.55, "General requirements for fissile material packages" and the specific sections as outlined below:

- 10CFR 71.55(b) subcritical with water in-leakage
- 10CFR 71.55 (d) subcritical under the test specified in 10CFR 71.71: Normal Condition of Transport (NCT), specifically
    - 10CFR 71.55 (d) (2) the geometric form of the package contents would not be substantially altered
- 10CFR 71.55 (e) subcritical under the test specified in 10CFR 71.73: Hypothetical Accident Condition (HAC)

The design of transportation packages to demonstrate compliance to these specific requirements becomes challenging when HBU fuel cladding is considered because of the uncertainty associated with cladding integrity. In summary, demonstration of compliance to these requirements implicitly requires that the fuel cladding integrity is assured during NCT and HAC.

HBU FUEL CHALLENGES FOR TRANSPORTATION

Based on the issues associated with the HBU fuels described above, following are some of the challenges for licensing and transportation of the HBU fuels:

- Uncertainty associated with mechanical properties in particular for transportation following extended storage resulting in potential issues with compliance to 10CFR 71.55 (b), 71.55 (d), and 71.55 (e)
- Benchmarking of computer codes is required to perform calculations to determine decay heat, neutron and gamma source terms
- Ductile Brittle Transition Temperature (DBTT) determination for HBU fuels
- Retrievability, although not required, maybe implied after transportation
- Fuel reconfiguration may be required to demonstrate additional safety margins

DESIGN APPROACHES FOR TRANSPORTATION OF HBU FUELS

In order to demonstrate compliance with the specific regulatory requirements detailed above in consideration with the challenges associated with HBU fuel listed above, a bounding approach can be employed for design and licensing of transport packages. This approach is based on the demonstration of safety (compliance to regulatory requirements governing package performance) irrespective of cladding integrity for both NCT and HAC. Additional details are provided below:

- Licensing Approach for Compliance with 10CFR 71.55 (d)

Due to the uncertainty associated with the properties of the cladding materials for the HBU BWR and PWR fuels, the transportation packaging may be designed to meet 10 CFR Part 71 requirements by not relying upon cladding integrity of the fuels. Then the criticality, thermal and shielding analyses are performed assuming fuel reconfiguration to demonstrate the adequacy of the transportation package design. This approach provides assurance that all applicable regulatory requirements are satisfied even under the non-mechanistic loss of cladding integrity assumed in the safety analyses.

In order to provide reasonable assurance of compliance with 10 CFR 71.55(d)(2), an analytical evaluation may be performed based on available material data for fuel cladding to demonstrate the fuel integrity under NCT. In addition to the structural evaluation of the fuel under NCT, aging management program, administrative controls during unloading, also can provide further assurance of safe transport of HBU fuels. Additional guidance [5] from the NRC for regulatory compliance is currently under preparation and will result in a more informed licensing approach for this purpose.

- Approach for Compliance with 10CFR 71.55 (e)

Moderator exclusion can be employed as a licensing basis to demonstrate compliance with the subcriticality requirements of 10 CFR 71.55 (e). The guidance and criteria provided in Interim Staff Guidance 19 (ISG-19) [4] are employed for this purpose. Specifically, 10CFR 71.55(e)(2) requires that to demonstrate subcriticality under HAC, it must be assumed that "water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents." However, ISG-19 establishes these criteria under which it is possible to demonstrate that the worst case damaged condition of the package does not result in water in-leakage. This allows the criticality calculations to be performed assuming that there is no water in-leakage. Fuel integrity is not credited in the safety analyses for HAC. The thermal and shielding evaluations are performed assuming the worst case fuel reconfiguration to demonstrate compliance to the applicable regulatory requirements.

CONCLUSION

Due to the uncertainty associated with the mechanical properties of HBU fuel cladding, the design and licensing of high capacity transportation packages with HBU fuel contents is very challenging. The licensing approach described herein provides for the use of bounding evaluations assuming worst case fuel damage including reconfiguration to demonstrate compliance to the regulatory requirements for transportation.

As a potential consequence of the Fukushima event, the utilities maybe required to reduce their used fuels inventory in the pool earlier than expected. Some of the fuels will be stored in the ISFSI at the site, some will transport to an interim storage facility, and some will be transported to a final disposal site or a recycling facility. Therefore, design and licensing of transportation packages to transport the HBU fuels become important over the coming years. Significant research is being conducted worldwide on HBU cladding behavior, the results of which are expected to provide for additional assurance on the integrity of HBU cladding under transportation conditions.

References

1. U.S. Code of Federal Regulations, 10 CFR Part 50, Title 10, "Domestic Licensing of Production and Utilization Facilities".
2. U.S. Code of Federal Regulations, 10 CFR Part 72, Title 10, "Licensing Requirements for the Independent storage of Spent Nuclear fuel, High-Level Radioactive, and Reactor-Related Greater Than Class C Waste".
3. U.S. Code of Federal Regulations, 10 CFR Part 71, Title 10, "Packaging and Transportation of Radioactive Material".
4. U.S. NRC, Spent Fuel Project Office, Interim Staff Guidance, ISG-19, Moderator Exclusion under Hypothetical Accident Conditions and Demonstrating Subcriticality of Spent Fuel under the Requirements of 10 CFR 71.55(e).
5. Huda Akhavannik, Division of Spent Fuel Storage and Transportation, U.S. NRC, "Certification/Licensing Approaches for High Burnup Spent Fuel," Regulatory Information Conference, Rockville, March 2013.