TRANSPORT OF SPENT VVER-440 FUEL USING THE TK-6 FLASK

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SUMMARY

The TK-6 spent fuel flask (Figure 1) is used to transport spent VVER-440 fuel in Russia and some of the countries of Central and Eastern Europe and Finland. It has been in use since 1979 and is currently operated as a Type B(M) package. As part of its TACIS Programme (Technical Assistance to the Commonwealth of Independent States) the European Commission is supporting a detailed review of the TK-6 flask design, against the 1985 IAEA Regulations (IAEA, 1990). The work is currently being carried out by Ove Arup & Partners, with VNIPIET and AEA Technology as sub-contractors. This paper describes the TK-6 flask design and operating conditions, and presents the results of some of the assessment work completed to date.

INTRODUCTION

The TK-6 flask consists of a thick-walled forged carbon steel body, and stainless steel lid which is bolted to the body by means of 24 No. 64 mm diameter high strength bolts. Its maximum weight when loaded is 92 tonnes. Two sides of the lid are chamfered due to constraints of the rail gauge. The inner surfaces of the body, as well as the external surfaces of the container bottom are lined with stainless steel. Elastomeric seals are provided on the lid to maintain containment. Two trunnions are provided for lifting, and a support ring and two guide plates locate the flask in the vertical position in the rail vehicle.

The fuel consists of UO_2 pellets with a maximum enrichment of 3.5% ^{235}U, each fuel assembly contains 136 kg of UO_2. The maximum burnup of an individual fuel assembly is 42 GWd/tU for a flask with water coolant , and 24 GWd/tU for a flask with gas coolant. The capacity of the flask is 30 fuel assemblies, which are supported in a basket. Crush tubes are provided between the fuel and the lid, to reduce the impact loading of the fuel on the lid in lid down impact attitudes.

The lid contains penetrations for temperature and pressure sensors, and a water level lowering device. These penetrations are closed with protective caps which are also designed to function as shock absorbers in lid down impacts. The body contains penetrations for an overflow unit at the top and a drain unit at the bottom.

Fins are provided on the outer surfaces of the body to decrease the loading on the flask and fuel assemblies in the case of a drop onto its side, and to assist removal of decay heat. The flask may be operated with either water or nitrogen in the cavity, the choice depends mainly upon the need for radiation safety provision, as water serves as neutron shielding. The main criterion for choice of coolant medium for the flask is fuel burnup, and the secondary one is spent fuel decay heat. After loading and prior to transport, the flask is leak-tested and stored for a few days to allow the temperatures within the flask to stabilise.

The flask transporter (Figure 2) is a 12 axle rail wagon which consists of three compartments. The central compartment contains the TK-6 package and support equipment. This compartment has thermal insulation and ventilation-heating equipment to provide safe thermal conditions for the package. Four deflectors are installed in the roof of the compartment and four filtered vents in the side walls, for heat rejection by natural ventilation. One train contains a maximum of eight container wagons and two escort wagons. Electrical power supply sources and the control system of the ventilation-heating and monitoring equipment are found in the escort wagon.

The following sections describe the assessment work completed to date in the areas of impact performance, thermal performance, shielding and criticality.

IMPACT ASSESSMENT

The performance of the TK-6 flask in the IAEA 9 metre drop test was assessed using the computer code LS-DYNA3D (OASYS Ltd.). Figure 3 shows the finite element model used. It consists of about 100,000 elements for a half model, including basket, crush tubes, fuel and water. Solid elements were used everywhere except for the basket, which was modelled using shell elements. The fuel was considered to be rigid, and the crush tubes between the fuel and the lid were modelled using non-linear springs, whose properties were derived from a separate LS-DYNA3D analysis. Impact attitudes examined included:

- Lid edge onto the chamfered portion of the lid
- Lid edge onto the unchamfered portion of the lid
- Flat side onto side without trunnion
- Flat side onto trunnion

The critical impact attitude was found to be the lid edge onto the unchamfered portion of the lid. In this attitude the maximum loss of compression on the seal due to the formation of a lid-body gap was calculated to be about 1 mm. The principal loading on the lid bolts was combined shear and bending, tension forces in all the bolts were found to be small. Figure 4 shows the calculated force-time history between the flask and the unyielding target in this attitude. The following table shows the comparison between the results calculated by VNIPIET and those calculated by Ove Arup in this attitude.

