Abstract

The paper describes burnup credit activities being conducted in the U.S. where burnup credit is either being used or being planned to be used for storage, transport, and disposal of spent nuclear fuel. Currently approved uses of burnup credit are for wet storage of PWR fuel. For dry storage of spent PWR fuel, burnup credit is used to supplement a principle of moderator exclusion. These storage applications have been pursued by the private sector. The Department of Energy (DOE) which is an organization of the U.S. Federal government is seeking approval for burnup credit for transport and disposal applications. For transport of spent fuel, regulatory review of an actinide-only PWR burnup credit method is now being conducted. A request by DOE for regulatory review of actinide and fission product burnup credit for disposal of spent BWR and PWR fuel is scheduled to occur in 1998.

1. INTRODUCTION

The US does not reprocess its spent nuclear fuel, and the fuel is stored at about 100 reactor sites in pools or in dry storage units. Furthermore, there is little expectation that new reactors will be built. A geological repository is planned for the ultimate disposal of this material as a nuclear waste. The US expects to receive about 84,000 tU of spent nuclear fuel after the end-of-life for all current reactors. After a start-up period, the fuel will be accepted into the Civilian Radioactive Waste Management System (CRWMS) at a rate of about 3,000 tU per year. Figure 1 shows the location of U.S. commercial reactor sites and other sources of radioactive materials that will be disposed of as waste. The proposed disposal site at Yucca Mountain is located in the southeast corner of Nevada.

Light water reactor systems which are used by the US commercial nuclear power industry use fuels with low concentrations of fissile uranium (typically less than 5% initial concentration of U-235 by weight). The fission process consumes the fissile U-235 and produces new isotopes which include various actinides and fission products. The actinides produced include fissile materials (e.g., Pu-239 and Pu-241) and neutron absorbers (e.g., Pu-240 and Pu-242). Hundreds of fission products are also produced; however, only a small number of them are significant neutron absorbers.

Only spent fuel that has been discharged from a reactor and cooled five years or more will be accepted into the CRWMS. This older fuel has undergone significant and rapid decay of its gamma and heat emitting radioactive contents, and the neutron absorbers have begun to stabilize. The reactivity potential of the spent fuel continually decreases for a few hundred years after discharge from the reactor. Then slight, but continued, increases in reactivity occur, peaking at between 10,000 and 30,000 years, the cycle repeats, peaking again at about 300,000 years and decreasing thereafter. However, these peaks in reactivity do not exceed the value at five years after discharge.

In the U.S., the use of burnup credit for spent fuel management has been pursued by the private sector and by the Federal government. The private utility companies and their member sponsored research and development organization, the Electric Power Research Institute (EPRI), have pursued burnup credit for various storage applications. Burnup credit development activities conducted by the US Federal government have been performed primarily by DOE. DOE began these efforts in the mid-1980's to support its CRWMS activities which included storage, transportation, and disposal of spent nuclear fuel from light water reactors. In 1995, the DOE submitted a topical report to the Nuclear Regulatory Commission (NRC) for the use of actinide-only burnup credit for transport of PWR fuel (DOE, 1995). The NRC has reviewed the report and given comments to DOE, and a revised report was submitted to them in May 1997 (DOE, 1997).
FIG. 1. Nuclear Fuel and High-Level Radioactive Waste in the United States
The private sector has generally been interested in burnup credit, and has been successful in its efforts to gain approval for burnup credit in wet (pool) storage applications. Industry has been actively involved in the transportation and storage aspects of burnup credit conducted by the DOE. EPRI has been a focal point for industry involvement in burnup credit. EPRI has consulted with DOE on burnup credit, and has conducted a number of activities that have been beneficial to the DOE's efforts. EPRI is a research and development organization funded by member utility companies. Recently, EPRI has increased its involvement, and cask vendors, instrumentation and transport service organizations, and utilities have become involved in burnup credit activities.

The DOE also plans to use burnup credit for disposal of spent nuclear fuel. The waste package (WP) which is being designed for disposal of spent nuclear fuel in a deep geological repository is expected to provide criticality control during some time period after disposal. Currently, the design life of the WP is expected to be about 3,000 years, while the licensing period for the repository is 10,000 years or more. Since the licensing period for a repository will exceed the life expectancy for the WP and its engineered criticality control systems, the need to consider the actual reduced reactivity of spent nuclear fuel is evident.

