MECHANICAL EVALUATION OF A 48Y DURING IAEA FIRE TEST

B. Duret (1),E. Pinton (1), G. Sert (2).

(1) CEA/Grenoble, DRN/DTP, 17 rue des Martyrs, 38054 Grenoble Cédex 9, France
(2) IPSN/DSMR, BP6, 92265 Fontenay-aux-Roses, France

SUMMARY

From the TENERIFE results and using the DIBONA model we predict the thermal behavior and the inner pressure of an UF6 container engulfed in a fire recommended as by IAEA. Following this approach, the mechanical phenomena has been represented by elastic then plastic mechanisms. The experimental stress/strain curves have been implemented from CRIEPI tensile tests interpretation from ambient temperature up to 900°C. The evolution of these previous curves according to the temperature, has been considered and extrapolated in term of minimal and maximal value. For every case of steel type and thickness value, we discuss and evaluate wether rupture occurs. Finally, our tool seems acceptable for predicting mechanical behaviour, but a rupture criterion has to be implemented into the model in order to predict the rupture time for every case.

INTRODUCTION

During the TENERIFE program we have developed a 2-D thermo-hydraulic model called DIBONA previously described during PATRAM 95 (Pinton and al 1995). After the tests (Saroul and al 1995) and their interpretation (Duret and al 1995), this model has been validated with three tests from the TENERIFE experiments (TEN2, TEN4, TEN6). In the main, the numerical results were corroborated by the experiments (Pinton and al 1995).

It is now possible to extrapolate in the case of a 48Y container in a IAEA fire test of half an hour with a steel emissivity of 0.8 and a fire emissivity of 0.9 (about 54 kW/m² at the beginning but decreasing with the steel temperature).

THERMAL EVALUATION

The results show that the critical pressure is reached before 30 min and with a maximum steel temperature greater than 600C.

Above the critical conditions of the fluid (46.1 bar and 230.2°C) the model is normally unusable. In fact, it is impossible to distinguish between the 2 phases (superficial tension and latent heat of vaporisation are zero) and mass transfers do not exist. The computation method of the pressure cannot be used and transfers are considerably modified, it has been necessary to solve numerical instability problems over the critical point (at a given temperature for example 210°C, we lock the UF6 physical properties).

If we use an initial temperature equal to 38°C (but without thermal flux from the sun) and an IAEA fire test, the main results are provided in the following figures :

