DRY STORAGE OF SPENT FUEL WITH DEMONSTRATED DESIGNS AND TECHNOLOGY: THE TRANSNUCLEAR TN-24

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ABSTRACT

The Transnuclear TN-24 is a spent fuel storage cask that has been developed for use in future Independent Spent Fuel Storage Installations. This design is the latest innovation in spent fuel cask design from Transnuclear, but the basis of the design and its technological foundations are firmly anchored in two decades of spent fuel cask experience within the Transnuclear Group. Predecessor casks such as the TN-12 series and the TN-1300 show the demonstrated and operationally proven bases of the TN-24. This provides the prospective user with assurance of an economic and licensable approach to spent fuel storage, and confidence in the TN-24's operational performance.

INTRODUCTION

Over the next two decades, the on-site or at-reactor (AR) storage of spent fuel is going to take on a new look. While pool storage will remain as the most widely used storage method, dry storage of older, cooler fuel in modularized Independent Spent Fuel Storage Installations (ISFSI) is going to increase - slowly at first but later with a strong growth rate. This change, helped along in part by the Nuclear Waste Policy Act of 1982, will rival such earlier changes within the industry as the shift to high density fuel storage racks in its cost and operational impact.

One of the attractive options for this dry, modular storage of spent fuel will be the thick-walled, metal storage cask. Transnuclear, Inc. has developed the TN-24 for this application, and the following sections provide some details of the TN-24 design. However, the main thrust of this paper is that the TN-24 is more evolutionary than revolutionary, that the TN-24 is a modest extension of what has been shown to work, and is based upon the world's most extensive dry cask design, licensing, manufacturing and operating experience over the last two decades.

Transnuclear believes that the demonstrated designs and technology that have been incorporated into the TN-24 will provide the prospective user with a significant licensing and operational advantage when compared to storage approaches that are not firmly grounded in operating experience. The knowledge gained over the last two decades can make the next two a lot less uncertain.

DEMONSTRATED DESIGNS AND TECHNOLOGY: THE BASIS OF THE TN-24

The Transnuclear Group has been involved with the design, testing, licensing, fabrication, operation and maintenance of dry, spent fuel transport casks for almost 20 years. Starting with the TN-2 in 1966, the Group pioneered the use of dry transport of spent fuel, the only method now being used in the United States. Over the last decade, the group has developed a family of high payload, dry casks for the transport of spent fuel from light water reactors to storage facilities or reprocessing centers [1]. These transport casks are designed for rail and marine transport, and, therefore, have payloads in excess of Transnuclear, Inc's TN-8/9 family of dry truck casks (3 PWR, 7 BWR assemblies). Many of these casks are presently being used for shipments within Europe and between Japan and Europe. These casks, called the TN-12 series, consist of four models: the TN-12/1, TN-12/2, TN-13/2 and TN-17/2. The design details of these casks are presented in Table I. There are 42 of the TN-12 series of casks now in operation throughout the world, with 28 in fabrication or on firm order and an additional 16 planned for the future.

TABLE I

Design Features of

Transnuclear's Large, Dry Transport Casks

Cask Model	Weight (when loaded) (lb)	Heat Rate (kW)	Quantity of fuel assemblies BWR	PWR	Cavity Diameter	Shell Thickness	External Diameter	External Length
TN-12/1	216000	120	-	12 (900MW)	1220	303	2500	5920
TN-12/2	225000	93	32	12 (900MW)	1220	303	2500	6150
TN-13/2	242500	109	-	12 (1300MW)	1220	300	2500	6670
TN-17/2	167500	43	17	7 (900MW)	920	316	2000	6150

These casks have a forged, carbon steel body for gamma shielding and structural strength, a solid, borated resin for neutron shielding, fins welded to the cask outer body for convective and radiative heat rejection, and a removable basket designed for the transport of spent fuel. Since these casks provide the bases for the TN-24 design, the following sections summarize certain of the key design features of the TN-12 series and the reason for their selection.

