# BR-100 Spent Fuel Shipping Cask*

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## INTRODUCTION

The Nuclear Waste Policy Act of 1982 mandates that the U.S. Department of Energy (DOE)* establish an integrated waste management system leading to permanent, deep geologic disposal of spent nuclear fuel and high-level wastes. The transportation component of this system must satisfy requirements of safety, reliability, and schedule. System interfaces include the utilities' reactor sites and other radioactive waste generators, the monitored retrievable storage (MRS) facilities, and the receiving facilities at the geologic repositories. As part of this program, B&W Fuel Company (BWFC) is under contract to the DOE to develop a Nuclear Regulatory Commission (NRC) certified shipping cask for spent nuclear fuel that is compatible with both rail and barge modes of transportation.

The BR-100, shown in Figure 1, is a 100-ton rail/barge cask with a capacity of 21 PWR or 52 BWR 10-year cooled, intact fuel assemblies. Optional basket designs may permit licensing the cask for a variety of payloads, including consolidated fuel. The BR-100 uses a multi-layer cask body construction with lead gamma shielding and borated concrete neutron shielding sandwiched between stainless steel shells. Copper fins embedded in the concrete enhance the heat transfer through the concrete during normal operations, while during the fire accident, localized release of steam formed on the outside of the concrete retards the heat flow into the cask. The thicknesses of lead and concrete layers are established by the shielding analysis so that the external dose rates for the cask packaging will be below the limits set by 10CFR71. The all-aluminum basket consists of a central cluster of square fuel cells surrounded by circle-to-square formers, which provide lateral support and an efficient heat path. Flux traps are formed by water gaps between high density $B_4C$ cermet plates attached to each fuel cell; even without burnup credit this configuration ensures an acceptable K-eff for PWR fuel with initial enrichments less than 3.75 w/o and BWR fuel up to 4.5 w/o. With credit for a minimum assembly burnup of 18,000 MWd/mtU, initial PWR enrichments of up to 4.5 w/o can be safely accommodated. A lightweight impact limiter is fabricated from a Kevlar composite containing a combination of balsa and redwood.

The following sections describe the philosophy used in establishing the BR-100 cask design and provide a review of results from the life-cycle cost analysis used to prioritize the design parameters.

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The last section contains a description of the cask design and an outline of the analytical evaluations.

**DESIGN PHILOSOPHY**

The charter for the BR-100 cask development effort is to develop a spent fuel shipping package that provides for optimal public safety and receives NRC certification while minimizing the overall system's operational costs and providing flexibility and service to its users.

Compliance with Federal regulations as described in 10CFR71 will ensure public safety. These requirements have undergone extensive review, both in the scientific community and by the general public. The consensus is that shipments of radioactive material in a package designed, analyzed, tested, and fabricated to these requirements adequately protect the public's safety. The BR-100 Safety Analysis Report for Packaging (SARP) will be submitted for NRC certification in early 1991.

Operational cost parameters were evaluated through life-cycle-cost (LCC) studies performed to identify the relative value of various cask design parameters. By knowing what areas of the cask design could potentially produce the greatest cost reduction, the designer could then concentrate on which design option should be pursued. Using this approach, the designer is not just solving a cask design problem but is developing the best overall solution for the entire transportation system.

The keys to optimizing cask capacity and performance are the use of innovative approaches to material and design problems, but they must be supported by advanced analytical methods and computer codes, and an extensive testing program to verify the design. LCC analysis is used to identify areas where innovation will have the greatest cost effectiveness.

An example of innovative design is the BR-100 impact limiter. Development of a lightweight limiter design was identified as an area for a potentially large improvement in cask capacity and/or safety margin. A reduction in impact limiter weight translates directly to potential increases in either cask payload, railcar/handling skid weight or extra equipment on the railcar. Composite technology using Kevlar fibers offers a way to reduce greatly the impact limiter weight while maintaining performance.

Traditional materials may also be used in innovative ways, such as the neutron shield/thermal switch construction used in the BR-100 cask body. The use of copper fins in a borated concrete matrix to function both as a neutron shield and as a thermal switch was developed and patented by team member Robatel SA of Lyon, France. Neutron shielding is provided by the boron in the form of a colemanite powder in the concrete. While the copper fins enhance the thermal conductivity through the layer during normal operation, phase changes to the water in the concrete limit the amount of heat transmitted to the cask interior from the hypothetical fire accident. Other important factors in deciding to use the concrete were the permanence of the shield, which is only negligibly reduced in effectiveness after accident conditions, and the fabrication technique, which allows detailed inspection of the lead before the concrete is poured and allows no gaps between the concentric shells after fabrication is complete.

