THE U.S. DEPARTMENT OF ENERGY'S TRANSPORTATION BURNUP CREDIT PROGRAM

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SUMMARY

Aspects of the U.S. Department of Energy's (DOE's) transportation burnup credit program, the Department's motivation for conducting the program, and the status of burnup credit activities are presented. The benefits, technical, and regulatory considerations associated with using burnup credit for transport of irradiated nuclear fuel are discussed. The methods used in the DOE's actinide-only topical report are described in terms of the technical and regulatory issues.

INTRODUCTION

Since the mid-1980's, DOE has pursued the use of burnup credit for transport of irradiated nuclear fuel. Burnup credit, which recognizes the reduced reactivity of irradiated fuel in demonstrating criticality safety, offers a means of increasing capacities for transport casks used in the U.S. nuclear waste management program. The waste management program which is prescribed by the Nuclear Waste Policy Act, as amended (U.S. Pub.L., 1987), calls upon DOE to manage the disposition of irradiated (spent) nuclear fuel generated by commercial reactors in the U.S. One of DOE's responsibilities under the Act is the transport of the spent fuel to federal waste management facilities. Before initiating this activity, studies were conducted to assess the potential benefits of using burnup credit, and to determine the technical and regulatory issues that would have to be addressed to permit its use in the U.S. (Sanders et al., 1987).

Spent fuel accepted for disposal in the U.S. will out of a reactor for at least five years. Casks used to transport older, colder spent fuel, can accommodate closer packing of fuel due to reduced heat generation by the fuel and a lessening of thermal constraints. For criticality control in multi-assembly casks, spent fuel has generally been treated as unused or "fresh fuel," and the thermally required geometric separation accommodates the use of flux traps for criticality control. In the U.S., spent pressurized water reactor (PWR) fuel will be transported dry, but assumed flooded with water for demonstrating subcriticality. The flux trap forms a gap between neutron absorber plates that surround each assembly, and comprise the fuel basket. Under the assumed flooded condition, the gaps become filled with water which moderates the neutrons, enhancing the effect of the neutron absorber plates. A flux trap is usually needed when the fresh fuel assumption is used for multi-assembly PWR cask designs.

For older fuel, the spacing inherent in the flux trap is not needed for thermal control, and their elimination is possible if not needed for criticality. Burnup credit which accounts for the spent fuel's reduced reactivity eliminates the need for flux traps, and offers an opportunity to significantly increase cask capacities. Benefits of increased capacity and fewer shipments include reduced worker and public exposure resulting from cask preparation and transport, reduced transportation risks (radiological and non-radiological), and reduced costs.

Cask designers and regulators who comprise the technical community, generally agree that burnup credit can be accomplished; they also agree on the specific issues that need to be addressed. The issues, however, are somewhat complex, and the available data although believed by some to be adequate, are somewhat limited, making resolution of regulatory concerns a challenge. The three major issues are calculational methods used to demonstrate subcriticality, experiments used to validate the calculational methods, and reliable implementation of burnup credit. The process to resolve these issues was formally started in the U.S. when the actinide-only burnup credit topical report was submitted to the U.S. Nuclear Regulatory Commission (NRC) in May 1995 (DOE, 1995). DOE is evaluating the advantages available from additional burnup credit beyond the actinide-only method which is currently being reviewed by the NRC.

ESTIMATED BENEFITS AVAILABLE FROM BURNUP CREDIT

Use of burnup credit can increase cask capacities, and result in fewer shipments and reduced transportation costs. The economic benefits of using burnup credit in the U.S. for storage and transport have been reported (Lake, 1997). Analysis is presented here for transportation.

If no new reactor orders are assumed in the U.S., about 132,000 PWR assemblies will eventually have to be shipped to a repository. Two transport systems are considered, a legal weight truck cask system, and a large canistered rail cask system (which weighs about 112 tonnes or 125 tons). To accommodate a cost-benefit analysis, a number of assumptions are made about casks and transport systems that may be used. Both cask systems have a 25-year life, and each has an average round trip shipping distance of about 8000 km (5,000 miles). A truck shipment costs $US 38,000, and a truck cask which costs $US 3.5 million can make 500 shipments in a lifetime which is $US 7,000 a shipment. The resulting total cost is $US 45,000 a shipment. A rail cask shipment costs $US 76,000, and the reusable cask which costs $US 4.25 million can make 200 shipments in its lifetime which is $US 21,250 a shipment. The resulting total cost is $US 97,250 a shipment.

