DESIGN, ANALYSIS AND FABRICATION OF THE TN-BRP AND TN-REG TRANSPORT/STORAGE CASKS

D.J. NOLAN, K. GOLDMANN, C. MILLER,
C. FERNANDEZ, F.J. WILLIAMS, Jr., M.E. MASON
Transnuclear, Inc.,
White Plains, New York,
United States of America

Abstract

DESIGN, ANALYSIS AND FABRICATION OF THE TN-BRP AND TN-REG TRANSPORT/STORAGE CASKS.

The paper presents information on the design, analysis and fabrication of two casks (TN-BRP and TN-REG) for the transport and storage of specific spent fuel assemblies in storage at the West Valley, New York, facility. The TN-BRP cask was designed for 85 Big Rock Point BWR fuel assemblies and the TN-REG cask was designed for 40 R.E. Ginna PWR fuel assemblies. The cask designs differ in body size and basket configuration in order to accommodate the different fuel types. The same set of impact limiters and the same transport frame are used for transport of the loaded casks. The design criteria document was issued in January 1984. Fabrication of the casks was awarded to Kobe Steel, Ltd of Japan in August of 1984. The first cask (TN-BRP) was delivered to West Valley on July 23, 1985, along with the transport frame and impact limiters. The second cask (TN-REG) was delivered to West Valley on August 19, 1985.

INTRODUCTION

In early 1984, Nuclear Fuel Services (NFS) entered into a cost-sharing contract with the Idaho Operations Office of the U.S. Department of Energy (DOE) to develop and demonstrate dual-purpose shipping and storage casks which would be used for transporting NFS-owned fuel from West Valley, New York to DOE's Test Area North (TAN) facility at the Idaho National Engineering Laboratory (INEL) and for demonstrating extended storage at that facility. The broader objectives of this program are to:

- Demonstrate the feasibility of a large transportable storage cask for aged spent fuel.
- Provide a design and develop the manufacturing techniques for such a cask.
- Provide data and information useful in demonstrating dry cask storage technology.
- Provide verification of spent fuel integrity in long-term dry storage.

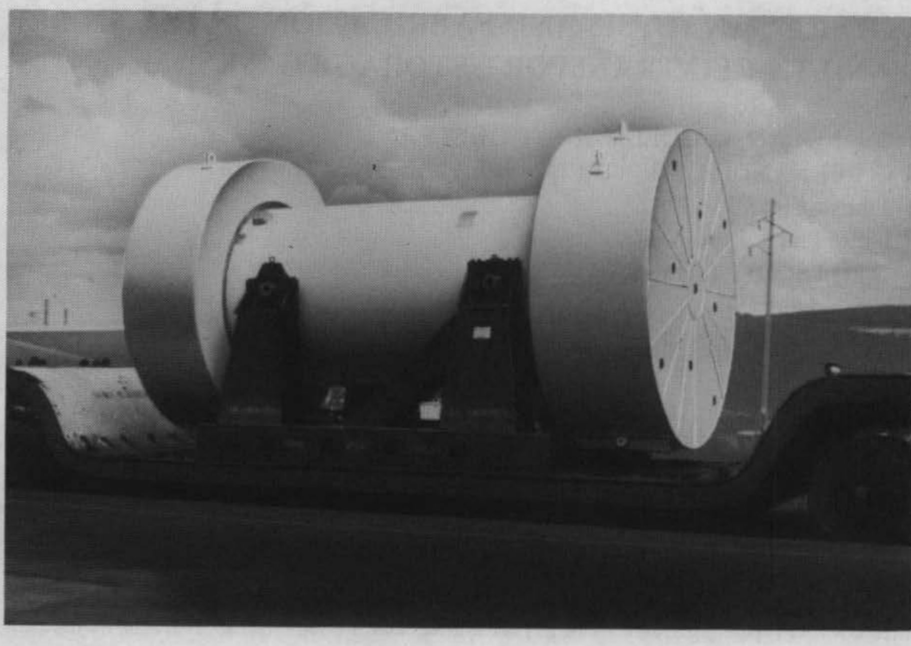

FIG. 1. A TN-BRP cask with impact limiters on a railcar.

NFS selected Transnuclear, Inc. (TN) to provide two casks for this purpose, one for the transport and storage of 85 Big Rock Point (BRP) fuel assemblies and the other for 40 R.E. Ginna (REG) fuel assemblies. The casks were designed by TN, fabricated by Kobe Steel, Ltd (KSL) and delivered to the West Valley site on July 23, 1985 and August 19, 1985, respectively - both two weeks ahead of schedule. The total elapsed time between start of design and delivery of the first cask to West Valley was less than 19 months. FIG. 1 shows the TN-BRP cask with impact limiters on the railcar after arrival at the West Valley site.

