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DESIGN AND DEMONSTRATION OF THE TN-24 SPENT FUEL CASK FOR DRY STORAGE AND TRANSPORT

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Abstract

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Storage of spent fuel is a common problem for many nuclear power plant operators worldwide. A shortage of space will soon become a reality because spent fuel storage pools, even after re-racking, are too small for plant lifetimes, which, in turn, are tending increasingly to be longer. The storage pools currently represent the only possibility to store these spent fuels, though some systems have been proposed to solve this problem. While most of these systems are uncertain, or have not been tested, the metallic storage/transport casks of the TN-24 family are currently available to expand at the reactor storage capacity until an away from the reactor storage site, either a final disposal or a reprocessing site, becomes available. The paper deals with the TN-24 concept and the experience accumulated with a TN-24 cask which was fabricated and tested under active conditions.

INTRODUCTION

As generally predicted, the space available in pools at many nuclear power plants worldwide for the temporary storage of spent fuel assemblies will probably not be sufficient in the near future. To safely continue operation of their installations, electric utilities must circumvent such a bottleneck. Dry storage in metallic containers offers utilities a viable solution to this problem in those cases where they either do not wish to reprocess or want additional buffer capacity.

This paper describes a contribution of the Transnuclear group of companies in this field and the results which were obtained after several years of studies and developments. A system, named the TN-24 Storage/Transport Cask, which can be tailored to any type of LWR spent fuel and can be easily adapted to fulfil specific site requirements, has been designed. It is currently undergoing active testing.

DESCRIPTION OF THE TN-24 CONCEPT

The casks of the TN-24 family are primarily intended to be used for medium term storage of LWR spent fuels, but they also allow for their transportation without repacking. The TN-24 casks have a maximum payload associated with the optimum shielding and weight consistent with the dry transport of LWR spent fuels. This concept is an evolution from the large transport packagings designed by Transnucléaire, Paris (TNP), which have themselves been continuously developed over the last two decades. The TN-24 casks can be optimized to meet any specific requirements (weight or dimension limits, fuel size or irradiation characteristics, local acceptance criteria or safety rules, etc.).

During storage periods, casks are normally placed in a vertical position, while they rest horizontally during transport. The main features of the TN-24 storage/transport cask concept are summarized below:

(1) Basic technology:
- Main gamma shielding constituted by carbon steel forgings
- Solid neutron shielding in a leaktight envelope
- Passive heat transfer
- Fuel in a dry inert gas atmosphere
- Highly reliable metallic gaskets.

(2) Design adaptability to:
- Different fuel types and characteristics
- Specific site requirements
- Vertical and horizontal storage
- Remote handling.

(3) Ease of operation:
- Smooth external surface, easy to decontaminate
- No waste generation
- Double gaskets allowing monitoring of cavity leaktightness
- Single penetration to cavity
- No required maintenance during storage
- Simple loading procedure
- Possibility of using the protective cover as an additional containment barrier.

(4) Conformity to regulations:
- IAEA Transport Regulations
- US regulations for an independent spent fuel storage installation (dry storage type)
- IAEA quality assurance recommendations

(5) Design limits met by TN-24 casks:
- Dose rate < 0.1 mSv/h at 1 m during transport
- Dose rate < 0.4 mSv/h at contact of accessible external surfaces during storage

– $K_{eff} + 3\sigma < 0.95$ (with fresh fuel).
– External surface temperature < 130°C.
– Fuel rod cladding temperature < 350°C.

As shown in Fig. 1, the TN-24 concept consists of an assembly of the following items:

(a) A forged carbon steel containment vessel, including a thick cylinder with an integrally welded bottom and a flanged and bolted top lid. This vessel also provides primary gamma shielding and mechanical strength. Its material has been carefully selected to prevent brittle fracture, especially at lowest service temperature (−40°C). The lid has a single multipurpose penetration which allows smooth and easy operations when a connector, which engages into the cavity tube, is used. Highly reliable double metallic O-ring gaskets equip all containment-vessel closure components.
(b) The containment vessel is radially surrounded by a thick layer of polyester resin which is enclosed in a tight metallic outer envelope. The resin provides the main neutron shielding, while the fuel decay heat is conducted to the external surface through copper or aluminium plates. The outer surface is totally smooth, except when required to accommodate high heat output.
(c) Four removable trunnions, used for lifting, supporting, tie-down and rotating the cask, are fastened to the containment vessel. In order to protect the trunnion lodgements and to keep the trunnions in good condition, shielding covers may be substituted for the trunnions during the fuel storage period.
(d) A fuel rack inserted inside the containment vessel cavity, consisting of a multi-tiered egg-crate assembly of interlocking flat plates which form square fuel compartments over the full cavity length. The plates can be made of boronated aluminium, which combines good absorption of thermal neutrons and good thermal conductivity, or boronated stainless steel with a copper coating can also be used. This structure retains its original geometry in any normal condition of operation (including a free drop, as called for by transport regulations, from a height of 0.3 m). However, it may permanently deform during a 9 m regulatory transport accident free drop without jeopardizing nuclear safety as the plates cannot rupture because of their good ductility.
(e) In the case of PWR assemblies, some of the guide tubes are equipped with neutron poison rods. Together with the basket (fuel racks) plates, they guarantee that the fissile materials are at all times in a subcritical configuration. This is an interesting feature of the TN-24 concept for PWR spent fuel assemblies as voids (generally required in classical concepts) within partitions between contiguous fuel assemblies are no longer necessary. In fact, should the fuel rack deform, the whole reactivity would only decrease because of more compact fuel medium on the one hand and the neutron poisons remaining between and within the assemblies on the other. A simple, manually operated, tool has been developed to easily insert and recover the poison

