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Research Reactor Spent Fuel Storage in Transport Casks

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AUTOR	Rubrica	Data	VERIFICADOR	Rubrica	Data
Rogério P. Mourão (CDTN)		26/03/02			
Miguel Mattar Neto		26/03/02			

APROVAÇÕES		Rubrica	Data
Chefe de Área	Miguel Mattar Neto		26/03/02
Lider	José A. Perrotta		26/3/02
Gerente do Centro	José A. Perrotta		26/3/02

ARQUIVO	Vanda Scandiuzzi Costa		28/3/02

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R. P. Mourão
Centro de Desenvolvimento da Tecnologia Nuclear
Comissão Nacional de Energia Nuclear
Belo Horizonte, MG, Brazil
mouraor@urano.cdtn.br

M. M. Netto
Instituto de Pesquisas Energéticas e Nucleares
Comissão Nacional de Energia Nuclear
São Paulo, SP, Brazil
mmattar@net.ipen.br

ABSTRACT

An alternative for the interim storage of the spent fuel from the research reactors in the countries participating in the IAEA Project RLA/4/018 is the use of dual-purpose storage/transport casks. To set the basis for a sound technical and economic assessment and – should this become the chosen storage method – to initialize the cask conceptual design, a bibliographic survey was carried out on the different existing cask concepts. This paper presents the results of this review, details the infrastructure and manpower available for the design and qualification of this cask, and discusses the main design guidelines to be met by Type B transport packages carrying fissile materials.

1 INTRODUCTION

The IAEA Project RLA/4/018 aims at establishing local capability for the management of spent fuel elements from the research reactors of the participating countries. This initiative was spawned by the decision of the United States government to set a deadline – the year 2006 – for taking back all American research reactors' fuel elements.

Among the options for the long-term storage of these spent fuels, the dry storage in casks will be studied, both technically and economically.

This paper presents a bibliographic survey of the existing concepts and details the material infrastructure and human resources available in the participating Brazilian institutes to carry out the assigned tasks.

2 ALTERNATIVES FOR THE STORAGE IN CASKS

The storage of research reactor spent fuel elements – SFE – in casks is an advantageous means of enhancing the plant storage capacity – and consequently, its life time– without the burden of costly structural modifications of the reactor building. This system is a flexible way of expanding the plant storage capacity, in that the used fuel can be stored *in situ* or in other facilities outside the reactor site. Moreover, this option prepares the fuel elements for the future transportation to the final repository.

As regards the environment the SFE will be submitted to, the storage in casks can be a wet or a dry storage. Iran (Zamier, 1993) and the Czech Republic (Listik, 1994), for instance, have developed the first storage system, which has the advantage of allowing a shorter cooling period in the reactor pool, but which, on the other hand, calls for a strict control of the quality of the cooling water. The second system, much more popular (J. M. Creer, 1990; Stevens-Guille, 1991; Clements, 1995; Closs, 1997, Gubel, 1997; Doyle, 1997; Michels, 1998, Prabhakar, 2001), even if handicapped by the necessity of longer cooling periods in the pool, has important advantages, such as minimum maintenance (and, consequently, lower costs) even for long storage periods and great flexibility, given that the cask can be easily moved to other sites, if needed.

Concerning the cask concept, the options lie between a simple storage cask or a double purpose storage and transport cask. The latter is clearly more advantageous, both from the economic point of view – only one cask is used for the complete management of the spent fuel until its final disposition (or until its reprocessing, which is today not yet envisaged by the participating countries) – and from the operational point of view, since the transfer step from the storage to the transport cask is skipped.

A third difference has to do with the shielding material used in the cask. The most common materials are lead, concrete (normal or heavy), cast iron or a combination of them. In the wet fuel casks, the biological shielding is provided by a combination of water and other materials (concrete, in the case of Iran).

Some of the most traditional world cask suppliers have developed units specifically for the storage and/or transport of SFE from research or test reactors. Some examples are shown below.

2.1 Large capacity casks

In Germany, the cask CASTOR MTR2 was developed for the storage and transport, *inter alia,* of MTR tubular or box type MTR fuel assemblies and also for TRIGA assemblies (Closs, 1997). Figure 1 shows schematically the main components and dimensions of this cask. It is a cylindrical massive ductile cast iron container, provided with sealed double lid and interchangeable internal basket, which can be replaced according to the element type. Its main external dimensions (without the shock absorbers) are 1,430 mm external diameter by 1,679 mm total height. The cask total weight when fully loaded is approximately 16 t. Cask payload: 33 box type or 28 tubular MTR fuel assemblies or 78 TRIGA fuel assemblies. The cask can be loaded inside the pool or, alternatively, if this operation is not technically feasible, a transfer cask can be used (Figure 2).

