Packagings in the Silicon Era

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INTRODUCTION

ENEA is the main Italian Board involved in the temporary disposal of radioactive wastes produced by its own laboratories and national industries. In this context ENEA is studying, with the collaboration of the DCMN of the Pisa University, a new packaging to collect wastes in various facilities while proceeding to find a final disposal. Moreover it supports technically the Department of Industry and the Department of Civil Protection to cope with emergencies due to the unsafe storage of dangerous and poisonous wastes temporarily stored in various sites in the country. So, following a survey on the wastes that could be transported in the future, it was agreed to design a packaging able to contain an industrial drum, with a maximum capacity of 220 litres and a total weight less than 4000 N, previously filled with solid wastes in bulk or in a solid binding material.
The packaging, to be approved as a Type B in agreement with the IAEA Regulations, will be useful to transport not only radioactive wastes but any kind of dangerous goods and also those not in agreement with the UNO Regulations.

In the early stage of the design of this new packaging it was agreed that the use of silicon foam, a very fashionable material today, could have been a good solution to comply with the IAEA Regulations. In fact the silicon foam has the following general characteristics:
- good thermal and mechanical behaviour for the Type B packages with negligible decay heat and moderate density content;
- light variation of thermal/mechanical properties in the range of temperature 40/70°C;
- well known and qualified procedure of pouring/forming since this type of foam is largely used in the power plants as fire protection;
- reliability in the manufacturing and in service of shock absorbers.

As a first step in the approval procedure, it was decided to built a 1/2 scale model of the packaging with some simplifications and to develop a test program in order to obtain data to support the theoretical analysis and to forecast the prototype behaviour in the relevant test conditions.

Model design description

The 1/2 scale model of the packaging is formed by two concentric vessels of mild steel obtained by welding commercial shells to cylindrical walls and joined throungh a flange (Fig. 1). The uniform thickness of the steel shells is 2 mm.

The 75 mm gap between the two vessels is filled with the silicon foam layer that is divided in two halves as the vessels.

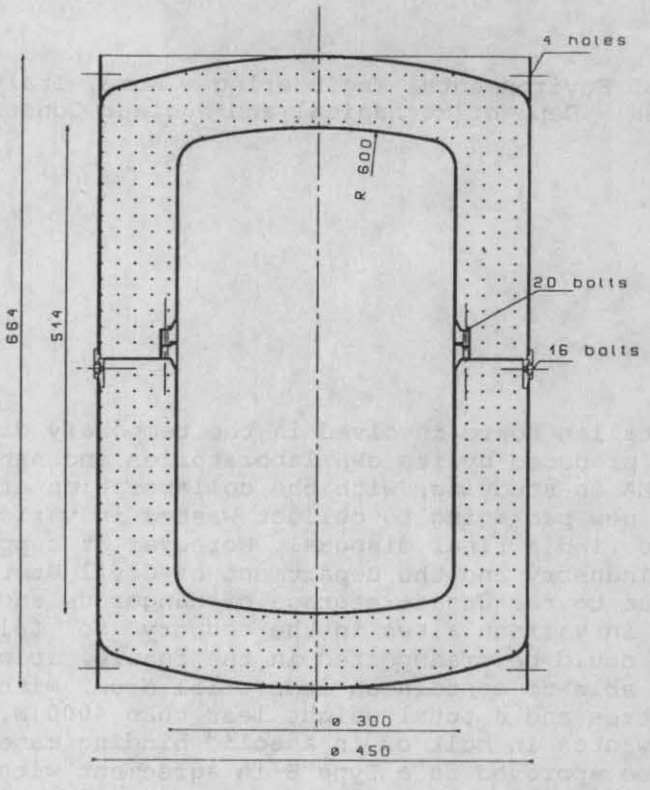

Fig. 1 - Section of 1/2 scale model

The external vessel and the foam layer constitute the mechanical and thermal protection of the package.
The bolts on the external vessel flange, in this stage of the design development, are perpendicular to the axis of the packaging and hold tight the two vessel parts only in the vertical direction in order facilitate the assembling. Some openings with meltable plugs are provided on the external vessel to allow expansion of the foam and leakage of the gases generated during the fire test.
The silicon foam was poured in two steps directly in the model, taking care of the need to remove completely the internal vessel.
The selected silicon foam has the following main characteristics (supplier's data):

density	300	kg/m^3
tensile strength	0.23	MPa
Young's module (in the elastic range)	0.2	MPa
Specific heat capacity	1.50	kJ/kg^oK
Thermal conductivity	0.075	W/m^oK
Linear coefficient of thermal expansion	3.2x10-4	$m/m/^oC$
Closed cell: perc. of the cell structure	= 50	%

The internal vessel is intended to be the containment system of the

packaging and its flange, with 20 small bolts, has one O-Ring gasket (on the present model) to allow obtaining of rough information on the extent of the possible leaktightness degradation as consequence of the IAEA tests.
The dummy content of the model is constituted by a steel drum filled with 50 kg of solid material (steel or lead bars) to simulate, in a ratio 1/8, the real content and is intended to be laid in the internal vessel with no further packing material.

