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PROGRESS IN DESIGNING THE INTERNAL ARRANGEMENTS OF PACKAGINGS FOR LWR SPENT FUEL

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Abstract

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The internal arrangements (baskets) of casks for LWR spent fuel must provide subcriticality control, decay heat transfer, additional shielding, resistance to mechanical strain and ease of operation for a number of spent fuel assembly specifications (i.e. up to 3.7% initial enrichment, down to 8 months cooling time). The Transnuclear group of companies has developed, over three generations and according to such design criteria as structure, subcriticality control and heat transfer, large-capacity baskets for transport casks. Thus, the trend has been to simplify from 'one specific material for a specific task' to 'one material for all purposes'. Transnucléaire is now engaged in the next step, which has resulted in a new high performance cast basket for highly enriched fuel. In order to further increase the payload for transport/storage casks, Transnucléaire has also developed a new basket concept in which water gaps have been replaced by 'poisoning' the fuel medium itself. This is accomplished by inserting poison rods in the spent fuel assembly guide thimbles and by building a basket with thin partitions made of interlocking Al-B plates. This basket is designed to deform under heavy accidental loads, while continuing to perform all its functions, especially subcriticality control. An active test of such a basket at the Idaho National Engineering Laboratory is under way to verify the predicted behaviour under normal conditions. This concept provides an approximately 20% increase in the payload of a given cask and decreases the manufacturing cost by almost 50%.

1. INTRODUCTION

The Transnuclear (TN) group of companies designed and developed several large-capacity casks for the dry transport and/or storage of spent fuel, numerous units of which are now currently operated throughout the world. These different cask designs have been extensively described at recent PATRAM meetings, but up to now their internal arrangements, specially designed for dry transport, have been inadequately discussed. This paper will discuss the main features in the ten-year evolution of TN-designed internal arrangements and, in particular, TN baskets.

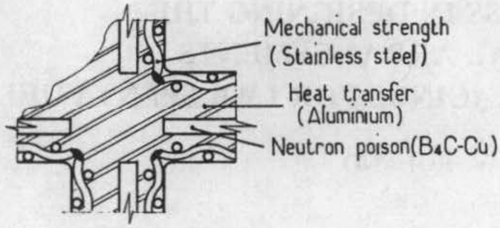

FIG. 1. Early designs of a typical wall section.

The internal arrangements of a spent fuel dry cask are intended to fulfil several functions. The first one, subcriticality control, must be fully satisfied in any case. The other ones (below) should to be optimized:

(1) Decay heat transfer under dry conditions
(2) Additional shielding
(3) Resistance to mechanical strain
(4) Ease of operation.

Moreover, the basket is designed to meet such utility requirements as fuel initial enrichment, burnup, cooling time, possible weight limitations and maintenance considerations, and to optimize the economics involved (price-to-capacity ratio).

2. FIRST-GENERATION BASKETS FOR LARGE-CAPACITY CASKS

The first basket design, developed in the late 1970s by Transnucléaire, Paris (TNP), combined three different materials in a general manufacturing process using an aluminium-alloy casting (Fig. 1):

(1) Neutron 'poison' in the form of B_4C-Cu sintered plates to ensure subcriticality.
(2) Stainless steel wire mesh to provide structural strength so as to keep the basket geometry unchanged even under regulatory accident conditions.
(3) Aluminium alloy (AS 13) to transfer the decay heat from the fuel assemblies to the cask shell.

A number of such baskets have been, and are still being, used to serve different PWR reactor sites located in several countries for fuels having the characteristics shown in Table I (column 1). The operating experience with this type of basket showed that the main improvement that could be made to its design would be to reduce the drying time after wet loading in the reactor pool. The drying process can last almost 2 days for a 30 kW residual heat power, owing to the water trapped within the sintered plates cored in the aluminium casting, which cannot be made fully leak-tight. Although this basket type fully met all of the main requirements, its design was

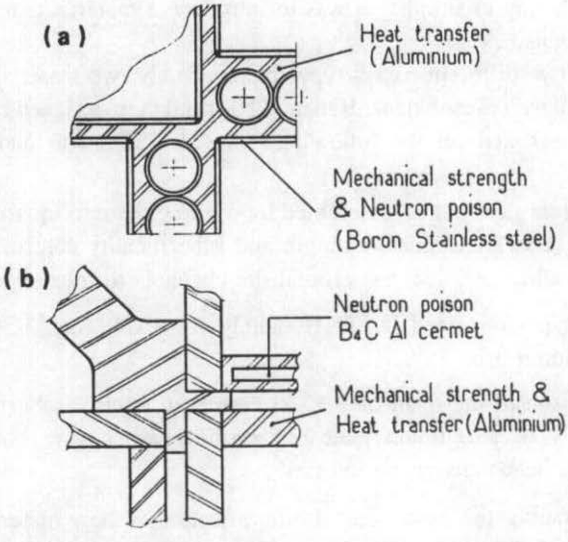

FIG. 2. Intermediate and current designs of a typical wall section.

