A New Use for the TN Vyal B^{TM} Neutron-Absorbing Resin

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ABSTRACT

TN International proposes to its customers a wide range of solutions for the transport of nuclear material and takes part in all the phases of the Nuclear Fuel Cycle. Thus TN International has developed neutron shielding materials for various customer transportation needs, which have been adapted to the characteristics of transported nuclear materials. The shielding material is fitted on the casks as an external layer of the containment shell in the radius gap. For example the TN Vyal B^{TM} resin (made by mixing a thermoset resin and two minerals fillers) is used on casks requiring a maximum temperature. This resin can resist up to 160°C.

At the moment, the manufacturing process involves pouring the mixture directly into the cask external shell under temperature control. This process need to be monitored very precisely for two reasons:
On one hand, the pouring operation is not reversible. After pouring the resin, there is no way to remove it (except by destroying the external shell) or to access it directly (no possibility to cut a sample). On the other hand, some resin (for example TN Vyal B^{TM} resin) need to stay in a temperature range during the polymerisation. As the casks have a significant thermal inertia and are located in boiler workshops, the pouring becomes a complex operation that needs to be performed by qualified operators and following a qualified procedure.

TN International manufacturing and R&D departments are jointly developing alternative solutions to the in-situ pouring. One of these solutions is to manufacture the resin layer as blocks that are poured in separated moulds and subsequently installed on the cask. This new process enables the control of the resin after pouring permitting the rejection of any defective blocks before their mounting in the cask.

Even if these resins have been developed for casks, their use is now being adapted to other needs such as nuclear installation. For example, this technology was successfully adapted by TN International in EPR^{TM} reactors. Actually, TN International recently received an order for the procurement of neutron shielding in the core of the EPR^{TM} reactor (OL3) in Olkiluoto (Finland). This contract opens new perspectives for the TN Vyal B^{TM} application in Nuclear Power Plants or fuel plants.

1 Introduction

Neutron shielding materials are very important for nuclear safety. Their function is to provide sufficient protection to the public and to the operators and to maintain the integrated ALARA dose. As the transport and storage casks will contain more and more used fuel elements with higher burn-up values, a full range of very high performing neutron shielding resins have been developed and tested by TN International. These resins are to withstand high temperatures and have been fully qualified to be used in our high capacity range of casks.

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TN Vyal B™ resin developed by TN International meets the needs of AREVA NP with its high performances and its high level of qualification. TN International succeeded to propose innovative solutions for EPR™.

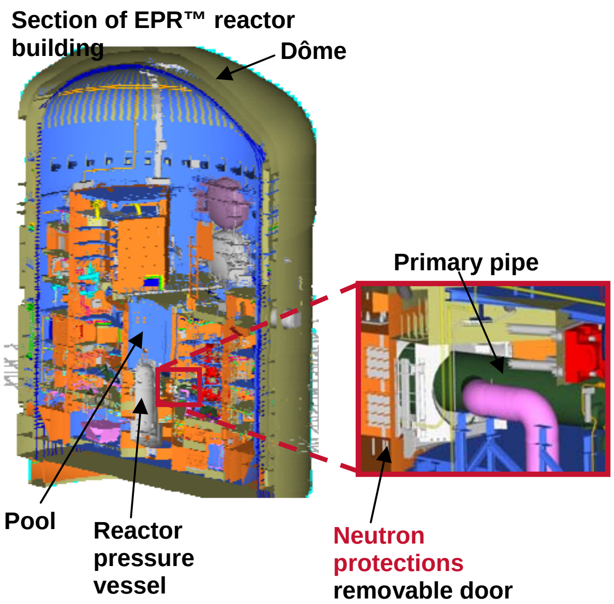
In EPR™ reactors, inspections can be made during the reactor operation. Thus an effective and removable neutron shielding in the primary loop is to be inserted to protect the inspectors. The TN Vyal B™ is used in the Olkiluoto (OL-3) EPR™ shielding in different areas in the reactor building. These new devices called neutron protections are removable and, of course, have an adapted shape.

2 Focus on the EPR™-Neutron protection in TN Vyal B™ project

Neutron shielding is to be installed around the reactor to minimise the neutron radiation effect on workers during the inspection phases.

Neutron protections consist on removable doors witch are designed to meet the needs of the final operator by reducing the dose rates inside the reactor building. Neutron protections are parts of EPR™ new safety improvement features.

