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BR-100 SPENT FUEL SHIPPING CASK DEVELOPMENT

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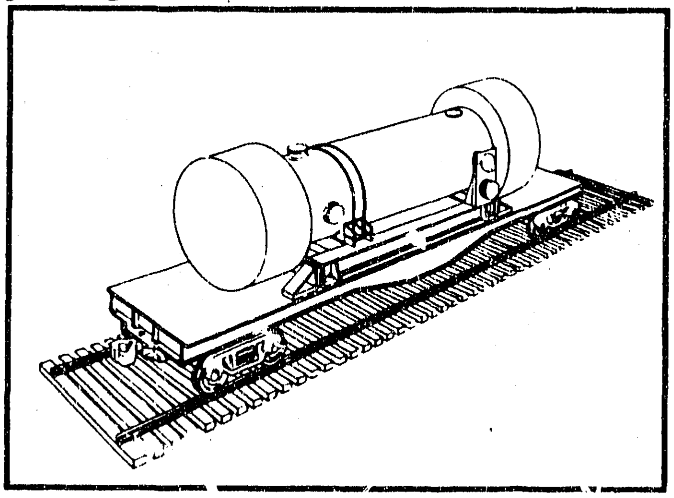
Abstract

Continued public acceptance of commercial nuclear power is contingent to a large degree on the U.S. Department of Energy (DOE) establishing an integrated waste management system for spent nuclear fuel. As part of the from-reactor transportation segment of this system, the B&W Fuel Company (BWFC) is under contract to the DOE* to develop a spent-fuel cask that is compatible with both rail and barge modes of transportation. Innovative design approaches were the keys to achieving a cask design that maximizes payload capacity and cask performance. The result is the BR-100, a 100-ton rail/barge cask with a capacity of 21 PWR or 52 BWR ten-year cooled, intact fuel assemblies.

Introduction

In response to the Nuclear Waste Policy Act of 1982, the DOE is developing an integrated nuclear waste management system leading to the permanent placement of spent fuel and other nuclear wastes in a deep geologic repository. The transportation component of this system is responsible for the safe shipment of the spent fuel between the key interfaces with 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, 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 ten-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 multilayer cask body construction with layers of 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. During the hypothetical fire accident, the concrete acts as a thermal switch by retarding the heat flow into the cask. The fuel baskets use a unitized design concept that consists of a cluster of individual square fuel cells surrounded by circle-to-square formers. Their all-aluminum construction provides an efficient heat path between the fuel payload and the cask body. In the PWR basket, flux traps formed by water gaps between high density B_4C Cermet (ceramic-metallic) plates attached to each fuel cell ensure subcriticality. Water gaps are not required for the BWR basket. Lightweight impact limiters fabricated from a Kevlar^R composite containing a combination of balsa and redwood limited the impact forces during a drop accident. A personnel barrier between the impact limiters limits assess to the cask body.

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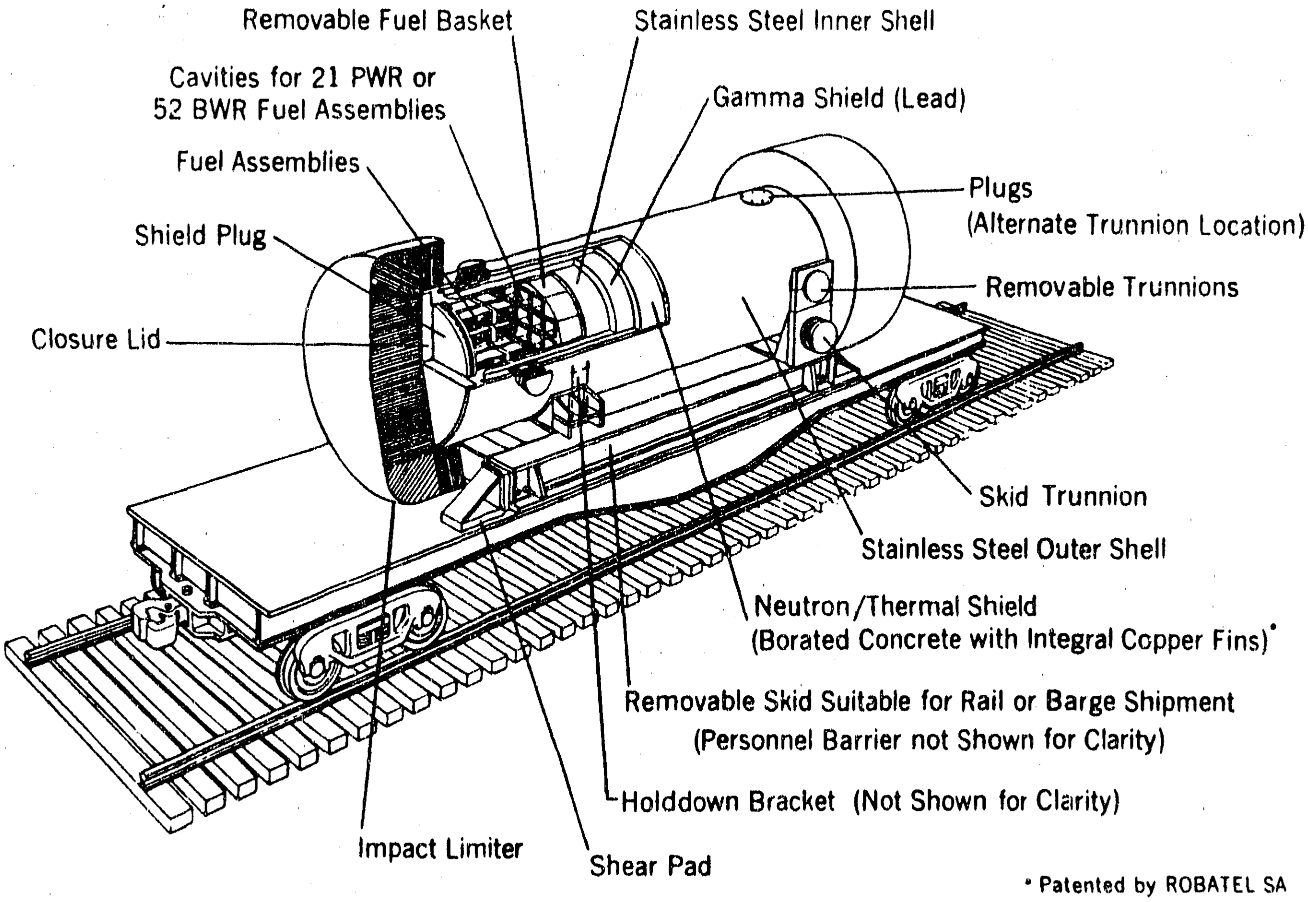