FUEL CHARACTERISTICS

Pertinent characteristics of the BRP and REG fuel are shown in Table I. The boiling water reactor (BWR) fuel bundles for BRP are only half as long as typical BWR bundles, while their cross-section is somewhat larger. The shorter length allows bundles to be stacked on top of each other within the basket

TABLE I.
FUEL CHARACTERISTICS

	BIG ROCK POINT	R.E. GINNA
TYPE	7x7, 9x9 and 11x11 BWR	14x14 PWR
INITIAL ENRICHMENT, %U-235	4.5 max rod (3.5 assy average)	3.5 max.
CROSS-SECTION, IN (MM)	6.516x6.516 (165)	7.766x7.766 (197)
LENGTH, IN (MM)	84.2 (2139)	160 (4064)
WEIGHT, LB (KG)	465 (211)	1271 (577)
NOMINAL BURNUP, MWD/MTU	13,000	10,000
DECAY TIME, YEARS	>13	>13

compartments of the TN-BRP cask. The pressurized water reactor (PWR) fuel assemblies for REG have about the same length as typical PWR assemblies but their cross-section dimension is smaller.

Low burnups result in minimal neutron sources and allowed the casks to be designed without neutron-specific shielding. Also, low burnup and relatively long decay times reduced the heat transfer design requirements and allowed the casks to be designed without extended external surfaces.

BASIS FOR CASK DESIGN

The designs of the TN-BRP and TN-REG casks are based on Transnuclear's standard TN-24 storage cask design. This standard cask design is an evolution of the dry transport cask designs which have been developed over the last two decades by the Transnuclear Group of companies.

The TN-BRP and TN-REG casks are the first casks which have been designed to comply with the U.S. Nuclear Regulatory Commission's (NRC's) transport regulations 10CFR71 [1] as well as the storage regulations 10CFR72 [2]. Of course, they are also designed to comply with the U.S. Department of Transportation (DOT) regulations 49 CFR173 [3]. In addition, the NRC's Regulatory Guides, Series 7 served as a basis for the designs and preparation of the Safety Analysis Reports (SAR's). The casks were designed, fabricated and tested in compliance with TN's NRC approved Quality Assurance Program under 10CFR71.

Crane capacity at West Valley limits the weight of a loaded cask on the hook to 105 t. This limit had a major impact on dictating the cask design and precluded the possibility of using a standard cask design such as the TN-24, or even the same cask design for both batches of fuel. Thus, while the two casks have many common features, such as materials and types of construction, their dimensions are different to accommodate the specific fuel within the allowable weight limit. This led to completely separate sets of drawings, calculations and SAR's for each cask.

CASK DESIGN

FIG. 2 shows longitudinal and cross-sections of the TN-BRP cask. The TN-REG is the same basic design. Principal dimensions of both casks are given in Table II.

The containment vessel consists of a body which is a thick-walled, forged steel cylinder with an integrally welded forged bottom closure and a flanged and bolted forged top lid. SA-350, Grade LF3 material was selected for the forgings on the basis of its high fracture toughness at low service temperatures.

Four removable trunnions are provided for handling, tiedown and rotation of the casks. The trunnions extend radially the same distance from the center lines of the casks and have identical longitudinal spacings to allow a single shipping frame to be used for both casks. Each trunnion has two shoulders of different diameters. The outer shoulder is used for lifting the cask, while the inner one is used for rotation, tiedown and support during transport.

The lid is attached to the body with 48 1-5/8 in (41mm) diameter, high strength bolts. The lid closure is provided with two concentric O-ring seals, one made of viton and the other being metallic. Viton O-rings have been successfully utilized by the Transnuclear Group during many years of transport operations. The metallic O-ring was selected as added protection against leakage over the twenty year storage design life. The torquing requirements of the closure bolts are governed by considerations of resistance to inertial loads rather than by seal compression. The lid contains the TN-24 standard drain and vent port which are also provided with double seal closures during transport. The interspaces between double seals are utilized for leakage testing prior to transport. At the beginning of the storage period the interspaces are prepressurized to prevent gas out-leakage from the cavity and to monitor the effectiveness of the seals.