TABLE I. CHARACTERISTICS OF EXISTING INTERNAL ARRANGEMENTS

Basket type	1	2	3	4	5	6
See Fig. No.	1	2(a)	2(b)	3(a)	3(b)	4
Type of contents	PWR[a]	BWR[b]	PWR[c]	PWR[a]	BWR[b]	PWR[a]
Structure	St.St[d]	Boron St.St[d]	Al	Al-B	Al + Al-B	Al-B
Subcriticality control	B_4C-Cu	Boron St.St[d]	B4C-Al	Al-B	Al-B	Al-B
Heat transfer	AS 13	AS 13	Al	Al-B	Al Al-B	Al-B
Water gap	Yes	Yes	Yes	Yes	No	No
Max. initial enrichment (%)	3.5	3.5 or 4.0	3.5	3.5	3.3	3.7
Cooling time (months)	8	8	24	8	16	40
Max. heat power (kW)	93[e]	93[e]	50	93[e]	30	35

[a] Fuel cross-section 215 × 215 mm.
[b] Fuel cross-section 140 × 140 mm.
[c] Fuel cross-section 230 × 230 mm.
[d] St.St = Stainless steel.
[e] For transport only.

fairly complex. A way to simplify it was to introduce a material that could provide for several functions.

This led to two different basket types made of only two materials. One basket type, pre-designed by Transnuklear, Hanau (TNH) and then designed by TNP mainly for BWR fuel, is based on the following: (see also Fig. 2(a) and column 2 of Table I):

(a) Boron stainless steel plates, assembled by welding them to square section channels, giving both mechanical strength and subcriticality control.
(b) Aluminium alloy (AS 13) cast around the channels to transfer decay heat.

Another basket type, designed by TNH mainly for PWR fuel, is based on (see Fig. 2(b) and column 3 of Table I):

(i) Neutron poison in the form of B_4C-Al cermet to control subcriticality
(ii) An assembly of aluminium plates or profiles which give both mechanical strength and heat-transfer capabilities.

Finally, pursuing the same line of simplification, a new material, boronated aluminium (AlB), performing all of the three main functions itself (mechanical strength, neutron poison and heat transfer), was developed, patented and used to design new PWR baskets. Five baskets to such a design, using the casting process (see Fig. 3(a) and column 4 of Table I), were supplied by TNP to Cogéma and SKB and have now been in operation for one year. They have a drying time which is now reduced to a few hours, even for very low heat power.

Furthermore, as several grades of AlB have become available, not only for the casting process but also for rolling or extruding, new basket designs have been made possible. In particular, TNH recently designed a BWR basket combining AlB sheets with standard aluminium profiles. Whenever neutron poison is not necessary, standard aluminium is preferred because of its lower cost (see Fig. 3(b) and column 5 of Table I). The fabrication of six baskets to this design is now under way.

The main advantage of AlB material is that it allows the best possible use of both the limited room available within the cask cavity and the limited weight credit available to fulfil the different functions required of the internal arrangement. Thus, in addition to the reasonably low drying time made possible by a massive homogeneous metallic alloy, AlB material presents the option, for the same price range, of significantly increasing basket performance according to the user's needs, i.e. one or several of the following possibilities:

— Higher capacity in terms of the number of fuel assemblies loaded in the cavity.
— Possibility of providing larger lodgements to accommodate encapsulated fuel assemblies.
— Higher initial enrichment of fuel.
— Higher residual power of the fuel resulting from burnup and cooling times.

Transnucléaire has almost completed the design of a new high performance cast basket with very promising characteristics for highly enriched fuel.

