## Use of Boron in Structural Materials for Transport Packagings

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## INTRODUCTION

The use of borated materials for criticality control is a well-proven technique in the field of spent-fuel transport packagings. Because these packagings are usually designed for a class of spent fuels with a range of enrichment, burnup ratios, and decay time, the safe approach and accepted practice is to consider that the fuel is new and in pure water. Low levels of burnup credit have been considered only if the burnup can be and is measured individually on each spent-fuel assembly (SFA) before loading it into the packaging. Furthermore, no credit is taken for boron present in the loading pool water, contrary to what is sometimes done by the designers of "storage only" casks.

Therefore, boron has been included in the internal arrangements (baskets) of transport packagings in a number of ways described in previous PATRAM conferences (see references). The advantages of aluminum and/or boron aluminum for efficient decay heat transfer in dry transport/storage casks have also been described previously.

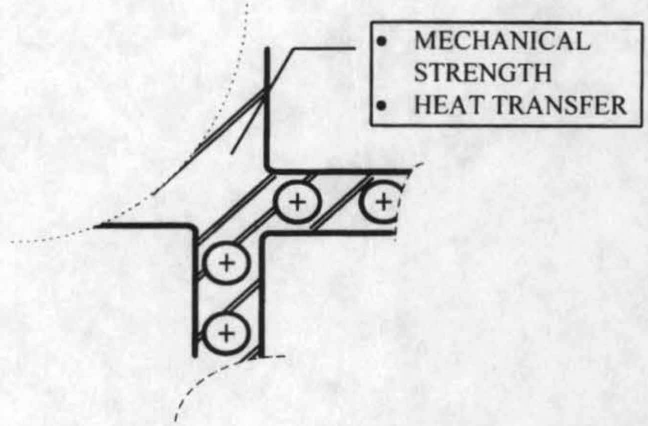
The present paper reviews the developments of Transnucléaire in basket technology and shows the advantages for public and operators health and safety of taking into account the structural contribution of these materials to mechanical behavior of the basket.

## BORON ALUMINUM BASKETS

Transnucleaire has developed several types of boron aluminum baskets, based on two basic manufacturing technologies, casting and extrusion. These two techniques correspond respectively to short cooling time SFAs and to long cooling time SFAs.

Both combine in the same material the functions of criticality control, decay heat conduction, *and* structural support of SFA under normal and accident conditions.

FIGURE 1: Cast boron aluminum basket




**High Performance Cast Boron Aluminum Basket**

This basket, which equips the TN12, TN13, TN17, and LK 100 transport casks, is made of cast aluminum (Figure 1). It can accept up to 4.3% enrichment and 8 months cooled SFAs. It has been in service since July 1985 and has allowed drying times to be reduced dramatically and therefore has contributed to lower integrated doses to operators during loading at power plant.

To date, more than 30 such baskets have been delivered and have transported thousands of SFAs to La Hague reprocessing plant from Europe and Japan. The basket (Figure 1) is made of standard aluminum alloy in which the boron is scattered in the matrix, with a minimum segregation.

In 10 years of ongoing implementation, more than 280 boron aluminum castings have been made, each among the largest one-piece castings ever (nearly 1 ton each). These castings are the basic part of the baskets.
Coming after an indepth development program, the production baskets have further confirmed that distribution of boron in the matrix is adequately even. We have developed procedures to allow traceable demonstration of this result for each new fabrication. These procedures involve the implementation of measurements with calibrated neutron sources and isotopic analysis of samples. Effective boron 10 content for criticality assessment is the one measured after deduction of all uncertainties. Reproducibility of the process is demonstrated, and values of mechanical strength considered in our safety analysis reports are validated. Thorough tests were performed, and comparison of static tensile tests and of dynamic ones were performed in order to account for the regulatory drop test conditions that feature high velocity of load application.

To quote our sixth reference, "because their crystal lattice is face-centered cubic, that is stable at all temperatures, the aluminum alloys display no embrittlement phenomenon at low temperature, unlike metals with body-centered cubic lattices such as iron and some steels. In fact, at low temperatures, yield strength, tensile strength, and rupture elongation increase." We did, however, run some tests. The following table shows values from V-notch Charpy test:

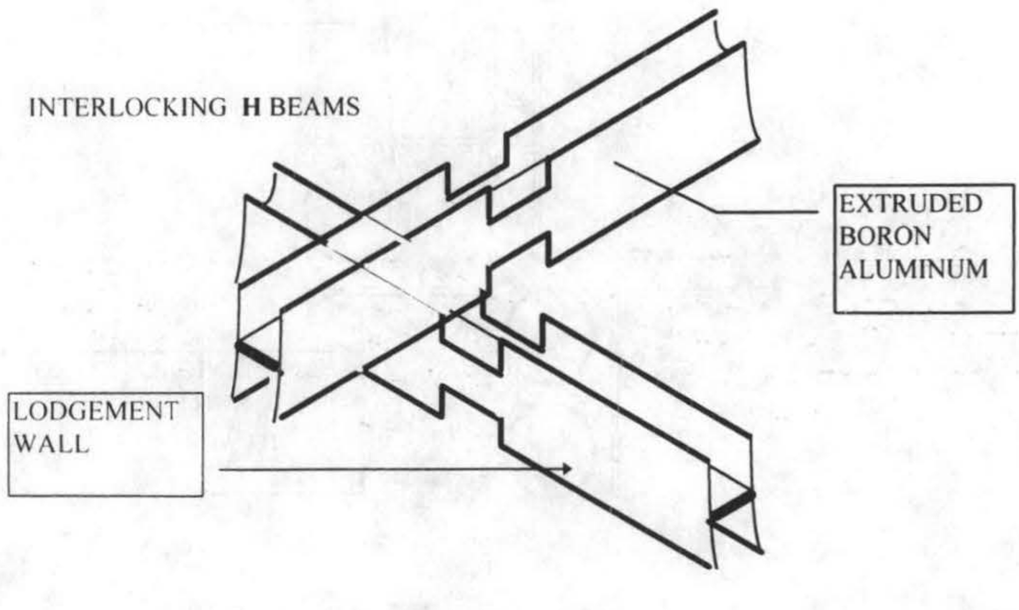
| **test temperature** | **KCV in J/cm²** |
|---|---|
| aluminum matrix without boron (20°C) | 3.8 |
| aluminum with boron at 20°C | 2.8 |
| aluminum with boron at -40°C | 2.3 |
| aluminum with boron at 350°C | 5.1 |

The results observed show that the presence of boron does lower the fracture toughness of the material but that, as expected, no transition temperature appears.

**Extruded Aluminum Basket for Long Cooled Fuel**

These baskets equip the family of TN 24 transport/storage casks. They are designed for the large capacity warranted by the long cooling times involved, from 5 years on. The TN 24 D casks, holding 28 spent-fuel assemblies, delivered to Synatom (Belgium) are among those. One of the models features H-shaped profiles mechanically assembled that make up the wall partitions (Figure 2). For each basket, more than 1 km length of profiles is used.

FIGURE 2 : Extruded aluminum basket



The procedures implemented allow to guarantee the minimum boron content in the profile with the adequate dispersion for criticality control. The procedures involve neutron attenuation measurements on the aluminum billet before extrusion and on samples from profiles thereafter.

The mechanical characteristics were measured at various temperatures and were of the order of 100 MPa, with fair elongation characteristics.

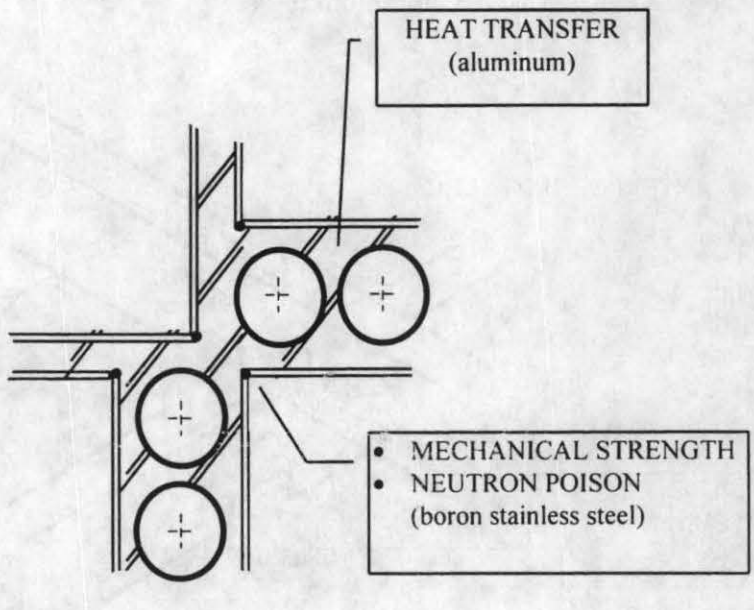
## BASKETS WITH BORON STAINLESS STEEL

### Dry Transport Baskets

These baskets have been developed for the transport of short-cooled BWR SFAs. They feature the following (Figure 3) :

- Boron stainless steel plates, assembled into a square section channel by welding. Criticality control is provided by these channels.
- Aluminum alloy is cast around the channels to transfer decay heat.

FIGURE 3: Basket with boron stainless steel channels



The structural analysis takes into account the contribution from the aluminum *and* from the boron stainless steel to the mechanical strength. The following table shows values from the ASTM A 887 values, which is the first standard dealing explicitly with nuclear-grade boron stainless steel.

| material | yield strength (0.2% elongation) MPa | tensile strength MPa | elongation (%) |
|---|---|---|---|
| ASTM A 887 grade A minimum values | 205 | 515 | 17 |

As in the case of boron aluminum, Transnucléaire has developed and qualified procedures that allow the proper distribution of boron in the alloy to be confirmed.