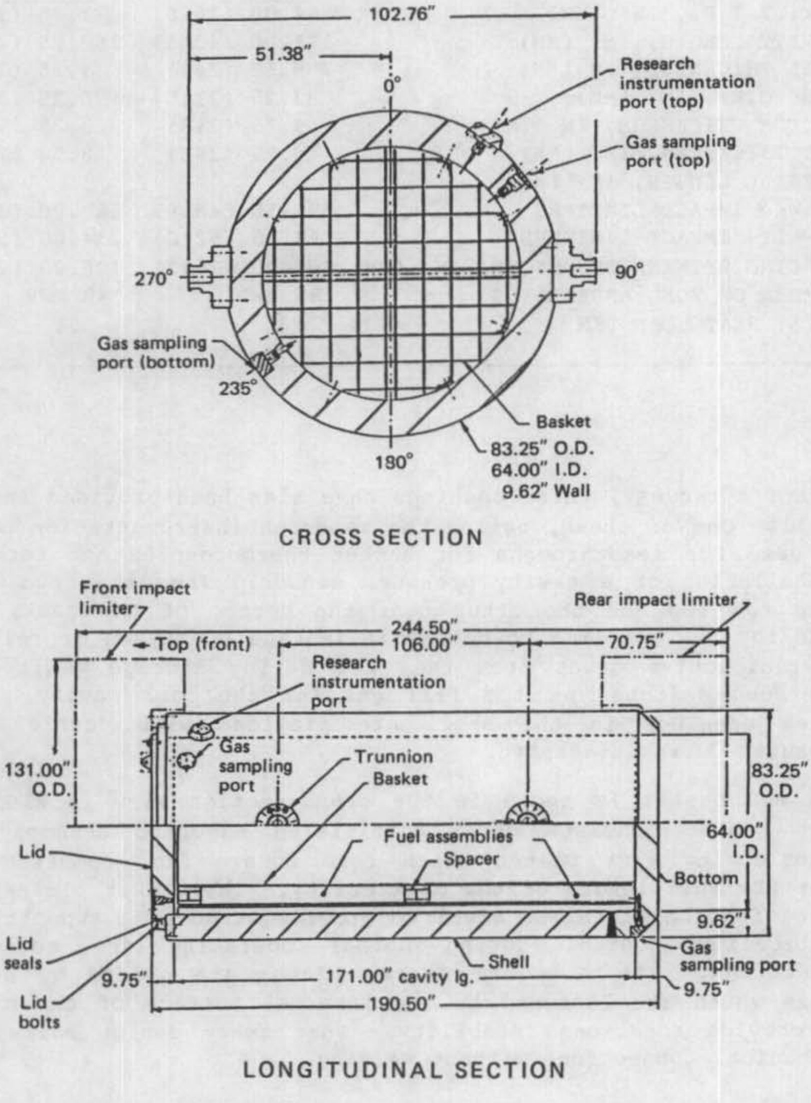

FIG. 2. A TN-BRP transport/storage cask (1 inch = 25.4 mm).

TABLE II.
CASK PARAMETERS

	TN-BRP	TN-REG
CAVITY I.D., IN (MM)	64.00 (1626)	71.75 (1822)
CAVITY LENGTH, IN (MM)	171.00 (4343)	163.25 (4146)
WALL THICKNESS, IN (MM)	9.62 (244)	9.25 (235)
CASK O.D., IN (MM)	83.25 (2115)	90.25 (2292)
BOTTOM THICKNESS, IN (MM)	9.75 (248)	8.25 (210)
LID THICKNESS, IN (MM)	9.75 (248)	8.50 (216)
OVERALL LENGTH, IN (MM)		
-w/o IMPACT LIMITERS	190.50 (4839)	180.00 (4572)
-WITH IMPACT LIMITERS	244.50 (6210)	234.00 (5944)
SPACING BETWEEN TRUNNIONS, IN (MM)	106.00 (2692)	106.00 (2692)
NUMBER OF FUEL ASSEMBLIES	85 BWR	40 PWR
DECAY HEAT LOAD, KW	6	5.5

At DOE's request, three openings have also been provided in the shell. One of these, called the research instrumentation port, is used for leadthroughs for basket thermocouples and for the installation of a cavity pressure sensor. The other two, one near the top and the other near the bottom of the cask, are used for gas sampling to detect in-leakage of oxygen or release of radioactive gases from the fuel during storage. Nitrogen has been selected as the fill gas for the cask cavity. The three openings in the shell are provided with double seal closures during transport.

The BRP basket is shown in the cross-section view in FIG. 2. Each basket consists of a multitiered eggcrate assembly of interlocking flat plates which form square fuel compartments over the full length of the cask cavity. The basket plates are made of boron stainless steel to provide structural support and criticality control during normal operating and accident conditions. The ends of several plates are guided by axial rails which are fastened to the internal surface of the shell to provide rotational stability. The basket design relies on mechanical connections without welding.