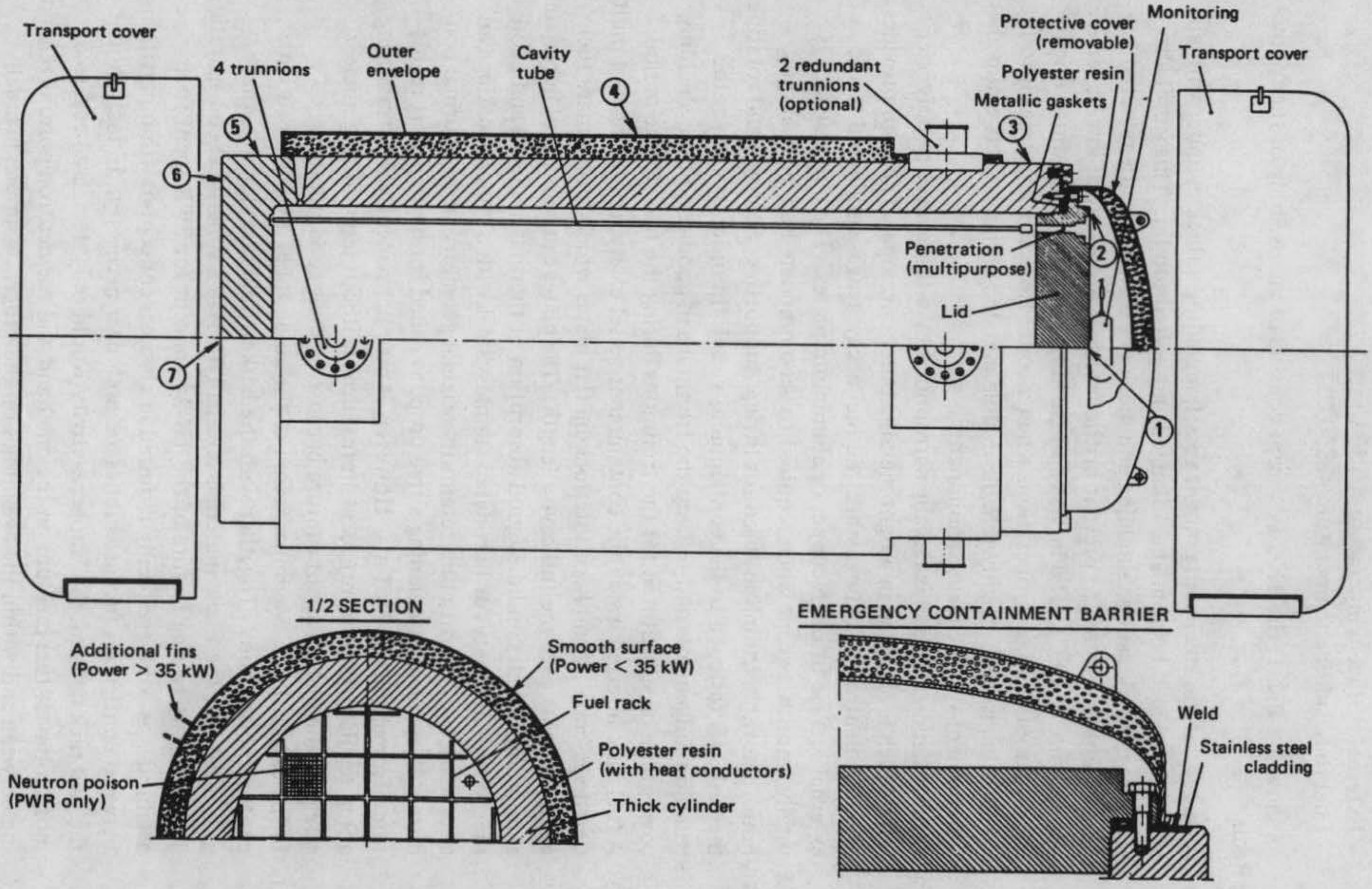

FIG. 1. The TN-24 storage/transport cask concept.

TABLE I. DESCRIPTION OF TYPICAL CASKS OF THE TN-24 FAMILY

	Version A (TN-24P)	Version B	Version C	Version D
CONTENTS				
Assembly (typical)	PWR 17 X 17	PWR 17 X 17	BWR 8 X 8	BWR 8 X 8
Number of assemblies	24	32	52	68
Mean burnup (MW·d/t U)	35 000	35 000	33 000	33 000
Decay time (years)	5	5	5	5
Thermal power (W)	24 000	32 000	24 000	31 000
U-235 enrichment (%)	3.7	3.7	3.5	3.5
DIMENSIONS (mm)				
Cavity diameter	1 455	1 650	1 400	1 560
Cavity length	4 150	4 150	4 510	4 510
Fuel compartment sections	220 X 220	220 X 220	140 X 140	140 X 140
External diameter	2 280	2 475	2 220	2 380
Length during transport	6 000	6 050	6 350	6 400
Length during storage	5 100	5 150	5 450	5 500
MASSES (kg)				
Body	65 000	72 000	68 000	75 000
Lid	4 300	5 500	4 000	5 000
Protective cover	800	900	800	900
Transport covers	6 000	6 500	6 000	6 500
Fuel rack	1 700	3 000	2 500	3 200
Fuel assemblies	16 000	21 400	15 000	19 400
Water in cavity	4 300	5 700	4 200	5 500
Handling yoke	4 000	4 000	4 000	4 000
Total at crane hook during loading	91 000	105 900	93 500	106 600
Total during transport	93 000	108 400	95 500	109 100
Total during storage	87 800	102 800	90 300	103 500

Note: For spent fuels with shorter decay times, external cooling fins are added to the casks.

rods. This operation is very quick and it can be performed during cask loading or in advance without disturbing normal work in the pool. No neutron poison is necessary inside BWR fuel assemblies.

(f) One monitoring system used during storage to detect variations in the leak-tightness level of the containment vessel metallic gaskets. This system consists of a tank, fixed on the outside of the lid, connected to interspaces between concentric metallic gaskets and filled with helium at an overpressure.

(g) One protective cover which isolates the containment vessel closure components and the tightness monitoring system from the external environment, but which also provides additional neutron shielding at the top. Furthermore, it can be used as a containment barrier during storage, especially in the unlikely event of a lid gasket failure.

(h) Two transport covers fastened at both ends of the cask. They are designed to provide protection during the most severe transport accidents specified by IAEA Regulations (i.e. a drop from a height of 9 m and a thermal test at 800°C).

(i) Special attention has been given to surface conditions.
   - All gasket seats are clad with stainless steel welding.
   - The cavity and external surfaces are protected by metallization.
   - The external surfaces are also coated with a high-grade paint.
   - The cavity surface is also coated with a special deposit to improve basket-to-cavity heat transfer.

Examples of typical casks of the TN-24 family are given in Table I.

APPLICATION TO A PARTICULAR CASE

Within the framework of a joint programme between TNP and Kobe Steel Ltd (Japan), the latter manufactured in 1985 one TN-24P cask (see Table I) and a two-fifths scale model. Copper plates, welded to the outer envelope and in contact with the thick cylinder, were used to conduct the fuel decay heat through the radial neutron shielding. The basket was made of boronated aluminium plates. The material of the containment vessel is ASTM SA-350 grade LF1.