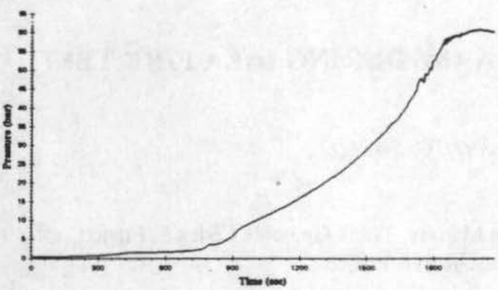

Figure 1 : Inner pressure evolution / IAEA fire

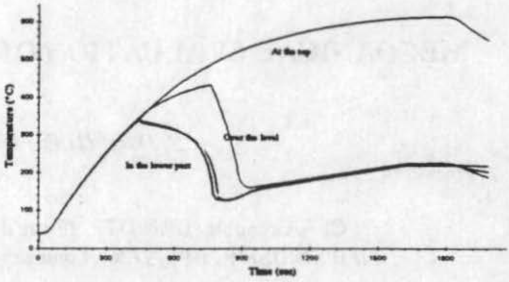

Figure 2 : Steel temperature

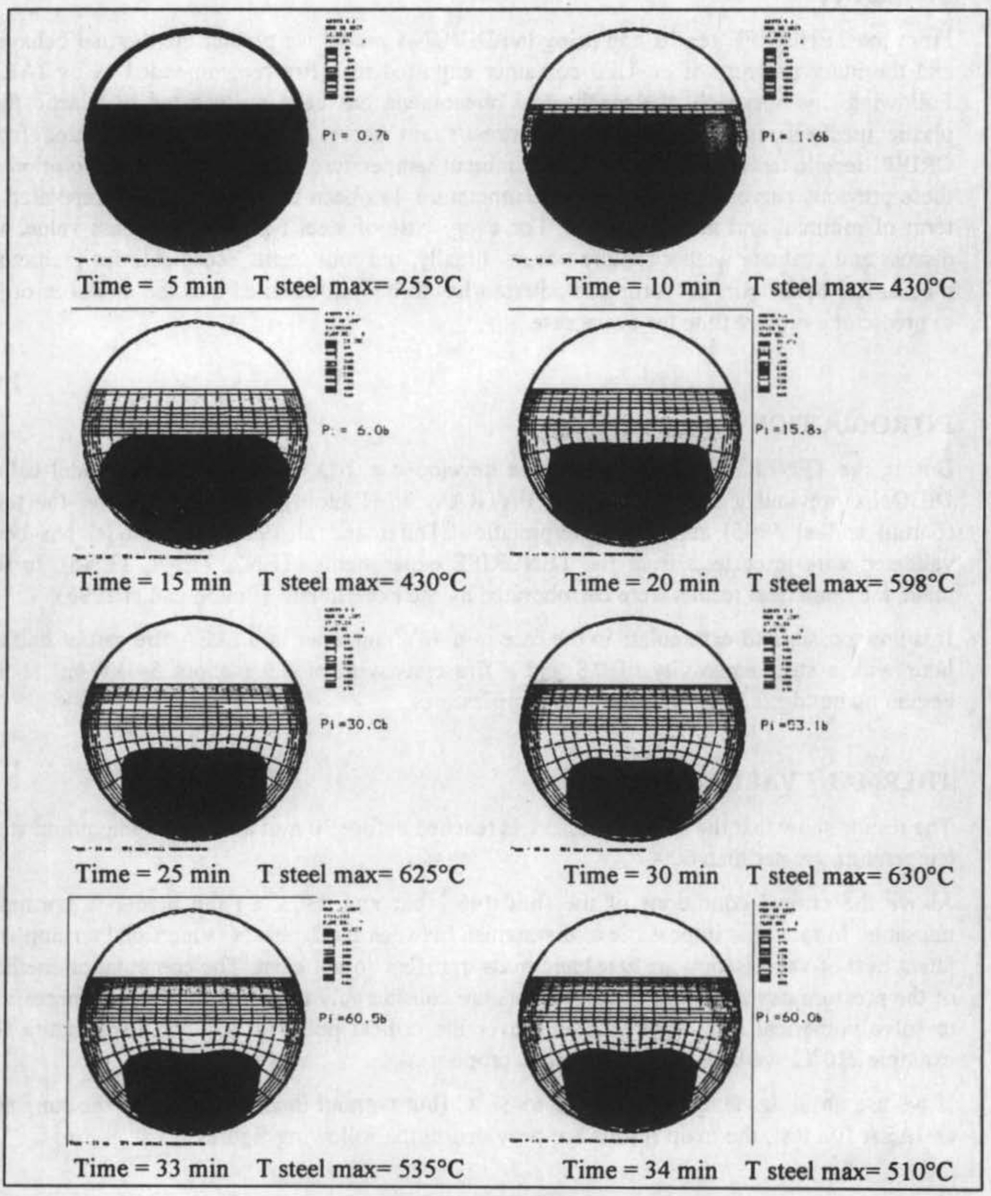

Figure 3 : UF6 and steel temperature card

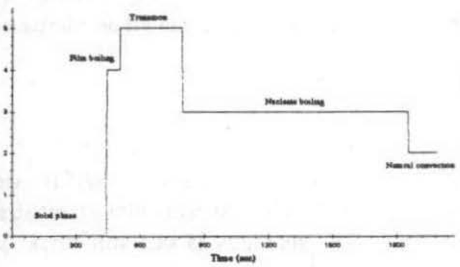

Figure 4 : Kind of transfer

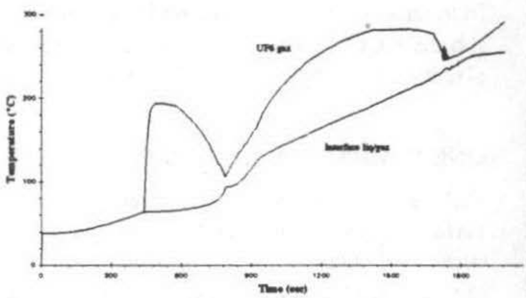

Figure 5 : Gas and interface temperature

RUPTURE ANALYSIS

The 48Y containers are made from welded-rolled steel plates. They have to meet the Specifications of ANSI or ISO standards. The steel has to be typically ASTM A516 Gr.55, Gr.60, Gr.65 or Gr.70 or equivalent foreign grades.

Permanent and elastic deformations that take place at the level of atoms and crystalline planes ensure that the matter is cohesive. The rupture destroys this cohesion by the creation of surfacic or volumic discontinuities within the material. The two main elementary mechanisms of local rupture are the fragile rupture by cleavage, and ductile rupture.

Laws of behaviour that characterise the deformation of the container when submitted to limit conditions of temperature and pressure are input into a finite element code developed in the framework of the TENERIFE program.

Calculations couple the thermal to the mechanics and process the non -linearities in the plastic zone (we do not take into account the creep mechanism for the moment). In our modelling, it is difficult to anticipate the rupture and the calculation of the time of rupture will have to be made according to a criterion that one has to determine (constraint limits, deformation limits ...?), by use, preferably, of experimental data.

The envelope steel is considered as a solid plastic, its behaviour follows a strain versus deformation curve that depends on the steel grade.

MECHANICAL METHODOLOGY