Figure 1 - BR-100 SPENT FUEL SHIPPING CASK

Preliminary design verification analysis has been completed. 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 criticality analysis of the fuel baskets designs verifies an acceptable K_{eff} for PWR fuel with initial enrichments less than 3.2 w/o for the PWR; 4.5 w/o for the BWR. 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. For its design 13 kW heat load, the temperature profile is within regulatory and material limits. Basket temperatures are below 300°F, the traditional limit for aluminum in structural applications. Positive structural margins were computed for all normal operation and accident conditions.

Innovation In Design

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 ten-year cooled fuel. Consolidated assemblies in canisters of the same cross-section as intact fuel can also be accommodated but not in every cell due to weight restrictions. Optional basket designs may permit licensing the cask for other types of fuel and high level wastes, including shipments of nonfuel hardware.

Innovative design features are the keys to optimizing the BR-100 cask. A life cycle cost (LCC) analysis was used to identify areas of the design where innovation will have the greatest impact. The following sections discuss three unique features were an innovative approach was applied to the BR-100 design.

NEUTRON SHIELD/THERMAL SWITCH

Traditional materials are used in innovative ways in the neutron shield/thermal switch construction used in the

BR-100 cask body. The concept of using copper fins in a borated concrete matrix 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 (Figure 2). Fusible plugs limit the pressure build-up between the inner and outer shells. 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.

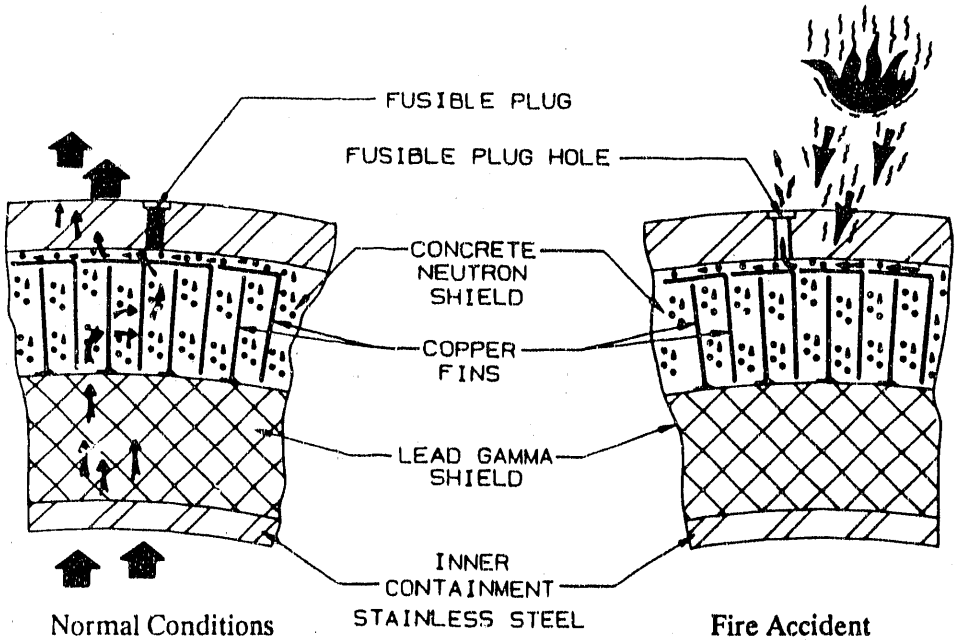

Figure 2 - MULTILAYER CASK WALL

Closure System
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.

