NUMERICAL STUDY OF THE THERMAL BEHAVIOUR OF PACKAGES SUBJECTED TO FIRES OF LONG DURATION

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SUMMARY

The purpose of this study is to improve the knowledge of the behaviour of type B packages used for the transportation of radioactive materials, when subjected to fires of long duration and at different flame temperatures, and to evaluate the safety margins when performances are compared to regulatory requirements.

This paper outlines the approach and the results obtained in the specific case of the FS 47 package.

Firstly, a long duration fire test has been performed in 1993 upon request of IPSN and competent authorities. The fire lasted 3 h 25 min without loss of the leak tightness of the full-scale tested package.

Secondly, an experimental simulation has been performed in a laboratory to simulate with a sample the thermal behaviour of confined plaster.

Thirdly, specific behaviour simulation laws were incorporated in the selected Finite Element (FE) code THERMX and their validation was performed by comparison with the results of the long duration FS 47 fire test.

Fourthly, the proper sensitivity study with respect to the duration and temperature of fire is being carried out.

Hence, it was possible to evaluate the performance of the package and to determine its limit of resistance for different fire conditions.

INTRODUCTION

In accordance to the IAEA regulations (Safety Series n° 6), type B packages have to keep their safety functions under accidental conditions including, amongst others, a 30 min fire test with engulfing flames at 800 °C.

This test has been defined to embrace the majority of the accident scenarios involving a hydrocarbon fuel fire. However, more severe fire conditions could be encountered either with higher temperatures, or with longer durations.

This issue is often adressed, in particular, for maritime fires whose total duration may reach several days, though their temperature is expected to be lower than 800 °C on the average. Also a new requirement is the assessment of reinforced fire test for type C packages (1 h at 800 °C).

This explains the need of having a realistic, but still conservative, computer thermal model that can be used for sensitivity assessments.

Numerical simulations are now preferred to real tests, due to their flexibility and reproducibility, in so far as FE codes are user-friendly and computer speed has increased.

However, the model should be as realistic as possible, thus it is essential to take precisely into account the thermal behaviour of specific materials, such as plaster, resin, compound, concrete and wood, which bring an active fire protection through physical or chemical transformations. These transformations prevent the transfer of a large part of the energy from the fire to the packaging.

FS 47 PACKAGING

This packaging is about 2 m high, has a diameter of 0,6 m and weighs 1380 kg. It is used for the transportation of plutonium powder, as part of the nuclear irradiated fuel reprocessing program.

It is provided with a tight lid equipped with elastomer O-rings which are the weakest part of the package when subjected to a fire.

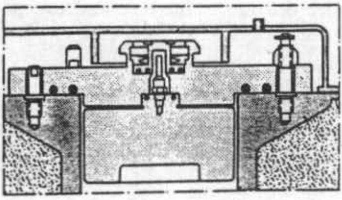
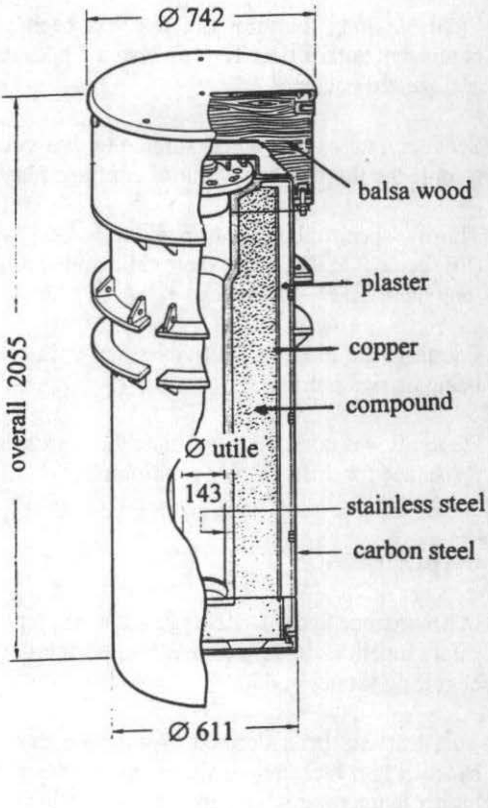


Figure 1 - FS 47 packaging



REAL TEST

In order to assess the performance of the FS 47 package involved in a fire of long duration, in 1993 a real fire test with a full-scale FS 47 packaging was conducted.