We have used the DIBONA model that has been validated by the TENERIFE program (Pinton and al 1995). We determine the temperature distribution of the steel envelope meshed in 3 dimensions in the mechanical model and model the plastic behaviour of the container until its rupture.

There are two main sources of non-linearity :

- geometric non-linearities (large deformations and displacements
- non-linearities due to the material (non-linear stress/strain relationship).

We use the ANSYS code where the solver works on linear equation systems. Consequently non-linear behaviour structures cannot be dealt with directly.

A series of linear approximations with correction are necessary to solve non-linear problems. One approach to non-linear problems is to divide the total loading into a series of loadings. Individual loadings are then divided again, manually or automatically, into sub-loadings. The subsets are calculated in such a way that an incremental loading does not entail an increase in plastic deformation of more than 5%.

ONE-DIMENSIONAL STUDY

Test reports are available concerning standard, cylindrical tensile tests on SA516 steel performed by CRIEPI laboratories (Wataru, Kozaki 1992). The experimental stress/strain curves are obtained for ambient temperatures of 900°C. The geometry is axisymmetrical and can be modelled in a plane with symmetry conditions.

From experimental measurement, we can draw a conventional tensile curve (figure 6).

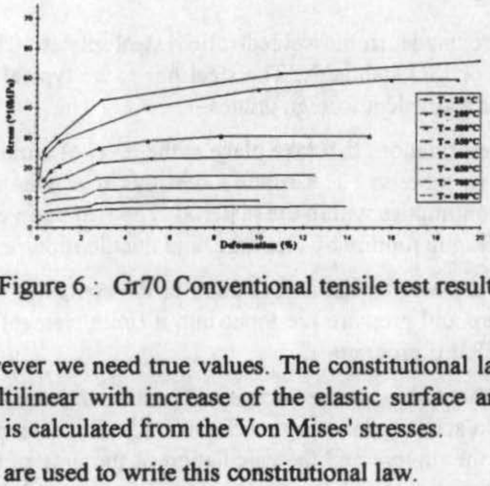

Figure 6 : Gr70 Conventional tensile test results

For ANSYS code however we need true values. The constitutional law used is a MISO type elasto-plastic law (multilinear with increase of the elastic surface area in the stress space). The plasticity criterion is calculated from the Von Mises' stresses.