2. STORAGE

2.1. Wet Storage

2.1.1. Wet Storage of PWR Spent Fuel

To accommodate increased inventories of spent fuel which must be stored at US reactor sites, some utility companies have relied on their existing fuel storage pools. Most of these pools were designed for a reprocessing economy and were never intended to accommodate a reactor's lifetime inventory. Some utility companies have used burnup credit to increase storage capacities at their PWR fuel pools. The NRC has approved burnup credit for these pools, but only if boron content of pools is also considered for criticality safety (Lesko and Newmyer, 1997).

For approval, a utility company must first show equivalence between reactivities of burned and unburned systems at different initial enrichments (initial U-235 concentrations). For example, a pool approved for 3% enriched fuel with no burnup may be used for 4% enriched spent fuel if the burnup of the spent fuel is sufficient so that reactivity of the two systems are shown to be equivalent. The utility company must also show that some minimum boron concentration in the pool has enough negative reactivity to provide for a 5% criticality safety margin, and cover any uncertainties associated with the use of burnup credit.

There are also a number of other conservative assumptions used in this approach. The reactivity equivalence uses a harder than normal depletion spectrum to maximize the predicted production of fissile actinides. Not all fission products are considered in determining reactivity equivalence. Also, boron concentrations are generally three to four times higher than the minimums predicted for the 5% margin and uncertainties. Recently, the utility industry has gotten NRC approval for consideration of actinide decay effects on reduced reactivity.

2.1.2. Wet Storage of BWR Spent Fuel

BWR pools do not contain boron, and burnup credit is not used.

2.1.3. Wet Storage of MOX Spent Fuel

The US does not use MOX reactors.
2.1.4. Wet Storage of WWER Spent Fuel

The US does not use WWER reactors.

2.2. Dry Storage

2.2.1. Dry Storage of PWR Spent Fuel

Once burnup credit is approved for dry transport of spent PWR fuel, it can also be used for dry storage applications. Currently a moderator exclusion concept may be used for dry PWR storage systems. Under this approach, a storage cask is loaded in a borated pool, and later located at a storage site having no possibility of water intrusion. The minimum boron concentration that is determined necessary to achieve a 5% criticality safety margin must be maintained during cask loading. To accommodate possible off-normal and accident conditions, a criticality analysis is also performed for a cask flooded with fresh (non-borated) water. For storage configurations not having a minimum 5% criticality safety margin when flooded with fresh water, burnup credit is used to show that the necessary margin is achieved. The approach works in some cases for storage only systems, but cannot be used for storage transport systems because a claim of moderator exclusion can not be used for transport.

Many of the NRC approved storage only systems were developed with plans of later seeking NRC approval for transportation as well as storage. Systems now under development are typically dual purpose systems for storage and transport rather than single purpose (storage or transport). For many of the existing PWR storage units that use moderator exclusion, burnup credit will have to be used if they are to be transported at some time after the at-reactor storage period ends. For PWR systems now being developed, moderator exclusion may still be used while the use of burnup credit continues to be reviewed by the U.S. regulatory authorities, allowing to continue a practice that assures maximized cask capacities.

If no new reactors are assumed in the U.S., about 132,000 spent PWR fuel assemblies will have to be stored at reactors or at a Federal storage facility. If a canistered dual purpose system is assumed the cost of storage with and without burnup credit can be estimated. What follows is a simple cost estimate for hardware associated with storage of spent PWR fuel. The storage system consists of a canister and storage overpack. A canister is assumed to cost at least $US 300,000, and an overpack is expected to cost at least $US 150,000. The canister is assumed to hold 24 PWR assemblies without burnup credit, and 32 assemblies with burnup credit. For this cost model a no burnup credit storage system would cost $US 2,475 million, while a burnup credit storage system would cost $US 1,856 million. The analysis shows a savings from burnup credit of $US 619 million. The results of the storage cost analysis are summarized and presented in Table 1.

2.2.2. Dry Storage of BWR Spent Fuel

There are currently no plans to pursue burnup credit for BWR spent fuel.

2.2.3. Dry Storage of MOX Spent Fuel

The US does not use MOX reactors.