Impact limiters are installed at each end of the cask during transport for energy absorption under accident conditions. The impact limiters are made of redwood and balsa wood enclosed in a welded steel container and are identical for each cask.

A protective cover is provided for weather protection during cask storage. It is a flanged torispherical head made of 3/8 in (9.5mm) steel plate. Instrumentation penetrations are provided in the cover for pressure monitoring. In the unlikely event of excessive leakage from the cask cavity, the protective cover could be seal welded to the cask body.

Transnuclear also supplied ancillary equipment including a shipping frame, lifting equipment, vacuum drying and leak testing systems and in-cask instrumentation.

ANALYSIS

NRC's Regulatory Guides 7.6 [4] and 7.8 [5] form the design basis for satisfying the requirements for the packaging and transportation of radioactive materials as established in the U.S. Code of Federal Regulations, 10CFR71.

The structural designs of the TN-BRP and REG containment systems conform to Regulatory Guide 7.6 and the design-by-analysis approach of the ASME Code, Section III, NC-3200 [6] was utilized.

To facilitate finding the cask orientation for maximum damage or maximum inertia G loadings for the 30 ft free drop accident condition, a computer program was developed which calculates the G forces as a function of deformation of the wood in the impact limiters. A stress/strain relationship for the wood was established by test.

Of particular concern for shallow-angle side drops is the deceleration when the second impact limiter strikes the target. Peak loadings were calculated for several angles of impact between 0 and 90 degrees. It was determined that the highest G forces for side 'slap down' conditions occur at a body angle of 15°.

Stress intensities were calculated for each loading combination and were compared to the allowable stress intensity limits of Regulatory Guide 7.6 and the ASME Code.

The casks will be loaded with fuel only once, sealed and then transported to a storage site. Therefore pressure and thermal cyclic loadings are small. The only significant cyclic loading occurs due to transport vibrations and inertia G loads. A fatigue analysis was performed in accordance with Subsection NC-3200, Paragraph NC-3219.2 to evaluate cyclic loading. Brittle failure is precluded on the basis of the fracture toughness properties of the containment vessel materials.

The containment vessel was also analysed to determine critical buckling loads for different modes of buckling. The results show that the actual applied loads are significantly less than the critical buckling loads and therefore buckling is precluded.

The finite element computer code ANSYS was used to perform both the structural and thermal analyses. The thermal performance of the casks were analysed in three stages:

(i) Cask body evaluation which includes the lid, the shell, the seals and the impact limiters,
(ii) Basket evaluation, and
(iii) Fuel rod temperature evaluation.

Computer modeling was performed only for the cask body and basket stages. Maximum fuel rod temperatures were estimated using the Wooton-Epstein correlation, with the average basket temperature calculated in the hottest fuel compartment.

An axisymmetric cask body model was developed for use with both structural loadings and thermal boundary conditions. As a result, a thermal-stress analysis was easily performed. The model included the lid, shell and the impact limiters.

For analysis of the fire accident, a slice through the cask body was analysed. The thermal mass of the cavity contents were neglected to simplify the analysis. Heat transfer was allowed in the radial direction only and thermal properties were entered as a function of temperature.

Owing to the complicated "egg-crate" construction of the basket, a three-dimensional model of the basket was developed. Heat transfer was simulated along a plate around slots, and across gas gaps at the slots to the intersecting plates. Boundary conditions were radiation heat transfer from the periphery of the basket to the cavity wall. Natural convection was neglected.

Radiation source terms and decay heat values for the fuel were generated by the computer code ORIGEN. Because of the relatively low radiation source terms due to the fission products (low burnup and long decay), special attention was given to ^{60}Co activation of the end fittings. The methodology given in ORNL/TM-6051 [7] was used to evaluate the ^{60}Co source.

The shielding evaluation was performed using the 1-D, discrete ordinates computer code ANISN with the BUGLE-80 coupled 47 group neutron, 20 group gamma cross section library. The computer code XSDOSE was used to process the ANISN generated surface dose rates (fluxes) and to calculate dose rates at positions away from the cask surface.