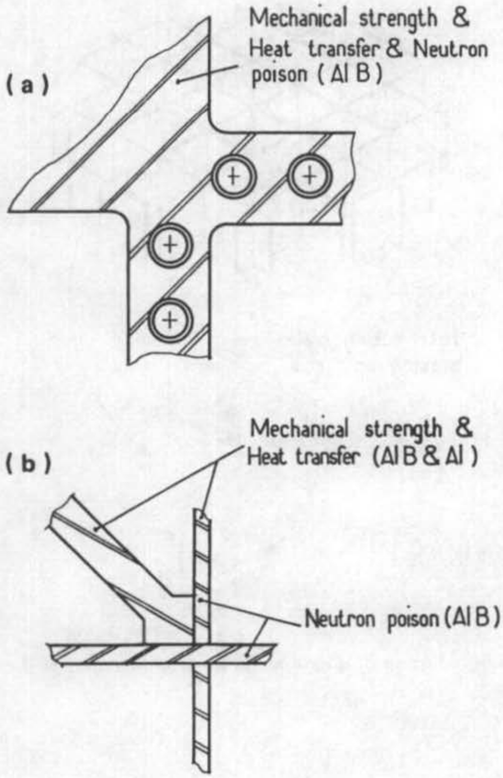

FIG. 3. Advanced designs of a typical wall section.

3. A NEW CONCEPTUAL DESIGN OF A BASKET FOR DRY TRANSPORT/STORAGE CASKS

In the case of dry storage casks, on which the TN group has carried out an extensive research and development programme, optimizing cask capacity has become essential. Therefore, it was natural to look for further space savings in order to offer additional lodgements. The only way to achieve this goal was to design out the water holes. This can be done, providing subcriticality control is ensured by other means, for instance by poisoning the fuel medium itself.

From these considerations, TNP designed and developed a new concept of internal arrangement for PWR transport/storage casks consisting of two parts:

(1) Poison rods inserted in the guide thimbles of each fuel assembly.
(2) Thin partition plates, made of AlB, separating the fuel assemblies from each other and making up a relatively light basket (see Fig. 4 and column 6 of Table I).

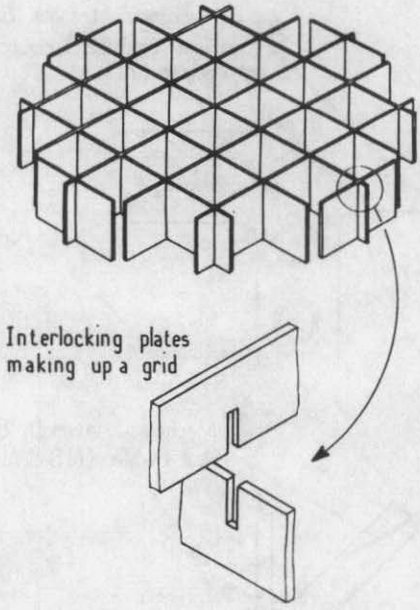

FIG. 4. Section of a new basket for a storage/transport cask.

Under normal transport conditions, subcriticality control relies both upon the poison content per unit length of the poison rods and upon the boron content per unit area of the basket partitions. Under accident conditions, it may be shown that reactivity can only decrease if the basket partitions are deformed, or collapse (owing to the increased under-moderation of a fuel medium made more compact), provided that the relative positions of fuel pins, poison rods and basket partitions are kept unchanged, i.e. provided that the basket partitions are not ruptured.

A basket conforming to this new concept has been fitted in the TN-24 storage cask now undergoing long term active testing at the Idaho National Engineering Laboratory (INEL). Designed to hold 24 PWR assemblies, it has been manufactured from AlB extruded sheets, slotted and interlocked to each other like an egg crate (see Fig. 4). The AlB material grade is selected with a yield strength high enough to withstand normal transport and handling conditions and with a ductility sufficient to guarantee that there is no rupture under accident conditions. Heat transfer takes place from the central lodgements by conduction in the sheets and at the periphery by radiation between sheets and the cavity wall. The current series of active tests at INEL has confirmed the good thermal behaviour predicted.

The insertion of poison rods into the fuel assembly guide thimbles has recently been carried out at the Surry reactor pool by means of a simple system. This manually operated device, designed for a one-at-a-time insertion, proved capable of processing all 24 assemblies in approximately 24 h. A 'poison-rod inserting' machine has also been designed that can perform this task for each complete fuel assembly. Both systems also allow for the recovery of the poison rods, if necessary.

This internal arrangement concept can only accommodate fuel assemblies with guide thimbles free from control-rod spiders (if this is not the case, conventional rigid baskets remain available). It also has the advantages of:

- Increased capacity (approximately 20%) for a given cavity diameter.
- Weight reduction and material saving.
- Simple manufacture without the need for high investment (such as a mould for casting).
- Costs brought down to almost half that of a traditional rigid basket.