The content, usually PuO_2 powder, was simulated by an electrical resistance providing the appropriate power.

Close to 13 000 l of hydrocarbon fuel provided a 3 h 25 min fire with an average temperature somewhat greater than 800 °C.

The packaging was equipped with 15 thermocouples, meanwhile 9 other thermocouples measured the ambient temperature.

After 1 h 18 min of fire, an electric failure happened entailing the breakdown of the resistance and a loss of the temperature recording for several minutes.

After 3 h 20 min the thermocouples failed due to superheating of the connecting wire sheaths and the test was stopped.

The main result is that the gasket temperature did not exceed 120 °C, far from its limit.

Despite the fact that such a test provides a concrete idea of the performance of the package, following limitations are to be noticed :

- thermocouples are used at their limit of resistance,
- representativeness is not perfect in so far as the specific heat of the content was different from those of Plutonium and the fire can not be under total control (wind),
- it is not possible to do sensitivity analysis of various parameters such as the fire temperature or its duration.

That is the reason why IPSN decided to develop numerical simulations.

CHARACTERIZATION OF THE PLASTER

All the available valid thermal models were too pessimistic to give a good idea of the true performance of the package because assumptions on the behaviour of thermal protection are too crude.

The thermal protection of the FS 47 is made of plaster and compound composed of plaster, and polyethylen.

Plaster is an active material which includes water molecules in the crystallized state, and free water. Free water vaporizes at 100 °C, one and a half molecule of crystallized water is released between 115 and 175 °C and another half molecule between 200 and 220 °C (see table below).

Stage	Chemical composition	Temperature (°C)	Comments
1	$SO_4Ca, 2\ H_2O$ + excess of water	$T < 100$	linear behaviour
2	$SO_4Ca, 2\ H_2O$	$100 < T < 115$	vaporization of water in excess
3	$SO_4Ca, 2\ H_2O \rightarrow SO_4Ca, 1/2\ H_2O + 3/2\ H_2O$	$115 < T < 175$	1st phase change
4	$SO_4Ca, 1/2\ H_2O$	$175 < T < 200$	linear behaviour
5	$SO_4Ca, 1/2\ H_2O \rightarrow SO_4Ca + 1/2\ H_2O$	$200 < T < 220$	2nd phase change
6	SO_4Ca	$T > 220$	linear behaviour

These transformations account for a large part of the energy transferred to the package. On the contrary, vaporized water migrates from hot external parts to colder inner parts of the thermal protection, giving rise to an increase of the heat flux inside the package.

The Special Applications in Physics Laboratory (LASP) of CEA - Grenoble performed several heating experiments to characterize the behaviour of plaster when heated by a fire. Four cylindrical plaster samples equipped with thermocouples were heated in a furnace that provides IAEA standard thermal accidental conditions. These samples had different moisture contents and were confined or not to identify the effect of condensation.

Then a unidimensional numerical model of the plaster has been developed, taking into account the non linear behaviour described above. The plaster is divided into two parts : a squeleton and internal water. The conductive flux is associated to the squeleton while each node has a reserve of water (i.e. energy) that can be transferred to the colder neighbouring nodes. The water vaporization is simulated by enthalpies of transformation and the release of energy by condensation of water is modelled by temporary thermal sources.

This model was validated by simulation of the experimental configurations and comparison between experimental and calculation results.

CALCULATIONS

Thereafter, the model of plaster had to be incorporated in the FE code THERMX selected by IPSN for that study.

The enthalpies of plaster transformations have been converted into latent heats. Specific subroutines have been developed to generate sources modelling the water condensation phenomenon.

Besides, that model allows 2D and 3D simulations and takes into account the thermal behaviour of the plaster when it is cooled after the fire ends.