Rail systems currently being developed in the U.S. are canister based storage/transport types. They consist of a non-reusable canister which is used to hold spent fuel for storage and transport, a reusable transport module, and storage module which is not reusable. The canister, which is not considered in this analysis is assumed to cost $US 300,000. It should be noted that the canister of a dual purpose, or storage transport cask, serves as a fuel basket for transport. For a single purpose, or transport only cask, a reusable fuel basket would be needed for each reusable transport cask. However, this cost was not included in this analysis.

The truck cask is assumed to carry four PWR assemblies with burnup credit, and two without burnup credit. The canisters which dictate the rail cask capacities are assumed to carry 32 PWR assemblies with burnup credit, and 24 without burnup credit. Although capacities vary depending on burnup credit use, transportation and hardware costs are assumed independent of capacity.

The costs for shipping all 132,000 PWR assemblies by truck, using the above assumptions are $US 2.97 billion without burnup credit and $US 1.49 billion with burnup credit. That is, burnup credit could save $US 1.48 billion for a truck only system. The total costs for a system with all shipments made by rail are $US 535 million without burnup credit and $US 401 million with burnup credit. That is, burnup credit could save $US 134 million for a rail only system. These results indicate that rail transport, because it is less costly, should be maximized, and burnup credit used for either transport mode.

This analysis neglects a number of factors that could impact costs and savings. On the savings side, such things as reduced worker exposure and handling at reactors and receipt facilities are neglected. On the cost side of burnup credit, such things as design, development, and implementation costs are neglected. Finally, the predicted savings may be reduced somewhat by the degree of burnup credit used, and other cask capacity limitations not considered in this analysis.

TECHNICAL CONSIDERATIONS

A substantial amount of data and experience exists for demonstrating criticality safety for transport casks using the fresh fuel assumption. This information, supplemented with additional technical data specific to burnup credit, will provide a technical basis for using burnup credit.

Computer programs are available to predict isotopic inventories for spent fuel, and to perform criticality safety analysis for casks containing spent fuel. Although these analysis tools are used with confidence for various applications, using them for demonstrating criticality safety for transport casks using burnup credit will require additional justification.

Depletion codes are used routinely for reactor core analyses, and isotopic prediction for shielding safety analyses for transport casks. However, for demonstrating criticality safety for transport casks that use burnup credit, additional chemical assay data may be needed to benchmark these computer codes. The assay data should be developed with sufficient precision, and should include all fissile elements, and the neutron absorbing actinides and fission products that will be considered when using burnup credit. Since the fissile isotopes all contribute to reactivity, none should be ignored. However, nonfissile actinides and fission products which are neutron absorbers that decrease reactivity can be ignored. The choice of which neutron absorbers to be considered and which are to be ignored is generally dictated by balancing the difficulty of obtaining the necessary nuclear data and the benefits derived in terms of negative reactivity obtained for the isotopes of interest.

Additional benchmarks for criticality analysis computer codes that account for burnup credit may also be needed. A number of fresh fuel critical experiments are available and applicable for criticality analysis of systems using burnup credit. These experiments address the fissile uranium concentration for fresh fuel (i.e., U-235) and the effects of various materials of construction and geometries for spent fuel transport casks. There are also a number of experiments performed on mixed oxide (MOX) fuel which would be applicable to the actinide-only burnup credit method. The MOX experiments would provide data on the fissile actinides and various actinide absorbers that may be present in spent fuel. Additional experiments may be required to provide data for fission products that might be considered for burnup credit. Because these effects can be treated independently, a set of isotope specific experiments can be used to account for the variables of interest for burnup credit.

A characteristic of spent fuel that is important to criticality safety is the axial distribution of burnup. For PWR reactors which are controlled by borated water, the axial distribution of burnup is fairly uniform over the central region. Because of the higher neutron leakage at the top and bottom ends of a reactor core, fuel assemblies tend to be underburned in these regions. The resulting increased reactivity at the ends is the so-called "end-effect." This is of not important for the fresh fuel assumption, since all fuel is assumed to be unburned; however, it is a factor for spent fuel.