Forged Carbon Steel Body

A major advantage of the use of carbon steel forgings for the cask body is that design, fabrication and inspection can be performed in accordance with known and well-proven standards and codes. The process from design through fabrication and inspection is one that is uniformly repeatable with such high confidence that the outcome can be said to be assured. This is significant because such a process makes the licensing effort smoother and reduces the fabrication and inspection costs associated with quality assurance.

Compared with other potential cask materials, forged carbon steel has superior mechanical properties, and a high melting point and heat capacity which give very large safety margins for hypothetical accident conditions. Its more than adequate thermal conductivity provides good heat transfer for normal cooling, as well.

The use of steel as the primary gamma shield is very effective and does not significantly increase the weight of the cask. For these large diameter casks, the steel body has a low curvature, effectively increasing the average wall thickness seen by the gamma source. The use of lead as a shielding material offers almost no advantage since steel must still be used for the structural member.

Solid, Borated Resin Neutron Shielding

The use of a solid, borated resin for neutron shielding has been well established by the Transnuclear Group. The resin is composed of polypropylene bound in a borated polyester matrix, and has been in use for over 15 years on Transnuclear casks.

The resin forms a rigid shield and has a very high thermal breakdown point (> 250°C) after pouring and curing. It does not vaporize or require a high pressure design containment, nor is it corrosive. Because of these characteristics, it does not need a stainless steel jacket such as that required with the ethylene glycol/borated water shield. It is, therefore, a lighter shield with a shielding effectiveness comparable to borated water.

The borated resin is also less susceptible to the formation of gas pockets (no radiolytic decomposition, as with water), is more durable than a water shield for the range of realistic accident scenarios, and has no potential for leakage at penetrations through the shield.

Cask Sealing System

Transnuclear cask designs have historically incorporated a double O-ring sealing system. This system is comprised of two concentric elastomer O-ring gaskets with an interspace volume that has a test connection. This system has been used on the TN-12/1.

However, more recent models (TN-12/2, TN-13/2 and TN-17/2) are equipped with a three-piece sealing system to meet special criteria for unloading at the La Hague reprocessing center. This system consists of a shielded plug, a ring flange to hold the plug in the cavity opening, and a plug cover to protect the ring flange bolts and test/sampling connections. This system allows remote operation of all components and provides two independent leakage barriers. This approach, without the ring flange, has been incorporated into the TN-24 design.

For transport casks, O-ring seals can be replaced as necessary whenever the cask is empty. For storage casks, however, such regular replacement is not practical, and a cask sealing system with an expected lifetime comparable to that of the cask is desirable. This has prompted a change to double metallic O-rings with a stainless steel overlay on the seating surfaces. This is discussed later.

Fuel Basket Design

The fuel basket is the fuel support structure and conducts heat from the fuel assemblies to the cask body wall. It also contains neutron poison material to help assure that the fuel array remains subcritical during both normal and hypothetical accident conditions.

The TN-12 series of casks has used baskets made of aluminum alloy cast around stainless steel strength members. The aluminum alloy has good heat conduction properties. Borated stainless steel or boron carbide-copper plates on a stainless steel grid have been used as integral neutron poisons in the basket structure.

Transnuclear has also used stainless steel as the fuel support structure material in other transport casks such as the TN-8/9.

All basket designs have met the appropriate design criteria and have performed well in actual service. It should be noted that these baskets have been designed for heat rates up to 120 kw, five times the design value for the TN-24.

Ancillary Equipment

Although ancillary equipment is not a direct design feature of a transport cask, such things as lift beams, drying systems, leakage testing systems, cooldown systems and transport systems play critical roles in the handling and operation of these large, transport casks. Their design must be based on cask and facility interface requirements, and cannot be left to chance, or done as an afterthought. Transnuclear's design and operation of such systems for almost two decades means that the systems in use on the TN-12 series have been developed from experience, and have been selected based upon what works best.

These design features of the TN-12 series and the operating experience with these casks have played the major role in shaping the design of the TN-24. In addition, however, the Transnuclear Group designed a series of casks in the late 1970's that were dedicated to medium and long-term storage of spent fuel [2]. The experience in the design and testing of these casks has also played a role in the development of the TN-24, and is discussed below.

