ADDING WET TRANSPORT CAPABILITIES TO A DRY SPENT FUEL CASK - THE TN 13/2 EXAMPLE

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SUMMARY

The TN 13/2 cask was designed for the transport of spent fuel from 1300 MW reactors to reprocessing plants. It is capable of carrying relatively short cooled high burn-up fuel and came into service in 1983. The TN 13/2 normally transports fuel under 'dry' conditions, the cask cavity containing an inert gas at sub-atmospheric pressure during transport. The cask is designed for fuel loading operations under water and hence it is compatible with 'wet' environments. Some casks are designed to transport fuel with a water filled cavity, so called 'wet' transports. Fuel cladding temperatures tend to be lower in 'wet' transport casks but higher temperatures are of no consequence for fuel destined for reprocessing. However, in the case of fuel movements between reactors on the same site, it is desirable to limit the cladding temperature and 'wet' transport casks are the preferred option.

Transnucléaire decided to add 'wet' transport capabilities to the TN 13/2 cask and thereby give customers the option of using the cask in both wet and dry modes. This paper explains the particular challenge of applying wet transport parameters to a dry cask design and explains how this was achieved for the TN 13/2 without changing any of the cask components.

INTRODUCTION

The TN 13/2 is a thick-walled forged steel spent fuel transport cask (see figure 1). It can transport 12 PWR fuel assemblies from 1300 MW reactors. Fuel types may vary from 15x15, 16x16, 17x17 to 18x18 with or without capsules. During transport, the cask cavity is filled with an inert gas at sub-atmospheric pressure. The cask was originally designed for very short cooled fuel (6 months) and hence the design heat load for dry transports was 110 kW.

Transnucléaire decided to add the wet transport capability to the TN 13/2 and thereby give customers the option of using the cask in either mode. The main application for wet type transports will be the transfer of fuel between reactor cores. The design objective for converting to wet mode was to utilise the cask without changing any components from its dry mode configuration and thus making the operational change from dry to wet a simple administrative operation. This proved to be quite a challenge since the prospect of wet transports had never been envisaged during the original conception of this cask.