The BR-100 has also been designed to maximize both its usefulness and user acceptance. It can carry not only every PWR or BWR fuel assembly now in inventory, but all currently projected LWR fuel with the exception of South Texas fuel. Westinghouse and B&W fuel can be carried with burnable poison assemblies still in them with no reduction in capacity. The cask has four equally spaced trunnion receptacles on each end, but is designed for two-point lift per the guidelines of NUREG 0612; extra trunnion locations are provided for potential recovery operations per Association of American Railroad (AAR) recommendations.

## LIFE-CYCLE-COSTS

As viewed from the perspective of optimizing the overall transportation system, the issues in assessing the impact of cask design on LCC are more than simply defining which design feature contributes the most. In addition, the cask designer must identify what parameters are within his control, either directly or indirectly, and determine the design approach to address these parameters in a way that minimizes the LCC. Factors within the designer's control, such as fabrication costs or cask capacity, can be evaluated directly. Concurrently, the designer must try to limit the impact of indirect cost from factors outside his control, such as turnaround time. To do this efficiently, the designer must understand the complex relationships between cask design features and their effects on the system's LCC.

BWFC performed a sensitivity study on a simplified spent fuel cask transportation system to identify the significant factors affecting LCC over a range of realistic values for each of the parameters. Among the parameters investigated were those related to the cask design and fabrication effort (development and certification costs, cask weight, fabrication and decommissioning costs) and system operational aspects (capacity, turnaround time, maintenance costs, utilization). Total LCC can change significantly with the values chosen for the cask design parameters; however, the relative importance of the contribution on individual parameters to the overall LCC changes only marginally over a range of representative values. When viewing the complete system, the only significant deviations in handling time and maintenance costs affect the relative contribution of the parameters. A summary of the results from the sensitivity study is presented Table T-1.

**TABLE T-1. SUMMARY OF LIFE-CYCLE-COST SENSITIVITY STUDY**

| Key Parameters | Base Case Values | Range of Values | Impact on LCC |
|---|---|---|---|
| DIRECT FACTORS | | | |
| Capacity (PWR FAs) | 21 | 26 to 18 | -16% to +13% |
| Fabrication Cost | \$1.5M | \$1.0M to 3.0M | - 4% to +12% |
| Maintenance Cost | \$83.5K/yr | \$60K to 120K/yr | - 2% to + 4% |
| Cask Weight (lbs) | 165K | 155K to 170K | - 3% to + 2% |
| Development/ Certification Cost | \$6M | \$4M to \$8M | - 2% to + 2% |
| Handling Cost | \$102K/yr | \$70K to 120K/yr | - 2% to + 1% |
| INDIRECT FACTORS | | | |
| Utilization | 70% | 90% to 50% | - 5% to +10% |

As a result of this sensitivity study, a prioritized list of key parameters was developed for the BR-100 program. Cask capacity, fabrication costs, and maintenance costs were determined to be keys to minimizing LCC while still meeting regulatory and contractual requirements. As a result, the cask design process resembles a page from an aerospace design handbook: maximize performance while minimizing fabrication and maintenance costs. Within the confines of contractual weight restrictions, the principal factors limiting capacity are regulatory limits on dose rate (shielding), ensuring sub-criticality, and maintaining the structural integrity of the fuel payload. Fabrication operations available to address these factors include selection of shielding materials (lead or depleted uranium), choice of neutron absorbing material to control criticality, and designing a basket that maintains fuel rod clad temperatures within acceptable limits. Second tier improvements in LCC can be obtained by minimizing maintenance and operational costs; this includes incorporating low maintenance requirements into the design, while reducing the complexity of site interface operations to permit quick turnaround times with minimum personnel exposure.

The following paragraphs present a discussion of the BR-100 cask design developed based on results from these LCC studies.