Storage Cask Experience - The TN-1300

At the request of several German utilities, a first generation of casks was developed to transport and store spent fuel with cooling times of only 1.5 to 2.4 years. The largest of this group of casks, the TN-1300, was designed for transport and storage of spent fuel elements from the Biblis 1300 MW class of light water reactors.

The TN-1300 was developed with a choice of fuel basket designs to accommodate the ranges of cooling times for the fuel to be stored. For shorter cooled fuel, the basket design is the same as the TN-12 series. For longer cooled fuel, a simplified basket of borated stainless steel is used. Both basket designs have a maximum capacity of 12 PWR and 33 BWR fuel elements. Table II provides the TN-1300 Design Features.

The TN-12 series provided the basis for the design of the TN-1300 cask. However, there were two distinct changes from the TN-12 series that were incorporated into the TN-1300. The first was the use of cast ductile iron for the cask body. This change was made due to the utilities' requirements for use of that material. The other basic change was the use of double metallic O-rings in the cask sealing system. The TN-1300 cask sealing system is comprised of a double lid system, similar to the later models of the TN-12 series, but with double metallic O-ring seals that also have an interspace test connection.

The TN-1300 cask design has undergone a full series of licensing tests, including drop tests and fire tests. Two 1/3 casle models have been used in the testing. Additionally, a full scale cask weighing about 100 metric tones was subjected to simulated aircraft impact tests. The projectile used in the tests had an impact speed close to sonic velocity and weighed about one metric ton. The impact area of the projectile was the center of the cask lid. The cask was backed by a soil embankment to insure maximum energy absorbtion by the cask. Two such projectile tests were conducted on the cask lid. During all the testing - drop tests, fire tests and aircraft/missile tests - the performance of the double metallic O-rings was superior, with post-testing leakage rates of 10^{-6} Torr/sec. or better [3].

TABLE II

TN-1300 Design Features

Dimensions	cavity length	5050 mm
	cavity diameter	1220 mm
	overall length	6890 mm
	overall diameter	2500 mm
Weight	max. during handling	116 tons
	max. during transport	122 tons
Design heat load		50 kW
Capacity	12 PWR assemblies, 2.5 yr. cooling	
	9 PWR assemblies, 1.5 yr. cooling	

An analysis of the long term performance of the metallic O-ring gaskets has also been conducted, taking into account mechanical effects, such as stress relaxation of the O-rings, corrosion of the O-rings and sealing surfaces due to such corrosive agents as CsI and CsOH, and radiation effects. This analysis has shown that the design of the O-rings is certainly adequate for long term containment.

During the summer of 1983, the TN-1300 cask was granted a Type B (U) transport package approval by the cognizant authority in the Federal Republic of Germany. The first TN-1300 will be loaded with short cooled (~ 1.5 years) Biblis fuel elements in the spring of 1984 for testing. Currently there are 10 TN-1300 casks on order, with options for an additional forty.

The preceding sections have described the demonstrated design and technological background of the TN-24. The following sections show that the design of the TN-24 contains no radical or unproven departures from the designs that have preceded it.

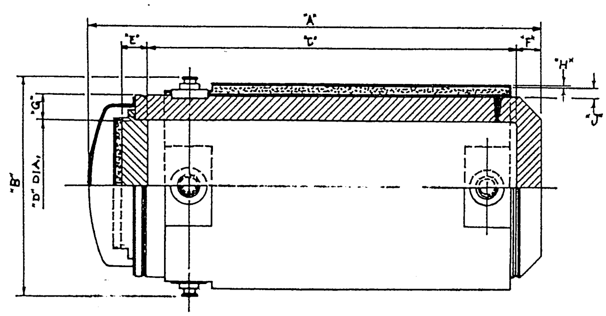
The innovation of the TN-24 comes from the effective combination of a number of demonstrated approaches in a new and expanded application.

