Design and Testing of a Transport Package System for PCM

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Introduction

Alpha-active intermediate level waste (ILW), also know as PCM (Plutonium Contaminated Material) is generated from handling plutonium and other alpha-active materials. Although the quantities of activity often give rise to low radiological and shielding problems (e.g. for transport, up to15gm of this material is deemed to be non-fissile), criticality is usually a dominant issue, and containment is very important because of the potential hazard from inhilation. The Type-A package limit for Pu^{239} is about 90mg, so Type B packages are required for the transport of PCM in workable quantities.

General Requirements

In 1991 the UKAEA anticipated a long-term requirement to transport 200-l drums of PCM waste in Type-B quantities between sites in the United Kingdom. Studies of the expected waste streams resulted in an engineering specification for a simple, cost-effective packaging system that could be used at various facilities without the need for specialized or hazardous handling equipment.

The system devised - the "Nupak-200" - has a high degree of inherent safety, and allows operation within buildings which have little or no cranage facilities. It meets these requirements by providing a twin-box assembly which provides full Type B protection to 4 200-l drums. Operational flexibility can be achieved by using more inner boxes than outer boxes, as vehicle turnaround time can be minimized because sets of inner boxes may be handled whilst the outer boxes remain attached to the trailer. All loading and unloading operations can be undertaken with a fork-lift truck.

The combination of an inner and an outer box provides a safe, robust package. The outer box provides the necessary impact and thermal protection and the inner box provides the containment. See Figure 1.

Design of the outer packaging

Considerable development work was undertaken on all aspects of the container design and associated waste handling system. The outer packaging framework is constructed from 3mm thick stainless steel rolled hollow section (RHS) which surrounds a flat panelled box with side opening door. The panels are constructed from a 75mm thick cork resin composite, clad both sides by a 3mm stainless steel skin. The panels provide a tough puncture resistant and impact absorbing shell which cushions and insulates the inner containment vessel during all conditions of transport.

Computer modelling

Dynamic elastic/plastic finite element techniques were used to assess the degree of damage to the outer container skin. The non-linear finite element analysis package ABAQUS was used for these assessments (Ref 1).

Early analyses, which were based upon the resin/cork material properties obtained from data sheets, showed that there was insufficient accommodation of the kinetic energy during simulation of the 1m punch test. At the termination of the analysis, the model still retained a downward velocity of 3m/s and it was likely that, with about half the energy still remaining (25kJ), the punch would continue to penetrate the remainder of the cork and inner skin, and possibly contact the inner containment tubes.

Composite material data generation

To resolve this situation, as there were uncertainties in the reference data for the cork material, it was decided that practical development tests should be carried out to validate the finite element model. Therefore, three prototype side panels were constructed and subjected to simulated punch impacts.

The first of these tests was carried out on a model panel of 75mm thick cork clad both sides with 3mm thick stainless. The results from this test were used in an iterative process to validate the cork/resin dynamic material properties using the original finite element model. After this, the original finite element analysis was repeated using the modified cork properties. Fig. 2a shows the displaced shape of the model after 50 ms, and Fig. 2b shows the plastic deformations and strain contours. At the point the analysis concluded, the residual energy (2.5kJ) was an order of magnitude smaller than that predicted using the original material properties. The design team were encouraged by these results, although remaining uncertainties in the dynamic elastic/plastic analysis prevented conclusive determination that the outer skin would provide full protection to the inner containment system against punch penetration. It was essential that the puncture resistance should be confirmed early in the design process, as this formed the basis of the outer packaging design. To misjudge the panel performance at this point would lead to major problems later in the project.

Experimental verification

The next step in the development of a puncture-resistant outer box was the manufacture of two full size test panels. The two panels differed only in their boundary restraint : the first panel was an exact replication of the proposed package design and the second had strengthened boundaries to simulate the added stiffness that would result from the attachment of the four adjacent sides of the outer packaging shell.