## BR-100 TRANSPORTATION CASK

### GENERAL DESIGN DESCRIPTION

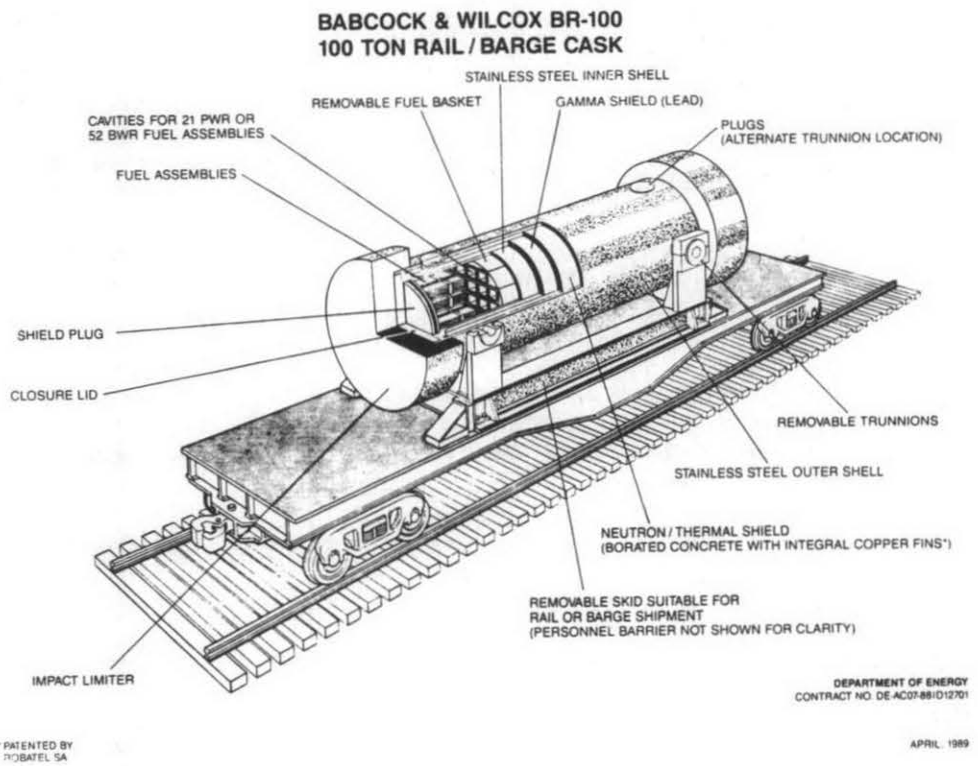


**FIGURE 1**

The BR-100 spent fuel cask (Figure 1) is designed for rail or barge shipments and has a maximum gross vehicle weight on rail of 263,000 pounds. As configured for handling at a reactor site, the loaded cask has a maximum hook weight of 200,000 pounds. With one of its standard baskets, the BR-100 cask can accommodate 21 PWR or 52 BWR intact assemblies of 10-year cooled fuel. Consolidated assemblies in canisters of the same cross-section as intact fuel can also be accommodated, but not in every cell because of weight restrictions. Optional basket designs may permit licensing the cask for other types of fuel and high-level wastes, including shipments of non-fuel hardware.

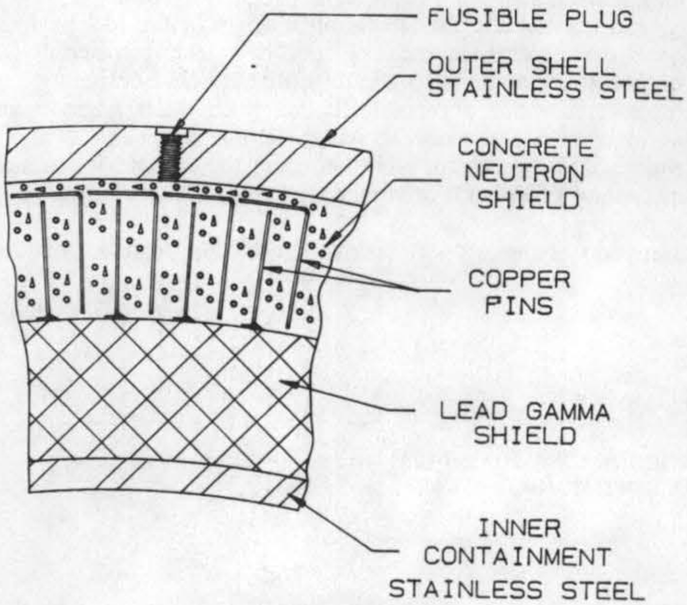


**FIGURE 2**

A multi-layer wall shell construction (Figure 2) is used for the cask body, with two intermediate layers of shielding sandwiched between the containment boundary inner shell and a thicker puncture-resistant outer shell. Neutron shielding is provided by the boron and water in the concrete, while the copper fins and absence of as-built gaps enhance the thermal conductivity through the layer during normal operation. Phase changes to some of the water in the concrete are induced by the external fire and limit the amount of heat transmitted to the interior. A fusible plug limits the pressure built up between the inner and outer shells. This "thermal switch/neutron shield" arrangement has undergone extensive testing in France, where it has been incorporated into several cask designs.