Using the fresh fuel assumption requires assurance that spent fuel loaded into a transport cask meets the fuel specifications that pertain to criticality safety. These specifications are the initial enrichment and identification of the fuel design. Assurance of proper cask loading for the fresh fuel assumption is accomplished by administrative control. For burnup credit an additional factor must be assured. That is, burnup must be meet the minimum burnup required for the fuel's initial enrichment. The operation of a nuclear reactor requires the collection and retention of burnup data. It is believed that this data is adequate to assure knowledge of a spent fuel assembly's burnup. Verification of the assembly's burnup can be accomplished by currently practiced administrative controls could be enhanced to include a measurement of burnup.

REGULATORY CONSIDERATIONS

The NRC transportation regulations require subcriticality for transport casks. However, these regulations do not elaborate on how subcriticality should be assured, nor do they prohibit the use of burnup credit for criticality safety (NRC, 10 CFR 71, 1996).

The NRC has, in the past, approved one cask which uses burnup credit. This cask, the Model NLI-6502 (NRC certificate of compliance no. 9103) is used to ship highly enriched research reactor fuel. However, in the case of commercial light water reactor spent fuel, the NRC has established a long standing precedent of assuming that spent fuel is unburned.

DOE began discussions with NRC on using burnup credit for transport of spent fuel in 1988. A number of issues were identified, but remained unresolved for some time. To accelerate resolution of issues related to using burnup, DOE and the NRC initiated a series of technical exchange meetings. Several technical exchange meetings have been held since November 1993 to address DOE's ongoing burnup credit activities.

DOE was developing a topical report on the use of burnup credit for the transportation of spent fuel for submittal to NRC by the end of 1994. The report would have considered the net fissile content (fissile actinides), actinide absorbers, and fission products present in spent fuel. Based on a recommendation by the NRC, submittal of this Topical Report was delayed, and a revised method which only considered actinide contributors to reduced reactivity was developed. The topical report for the actinide-only approach to burnup credit was submitted to NRC in 1995.

Knowledge of the specific isotopes and their concentrations are needed to perform criticality safety analyses for spent fuel. For fissile isotopes and neutron absorbing isotopes, absorption data must also be known (e.g., cross section data). This data already exists for fissile and neutron absorbing actinides. DOE has developed some chemical assay data for selected fission products (Bierman and Talbert, 1994). However, NRC has suggested that DOE enhance the existing fission product data if burnup credit activities are expanded beyond the current actinide-only approach.

Benchmarking of criticality safety analyses tools against appropriate critical experiments is the normal practice for design of spent fuel transport casks. Laboratory type experiments are available for fresh fuel, mixed oxide fuel (containing uranium and plutonium oxides), and several fresh fuel experiments having fuel doped with gadolinium. To account for the fission product contribution to burnup credit, critical experiments must be performed for the fission products of interest.

The issue of end effects was identified by NRC as a potential concern in using burnup credit (Marotta, 1989). DOE believes that end and other modeling considerations effects can be bounded in performance by criticality safety analysis (Marotta, et. al., 1992, Kang and Lancaster, 1997).

The loading of any transportation cask requires administrative controls and reliance on utility records. The utility records are subject to NRC rules and regulations through the reactor operating licenses (NRC, 10 CFR Part 50, 1997). Administrative controls for loading transport casks are subject to the same rules. The NRC staff responsible for transportation cask certification has suggested that utility records and administrative controls alone may not be sufficient for transport casks which use burnup credit, and have recommended using measurements to verify cask loading procedures. DOE believe that utility records and administrative controls which are subject to NRC's operating reactor licensing procedures will prove to be adequate, but plans to use a measurement device to verify proper cask loading. As experience is gained with burnup credit, and statistical data on cask loading is developed, DOE may seek revision from NRC for this verification approach.