ITEM	VNIPIET RESULT	OVE ARUP RESULT
Max. Acceleration (g)	217	180
Max. Force (MN)	194	174
Impact Duration (ms)	11.69	15

THERMAL ASSESSMENT

The 3-D finite element models of the flask were prepared based on the model used for the impact analyses. This model was a one quarter segment of the flask assuming a symmetrical distribution of temperature across the boundaries of the model. The same computer code, LS-DYNA3D (OASYS Ltd.), was used for the thermal analysis as well as the impact analysis.

Two models were produced, a gas filled model with 8 kW decay heat and a water filled model with 15 kW decay heat. The gas-filled analyses featured modelling of the thermal radiation exchange in the cavity of the flask. The water-filled model did not require this effect although radiation from the water surface to the underside of the lid was included. In order to obtain accurate modelling of the heat transfer properties of the water in the flask the model was correlated against experimental data provided by VNIPIET, and agreement in the order of ±7℃was achieved. Further confirmation of the models was obtained by comparing its results with those produced totally independantly by VNIPIET, again agreement in the order of ±7℃was obtained.

The results calculated were temperature distributions at discrete time intervals. These could be interrogated to provide time-history based information. The particular parameters of interest are the internal pressure and the temperature transients experienced by the sealing components.

Figure 5 shows the calculated temperature-time history at the position of the seal of the flask, for the case of a fire test with a 38℃ ambient temperature. The maximum seal temperature is 458 K (185℃). These results, along with the calculated loss of compression on the seal, are being used as input to the containment analysis.

The results were found to support the specified environmental conditions under which the TK-6 flask is operated.

SHIELDING ASSESSMENT

A shielding assessment has been carried out for the TK-6 flask transporting 30 spent VVER-440 fuel assemblies. The assessment was carried out using the latest version, 9C, of the Monte Carlo code MCBEND (Chucas et al., 1996) with UKNDL 8220 group nuclear data for neutrons and GAMBLE 400 point nuclear data for gamma-rays. The code and data have been validated for shielding assessment of transport flasks; for example they were used for analysis of the TN12 flask as part of the NEACRP intercomparison of codes (Locke, H.F.).

MCBEND allows explicit representation of the flask geometry and the flask was modelled in detail, including trunnions, fins, lid chamfer, pressure gauge and drain hole. The dose-rates at the lid surface, fins surface, base surface, 1m and 2m from the flask on all sides and at special positions such as trunnion surfaces were calculated. Dose-rates from neutrons, primary and secondary gamma-rays were included using source terms provided for fuel with maximum burnup. The neutron cases were run using burned fuel (with the fuel composition derived from the FISPIN code) so that the neutron multiplication is accurate. The MCBEND calculations were run until the Monte Carlo standard deviation on the total dose-rate was generally less than 2%.

The assessment considered a water filled flask in both normal conditions and accident conditions. The initial conclusions from this assessment are :

- For 3.6% initial fuel enrichment, burnup of 40 GWd/t and 3 years cooling the flask complies with the IAEA criteria for radiation dose-rates when operated under exclusive use.
- The maximum surface, 1m and 2m dose-rates for 3.6% initial fuel enrichment, burnup of 40 GWd/t and 3 years cooling under normal conditions are 382μSv/h, 91μSv/h and 39μSv/h, respectively.
- The maximum dose-rate at 1m under accident conditions is 2521μSv/h.
- For 3.6% initial fuel enrichment and 40 GWd/t burnup a cooling time of 6 months is sufficient for the flask to meet the IAEA dose-rate criteria. The maximum permissible decay heat of 15 kW is only achieved after 2.5 years cooling so if this criterion is met then so will the radiological criteria.
- For 3.6% enriched fuel and 3 years cooling the flask will comply with the IAEA criteria for all burnups less than 40 GWd/t.
- For 2.4% enriched fuel and 3 years cooling 34 GWd/t burnup gives acceptable dose-rates.
- For 1.6% enriched fuel and 3 years cooling 28 GWd/t burnup gives acceptable dose-rates.

Overall the flask complies with the IAEA criteria for dose-rates. There is reasonable agreement between the results calculated by AEA Technology and those calculated and measured by VNIPIET. One discrepency between which is being investigated is that the AEA results seem to overestimate the permissible burnup compared with the VNIPIET results.