CLOSURE

A variation of a two-piece lid system is used. Containment closure is provided by the closure lid, while the shield plug functions only as a radiation shield for areas above the basket. This system offers significant advantages over a one-piece closure lid design in its ability to shield the fuel payload underwater before removal of the tooling. Inconel closure bolts are used to attach the lid.

BASKET

The BR-100 basket consists of a cluster of square fuel cells contained by formers (Figure 3-PWR) that provide a geometric transition from the circular cask body and the flat-sided array of fuel cells. The assembly is bolted together to form a solid unit during handling and operation but can be disassembled for decon, inspection, or rework. Aluminum is used for the basket material to expedite heat removal from the fuel. Neutron poison plates consisting of a $B_4C$ cermet core with aluminum face sheets are attached to the cells on all four sides. All surfaces of the fuel cells and the aluminum covered poison plates are hard anodized to

**BR-100 Basket (21 PWR)**

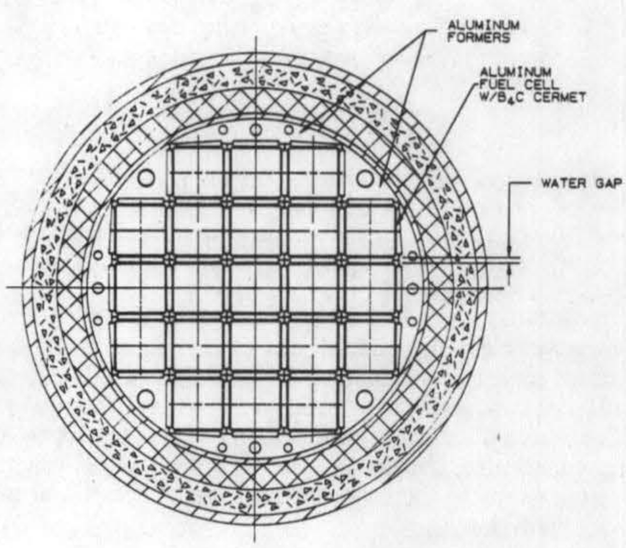


**FIGURE 3**

prevent corrosion or excessive wear. Figure 4 illustrates the BWR cross-section.

IMPACT LIMITERS

A combination of balsa and redwood is used for the energy absorption material for the BR-100 impact limiters; the balsa for the end drops, the more dense redwood for the side impacts. The unique feature of the BR-100 design is the use of Kevlar fibers in a semi-flexible epoxy matrix as the structural containment for the woods. BWFC is conducting an extensive testing program, including static and dynamic testing, to verify use of Kevlar in NRC-certified applications.

**BR-100 Basket (52 BWR)**

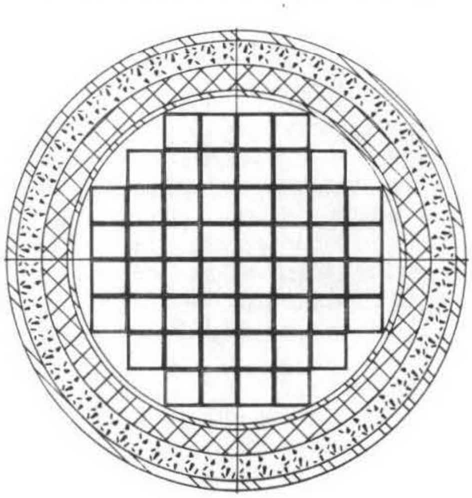

**FIGURE 4**

**DESIGN EVALUATION**

SHIELDING

The BR-100 has concentric layers of gamma and neutron shielding encapsulated between the inner and outer steel shell in the cask body. Preliminary evaluations, using the ANISN computer code, were done to determine the thicknesses for the shielding layers. The most limiting contractual case for the source term is based on PWR fuel assemblies with an enrichment of 3 w/o, a cooling time of 10 years, and a burnup of 35,000 MWd/mtU. An axial peaking factor of 1.25 was used in preliminary 2-D analyses to model the higher unit burnup in the middle of the fuel and to bound possible non--conservative geometric and material assumptions. Results show a dose of 9.6 mr/hr at 2 meters from the personnel barrier and 23.1 mr/hr at contact. Trade-off studies are being performed to evaluate the effects of higher burnups, various enrichments and shorter cooling times.