TN International undertakes to supply all the EPR™ reactor and proposes equivalent solutions to new prospects as ITER consortium and AREVA TA for submarine nuclear reactors.



There area three main types of neutron protection implementations around main coolant legs : Hot Leg 1, Cold Leg1 and Cold Leg 3. The neutron shielding will be provided by TN Vyal B™ blocks embedded in stainless steel boxes.

3 A fully-qualified product to be used for neutron shielding

High neutron shielding efficiency of a material can be achieved by concentrations of Hydrogen and Boron. A high content of these elements leads to a good neutron isolation effect due to an atomic concentration of Hydrogen that slows the fast neutrons which are then captured by the high cross section of Boron. The main function of the resin is to provide Hydrogen, and the functions of fillers are to provide Hydrogen, Boron and fire resistance.

Materials which minimize the impact on the environment and on human health at all stages of the product have been selected. Among the polymers, the environmental impact of the selected thermoset resins (without halogen contents) is minimum. Concerning Aluminium hydrate, reference <2> states that "from a toxicological and eco-toxicological point of view, there is no objection against using it as a flame retardant."
Determination of the properties of TN Vyal B™ resin has been necessary to do the design and to obtain design approvals. General properties are determined through tests: polymerization rate, density, chemical analysis. Mechanical characteristics are measured. Temperature long term resistance is evaluated with ageing tests and estimated through an Arrhenius extrapolation.
Typical density: 1.79

%	TN Vyal B™
H	4.77
C	24.1
B	0.9
Al	21.4
Zn	1.8
O	47

Table 1: Chemical analysis of TN Vyal B™ **neutron shielding resin**

Mechanical properties: the shielding material remains solid when submitted to permanent thermal load of storage conditions and to exposure to temperature changes (loading/unloading).

Characteristics	Values
Young modulus	20°C : 4000-5000 MPa 150°C : 1400-1500 MPa
Maximum stress (20°C)	140-150 MPa
Strain (compressive) at max stress (20°C)	6 - 8%

Table 2: Mechanical properties of neutron shielding resin

The acceptable temperature of TN Vyal B™ neutron shielding resin is between 160°C.

Ageing tests at different temperatures 150°C, 160°C and 170°C in an oven are performed during the qualification to evaluate the variation of shielding performance.

The designs of storage systems for used fuel elements or vitrified wastes must also resist to hypothetical fires. It is therefore necessary to use fire resistant neutron shielding systems. In the case of packaging, fire resistance is specified in IAEA safety standards <1> hypothetical transport accident conditions. For designers, self-extinction is requested.
Safety requirements for storage systems require that the neutron shielding resin does not burn or contribute to fire in any way. In order to address this safety issue, fire tests were successfully performed on TN Vyal B^{TM} neutron shielding resin.

Thermal expansion coefficient:
The thermal expansion coefficient was determined in the temperature range 25°C-250°C by thermo-mechanical analysis (TMA) according to Standard ISO 11359-2.
Two values, mentioned in Table 3, were measured before and after Tg (glass transition temperature 126°C).

TN^{TM}VYAL B	Linear thermal expansion coefficient (10^{-6}/K)
T < Tg (25°C - 110°C)	41
T > Tg (140°C - 210°C)	109

Table 3 : Values of the linear thermal expansion coefficient of TN Vyal B^{TM} **resin before and after Tg**

Thermal conductivity:
Typical values are given in Table 4

Temperature (°C)	λ (W/m/K)Vyal-B
23	1.001
100	0.897
150	0.852

Table 4 : Values of the thermal conductivity of neutron shielding resin at different temperatures

Specific heat:
The specific heat value was determined in the temperature range 20°C-250°C by differential scanning calorimetry (DSC) according to Standard ISO FDIS 1357-4. Typical values are given in Table 5.

Resin	Specific heat (J/g/°C)
Vinylester (TN Vyal B^{TM})	**1.31**

Table 5: Values of specific heat of neutron shielding materials

Lixiviation :
Lixiviation tests during a 1-week period in water (representing pool waters) at 90°C were performed in a closed circuit and with a flow of 27 cm^3/min. Each day, 500mL of water were removed from the reactor without refilling. Chemical analysis was performed and the sample was weighed at the beginning and at the end of the test showing that there was no dissolution of the resin.