DOE had originally planned to rely on industry to provide methods for burnup verification. Although this did not happen, it became evident that identifying and demonstrating such a device would expedite NRC's review and acceptance of burnup credit. A verification method using passive gross gamma and neutron measurement of individual spent fuel assemblies was identified by DOE (Ewing and Bierman, 1992). The device was later used by the Electric Power Research Institute, Sandia National Laboratories, and others to perform proof of principle tests (Ewing, et. al., 1994 and 1997). Recently, BNFL Instruments has offered a measurement service to utilities that uses gamma spectrometry, paving the way for DOE to reestablish its plan to leave this activity to the private sector.

THE DOE REPORT ON ACTINIDE-ONLY BURNUP CREDIT

DOE submitted a Topical Report on Actinide-Only Burnup Credit to the NRC in 1995 (DOE, 1995). The NRC has reviewed the report and requested additional information from DOE (Travers, 1996). A revised Topical Report on Actinide-Only Burnup Credit was completed and submitted to the NRC (DOE, 1997). DOE anticipates approval of this method by the NRC sometime in 1998.

The revised Topical Report on Actinide-Only Burnup Credit for PWR Spent Nuclear Fuel Packages describes a method for performing and applying nuclear criticality safety calculations using actinide-only burnup credit. The changes in the U-234, U-235, U-236, U-238, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, and Am-241 concentration that result from burnup are used in burnup credit criticality analyses. No credit is taken for fission product neutron absorbers.

The method described in the topical report consists of five major steps. These include validation of depletion codes, validation of criticality codes, treatment of end effects and other modeling considerations, generation of spent fuel loading curves, and loading verification procedures.

Validation of a computer code system to calculate isotopic concentrations of spent fuel created during burnup in the reactor core and subsequent decay is required. A set of 54 chemical assays are presented for this purpose of benchmarking depletion codes. The report also presents a method for assessing the calculational bias and uncertainty, and conservative procedures for applying correction factors for each isotope. Additional information related to validation of isotopics is included in a separate technical report (Rahimi, et al., 1997)

Validation of a computer code system used to predict the subcritical multiplication factor, k_{eff}, of a spent fuel cask is also required. Fifty-seven UO_2, UO_2/Gd_2O_3, and UO_2/PuO_2 critical experiments have been selected to cover anticipated conditions of spent fuel. The method uses an upper safety limit on k_{eff} (which can be a function of trending parameters) to assure that the calculated k_{eff} when increased for the bias and uncertainty is less than 0.95. Additional information related to criticality code validation is included in a separate technical report (Rahimi, et al., 1997)

Three bounding axial profiles are established for the isotopic concentration and criticality calculations. The three bounding profiles were established from examination of 3,169 axial profiles, to assure the "end effect" is accounted for conservatively. Additional information related to axial effects and other modeling assumptions are included in a separate technical report (Kang and Lancaster, 1997).

The validated codes and bounding conditions are used to generate cask loading criteria (burnup credit loading curves). Burnup credit loading curves show the minimum burnup required for a given initial enrichment. The NRC licensed utility's burnup record is compared to this minimum burnup requirement after the utility accounts for the uncertainty in its record. Separate curves may be generated for each assembly design, various minimum cooling times, and burnable absorber histories.

Verification that spent fuel assemblies meet the package loading criteria and confirmation of proper assembly selection prior to loading must be performed. A measurement of the average assembly burnup is required. The measurement must be within 10% of the utility burnup record for the assembly to be accepted, and the measurement device must be accurate to within 10%.

Each step is described in detail for use with any computer code system and is then demonstrated with the SCALE 4.2 computer code package using 27BURNUPLIB cross sections. However, the procedures described are intended for general use, and could be used with other calculational systems.

CONCLUSIONS

For spent fuel transport associated with U.S. federal waste management activities, the use of burnup credit promises significant reductions in shipments and associated transport costs. Other benefits that may accrue from using burnup credit, that are not quantified in this paper, include: reduced worked and public exposure, and reduced risks from spent fuel transport.

Technical issues associated with using burnup credit for spent fuel transport are understood and agreed upon by DOE and NRC. DOE is currently working to resolve these issues to the satisfaction of the NRC for an actinide-only method. Approval of the actinide-only approach to burnup credit is expected sometime in 1998. DOE is assessing continuation of its burnup credit activities beyond the current scope.

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