Numerous non-active design tests were carried out after completion of the fabrications.

(1) Heat-transfer tests on the cask in either the vertical or horizontal positions at several powers, with various filler gases and vacuum.

(2) Functional and operational tests on the cask.

(3) Drop tests on the model.

The results showed that the design is satisfactory and especially demonstrated that:

(a) The lowest fuel pin temperatures are achieved when the cavity is filled with helium.
(b) At a power of 35 kW, there is no need of external cooling fins to keep the maximum fuel clad temperature below 350°C, even when the ambient temperature is as high as 45°C. The maximum external surface temperature will then not exceed 120°C.
(c) There is no difficulty in limiting the maximum acceleration of the cask during impact after a 9 m drop to a low level.
(d) Routine cask operations can be performed smoothly without special personnel training procedures.

Transnuclear New York (TNY) prepared a report dealing with storage of a nearly identical TN-24 cask. It was submitted to the United States Nuclear Regulatory Commission for approval during the third quarter of 1985.

ACTIVE TESTS

TNY sold the TN-24 dry storage cask to Virginia Power (VP), which selected it for the VP/United States Department of Energy Cooperative Agreement-Federal Site Testing Program. This testing programme is being conducted under the direction of Pacific Northwest Laboratories (PNL), at the Idaho National Engineering Laboratory (INEL). The primary objectives of the programme are to conduct heat-transfer and shielding tests on dry storage casks with unconsolidated and consolidated fuel and to provide test information to VP in support of their at reactor dry storage licensing effort.

The cask was completely loaded with 24 Westinghouse 15 × 15 spent fuel assemblies on December 31, 1985. The fuel assemblies were irradiated to a level of 30 000 MW·d/t U at VP's Surry power station. Before shipment to INEL in two TN-8L casks, some guide tubes were equipped with poison rods in the reactor spent fuel pool. It was clearly demonstrated that this operation can be done safely at a commercial plant without disturbing normal activities. On a routine basis, only one day would be necessary to equip 24 assemblies.

Six heat-transfer tests were performed on the TN-24: helium-fill, nitrogen-fill and vacuum in both a vertical and horizontal cask orientation. Thermocouple lances, containing six thermocouples each, were inserted through a specially fabricated test lid into the guide tubes of several spent fuel assemblies. In addition to the research instrumentation provided with the cask, external thermocouples were also attached to the top, bottom and sides of the cask. A pressure transducer was used to monitor the cask cavity pressure. Thermal testing commenced in mid-January, 1986, and was completed in early February; the spent fuel assemblies had then been allowed to decay for about 50 months. Selected results of the thermal tests are shown in Table II.

TABLE II. ACTIVE TEST OF THE TN-24P CASK: MAXIMUM MEASURED TEMPERATURES (℃)
(Power: 21 kW; ambient temperature: 20℃)

Location	Helium		Nitrogen		Vacuum	
	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
Body surface	77.9	83.1	78.8	82.7	78.8	87.4
Cavity wall	92.5	93.1	91.8	95.8	95.8	95.3
Basket plates	195	192	203	223	252	243
Fuel rod	219	213	242	258	288	278

TABLE III. ACTIVE TEST OF THE TN-24P CASK: MEASURED SURFACE DOSE RATE (10^{-2} mSv/h)

Location[a]	Neutron	Gamma
1[b]	37	70
2[b]	25	15
3	20	12
4	1.5	14
5	20	20
6[c]	40	45
7[c]	90	170

[a] The numbers refer to those given in Fig. 1.
[b] With thermal test lid and without protective cover; much lower in normal configuration.
[c] Not accessible during normal storage in a vertical position.

During thermal testing, dose-rate measurements were also performed. In addition to measurements taken with portable neutron and gamma instruments, 80 thermoluminescence dosimeters and track-etch dosimeters were attached to the cask top, bottom and sides. The dosimeters were attached to the cask for up to three days, as determined by energy spectra data obtained by PNL. Selected results of the measurements are shown in Table III.

The cask was moved to the outside, long term surveillance pad in March, 1986. While on the pad, temperature, pressure and cavity gas will be monitored on a monthly basis. INEL is now planning to load the TN-24P cask with consolidated fuel sometime in early 1987. A similar test programme will be implemented to obtain data on the TN-24P cask containing consolidated fuel.