Part of the lessons learned from the on-going DOE storage cask program and confirmed in our analyses is a renewed awareness of the special shielding considerations required for the hardware at the top and bottom of the fuel assemblies. Trace amounts of cobalt in the stainless steel and Inconel used for the non-fuel bearing components hardware are high gamma emitters. The gamma shield is expected to be augmented in the end fitting regions of the cask by locally decreasing the neutron shield thickness and using either more lead or more outer shell thickness.

CRITICALITY

Optimizing a cask basket design from the perspective of criticality control is highly dependent on the choice of neutron absorbing materials, the type and quantity of moderator, and the specific geometrical factors. An understanding of the relationship between the energy spectrum of the neutrons in the system being analyzed and the energy dependent nature of the absorber material is important in developing a basket design.

The system of computer codes used in the analysis of the BR-100 includes KENO-IV and NITAWL codes, in conjunction with the 123 cross-section group. KENO-IV was used because of the extensive experience base at BWFC with the code and the usefulness of the generalized geometry option for scoping calculations. The KENO-IV bias was determined from a comparison of the KENO results with those of 21 critical experiments as documented in published reports.

Using a fresh fuel assumption, the basket array has a K-eff less than 0.95 for most, if not all, of the PWR fuel currently in inventory, including all initial enrichments of up to 3.75 w/o. As the utility industry adopts extended burnup fuel designs, the initial enrichments are expected to increase to levels between 3.75 and 4.5 w/o. With credit for a minimum assembly burnup of 18,000 MWd/mtU for PWR fuel, and including fuel end effects which effectively reduce the burnup level further, the BR-100 K-eff is, at 4.5 w/o, still less than the 0.95 limit.

THERMAL

With a large capacity cask like the BR-100, thermal considerations assume a more important role. The DOE storage cask program has demonstrated that large thermal analysis codes can be used effectively to calculate cask temperature profiles. BWFC is using the PATRAN/P-THERMAL family of computer codes for the initial thermal analysis for the BR-100 cask. COBRA-SFS is planned to be used to calculate the convection input for the licensing analysis. The thermal loads for the specific basket analyses are developed from the assembly physics parameters as calculated by the ORIGEN code using a bounding case of a 3 w/o 10-year cooled assembly with a 35 GWd/mtU burnup (and a 1.125 axial peaking factor for 2-D analyses).

Determining the worst-case temperature profile and heat flows in the basket structure is a quite complex problem and is influenced by the mechanical reaction of the basket components. As the temperatures of the aluminum basket increase during the heat-up transient, the clearances between the hotter basket and the cooler cask body decrease, but sufficient clearances are provided to prevent the basket from going "solid". In its normal transportation mode--a horizontal orientation--gravity acts to ensure contact between components for a conduction heat load path. Projected temperatures range from a cask outer surface of 185°F and inner surface of 225°F to a maximum basket temperature of about 350°F and maximum clad temperatures of about 460°F.

STRUCTURAL

The goal of the structural analysis of a cask is to ensure both integrity over the design life of normal operation and also, for accident conditions, to provide containment and a geometry consistent with thermal evaluations. In general, the structural criteria is taken from Section III of the ASME Code and NRC Regulatory Guides 7.6 and 7.8.

In most cases, finite element analysis techniques using computer codes such as ANSYS will be used to calculate the stress distribution in the cask components. While ANSYS has a proven track record in cask evaluations, ABACUS and PRONTO are relatively new and attractive codes that will require some benchmarking before use in licensing analysis.

**SUMMARY**

The BR-100 rail/barge cask being developed for the DOE by BWFC is a state-of-the-art spent fuel transport cask design that offers significant improvement over currently licensed casks, both in saving in LCC and versatility in operation. Cask capacity of the BR-100 is 21 PWR and 52 BWR intact assemblies while cask cost is estimated in production to be about $1.5M (1989 dollars), thus optimizing the major LCC factors. The BR-100 has a hook weight of less than 100 tons and also meets the gross vehicle weight limitations for un-restricted rail service, thereby successfully interfacing with most reactors that have rail accommodations. As the permanent repository or MRS facility becomes operational, the BR-100 will be ready as a vital part of the Federal High Level Waste Transportation System.