Rational tensile curves are used to write this constitutional law.

The rational tensile curve expands stresses and contracts strains compared with a tensile curve. It represents a real tensile curve, where the stress $\sigma r = F/S$ and where the strains on the other hand are expressed in logarithmic terms, $\varepsilon r = \ln(L/LO)$. The model using the rational tensile curves provides a very good agreement between experimental and calculated results up to 900°C.

MATERIAL ANALYSIS

The evolution of these previous curves according to the temperature, has been considered for the different steels used during the CRIEPI experiment. For the same steel grade, we have noted differences in the order of 10% on their respective tensile and yield strengths.

This has resulted from, for example, measurements taken on grade 70 steels of the same type but of different origin (this difference between France and Japan can be explained by the difference of equivalence between norms).

Therefore, it is preferable when extrapolating to other types of steel, to use proposals of the norm ASTM (Specification for ASTM) that defines their tensile requirements.

Tensile strength (MPa)	Gr55	Gr60	Gr65	Gr70
Minimum value	380	415	450	485
Maximum value	515	550	585	620

As with the mechanical resistance, important differences appear not only between grade 55 and grade 70 but also between actual maximum and minimum values for the same material grade.

For example we have extrapolated values measured on these steels from the standard specifications at 20°. On a SA516 grade 70 steel, we can provide the rational curve, see figures 7 and 8.

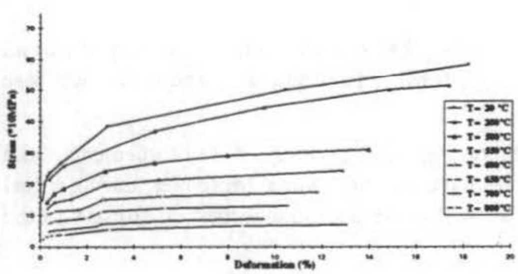

Figure 7 : Gr70 Rational tensile curve (min)

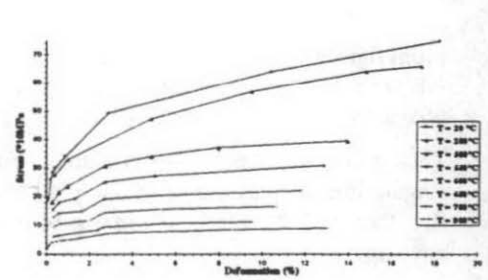

Figure 8 : Gr70 Rational tensile curve (max)

We have proceeded in the same manner with the other types of steel.

And to simplify and in order that this is more speaking, one gives on the next figures evolution according to the temperature of their yield and tensile strength.

Furthermore, on the same figures, we also give the corresponding elastic and rupture pressure using the cylindrical simplification (the stress is the circumferential one $\sigma_\theta = \frac{P * r}{e}$ with P: internal pressure, r : internal radius, e : thickness).