Other published values ( "Micro-Melt, NeutroSorb PLUS") confirm the good characteristics that are obtained in that field:

| material | yield strength (0.2% elongation) MPa | tensile strength MPa | elongation (%) |
|---|---|---|---|
| Carpenter Micro-Melt®NeutroSorb PLUS® at 2% boron | 345 | 760 | 30 |
| ASTM A 887 grade A minimum values | 205 | 515 | 17 |

Because austenitic stainless steels are not sensitive to brittle fracture, the influence of boron is limited, and minimum Charpy V notch values remain above 20 J.

Another issue in the structural behaviour of boron stainless steel is welding.
We implement two methods, TIG or electron beam welding for thicker material.

Using classical approaches to welding process qualification and weld inspection, the following results were reached with electron beam welding (1% boron in weight):

| test temperature | tensile strength MPa |
|---|---|
| 20°C | 540 |
| 200°C | 490 |

The values compare well with that of the base metal. Welding on boron stainless steel presents neither metallurgical defect nor compacity defects. The curvature of the weld seam surface is slightly higher than that of ASTM 304 steel welding; hence, it has a slightly higher superficial stress level.

**Wet Transport Baskets**

Transnucléaire has also developed wet transport baskets for the transport of very short cooled fuel (1 to 2 months cooling time).These baskets use a stainless steel frame that allows water to circulate in natural convection inside the packaging and welded boron stainless steel channels made of perforated plates that allows water circulation between the fuel rods. The functions of the channels are of course criticality control but also load spreading onto the stainless steel frame supports. Thus they are considered as long continuous beams with multiple supports. his design has been used for the TN17/3 cask and the TN 12/3 cask design.

## INCREASED PAYLOADS

How does the use of the structural strength of borated materials contribute to increased payloads?

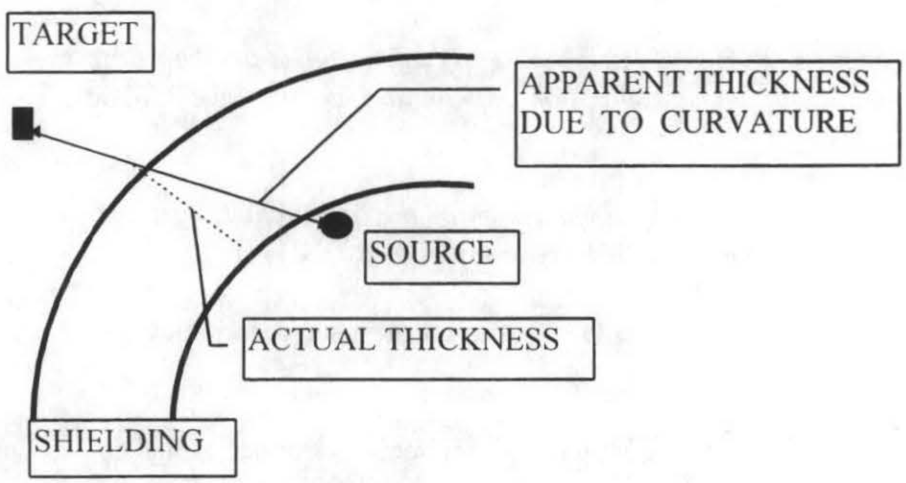
When their contribution to structural strength is considered, two benefits appear :

- Because their structural strength is generally sufficient to take care of normal and accident loads, there are fewer transitions between materials along the decay heat path, and the gradient of temperature between fuel and atmosphere goes down. Hence the fuel cladding is cooler, the basket material too, and hotter fuel can be accepted.

- Because unnecessary additional structural material is eliminated, the basket is more compact. This means that if one is limited by handling considerations, be they mass or dimensions, a compact basket accommodates more fuel within the same mass and dimensions constraints. A smaller cask cavity diameter concentrates the shielding mass nearer the radiation source, which has favorable effects. Higher curvature increases the geometrical effect of relative thickness of shielding between source and target, thus diminishing the overall thickness needed (Figure 4). Also, for a given shielding thickness, the shielding is lighter if the diameter is smaller.

As an order of magnitude, the current U.S. Department of Energy MPC concept could easily handle 24 PWR spent-fuel assemblies within the set dimensions and mass limits, *without burnup credit* and within the fuel cladding limit temperature considerations. This represents a 14% increase with respect to the expected payload of 21 PWR SFAs.

FIGURE 4: Effect of curvature on the apparent shielding thickness



## CONCLUSION

A contribution to public health protection:

Boronated materials as structural supports address effectively our most important and permanent task as transporters of radioactive materials, that is ensuring safe transports and protecting the health of populations under accidental circumstances as well as under normal circumstances. The present review of more than 10 years of design, manufacture, and operation of such baskets shows how this goal is achieved by increasing the payload of each transport operation and therefore limiting the number of transports.

Because the type B packagings are designed to prevent a release exceeding $A_2$ in one week after an accident and because $A_2$ depends only on "what type of content" and not on "how much" , it is clear that the risk of release is lower for a smaller number of heavy transports than for a larger number of lighter transports.

Taking advantage of boronated alloys for their mechanical characteristics allows the payload of a packaging for given maximum weight and dimensions to be increased and therefore serves the public.

## REFERENCES

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