The primary criticality design feature of the cask(s) is the fuel basket, which is divided into sections by water gaps (flux traps). The basket compartments are designed to retain the

TABLE III
ANALYSIS RESULTS

	TN-BRP Normal	TN-BRP Accident	TN-REG Normal	TN-REG Accident
Max Packaging temperatures*, (°C)				
Body Surface	87.2	294	83.3	290
Basket	307	359	327	387
Fuel Rod	336	387	339	396
Max Dose Rates (mrem/hr)¶				
Packaging Surface	86.9		38.6	
2 M from vehicle	8.7		9.3	
1 M from package		238#		82#
Multiplication Factor				
$K_{eff} \pm 2\sigma$	0.903 ± 0.010		0.931 ± 0.008	

* – with solar insolation
¶ – 1 rem = 1.00×10^{-2} Sv
\# – assumes impact limiter is not on package

fuel assemblies in both normal and accident conditions. The criticality evaluation is based on the calculation of a multiplication coefficient (keff) of an infinite number of casks, being less than 0.95 including 2σ of uncertainty.

The effective neutron multiplication factor (keff) was calculated using the KENO-IV Monte Carlo computer code. The NITAWL computer code was used to develop the working cross-section library from the 27 energy group SCALE cross-section library and to calculate resonance self-shielding for ^{238}U, ^{235}U and Zircaloy. Fresh fuel assemblies of infinite length were modeled discretely in the KENO-IV code. The multiplication factor was determined for the most reactive fuel with optimum water density.

Table III lists selected results from the thermal, shielding and criticality analyses of the TN-BRP and TN-REG casks.

FABRICATION

TN selected KSL for fabrication of the casks primarily on the basis of that company's proven record of successfully fabricating similar units and delivering them on schedule. Timely delivery was of utmost importance.

KSL's quality assurance system was established to be fully compatible with TN's approved quality assurance program. KSL is an authorized manufacturer for ASME Boiler and Pressure Vessel Code, Section III - Nuclear components. Although the casks were not N-stamped, they were fabricated in compliance with other requirements for Class 1 or 2 components. This included the utilization of a National Board certified Authorized Nuclear Inspector (ANI) who performed all the functions normally associated with such a project. Additionally, TN personnel performed audits, released selected hold points and witnessed acceptance tests to verify that the casks were fabricated and would perform as intended.

The basket plates were manufactured by two specialty steel companies who had extensive prior experience in the fabricaton of boron stainless steel plates. Both of these companies also established quality assurance systems which were in full conformance with TN's quality assurance requirements. TN approved the manufacturing and test procedures to assure that the basket plates would have properties at least as good as specified in the design criteria. TN personnel also performed audits, released hold points and witnessed material tests to verify compliance with quality assurance requirements. The plates were delivered to KSL where they were assembled into the baskets and installed into the cavities of the casks.

Because of the expected dependence of the crushing strength of redwood on density, strength tests were performed on statistically selected samples from the batch of redwood which was purchased for use in the impact limiters. The tests clearly demonstrated a linear dependence of crushing strength vs. density over the acceptable range of crushing strength for the impact limiters. Only wood within the acceptable range was used.

LICENSING

It was intended originally to perform the transports of the BRP and REG fuel under certificates issued by DOE. However, in August, 1985, a decision was made by DOE to perform the transports under NRC Certificates of Compliance (COC's), rather than under DOE certificates. TN submitted the TN-BRP SAR to NRC in mid September 1985 and the TN-REG SAR one month later. Since then, several meetings were held with NRC on NRC's questions and comments related to the TN-BRP cask and basket designs and TN's approaches for resolution. Because of the similarity between the two casks, it is expected that a successful resolution of the NRC questions and comments on the TN-BRP SAR will also lead to acceptability of the TN-REG cask. The principal NRC concerns relate to the performance of the impact limiters and the use of boron stainless steel as a structural material for the basket.

REFERENCES

[1] U.S. Code of Federal Regulations - Title 10, Part 71, "Transportation of Radioactive Material", U.S. NRC Washington, D.C., 1983.

[2] U.S. Code of Federal Regulations - Title 10, Part 72, "Licensing Requirements For The Storage of Spent Fuel In An Independent Spent Fuel Storage Installation", U.S. NRC Washington, D.C., 1982.

[3] U.S. Code of Federal Regulations - Title 49, Part 173, "Shippers - General Requirements For Shipments and Packagings", U.S. DOT, Washington, D.C., 1985.

[4] Regulatory Guide 7.6, "Design Criteria for the Structural Analysis of Shipping Casks", U.S. NRC Washington, D.C., 1978.

[5] Regulatory Guide 7.8, "Load Combinations for The Structural Analysis of Shipping Casks", U.S. NRC Washington, D.C., 1977.

[6] ASME Boiler and Pressure Vessel Code, Section III, Subsection NC, 1983.

[7] A.G. Croff, et al, Revised Uranium-Plutonium Cycle PWR and BWR Models for the ORIGEN Computer Code, ORNL/TM-6051, (Sept., 1978).