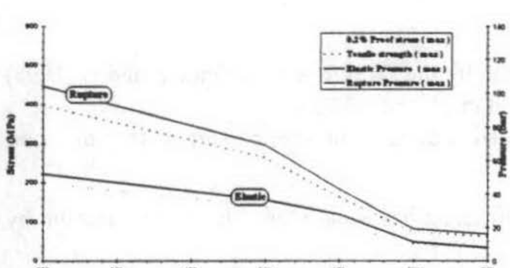

Figure 9 : Gr 55 Maximum values

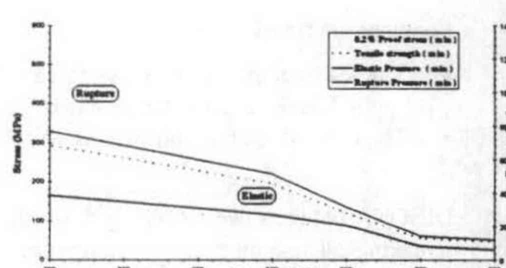

Figure 10 : Gr 55 Minimum values

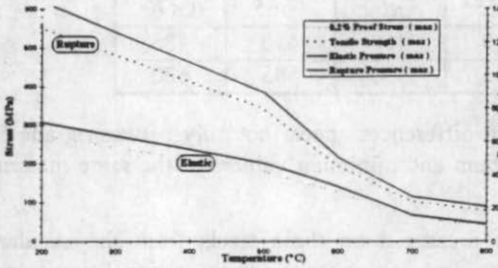

Figure 11 : Gr 70 Maximum values

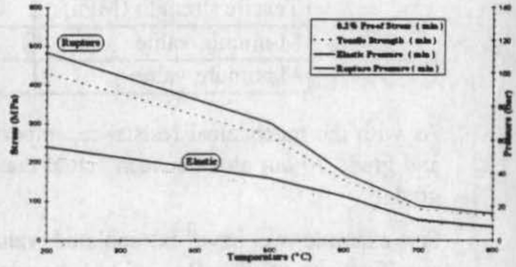

Figure 12 : Gr 70 Minimum values

From figures 10 and 11, it can be seen that at 600°C, the pressure leading to the rupture of an infinite cylinder in steel SA516 may be 31 bar (310 MPa) for a grade 55 and in the best case 60 bar (600 MPa) for a grade 70.

This gives an idea of uncertainties. Furthermore, skirts, rings of reinforcements, and singularities such as the valve and plug nozzles have an importance. Moreover, during a real fire, there will be a large thermal gradient that will cause additionnal thermal stresses to the envelope.

All is taken into account in our thermo-mechanical modelling.

3D AXISYMMETRICAL GEOMETRY

At every time step and in all point of the 3D mesh, we provide the internal pressure, the distribution of temperatures from the DIBONA code and from mechanical properties introduced. From this, we obtain constraints and deformations in 3 directions.

A 3-D axisymmetrical model is chosen, meshed with 3-D solid elements having 8 nodes and 3 degrees of freedom per node, Ux Uy and Uz. Two elements are placed through the thickness so that bending effects will be properly taken into account.

Loadings are transient :

- The loading consists of pressure calculated by the DIBONA code (Pinton and co 1995) applied on the edge of the elements located inside the cylinder.
- The thermal loading follows values obtained in calculations (see paragraph 2) of the code

DIBONA between two stiffening rings; the fin effect has equally been taken into account by remaking calculation on the reinforcements.

Figure 13 shows the results at time 30 min. The internal pressure is then 53 bars and the temperature towards the top and between two rings is 620°C ; on the other hand the fin ends are at 800°C.