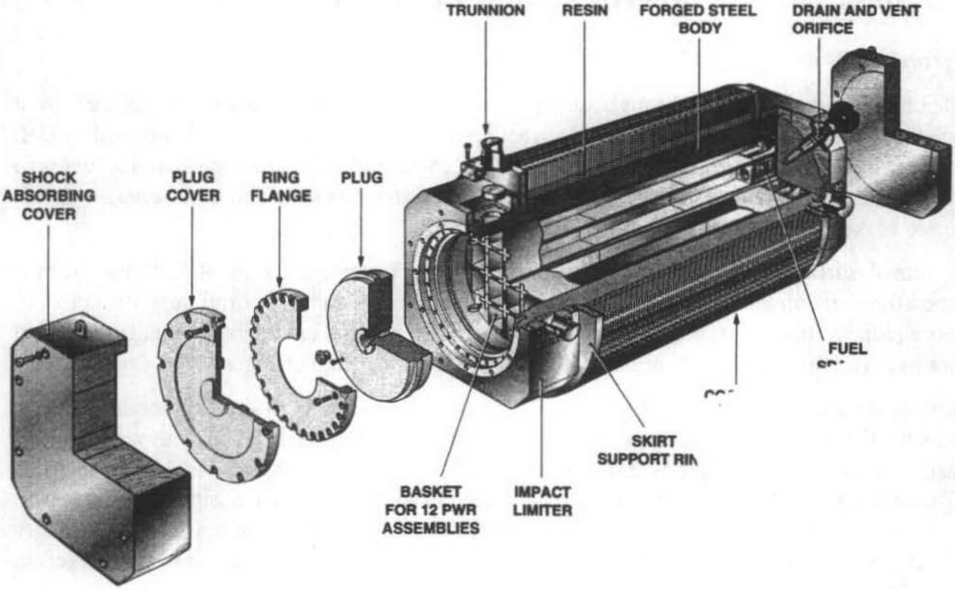

Figure 1: General view of TN 13/2 cask

SPECIFICATION FOR THE TN13/2 WET TRANSPORT CASK

The specification required no overall increase in the cask weight in transport configuration, which limited the loaded cask weight to 113 tonnes. The payload was reduced from 12 fuel elements to 10 to compensate for the additional weight of water and it was decided to leave the two upper fuel positions empty and thus submerge the fuel during horizontal transports. The fuel types were restricted to 17x17 types and the transport of encapsulated failed fuel was not required. The specification limited the residual power of each element to 4kW thus giving a total cask heat load of 40kW.

ADVANTAGES OF WET TRANSPORT

The main advantage of wet transport is the reduction in fuel cladding temperatures during transport. In a dry cask the fuel cladding may reach temperatures around 300°C whereas they are usually half this value in typical wet transport casks. This is of particular interest when transferring fuel elements between reactor cores and hence wet transports are the preferred mode in such applications. There are also operational advantages because the cask draining and vacuum drying operations are eliminated and hence the cask preparation time is reduced. The only additional operation is the adjustment of the water ullage level before finally sealing the cask.

TECHNICAL IMPLICATIONS OF ADDING WET CAPABILITIES

Thermal analysis (see figure 2)

Water helps to spread heat throughout the cavity. Radiative heat transfer is replaced by a much more efficient mode of transfer: Convection. Gradients found using a theoretical model, validated by a finite element approach (I-DEAS/TMG/ESC) demonstrate that the average temperature of the water in a basket allowing some water displacement can be taken as the average basket temperature.

The finned surface was originally designed for 110 kW and hence at 40 kW the surface temperatures are much lower. The basket is in aluminium and was originally designed to receive radiated heat from the fuel rods and to conduct it to the cavity wall. This system also operates perfectly in wet applications without any need for design changes.

The temperature inside the TN 13/2 cavity decreases from 350°C in the dry condition to as low as 65°C for a water filled cavity. The cavity cannot be completely filled with water during transport because water significantly expands with temperature (by 4% at 100°C, 14% at 200°C and up to 29% at 300°C). Hence an early decision in the wet design studies was to select the appropriate ratio of water to gas when the cask is sealed for transport. The water level in transport was studied in detail to ensure that all the fuel assemblies were submerged in the liquid medium.

The IAEA fire resistance test can be a challenge for wet casks as the transient increase in temperature may generate high internal pressures due to the combined effects of water expansion and vapour pressure. A cask with a water transport temperature of 120°C might reach temperatures of up to 200°C, compressing the gas volume tenfold. The fire test conditions determine the maximum allowable water level in the cavity.