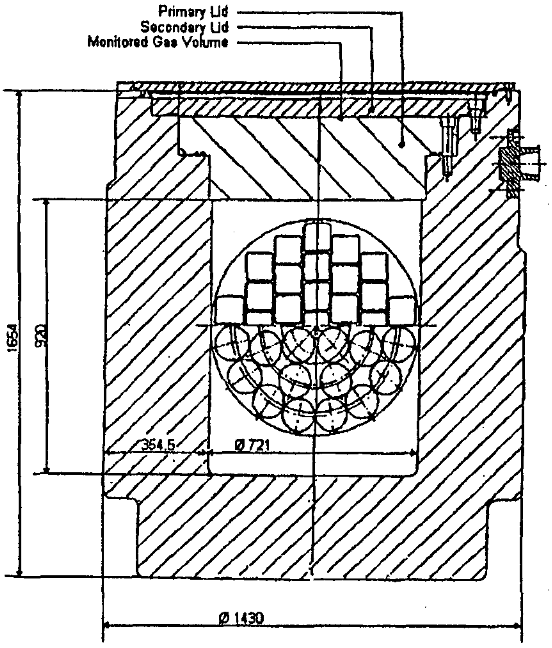

Figure 1. CASTOR MTR2 cask (Closs, 1997)

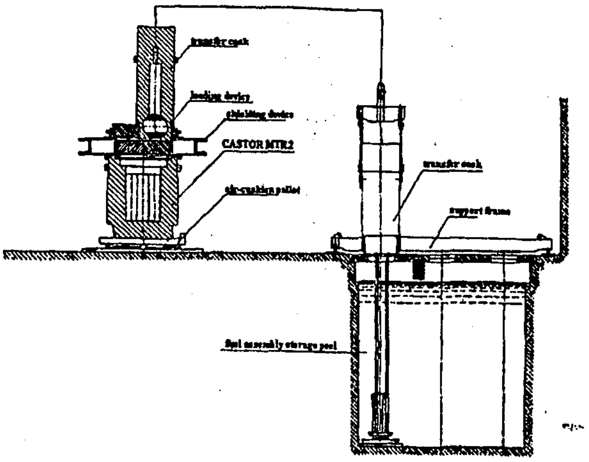

Figure 2. Mobile loading unit with transfer cask (Closs, 1997)

TRANSNUCLEAR has developed the TN-MTR cask for the transport of irradiated MTR and TRIGA fuels. This packaging consists of a cylindrical body with internal cavity and lid, an interchangeable basket, and the impact limiter (Michels, 1998). A lead shielding provides biological protection and is surrounded by a thermal insulation layer, which provides protection in case of fire. The net weight of this cask is 20.6 t and the maximum allowable mass in transport is 23.4 t. Maximum external dimensions (without shock absorber): 1,600 mm in diameter and 1,610 mm in height. Payload: 68 MTR elements and up to 220 highly enriched TRIGA elements.

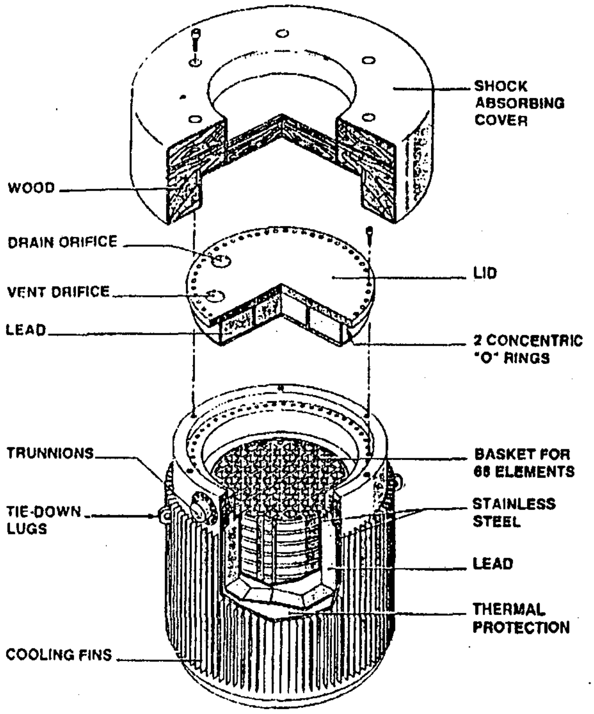

Figure 3. General view of the TN-MTR cask (Michels, op. cit.)