A first validation of that model has been performed on the basis of the CEA - Grenoble LASP sample experiments.

APPLICATION TO FS 47

A 2D axisymmetrical modelling of the FS 47 package has been developed by IPSN. The mesh is made of 2209 three- and four-nodes elements.

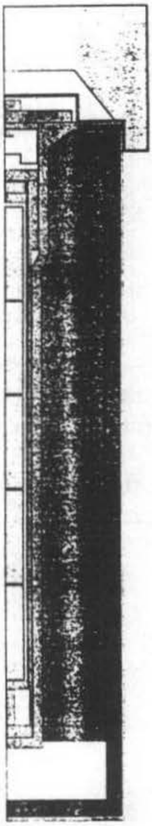
The model includes a representation of the internal container, in which the contents is placed, and a representation of the shock absorber.

Each material is taken into account, specially the plaster and the compound. The area of compound surrounding the oblique copper fins was homogenized.

The results of a calculation run using that complete model, were compared to the test results of the long duration fire test performed in 1993. Moreover, a preliminary study is being performed in order to determine the influence of various parameters such as the initial quantity of free water in the plaster or the temperature level of vaporization of the free water (despite the fusible plugs, the pressure in the plaster might be slightly above 1 atm absolute).

Though the sensitivity studies and the eventually necessary benchmarking are not finished, the model provides temperature results consistent with the long duration fire test results. It is then possible to start to apply this model for the evaluation of the thermal performance of the package exposed to the different following fire conditions.

Figure 2 - FS 47 modelling



		Fire duration					
		30 min	3 h 25 min	5 h	7 h 30 min	10 h	12 h
Temperature	600 °C	X			X	X	X
of	800 °C	X	X	X	X	X	
fire	1000 °C	X	X	X	X		

RESULTS

According to the first calculations the following results are noticed :

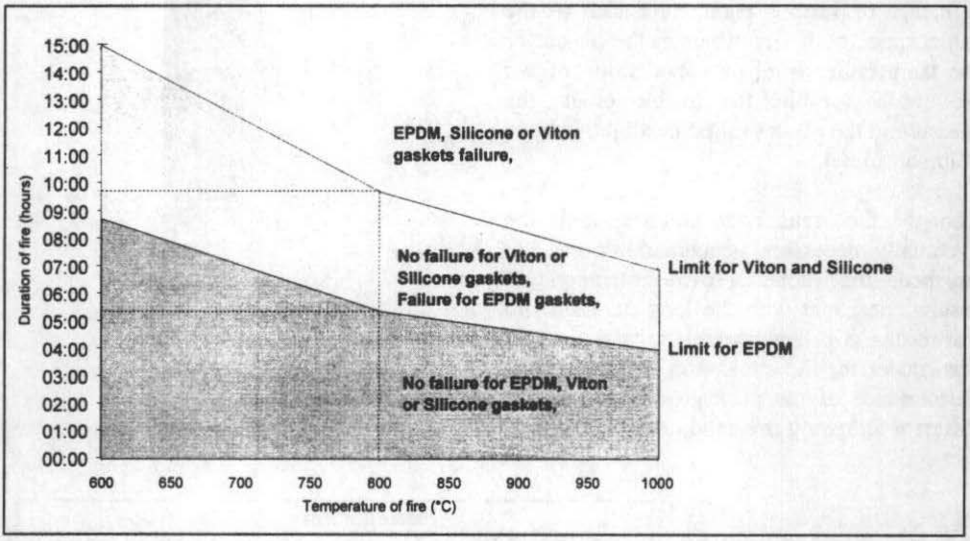
- the inertia effect brought by the compound and plaster protecting the content is significant.
- as expected, the weakest part of the packaging is the elastomer gasket.

In the following table, the maximum gasket temperatures and times when they are reached, are indicated for different fire conditions.