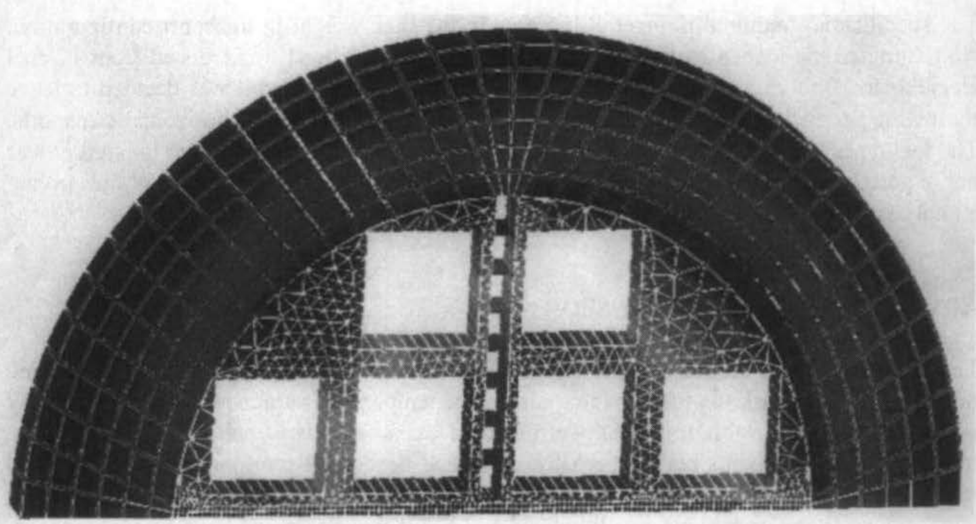

Figure 2: Thermal map of TN 13/2 with 929 basket

Radiolysis

When water is submitted to radiations, hydrogen and oxygen gases can be produced. At low concentrations these gases pose no problems but when the proportion of hydrogen reaches around 5 percent the gas mixture becomes flammable if there is sufficient oxygen in the system. At higher concentrations, the gas mixtures are potentially explosive and such conditions must obviously be precluded in a transport cask. Passive recombiners and chemical compounds can limit the production of these gases but these are not always acceptable solutions in transport applications.

The theoretical gas production rates for irradiated water are well documented (Reference 1) and are referred to as G values representing the number of molecules generated per 100eV of absorbed energy. For pure water the G value for hydrogen is 0.45 H_2/100eV. Walters (Reference 2) showed how the application of theoretical G values in transport casks results in gross overestimation of the gas generation rates. The primary products go on to react with each other, with other chemical solutes and with solid surfaces. In doing so their effective yield is reduced and the effective G value can be nearer to 0.005 as opposed to the 0.45 theoretical value.

Transnucléaire undertook an extensive literature search and noted the low effective G values from the CEA tests of the R62 cask (reference 3). We also initiated a specific radiochemical modelling of the TN 13/2 cask using methods described by Walters. Further data was collected from a full scale experiment at 10kW heat power that took place at Le Blayais EDF power station in 1995.

The result of these studies allows Transnucléaire to significantly lower the radiolytic gas production rates to the following more logical levels:

- GH_2=0,0055 H_2/100 eV in normal operation conditions
- GH_2=0,040 H_2/100 eV in accident conditions

With these rates of gas production, the TN 13/2 cavity gas remains well outside flammable mixture regimes for an acceptable transport duration.

Mechanical resistance

Under cask impact conditions, the water decelerates as would any normal static mass with one additional effect: it generates a pressure wave that imposes a load on the sealing system. This shock can be approximated using the simple fluid dynamic $P=\rho\alpha h$, where ρ is the density of the fluid, α it's net deceleration and h the height of water in the cavity. Drop tests validate this simple axiom.

The TN 13/2 was originally designed with a nominal internal pressure rating of 20 bars. Due to its very efficient heat transfer design, the TN 13/2 cask generates very low internal pressures in the wet mode and hence there are no mechanical problems with the structure.