Actual packaging prototype

At present, the design of the actual packaging is slightly different from the 1/2 scale model for the following main details:
- the silicon foam is not in contact with the internal vessel but is completely sheathed by means of a steel liner to allow a repeated removal of the internal vessel without foam layer damage. The bottom of the foam layer is locally reinforced to avoid large deformation and maintain tight the liner and the internal vessel;
- the containment system is provided with a more sophisticated gasket system, including at least 2 0-Rings, in order to allow for the package leaktightness testing before each transport. An upper and a lower skirt are present to make it possible to maintain the package in an upright position without further support and to facilitate the containment vessel removal. The outer vessel flange is provided with a quicker fastening device.

DESIGN AND TESTING OF THE PACKAGING

Preliminary analyses

The preliminary design phase was devoted to the definition of the general geometry of the packaging.
As the dimensions of the packaging containment system (inner vessel) were defined in accordance to specific needs of ENEA and other interested Institutions/Organizations, the overall packaging dimensions depend on the insulating/absorbing material thickness required to adequately protect the mentioned system in the IAEA testing conditions.

Due to the relatively low cost of the components it was decided that the packaging design would be checked not only by numerical analyses but mainly, expecially where the latter are too onerous or not completely reliable, by testing material samples and/or scale models or prototypes.
As regards to the packaging behaviour in impact conditions (i.e. IAEA mechanical tests), beside a first rough design approach after the results of which the external/internals steel vessel and the foam layer thicknesses were tentatively determined, several types of drop tests were foreseen for design confirmation as well as for demonstration of reliability or compliance to licensing requirements.

On the contrary, in order to study the thermal exchange behaviour of the packaging in normal and accident conditions, a preliminary analysis by means of the FD code HEATING6.1a was foreseen, while sample and scale model testing was reserved mainly, in this case, to determine the actual thermal characteristics of the foam and to validate the calculation models set up for the analysis of the actual packaging.
A preliminary thermal analysis was performed with reference to a 1/2 reduced scale packaging model, already available, which will undergo a furnace test. As is well known the results (e.g. the temperature profiles) of this analysis may not be scaled directly to the prototype but can be very useful, if compared with corresponding experimental data, to validate the calculation model to be used in the prototype study.
Several conservative assumptions were made in the analysis, namely:

1) Simplified cylindrical geometry (fig. 2).
2) Negligible heat capacity and thermal conductivity of the content in order to achieve maximum temperature levels in the foam.
3) No gap or contact thermal resistance at the steel vessel-foam layer interfaces.

For the steel thermal characteristics (specific heat capacity and thermal conductivity) the data were included in the Heating 6 code libraries, while for the foam the values (even if constant or limited to a 20-150 °C temperature range) included in the supplier's data sheets were assumed. The latter values were considered constant outside the indicated validity range/value.
As for the foam thermal conductivity only the value at ambient temperature was available. While of course a good evaluation of this parameter is very important for determining the corresponding thermal protection level, a limited sensitivity analysis was performed assuming also two other values (about 4 and 10 times respectively higher) besides the given one.
Taking account of the model dimensions, the main results obtained (as for instance the temperature profiles indicated in Fig. 2,3) seem to confirm that:

1) The thermal protection assured by the assumed insulating layer thickness might be suitable considering the envisaged gasket type, provided that the foam thermal characteristics are similar to the ones given by the supplier.
2) As foreseen the foam thermal conductivity in the high temperature range appears to be a very important (limiting) factor. For this reason the envisaged test program in this area, as indicated in the next Cap., seems to be fully justified.

Testing Program

As already roughly indicated in the previous considerations the test program, going on at present, includes the following main phases:

1) Characterization of the silicon foam (completion) and preliminary solution testing by means of:
1.1) Verification of the gaseous emissions of the foam in simulated as well as actual furnace test conditions.
1.2) Control of the reliability of the available data on the foam thermal exchange characteristics and qualification of the used calculation models, in the relevant high temperature range. The foreseen tests will be performed on samples and the available simplified 1/2 scale model of the packaging.
1.3) Determination of the foam shock absorbing capability by means of impact tests on plain material samples and 9 m drop tests on mentioned 1/2 scale model.
1.4) Leaktightness tests on the scale model after the previous drop and furnace tests. These tests, even if performed on a preliminary geometry, will give either confidence about the possibility of achieving the required containment performances or useful indications for optimizing the gasket design.