CRITICALITY ASSESSMENT

A criticality assessment of the TK-6 flask carrying up to thirty VVER-440 fuel assemblies of up to 3.6% enrichment has been carried out using the MONK7 Monte Carlo code (Smith and Morrell, 1995). MONK7 allows a model of essentially any degree of geometrical accuracy to be constructed and uses hyperfine group nuclear data with a continuous energy/angle slowing down treatment, thus avoiding the need for case-specific nuclear data pre-processing.

Two models of the flask were set up independently for the criticality assessment. The first was a detailed model of the flask and fuel which was also used as the starting model for the shielding calculations described above. The second was a simplified model which concentrates on the main features of criticality interest. This latter model neglects the grids and the non-fuelled end-sections of the fuel assemblies and considers the flask as a simple steel cylinder. This model will yield slightly conservative values of k-effective, especially at low water densities where absorption in the grids and sub-assembly end-pieces will be more significant. Fresh fuel was used in the analysis : no credit for burnup was taken.

The flask was taken to hold 30 unirradiated assemblies each containing uranium of 3.6 wt% ^{235}U, and to be either water-filled or dry. For the water-filled flask, the detailed model predicts a k-effective value of 0.8348 and the simplified model a k-effective value of 0.8393. Both results have Monte Carlo standard deviations of $\pm$.0015. These results are in reasonable agreement with the VNIPIET value of 0.840 ($\pm$.004) which was obtained using a Monte Carlo method with few group data.

With the flask dry (gas-filled), multiplication is very low (and criticality is impossible with uranium of less than 5% enrichment in the absence of moderator). The simple model predicts a k-effective value of 0.2436 ($\pm$.0014).

The displacement of assemblies following an accidental drop was modelled in a simple fashion by displacing all assemblies by the maximum observed in the experimental drop test, namely 111mm. Using the simplified model, two cases were set up, corresponding to a drop in mutually perpendicular radial directions. Those assemblies which were restrained by contact with the basket walls or the central rod suffer less displacement and the net effect is thus to compress the array. Results were checked using the detailed model. For comparison with the VNIPIET results a water density of 0.8g/cm^3 was modelled. The resulting k-effective values are between 0.9239 ($\pm$.0015) and 0.9309 ($\pm$.0015) which agree reasonably well with the VNIPIET value of 0.912 ($\pm$.006). Hence the broad equivalence of the accident analysis for the scenario so far considered with MONK and with the VNIPIET Monte Carlo code is confirmed.

FUTURE WORK

This project is still ongoing. Upon completion of the flask assessment work it is planned to carry out a risk assessment of the transport of VVER-440 spent fuel under one of the DG-17 Programmes, for which the results of this project will form an input.

ACKNOWLEDGEMENTS

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REFERENCES

LS-DYNA3D, Version 936, OASYS Ltd., 13 Fitzroy St., London W1P 6BQ.

Regulations for the Safe Transport of Radioactive Material. 1985 Edition (As amended 1990). Safety Series No. 6, IAEA, Vienna, 1990.

Chucas, S.J., Grimstone, M.J., Shuttleworth, E.S. and Morrell, G.A. *Advances in the Monte Carlo Code MCBEND.* ANS Topical Meeting on Radiation Protection and Shielding, 1996.

Locke H.F., *NEACRP Intercomparison of Codes for the Shielding Assessment of Transport Packages. Solution of the TN12 Benchmark Problem.*
Report Ref. AEA-RS-1063, AEA Technology

Smith, N.R. and Morrell, G.A., *An Introduction to MONK7*. International Conference on Nuclear Criticality Safety , 1995.

