STRUCTURAL ANALYSIS OF THE FINAL DISPOSAL CASK POLLUX FOR TYPE B(U) IMPACT TESTS

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POLLUX

ABSTRACT

It is shown that the mechanical design of transport and final disposal casks (so-called type B(U) packages) for radioactive materials can be done by means of the finite element method. Nonlinear geometric and material methods are used for this for the dynamic calculation.

1 INTRODUCTION

As an alternative respectively supplement to the reprocessing of spent fuel elements, the direct disposal is in the planning in Germany. One of the possibilities for final waste disposal of fuel elements is the horizontal disposal into drifts. For that purpose, the fuel elements are packed disassembled or assembled into thick walled casks.

Casks of the POLLUX type are intended to be used for such a packaging. A POLLUX for 10 PWR / 30 BWR fuel assemblies is a cylindric double-walled cask for the transport of 10 pressurized water reactor or 30 boiling water reactor fuel elements, consisting of an inner cask with a wall thickness of 161 mm, an outer diameter of 1012 mm and an outer length of 5076 mm as well as an outer cask with a wall thickness of 265 mm, an outer diameter of 1542 mm and an outer length of 5488 mm.

The inner cask, made of ferritic steel 15 \textit{Mn} Ni 6 3, is locked by means of a primary lid with bolts and a secondary lid using a weld seam. The latter forms the leaktight containment. The outer cask, made of nodular cast iron GGG 40, is bolted and has no sealing function. It serves as a radiation shielding and is, at the same time, an integral shock absorber. In addition to that, top and bottom part of the cask are equipped with an outer shock absorber.

Besides the requirements due to final disposal, the POLLUX cask has to meet those of the German Atomic Law and the Transport Regulations as well.

The requirements for the safe transport of a type B(U) package result from /1/. Under the aspect of mechanical behaviour, a series of tests are stipulated for mechanical and thermal loads due to hypothetical accidents. Two of these tests, i.e. 9 meter drop onto a rigid target and 1 meter penetration test, are dealt with below.
According to /1/, the demonstration of compliance that a type B(U) package meets the regulations for safe transport can, besides other methods, also be proved by calculations.

For this the finite element method is used for the POLLUX cask. Thus it is possible to compare the calculated stresses or strains to allowable figures and thus show the safety margin for the various load cases. By means of the finite element method highly accurate results can be achieved. This makes it possible to choose adequate allowable values under consideration of adequate material concepts.

2.9 METER DROPS

/1/ specifies that the incidental drop of a type B(U) package during a test has to be carried out in such a manner that the package suffers a maximum of damage. According to this, the following drop situations are verified by means of calculations: flat impact onto shock absorber at lid side, impact onto cylindrical shell of shock absorbers at top and bottom part as well as impact onto edge of shock absorber at top part. All impacts are, according to /1/, onto a rigid target. The latter two are explained further as an example.

2.1.9 Meter Drop with Impact onto the Edge of the Shock Absorber

In principle, the calculation of such drop cases can be carried out by two separate methods: either in the time domain (this procedure is explained in the following chapter) or quasi-statically.

The quasi-static calculation is divided into two calculation steps with generally two different finite element models: In the first calculation step static linear-elastic stresses due to dead load are evaluated for the drop situation in question. During the second calculation step the dynamic responses are found in an elastic or alternatively in an elastic-plastic manner by means of a further finite element model. The comparison to the static responses of the first calculation step results in the so-called dynamic load factor. The stresses of the first calculation step are multiplied by this factor. Hence the results are elastic stresses. Compared to the "fully dynamic" calculation, this procedure shows very conservative results.

The drop situation onto the edge of the shock absorber was calculated quasi-statically with the finite element program ADINA.

Fig. 1 shows the finite element model for the linear-elastic stress calculation. The cask is modelled with isoparametric solid elements, the shock absorber with truss elements. Taking advantage of symmetry, one half of the cask was analyzed. The load consists of dead load and loading.

Fig. 2 shows the finite element mesh of the outer and inner cask used for the calculation of the dynamic load factor and which could thus be somewhat coarser. The shell elements used are formulated on the basis of the Reissner-Mindlin theory, partially using elasto-plastic material laws. The shock absorber was modelled as a spring with non-linear characteristic. According to the 9 meter drop, the initial velocity of $v_0 = 13.3 \text{ m/s}$ was given as load.

Assuming a one-degree system, the dynamic load factor was found to 62.
The maximum stress was calculated to 65 N/mm² within the weld seam of the secondary lid which is equivalent to a utilization of 19 %.

2.2 9 Meter Drop with Impact onto Cylindrical Shell of the Shock Absorbers

Dynamic calculations in the time domain with elasto-plastic material laws offer a possibility for a better approach of strains and deformations. This, however, requires a higher amount of computer resources. By using one single finite element model applying nonlinear material and geometrical laws, all resultants are calculated in a transient way within a so-called "fully dynamic" calculation. The results are time-dependent strains and stresses.

The drop situation onto the cylindrical shell of the shock absorbers was calculated in the time domain. Fig. 3 shows the finite element model which, taking advantage of symmetry, covers one fourth of the cask. Isoparametric solid elements /2/ as well as truss elements with non-linear load displacement history for the shock absorbers are used. The gaps between the lids and between inner and outer cask can only transfer contact forces. This was considered for the calculation model. The load was once again given as initial velocity \( v_0 = 13.3 \text{ m/s} \).

Fig. 4 shows the time history of the displacement of the shock absorber, fig. 5 shows the time history of the reaction force.

The time history calculation resulted in a linearized plastic equivalent strain in the center of the inner cask at the edge of the cylindrical shell of nearly 0.1 % thus staying far below the allowable values.

3 1 METER PENETRATION TEST

Another type B(U) case is the 1 meter drop of a bar of defined length and diameter /1/.

One of the bar positions to be investigated is the impact of the cask in the center of its length. This case was analyzed by the method described in chapter 2.2. Fig. 6 shows the finite element model using isoparametric solid elements as well as truss elements for the bar. For reasons of symmetry, one fourth of the bar and the cask are modeled. The transient strains were analyzed by means of time history calculations using elasto-plastic material laws. Fig. 6 shows the plastic regions of the cask at the time of the maximum force within the bar. For the inner cask, a maximum tensile strain of 0.4 % was found which is a value that certainly meets the requirements.

4 SUMMARY

On the basis of finite element calculations, the drop cases specified in /1/ were analyzed for the final disposal cask POLLUX for 10 PWR / 30 BWR fuel assemblies and its compliance was shown. With regards to design calculations, this method has proved advantageous, especially since personal computers are sufficient for it.

5 REFERENCES

/1/ Verordnung über die innerstaatliche und grenzüberschreitende Beförderung gefährlicher Güter auf Straßen (Gefahrgutverordnung Straße - GGVs); 1985

/2/ ADINA - A Finite Element Program for Automatic Dynamic Incremental Nonlinear Analysis; ADINA R&D Inc., Watertown, Ma./USA