THE TN-24 DESIGN

The TN-24 is a logical extension of the cask designs described earlier. The main purpose of the TN-24 is to provide economical, long-term storage of spent fuel at the plant site. To fulfill that purpose, the payload had to be significantly better than earlier transport cask designs. Thus, the TN-24 has been designed for a capacity of 24 intact PWR assemblies or 52 intact BWR assemblies, with twice this capacity for consolidated fuel.

The TN-24 provides the primary spent fuel containment module in an Independent Spent Fuel Storage Installation (ISFSI). The cask can be stored in a vertical or horizontal position in the open or in a suitable building. Figure 1 provides dimensional details of the TN-24.

The TN-24 storage cask, designed for five year cooled spent fuel, utilizes the same basic design principles as the TN-12 and the TN-1300. It has a forged carbon steel body for structural strength and gamma shielding and uses the same type of resin for neutron shielding. The low heat generation rate of five year cooled fuel allows the use of a smooth outer surface. "Fins" located within the resin conduct the fuel decay heat from the body to the outer surface where it is dissipated to the atmosphere by radiation and natural convection. The cylindrical cavity is fitted with a basket to support the fuel, control criticality and transfer the fuel decay heat to the body wall. An inert gas atmosphere is maintained in the cavity. Several basket materials are currently being evaluated.



A. Length 5030 mm
B. Diameter 2400 mm
C. Cavity Length 4140 mm
D. Cavity Diameter 1460 mm
E. Lid Thickness 270 mm
F. Bottom Thickness 260 mm
G Wall Thickness 240 mm
H Shell Thickness 20 mm
J. Shield Thickness 140 mm

Fig. 1. TN-24 Dimensions

The double lid seals are metallic O-rings; the O-ring seats are overlaid with weld deposited stainless steel Internal and external surfaces of the cask are covered with protective coatings.

The body is provided with 3 pairs of removable trunnions. The four trunnions at the top of the cask allow redundant handling, if required. The total load on the crane hook with intact fuel is less than 100 tons, including the lift beam and with water in the cavity.

The general design requirements for the TN-24 Dry Storage Cask as an assembled system are given in Table III. Specific design features of individual components are provided in subsequent sections.

TABLE III
TN-24 General Design Requirements

1. Maximum weight on the crane hook	100 U.S. tons
2. Capacity	24 PWR or 52 BWR assemblies
3. Maximum fuel assembly weight	1500 lbs.
4. Fuel parameters	
a) Nominal burnup	35,000 MWD/MTU
b) Enrichment	3.7%
c) Decay time	5 years
d) Maximum heat generation	24 kw, total
5. Effective multiplication factor	keff $\leq$ 0.95
6. Maximum fuel clad temperature	375° C
7. Internal cask atmosphere	Inert gas
8. Ambient temperature	-30F to 116F
9. Solar heat load	1475 BTU/ft^2
10. Maximum dose at cask surface	site specific to to meet 10 CFR 72 criteria
11. Handling/Storage orientation	Horizontal or vertical

Cask Body and Containment Vessel

The containment vessel for the TN-24 Dry Storage Cask consists of a cask body which is a thick-walled, forged steel cylinder with an integrally-welded forged bottom closure and a flanged and bolted forged top lid. The wall thickness is controlled by shielding rather than containment considerations.

Six removable trunnions, attached to the cask body, are provided for lifting, tiedown and rotating the storage cask. Four of the trunnions are located near the top of the body and two near the lower end of the body. The four upper trunnions are redundant pairs, 90° apart, while the lower pair are 180° apart and in the same vertical plane as one of the pairs at the top. They are used for rotating the cask between vertical and horizontal positions. 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.

Design requirements are provided in Table IV for the containment vessel, protective cover and trunnions.