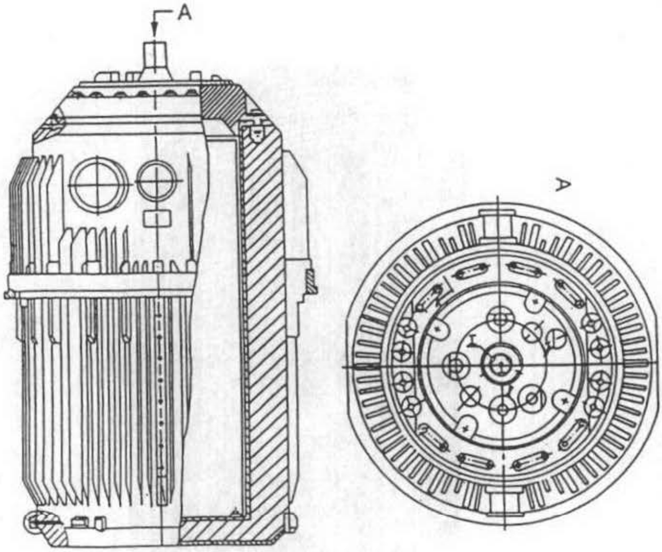

Figure 1 TK-6 Spent Fuel Flask

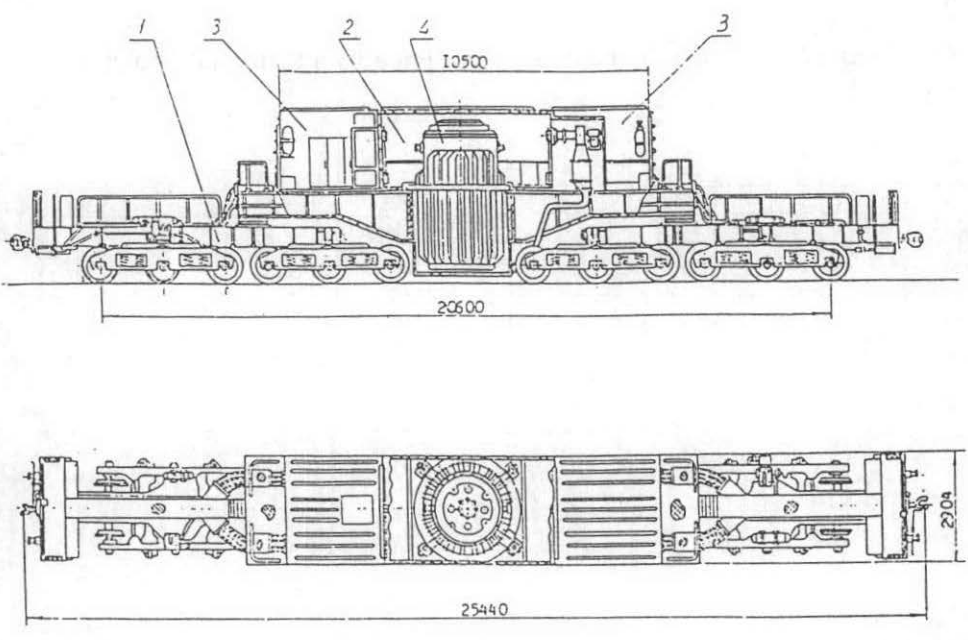

Figure 2 TK-6 Rail Wagon

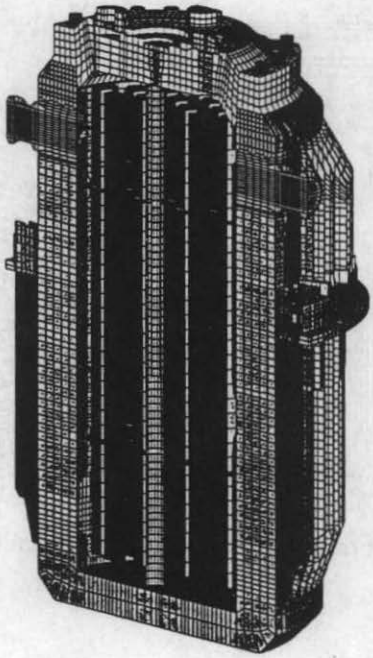

Figure 3 Finite Element Model for Impact and Thermal Analysis

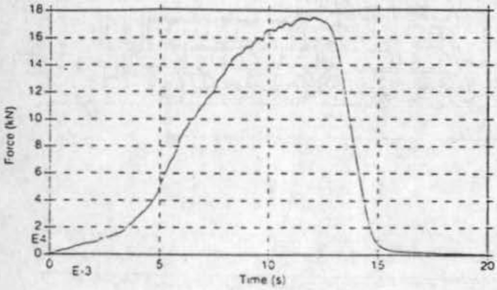

Figure 4 Force-Time History in Lid Edge Drop

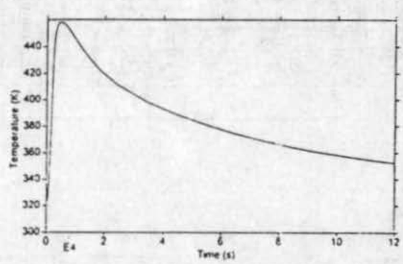

Figure 5 Temperature-Time History at the Seal Position during and after the Fire Test