Other examples of large capacity casks are the NAC-LWT and the IU-04 shipping casks, both being currently used to return foreign research reactor spent fuels to the US (DOE, 2002). The former consists of a 18 mm-thick gamma shield, a 30 mm-thick stainless steel outer shell, and a neutron shield tank. Its main dimensions (without the shock absorbers) are 726 mm in diameter and 5,075 mm in length, and total weight of 23.2 t (Figure 4). This cask can hold up to 42 parallel plate MTR or 190 TRIGA fuel assemblies. The latter has two concentric walls of steel, the area in-between being filled with lead for radiation shielding (Figure 5). The cylindrical body is attached to a pallet by means of four connecting rods.

The cask maximum dimensions (including the frame and the shock absorber) are 2.000 mm x 3.250 mm x 2.450 mm (W x L x H), and its total weight is 18.9 t. Its maximum capacity is 36-40 MTR, 40-44 TRIGA.

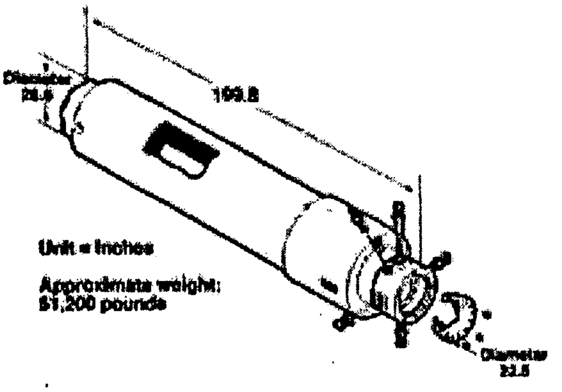

Figure 4. NAC-LWT shipping cask

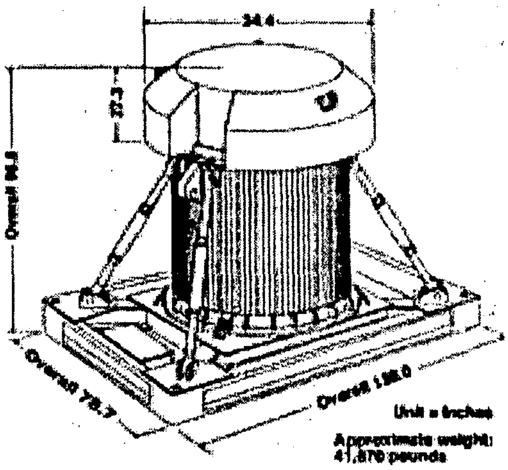

Figure 5. IU-04 shipping cask

2.2 Small casks

A cask has been developed in the United States especially for small facilities with TRIGA reactors (e.g., universities), for which the use of larger casks was not feasible (Clements, 1995). The packaging NRF TRIGA consists of an internal basket, a sealed inner vessel, an external vessel with lead shielding and double sealed lid, and shock absorbers. Figs. 6 to 9 show schematically the components of this packaging. Its maximum capacity is eighteen NRF TRIGA fuel rods and, according to Clemens (op. cit) , its design can be adapted to handle a variety of fuel payloads.

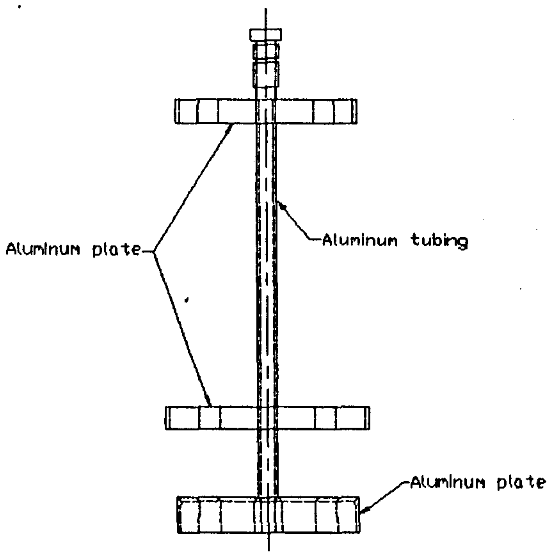

Figure 6. Internal basket (Clements, op. cit.)

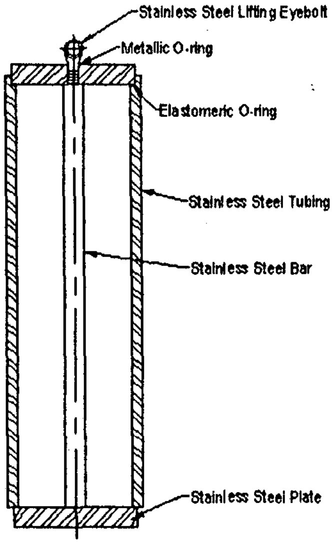

Figure 7. Inner vessel (Clements, op. cit.)