Impact Limiter
Another example of innovative design is the BR-100 impact limiter (Figure 3). Development of a lightweight limiter design utilizing composite technology was identified as an area for a potentially large improvement in cask capacity and/or safety margin. 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. A combination of balsa and redwood, used for the energy absorption material, limit the impact forces. A thin, metallic outer skin serves as an environmental barrier to protect the Kevlar composite. BWFC is conducting an extensive testing program, including static and dynamic testing, to verify use of Kevlar composites in NRC-certified applications.

Design Evaluation
Results from the preliminary design evaluation show that the BR-100 meets its design objectives. The following sections present the results of the evaluations in the shielding, criticality, thermal and structural areas. As the development program enters its final design phases, additional analyses and verification testing will be performed to demonstrate compliance with NRC requirements.

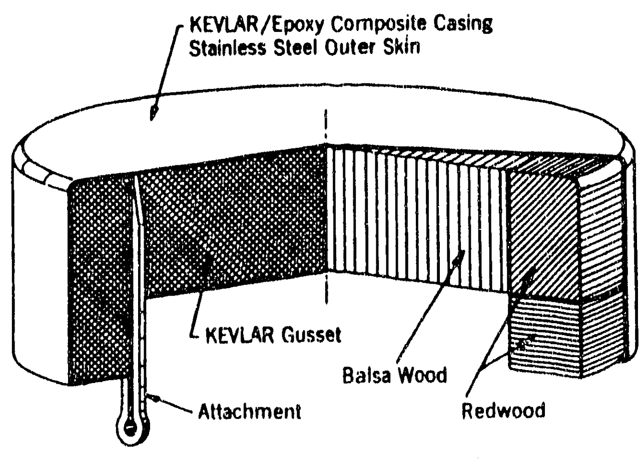

Figure 3 - IMPACT LIMITER

Shielding

Concentric layers of gamma (lead) and neutron (borated concrete) shielding encapsulated between the inner and outer steel shell ensure acceptable external dose rates for the BR-100 cask package. Results from the preliminary shielding evaluations using the ANISN computer code established the thicknesses for the two 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 two-dimensional analyses to model the higher unit burnup in the middle of the fuel and to bound possible nonconservative 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 nonfuel-bearing-components hardware are high gamma emitters. The gamma shield is augmented in the end-fitting regions of the cask by locally increasing the lead thickness. A lower neutron flux in these regions permitted a corresponding decrease in the neutron shield 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 moderators, 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 documents 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 3.2 $^{w}/_{o}$. 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, the BR-100 K_{eff} is, at 4.5 $^{w}/_{o}$, still less than the 0.95 licensing 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 $^{w}/_{o}$ ten-year cooled assembly with a 35 GWd/mtU burnup (and a 1.125 axial peaking factor for two-dimensional analyses).

Determining the worst-case temperature profile and heat flows in the basket structure is quite a 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. Results from the thermal analysis indicate cask temperatures will range from a cask body outer surface of 85°C(185°F) and inner surface of 107°C (225°F) to a maximum basket temperature of about 143°C (290°F) and maximum clad temperatures of about 237°C (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 are taken from Section III of the ASME Code and NRC regulatory guides 7.6 and 7.8.

Finite-element-analysis techniques using computer codes such as ANSYS are used extensively to calculate the stress distribution and deformations in the cask components. While ANSYS computer code has a proven track record in cask evaluations, other codes such as ABACUS and PRONTO are relatively new and will require benchmarking before use in licensing analysis. Internal force and stress distributions for the cask body are calculated directly from the dynamic analysis using the finite-element codes. Quasi-static analysis techniques are used to determine the stress levels and deformations in most other cask components, including the basket assembly.

BWFC has developed a proprietary code, ILAN, for the dynamic analysis of the cask impact during a drop accident. ILAN calculates the impact forces on the cask for both the initial and secondary impacts. It will be used to determine the "worst case" impact angle for the oblique drops. A comprehensive testing program will be used to demonstrate the impact-limiter performance for the Safety Analysis Report for Packaging, the SARP.

Summary

The BR-100 rail/barge cask being developed for the DOE by BWFC combines innovative features with an aggressive design approach to meet its design objectives. The result is a state-of-the-art spent-fuel transport cask design that offers significant improvement over currently licensed casks. As the permanent repository or MRS facility becomes operational, the BR-100 will be ready as a vital link in the Federal High Level Waste Transportation System.

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