2.2.4. Dry Storage of WWER Spent Fuel

The US does not use WWER reactors.
TABLE 1. STORAGE COST ANALYSIS

<table>
<thead>
<tr>
<th></th>
<th>UNITS</th>
<th>NO BURNUP CREDIT</th>
<th>BURNUP CREDIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWR INVENTORY (Number of assemblies)</td>
<td>#</td>
<td>132,000</td>
<td>132,000</td>
</tr>
<tr>
<td>CANISTER CAPACITY</td>
<td>#</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>NUMBER OF CANISTERS</td>
<td>#</td>
<td>5,500</td>
<td>4,125</td>
</tr>
<tr>
<td>CANISTER COST</td>
<td>$US 1,000</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>OVERPACK COST</td>
<td>$US 1,000</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>STORAGE UNIT COST</td>
<td>$US 1,000</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>STORAGE COST FOR PWR INVENTORY</td>
<td>$US Million</td>
<td>2,475</td>
<td>1,856</td>
</tr>
<tr>
<td>COST AVOIDED FROM USING BURNUP CREDIT</td>
<td>$US Million</td>
<td></td>
<td>619</td>
</tr>
</tbody>
</table>

3. TRANSPORTATION

3.1. Wet Transportation

Water cooled casks are not used to transport spent fuel in the US

3.1.1. Wet Transportation of PWR Spent Fuel

Not applicable.

3.1.2. Wet Transportation of BWR Spent Fuel

Not applicable.

3.1.3. Wet Transportation of MOX Spent Fuel

The US does not use MOX reactors.

3.1.4. Wet Transportation of WWER Spent Fuel

The US does not use WWER reactors.

3.2. Dry Transportation

3.2.1. Dry Transportation of PWR Spent Fuel

DOE’s initial motivation for pursuing burnup credit for transportation was to support its advanced technology cask development program. The use of burnup credit for weight limited transport cask designs can lead to increased capacity, fewer shipments, reduced costs, and reduced risk and exposure to workers and the public. Based on DOE’s experience with transport casks developed in the US, burnup credit will be used for PWR fuel where it has enabled the elimination of flux traps which results in increased cask capacity. Cost benefits of using burnup credit are presented here for transportation of spent PWR fuel.
If no new reactor orders are assumed in the US, 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 that weighs about 125 tons (113 tonnes). 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 8,050 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. The assumptions used in the transport cost analysis are presented in Table 2.

### TABLE 2. TRANSPORT COST ASSUMPTIONS

<table>
<thead>
<tr>
<th>TRANSPORT MODE</th>
<th>TRUCK</th>
<th>RAIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRAVEL DISTANCE (ROUND TRIP - km)</td>
<td>8,050</td>
<td>8,050</td>
</tr>
<tr>
<td>COST PER CASK TRIP ($US)</td>
<td>38,000</td>
<td>76,000</td>
</tr>
<tr>
<td>CASK UNIT COST ($US Million)</td>
<td>3.5</td>
<td>4.25</td>
</tr>
<tr>
<td>CASK LIFE (YEARS)</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>ROUND TRIPS IN A LIFETIME</td>
<td>500</td>
<td>200</td>
</tr>
<tr>
<td>COST PER SHIPMENT ($US)</td>
<td>45,000</td>
<td>97,250</td>
</tr>
</tbody>
</table>

Rail systems currently being developed in the US are canister based storage/transport types. They consist of a non-reusable canister which holds spent fuel for storage and transport, a reusable transport module, and a storage module, which is not reusable. The canister, which is not considered in this transport cost 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, the increased cost of the basket for a single use cask 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 use of canisters which can 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 1.485 billion with burnup credit. That is, burnup credit could save $US 1.485 billion for an all truck 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 an all rail system. These results indicate that rail transport, because it is less costly, should be maximized, and burnup credit used for either transport mode. The results of the transport cost analysis are summarized and presented in Table 3.

This simple cost model 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. Furthermore, the predicted savings may be reduced somewhat by the degree of burnup credit used, and other cask capacity limitations not considered in this analysis. Finally, it should be noted that the DOE will not handle fuel at reactor sites, and utilities will be responsible for costs associated with cask loading at their reactor sites. The individual utilities will
need to balance savings from using burnup credit against costs of implementation. One such cost will be the cost of measuring burnup.