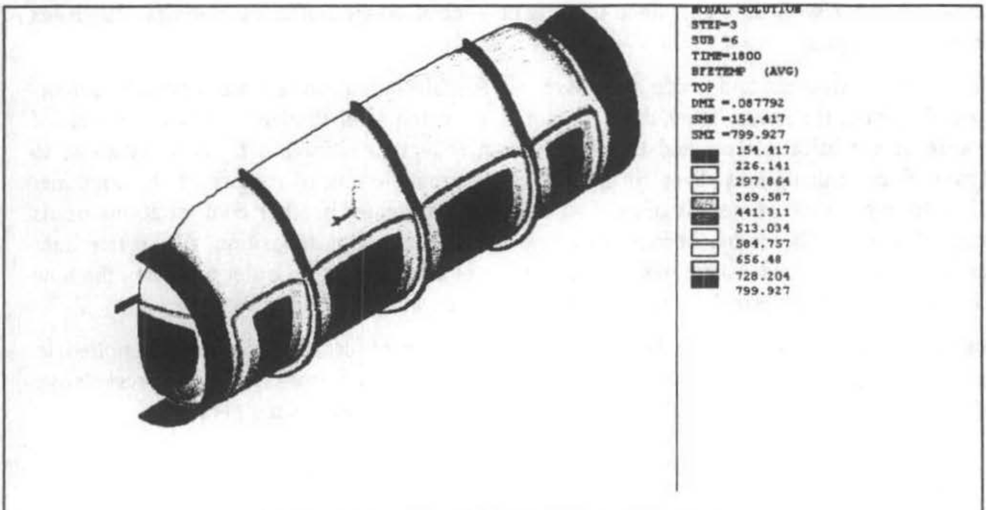

Figure 13 : Thermal repartition at 30 mn

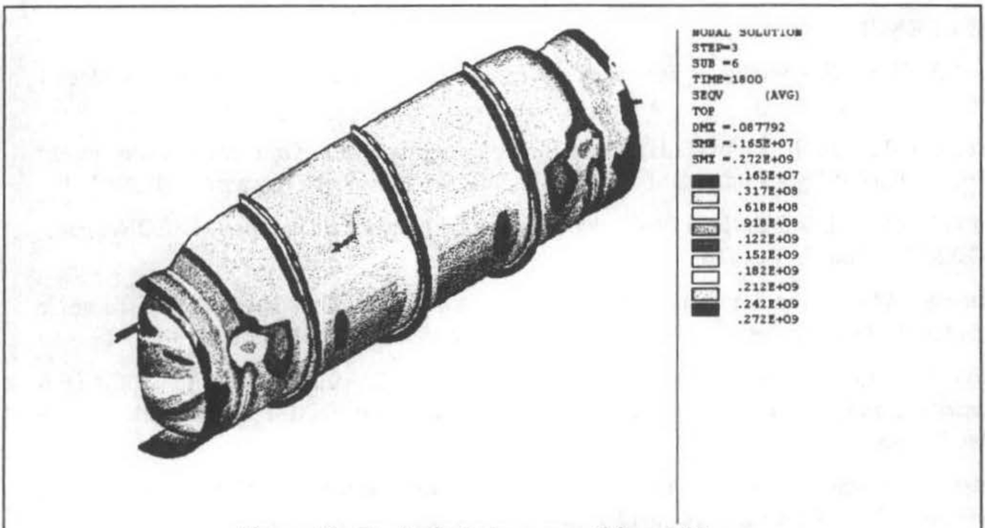

Figure 14 : Equivalent stress repartition at 30 mn

Since the grade of the material used (SA516) will not be finalised when the test containers are manufactured, all possible grades would be tested and for each, we have to introduce two tables (minimum and maximum values). Initially, we have performed calculations using a SA516 Gr70 steel with the greatest mechanical properties extrapolated from the CRIEPI experiment, the envelope thickness is : 16mm. In figure 14, we provide the distribution of equivalent stress with a maximum value of 272 MPa above the level of UF6. In this case yield-stress is largely exceeded, maximal plastic deformation is 14.8%. The pressure increases further with time and since there is no special cooling after 30 minutes, this leads inevitably to rupture.

For the other thickness and grade steel case, we find that the rupture occurs before ½ hour, especially for a thickness lower than 16 mm. Indeed the steel thickness may be decreased because of corrosion effects and the ANSI norm accepts a reduction in steel thickness to 14 mm. These calculations revealed that there is a probable risk of rupture of the container wall, whatever grade of steel is used. This risk is even greater if other configurations exists (external flux may be higher because of flame temperature, soot deposition, filling rate later than the normal, incondensable gas such as HF, steel thickness...). In order to satisfy the new IAEA requirements, thermal insulation seems necessary at least at the ends.

Finally, our tool is operational but a maximal deformation criterion has to be applied to predict the rupture time for every case. Burst experiments are envisaged on representative 48Y prototypes to show the actual rupture deformation of steel at this temperature.

ACKNOWLEDGMENTS

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Specification for pressure vessel plates, carbon steel, for moderate and lower temperature service SA516/516M (ASTM /ASME)