		Fire duration					
		30 min	3 h 25 min	5 h	7 h 30 min	10 h	12 h
Temperature	600 °C	100°C	X	X	165°C (7h55)	191°C (10h30)	249°C (15h35)
of	800 °C	100°C (2h30)	150°C (3h55)	175°C (5h30)	213°C (8h)	258°C (10h30)	X
fire	1000 °C	107°C (1h56)	170°C (3h50)	205°C (5h30)	267°C (8h)	X	X

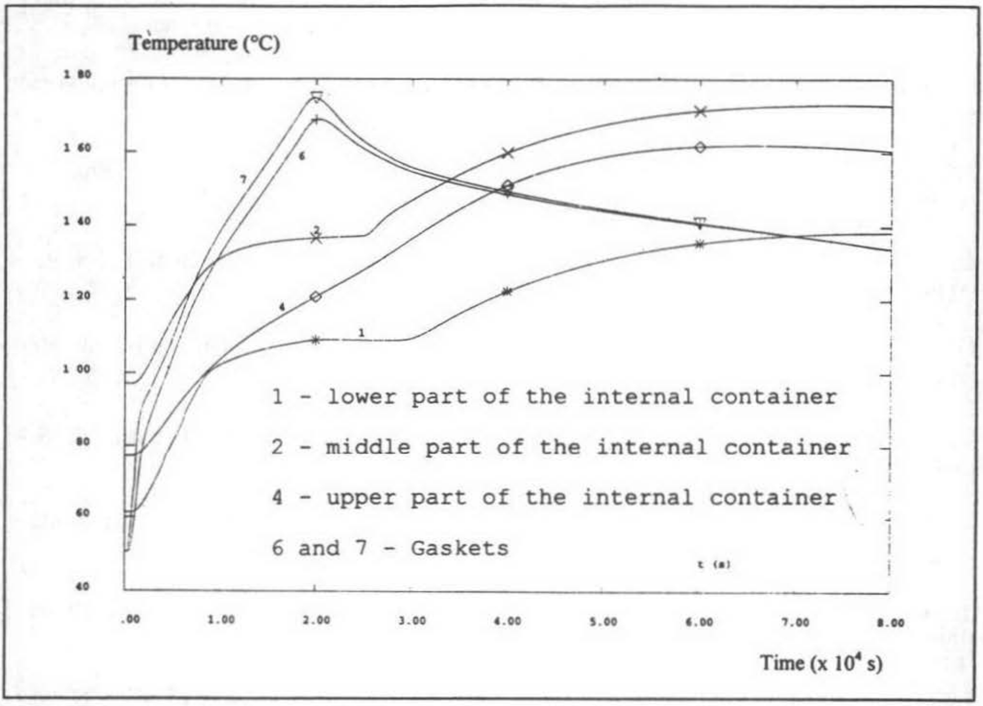
Assuming the allowable gasket peak temperatures of 180 °C for EPDM and 250 °C for Viton or Silicone, the figure below shows the fire duration corresponding to the preservation of gasket tightness, according to different homogeneous fire temperatures.

Figure 3 - Allowable fire times and temperatures for FS 47 package



For instance a FS 47 package equipped with EPDM gaskets could resist to a 800 °C fire during 5 ½ hours.

Figure 4 - Temperatures versus time curves for a 5 h - 800 °C fire test



CONCLUSION

1. The knowledge of the behaviour of thermally active materials was improved. A realistic numerical model of plaster is now available for 2D and 3D FE computer calculations. Through not yet completely validated, this model appears to be already well consistent with experimental fire test results. For 30 min fire tests, it provides representative simulations of the fast energy transfers through the active plaster and compound materials, leading to quicker rise of internal temperatures until 100 °C is reached. This new model is thus less optimistic than other existing ones, and its use could be interesting for safety analyses. For longer than 30 min fire tests, the model provides realistic results of temperatures and is less pessimistic than the other available models. It is thus attractive for the evaluation of consequences of potential fire accidents.

2. A realistic assessment of the performance of the package FS 47 exposed to different fire conditions has been carried out and shows large safety margins.

For the future, other thermally active materials will be characterized and modelled, like resins, concrete, etc ...

New studies will then be carried out in order to quantify the performance of other packages such as the casks used for the transportation of vitrified high level waste and spent fuel.

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