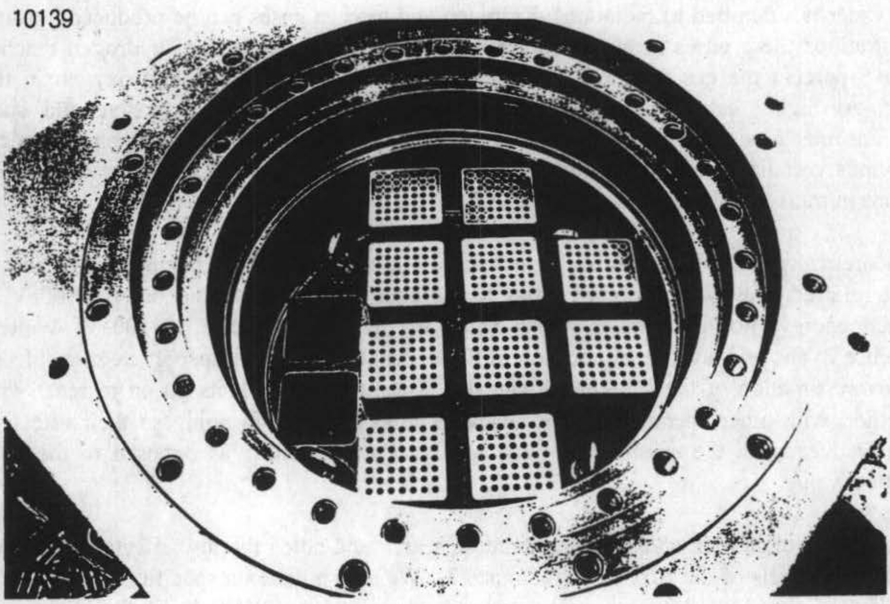

Figure 3: Cavity of scale model cask

Confinement

The dry cask confinement analysis only considered potential gaseous release but the wet cask condition requires analysis of potential liquid activity releases. Confinement of a pressurised, vaporised liquid is more complex than that of a pressurized gaseous compound. Water vapour may condense when going though the leakpath (the seal is normally colder than the inside of the cavity) and creates a viscous resistance to the flow. Fuel rod ruptures were assumed to be 1.5% of total payload for normal transport and 100% in accident conditions. The soluble dilution rates are taken from ref. (1) for both liquid and solid fractions.

Criticality

The wet loading regime is always considered for dry transport casks and hence there is no additional requirement for criticality analysis of the cask during wet transports.

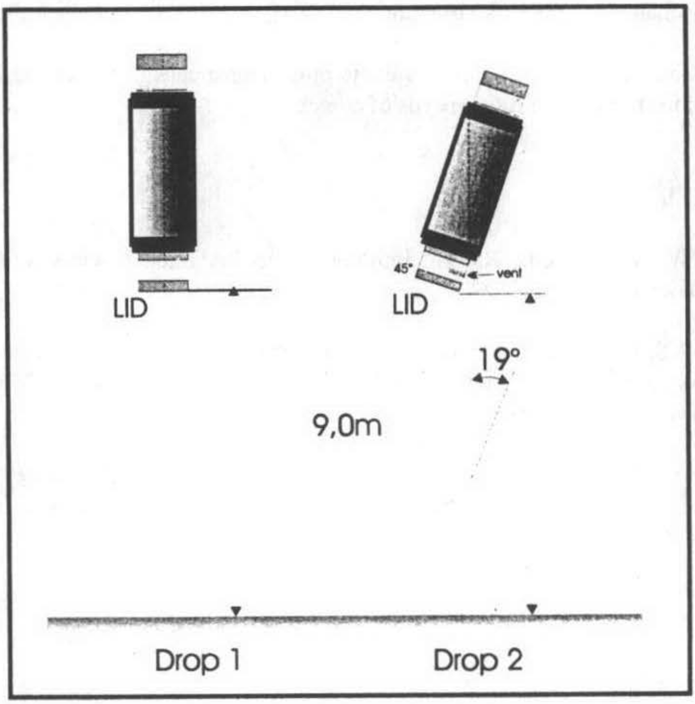

Figure 4: Drop test orientations

THE SCOPE OF WORK UNDERTAKEN

The wet transport addition to the TN 13/2 Safety Analysis Report required extensive studies to demonstrate the viability of a 40 kW wet load. Work ranged from scale model drop tests, research in convection heat transfer, radiolysis and confinement of liquid and gaseous activity. This extensive experience gives Transnucléaire the capability of adding wet transports to its existing extensive fleet of dry transport casks.

CONCLUSIONS

The TN 13/2 cask can transport 10 PWR 17x17 fuel assemblies in the wet mode with up to 40 kW of thermal power.

The cask can be transported for reasonable transport durations without generating flammable radiolytic gases in the cavity.

Casks originally designed for dry cavity transports can readily be adapted for wet transports without costly changes to the cask structure.

It is now possible to extrapolate these results to other Transnucléaire casks and introduce wet transport versions to meet the future needs of clients.

REFERENCES

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(3) J.J. Abassin, CEA « Expériences paramétriques sur la radiolyse de l'eau et application à l'emballage R62 pour le transport d'assemblages combustibles défectueux. » PATRAM 86.