Radiation degradation of neutron shielding resin
This effect was measured in real radiation conditions. The mechanisms of degradation depended on the type of polymer : break of the main chain, cross linking, production of unsaturated bonds and oxidization.
The degradation starts at more than 10^{15} n/cm^2 fast neutron fluence, corresponding to a dose of 10^6 Gy.

For the radiation degradation of TN Vyal B^{TM}, the fluence level for cask neutron shielding is 10^{11} n/cm^2 for 40 years of continuous use, corresponding to a dose of 10^3 Gy which is far less than the values given in reference <3>. Therefore, the radiation degradation of TN Vyal B^{TM} in interim storage casks is negligible.
Is there a risk of depletion of Boron 10 in TN Vyal B^{TM} ? The total neutron capture is less than 10^{13} atoms/cm3. The initial Boron 10 content of resin is approx 10^{20} atoms/cm^3. It can be concluded that no Boron 10 depletion occurs.

4 Interfaces

The management of interfaces is particularly difficult inside an EPR^{TM} reactor which requires extensive preliminary studies. Main issues of the use of TN Vyal B^{TM} resin inside an EPR^{TM} reactor building are the management of interfaces. Interfaces are multiple and include:

- Civil engineering
- Structural steelwork
- Reactor coolant system

- Piping of back-up systems
- Piping of secondary systems
- Nozzles and instrumentation probes

In the case of OL3 design, the interfaces were taken into account from the design phase and tight collaboration with the customer is necessary. Anticipation of resin block storage issues, introduction and assembly of resin blocks upstream to the manufacturing phase, OL3 on-site visits, meetings with site managers, training on NAVISWORK® software to perform a 3D navigation in the reactor general layout model, everything has been planned to ensure no interfaces issues. All dimensional were physically measured on site to be sure that the neutron shielding dimensions were compliant with the concrete dimensions. Positions and flatness of anchorpoints were also checked in order to define the assembly tolerances. As manufacturing of the resin blocks are not be made on site, precise measurements are essential. Hundreds of tubes, cables, metallic platforms and frames all interfere with the geometry of the neutron shielding resin. Thus, a global study is under way to determine all the interfaces during the block design phase.

5 Manufacturing

Different processes are necessary for the use of neutron shielding resin in casks and EPR™ reactor.
The direct pouring process of resin is simple and requires minimum equipment. Thus, it is very economical. It can be done at ambient temperature (recommended over 18°C). Depending on the volumes to be poured, it can be done manually or with a pouring machine.

For a transport/storage cask, neutron shielding material is poured between the body and the external steel envelope. For some casks, it may be poured in metallic compartments or between heat conducting fins.

For the EPR™ reactor shielding blocks, the chosen technical solution is to mould rectangular blocks which are machined and embedded in metallic boxes. This solution is advantageous for the following reasons:

- defective blocks may be rejected before machining
- traceability can be controlled
- logistic circuit is simplified

A thermo-regulated mould was built to produce 60 kg test blocks. The real block shapes have been carefully analysed and sorted out to identify the main types of blocks, the total number of blocks to be machined, the symmetry axis, the number of moulds to be manufactured. This analyse has lead to the identification of 8 main types of blocks. Twenty six different types of moulds will be necessary to make the 500 blocks for the whole reactor building. At the end, the 500 machined blocks will correspond to 10 tons of TN Vyal B™.

Specific procedures in addition to the already existing pouring procedures were developed to ensure the different phases of manufacturing from the pouring to the machining of the blocks.

In the actual OL3, after all the blocks will have been machined, they will be embedded in the individual stainless steel boxes and mounted on-site in a specific metallic frame. Not all of the blocks are mobile, some of them may be attached on the structure.

6 Conclusion

TN International has accumulated 20 years of experience in neutron shielding materials for transport and storage casks. The future use of the TN Vyal B^{TM} resin for the EPR^{TM} reactor neutron shielding opens new doors of opportunities of use. Furthermore, it is the result of an intensive R&D program and is of course, a major innovation for TN International. The R&D program first developed TN Vyal B^{TM} for the transport and storage casks. Its use has been extended to other applications in the nuclear industry. In the future, this extraordinary material will perhaps find further use outside of the nuclear realm.

13 References

<1> IAEA safety standards TS-R-1
<2> Umweltbundesamt: Substituting environmentally relevant flame retardants: assessment fundamentals. Berlin, jun. 2001.
<3> CERN Health&Safety division (08-1979) Compilation of radiation damage test data