TABLE IV
Cask Body Design Requirements

1. Design pressure	
a) Containment Vessel	250 psi
b) Protective Cover	70 psi
2. Design Temperature (normal conditions)	
a) Containment Vessel	350°F
b) Protective Cover	350°F
3. Internal atmosphere	
a) Containment Vessel	Inert gas
b) Protective Cover	Inert gas
4. Closures	
a) Cask Lid	Flanged & bolted; double metallic O-rings
b) Protective Cover	Flanged & bolted; Viton O-ring
c) Lid penetrations	Bolted, metallic O-rings, seal weld
5. Penetrations	
a) Cask Lid	2

Cask Sealing System

Double metallic O-ring seals with interspace leakage connections are provided for the lid closure. A monitoring system is also provided to verify cask tightness using confirmed and proven methods. In the unlikely event of seal leakage, the monitoring system provides indication of the leakage before any gases are released from the cavity.

There are two penetrations through the containment vessel, both located in the lid: one for a drain opening and one for venting. A double seal, mechanical closure backed up by a seal weld is provided for each lid penetration.

A torispherical cover is bolted to the body over the lid. Its primary purpose is to protect the gasket seating surface and the lid bolts from the environment.

Basket Assembly

The basket assembly for the TN-24 Dry Storage Cask is located in the cavity of the containment vessel and provides the storage locations for the proper spacing of the spent fuel assemblies, conducts heat to the cask body wall, and provides neutron absorbing material which helps assure that nuclear criticality safety requirements are met. The basket materials to be used will be the same as those of the TN-12 series and the TN-1300.

Neutron Shield

The neutron shield surrounds the containment shell and axially covers more than the active length of the stored fuel assemblies. The radial neutron shield consists of the borated, solid resin used in the TN-12 series and the TN-1300. Metal fins provide a heat conduction path from the containment shell through the resin to the outer carbon steel shell, constructed of two half-cylinders welded together. The openings in the neutron shield at the trunnion locations are filled with neutron shield plugs after the trunnions are removed.

Axial neutron shielding is located above the cask lid and provision is made for attaching neutron shielding to the bottom of the cask body during handling of the TN-24 cask or storage in the horizontal position.

INITIAL PROJECT FOR THE TN-24 DESIGN

Transnuclear has a contract with Nuclear Fuel Services, Inc., (NFS) to supply transportable, forged steel storage casks to be used in removing NFS' spent fuel from West Valley. The basic design of these casks is the same as the TN-24. They all have a forged steel body for structural strength and gamma shielding, forged closure lids, removable trunnions and the same basket design concept.

However, one cask for NFS will have a fuel basket designed to transport and store 85 Big Rock Point fuel assemblies, while the other will have a basket designed to transport and store 40 Ginna assemblies. This difference from the standard TN-24 basket design was necessitated by a desire to maximize the capacity of the 100 ton casks for these smaller assemblies.

Because both types of fuel have low burnup and cooling periods well in excess of 5 years, the casks will not require the solid, borated resin neutron shield of the basic TN-24 design.

Both casks are scheduled for delivery to the West Valley site in the summer of 1985. After being loaded with fuel at West Valley, the casks will be transported to a DOE site for future dry storage research and development activities.

There are several significant aspects of this project related to spent fuel transport and storage:

1. these casks will be used for both transport and storage of spent fuel; the SARP will be submitted this spring to initiate the DOE certification process;
2. these casks will represent the first domestic use of a forged steel cask design for either transport or storage;
3. because of the requirement to transport spent fuel in these casks, the transport system for such dual purpose casks will be designed and in use much earlier than had been anticipated by many in the industry;
4. experience with the fuel basket designs for these casks may lead to an earlier transition to higher payload casks designed for more than 24 intact PWR assemblies.

Transnuclear's work with Nuclear Fuel Services, Inc. is the first big step towards commercialization of the TN-24.

SUMMARY

The TN-24 is the latest innovation in spent fuel cask designs from Transnuclear. The effectiveness of its major design features has been demonstrated and proven in predecessor cask designs, and its expanded capacity offers an economic approach to the storage of spent fuel.

Additional strengths of the TN-24 include:

- established handling procedures;
- operationally proven ancillary equipment;
- capability for licensing as a transport cask, when equipped with impact limiters.

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