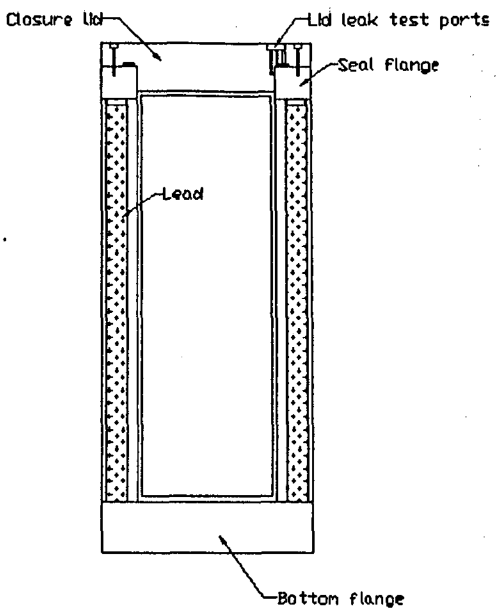

Figure 8. External shielded vessel (Clements, op. cit.)

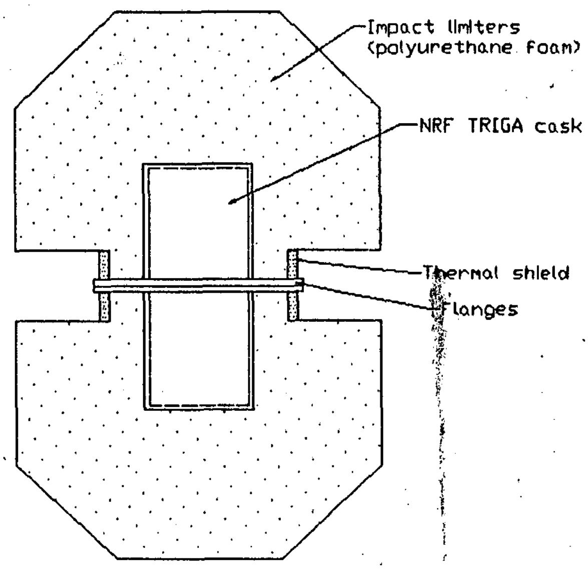

Figure 9. Impact limiters (Clements, op. cit.)

The basic design requirements established for this concept were:

- fulfilling the transport regulations;
- meeting the requirements for long-term storage of spent fuels;
- bearing small dimensions and weight and being user-friendly.

The internal basket of he packaging NRF TRIGA consists of a vertical aluminum tube with three perforated Al plates welded along its length. This basket holds the TRIGA elements and is intended to be loaded inside the reactor pool. The arrangement of the SFE is such that the criticality control is guaranteed under all possible configurations.

The inner vessel consists of a stainless steel tube welded to a thick bottom disk. A lid with elastomeric *o-ring* provides the necessary tightness to this component, which is considered the first confinement barrier to the elements.

These vessels are in turn loaded into the external vessel, which provides the radiation shielding (lead) and additional leak tightness. Its internal cavity is 270 mm in diameter and 760 mm high, whereas its external dimensions are 410 mm in diameter and 990 mm high.

To save storage space, the shock absorbers are used only for transportation. They consist of a shell-like structure with a stainless steel skin and a rigid polyurethane foam filling, whose objective is to absorb and dissipate the impact energy generated during transport accidents as well as to supply thermal protection in case of fire. This component consists of two halves, attached to each other by means of bolted flanges. As the connection region is not entirely protected by the foam, the upper part incorporates a protruding ceramic fiber layer, which provides extra thermal protection.

3 DESIGN CRITERIA FOR TYPE B PACKAGES TRANSPORTING FISSILE MATERIALS

Due to their activity, research reactor spent fuels shall be transported in the so-called Type B packages, as established in the IAEA´s Regulations for the Safe Transport of Radioactive Materials (IAEA, 2001). These regulations, adopted by the vast majority of countries, establish general requirements to be met by all transport casks and specific requirements for Type B packages and for packages carrying fissile materials.

The general safety requirements concern, among other issues, package tie-down, lifting, and decontamination, secure and closing devices, material's resistance to radiation and to thermal and pressure conditions likely to be found during transportation. The specific requirements for Type B packages establish the design tests these packages must withstand and the approval criteria. Finally, the regulations establish requirements which guarantee that fissile material is packaged and shipped in such a manner that they remain subcritical under the conditions prevailing during routine transport and in accidents.