2) Final test series in the relevant IAEA conditions on a prototype designed and assembled on the basis of the preliminary analysis and test results, including at least:
2.1) 9 m drop tests in lateral, angled and vertical axis conditions and subsequent drop on cylindrical bar.
2.2) Furnace test with temperature measurements in the foam layer and expecially in the inner containment gasket area (if required mainly for demonstration purposes by the licensing Competent Authority).
2.3) Final leaktightness tests.

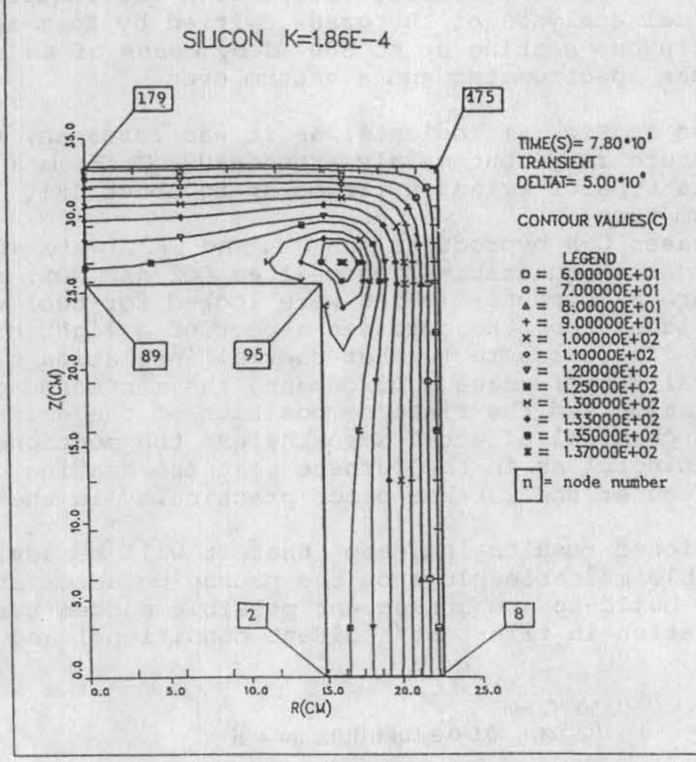

Fig. 2 - Temperature isocontours

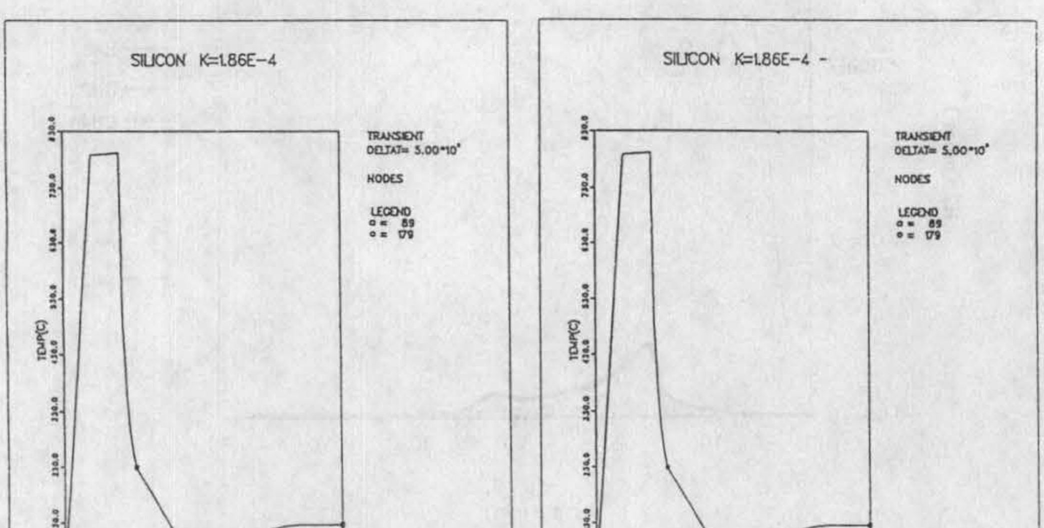

Fig. 3 - Temperature-time diagrams on the packaging vertical section

Available experimental results

So far the test program is in an early stage.
As regards the foam gaseous emissions information was acquired performing gaschromatographical analyses of the gases emitted by foam specimens undergoing a continuous heating up to 800 °C by means of an experimental set up including a mass spectrometer and a vacuum oven.