**TABLE 3. TRANSPORT COST ANALYSIS**

<table>
<thead>
<tr>
<th></th>
<th>TRUCK</th>
<th>RAIL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO BURNUP CREDIT</td>
<td>BURNUP CREDIT</td>
</tr>
<tr>
<td><strong>PWR INVENTORY (Number of assemblies)</strong></td>
<td>132,000</td>
<td>132,000</td>
</tr>
<tr>
<td><strong>CASK CAPACITY</strong></td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td><strong>NUMBER OF SHIPMENTS</strong></td>
<td>66,000</td>
<td>33,000</td>
</tr>
<tr>
<td><strong>COST OF SHIPPING ENTIRE INVENTORY ($US Million)</strong></td>
<td>2,970</td>
<td>1,485</td>
</tr>
<tr>
<td><strong>AVOIDED COST FROM USING BURNUP CREDIT ($US Million)</strong></td>
<td>---</td>
<td>1,485</td>
</tr>
</tbody>
</table>

In May 1995, the DOE submitted a topical report to the NRC for actinide-only burnup credit for transport of irradiated PWR fuel. The topical report describes a general method for burnup credit design, provides specific data for benchmarking depletion and criticality codes with examples for the SCALE system, and provides a general approach to verify fuel loading by measurement. The NRC reviewed the report and requested additional information on March 22, 1996 (Travers, 1996). In response, the DOE submitted a revised topical report in May 1997. Once the NRC approves the methods and data proposed for actinide-only burnup credit, they may be used by cask designers who apply for NRC approval of burnup credit for specific casks.

The technical issues that have been identified, and are being addressed for actinide-only burnup credit for PWR fuel, are benchmarking for depletion and criticality codes, modeling effects (e.g., axial distribution of burnup, horizontal gradients), and cask loading verification. Approval of the DOE's actinide-only topical report by the NRC is expected sometime in 1998. Once the methods described in the actinide-only report are approved by NRC, the DOE will consider the possibility of expanding its burnup credit efforts by seeking additional burnup credit.

DOE is currently assessing options to pursue burnup credit for PWR spent fuel beyond the limited actinide-only approach. A number of factors impact this assessment, including technical feasibility, cost, and benefits. If DOE pursues the use of fission products it will not be initiated until NRC accepts and approves the current actinide-only approach. Also, only a limited number of fission products would be used for burnup credit.

### 3.2.2. Dry Transportation of BWR Spent Fuel

In the case of BWR fuel, technical issues are expected to be more difficult than for PWR fuel. Furthermore, increased cask capacities are not expected because current BWR cask designs do not need flux traps for criticality control. Although burnup credit for transport of irradiated BWR fuel could lead to cost savings from decreased poison content in fuel baskets (e.g., boron), it is not being considered at this time.

### 3.2.3. Dry Transportation of MOX Spent Fuel

The US does not use MOX reactors.
3.2.4. Dry Transportation of WWER Spent Fuel

The US does not use WWER reactors.

4. REPROCESSING

Reprocessing of commercial nuclear fuel is not done in the US.

5. DISPOSAL

The use of burnup credit for disposal of irradiated fuel is needed to demonstrate criticality control in the current WP and repository designs. For the longer term, it can provide a means of demonstrating criticality control for a repository beyond the time period that the integrity of engineered criticality control features of a WP can be guaranteed. The methodology used for demonstrating long-term criticality control is both probabilistic and deterministic. For comparing alternative criticality control designs probabilistic methods are being used to weigh the importance of potential hazards and degradation modes. Deterministic criticality analysis is used to predict fuel and waste package behavior for the specific degradation modes and hazards of regulatory importance. For the disposal case, the DOE will consider burnup credit for both BWR and PWR irradiated fuel.

DOE plans to submit a topical report for disposal criticality to the NRC in 1998. In preparation for that submittal the DOE has prepared and issued a technical report on the methods it is developing to address disposal criticality. The DOE has also had a number of formal technical exchange meetings with the NRC on the subject.

6. CONCLUSIONS

In the U.S., the ability to use burnup credit for spent fuel management is being pursued by both the private sector and the Federal government. The use of burnup credit for wet and dry storage of spent PWR fuel has been pursued by the private sector. These applications of burnup credit, for spent fuel storage has been approved by the NRC. The use of burnup credit at reactor storage pools has been motivated by the need to store more fuel at reactor sites until a Federal facility becomes available to receive commercially generated spent fuel. For the same reason, the private sector has also gotten NRC approval for moderator exclusion for dry storage of spent PWR fuel. Approvals of this type are supplemented by reliance on burnup credit, where necessary, to show that a minimum 5% criticality safety margin has been achieved for an assumed fresh water flooding situation. The Federal government is seeking NRC approval for PWR actinide-only burnup credit for transport of spent fuel, and actinide and fission product burnup credit for disposal of PWR and BWR spent fuel. Reducing the number of spent fuel shipments which can result in reduced radiation exposure, reduced risk, and cost reduction is the primary motivating factor for using burnup credit for transport. For disposal, burnup credit is considered necessary to achieve an effective and efficient disposal facility.

REFERENCES