The design tests for Type B packages consist of mechanical, thermal and water submersion tests (Figure 10 shows schematically the test sequence). In drop test I – intended for packages weighing more than 500 kg or with an overall density greater than 1,000 kg/m^3 (based on the external dimensions) – the package is released in the most damaging orientation from a height of 9 m over a sturdy target (normally a concrete platform covered by a thick steel plate). If a worst-case positioning can not be undoubtedly determined, it is recommended that more than one test is performed. In drop test II, the specimen falls onto a cylindrical steel rod, the striking region being chosen in such a manner that maximum damage is inflicted to the specimen. Drop test III is meant for packages lighter and less dense than the previous ones. A square metallic plate weighing 500 kg is released from a 9 m height over the specimen, which shall be positioned on the platform as to suffer the maximum damage. The thermal test consists of exposing the specimen to a 800^0 C temperature for a period of 30 minutes, the specimen being then allowed to cool down naturally. Finally, in the water immersion test, the specimen shall be immersed under a head of water of at least 15 m for a period of eight hours, or to an equivalent ambient pressure.

After the test sequence, the specimen must keep its shielding integrity and thermal protection and must present no leakage or, at the most, a very limited contents leakage.

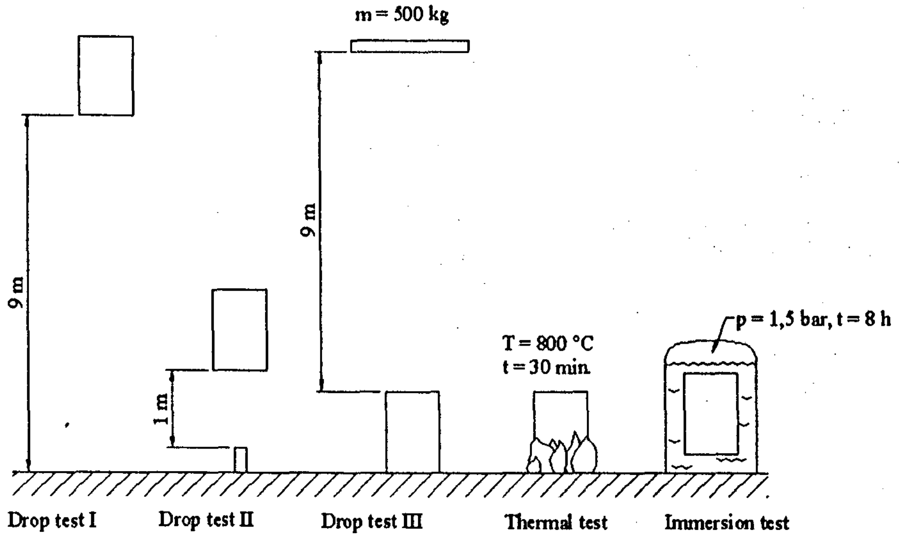

Figure 10. Test sequence for Type B packages

The tests prescribed for packages transporting fissile materials are basically the same as those above, but not all of them are applicable to all specimens. In fact, the package designer has to assess and choose the most damaging of the two following test sequences: 1) Drop test I or III (depending on the specimen weight and overall density), drop test II and thermal test; or 2) Immersion test. The criteria for approval establish that one package taken solely, either undamaged and damaged by the tests, and also a specific undamaged and damaged package arrangement, as defined in the regulations, shall be subcritical.

4 INFRASTRUCTURE AND EXPERTISE AVAILABLE FOR CASK DEVELOPMENT

The Brazilian institute CDTN has the basic laboratorial infrastructure to test Type B packaging prototypes up to 3 t in weight and maximum dimensions of 2 m. The drop tests I, II and III are carried out on a 3 m x 3m x 4 m concrete platform with a 25 mm thick steel plate on its upper surface, provided with a release mechanism. The water submersion test is performed in a pressure tank and the thermal tests can be carried out in industrial furnaces of local foundries.

As regards human resources, the two participating institutes IPEN and CDTN have personnel with experience in radioactive materials transport regulations, Type A packaging design and testing, structural design, instrumentation (accelerometers, strain-gages, thermocouples, load cells), finite elements codes (ANSYS, LS-DYNA, ABAQUS), and criticality analysis (SCALE 4.4A, MCNP). Also extensive research on the use of rigid polyurethane foam as cushioning material in transport packaging is being carried out jointly by both institutes.

This expertise can be made available for the development of a cask concept, should this storage method be chosen for the irradiated fuel elements of the research reactors of the participating countries.

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