The results (shown in Fig. 4) indicate, as it was foreseen, H emission, on the whole temperature range but mainly around 400 °C. From a quantitative point of view this type of emission ranged up to about $1x10^{-3}$ NPT m^3/kg for the reference foam type.
Among the other gases C-H byproducts, as CH_4 and CH_2, were also observed, even if in very smaller quantities, as well as CO_2 and NO_x; several other potentially dangerous compounds (which were looked for too) were not observed. The foam residues took the foreseen aspect of a light brittle silicate sponge reasonably fit to assure further thermal insulation capability.
Of course in actual fire/furnace environments the mentioned gases will be oxidated on production and the final composition of the emissions will depend on the related chemical effects. Nevertheless the mentioned results may be considered meaningful as in the furnace test the heating of the foam inside the packaging outer shell takes place practically in the absence of air.

Moreover the mentioned results indicate that it will be advisable to provide for suitable meltable plugs on the packaging outer shell (in order to avoid pressure build-up and subsequent possible sudden burnable gases release and combustion in fire test/accident conditions) and that no

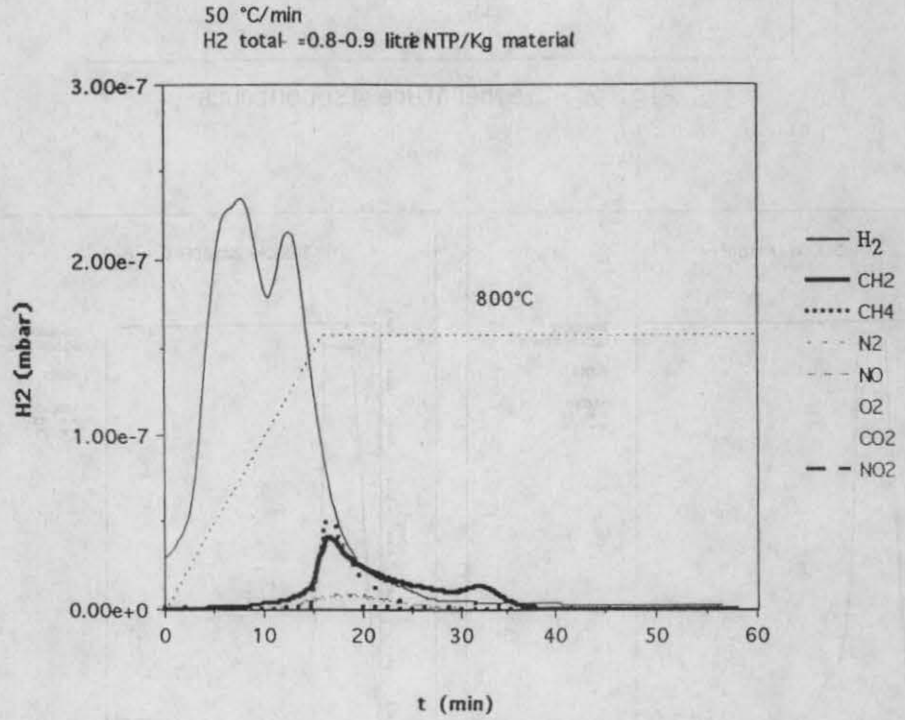

Fig. 4 - Analysis of gases emitted by foam

significant gas emission is to be waited for at any envisageable temperature level in normal transport conditions.
A first 9m lateral (with horizontal main axis) drop test was performed on

the available 1/2 scale model of the packaging in the ENEA-University of Pisa Scalbatraio testing facility (Forasassi et alii, 1991).
The content was simulated by means of a 51 Kg lead cylindrical mass inside the internal vessel. On the top half body of this vessel a couple of acceleration transducers were installed in order to monitor the acceleration components along the vessel axis and the vertical (drop) directions.
As it is possible to see in Fig. 5, the model overall deformations were not severe; the insulating layer (even if damaged) in the impact area mantained a residual thickness value over the 70% of the original one, mainly due to the elastic-plastic behaviour of the foam.
The inner vessel flange was maintained closed by its bolts, even if the vessel itself underwent rather large deformation due to the combined effects of the dynamic loads transmitted directly by the dummy load and the back pressure generated in the foam layer in the impact area.

Fig. 5 - 1/2 Scale model deformation after 9m drop test

CONCLUSIONS

The new packaging under development presents features that seem to be proper for its envisaged waste collection main use such as construction simplicity, relatively low cost, time and use endurance, low maintenance requirements.
The design analysis and testing program ongoing at present allowed for the preliminary definition of the packaging geometry and confirmed the necessity of further investigations in some key areas as the determination of actual behaviour of the silicon foam, used as energy absorbing/thermal insulating material, in the specific conditions of interest (mainly in the high temperature environment of the standard IAEA furnace test).
Nevertheless the available analysis and testing results, even if preliminary

and lacking completeness, seem to indicate sofar that the design is in fair agreement with the foreseen goals.

REFERENCES

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