In order to best simulate the impact parameters that would exist under the punch test, it was decided to drop a 5000 kg punch (i.e., of equal weight to a laden package) onto the stationary panels. This test arrangement allowed the maximum kinetic energy to be directed at the weakest part of the panel without the need to consider possible energy loss due to package rotation.

The two panels performed similarly, the non-stiffened boundary panel suffering from a large amount of edge distortion. The stiffened boundary panel overcame this problem, and performed extremely well with no visible panel boundary distortion. Results of this second test can been seen in Fig. 3. It is interesting to compare the revised finite element analysis (using the modified cork properties) with the performance of this second panel, noting particularly the plastic displacement on the inner skin and the outer circular removable section stamped by the punch. The design team were greatly encouraged by the results of these tests and were now confident that the actual package would perform satisfactorily.

Following the successful design of a puncture-resistant panel, the design team then turned its attention to the performance of the panels when combined to produce the outer packaging and the enclosure for the inner containment system.

The performance criteria of the panels in this configuration is different from that for puncture assessment in as much as the panel provides both impact and thermal protection. It was therefore necessary to consider two modes of failure. The first is the ability of the package to limit the impact damage to the inner containment system and the second is to ensure that the outer package thermal barrier remains intact. A second finite element model of the outer container was generated (Fig. 4a). The costs associated with this type of analysis were reduced by simplifying the model at the mesh generation stage. For example, it was decided to model the package as a closed box and assume that the door connection is as strong as the rest of the package.

A dynamic elastic/plastic analysis was carried out over a duration of approximately one second. Stresses, strains, displacements and energies were determined at various increments throughout the loading period. Figs 4b and 4c show the resulting displacement, permanent deflection and plastic strain contours at the end of the analysis. Maximum plastic strains of 14% were found.

From these analyses it was concluded that the outer container would readily withstand a 9m corner drop, as local collapse of the RHS box section (which was not modelled) would provide additional energy absorption beneficial to the impact behaviour of the system.

Design of the inner packaging

The next stage of the design development was to assess, by further computer modelling, the effect of the mechanical tests on the inn containment system in order to determine the suitability of the design to meet its main criteria - that of providing containment of the radioactive contents. This modelling was undertaken with fine meshes to generate the required accuracy.

This analysis focused on a direct 1.2m corner impact which was considered to be a severe representation of Type B accident conditions. Impact of this type causes considerable local deformation and distortion of the buffer. Note that this condition is excessive for the Type B situation where the inner is protected by the outer box, and is only likely to be encountered if the inner container is used on its own, for example, as a Type A packaging.

The performance of the container under this assessment was excellent, with only minor breaches of non-containment welds present in the region of the impact and only very minor displacements around the O-ring area. (These were smaller than the O-ring compression).

Comparisons between the modelling and the test results

Finally, Figs. 4d, 4e and 4f show the damage sustained to the prototype outer package following a full-laden 9m corner impact, a 9m flat base impact and a 1m punch impact. These figures show good correlation with the computer analysis shown in Figs 2, 4a, 4b and 4c. The degree of knockback of the package corner and the localised distortion is very representative of that modelled by finite element analysis, additionally if the finite element mesh was made finer in the impact region then the results would approach more closely those of the actual test.

Conclusions

The Nupak-200 design and development project was carried out over a period of 19 months and successfully concluded with a full drop test program on a prototype package. The final test in this program was a full scale hydrocarbon pool fire which fully engulfed the package for a period of 45 minutes.

The Nupak-200 packaging Design Safety Report was submitted to the UK Competent Authority on the 6th June 1994 and a type B(U)F approval certificate was issued on 23rd February 1995.

The first fully-operational Nupak-200 has been manufactured for use primarily within the UK. It is planned that Nupak will enter regular service in 1996. In March 1995, AEA Technology successfully completed the next stage of its Type B waste container design program with the successful testing of a privately-funded Type B(U)F 20' ISO Freight Container (Transhield-20) for PCM drums and other articles. This is due for approval later in 1996.

Acknowledgements

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Reference

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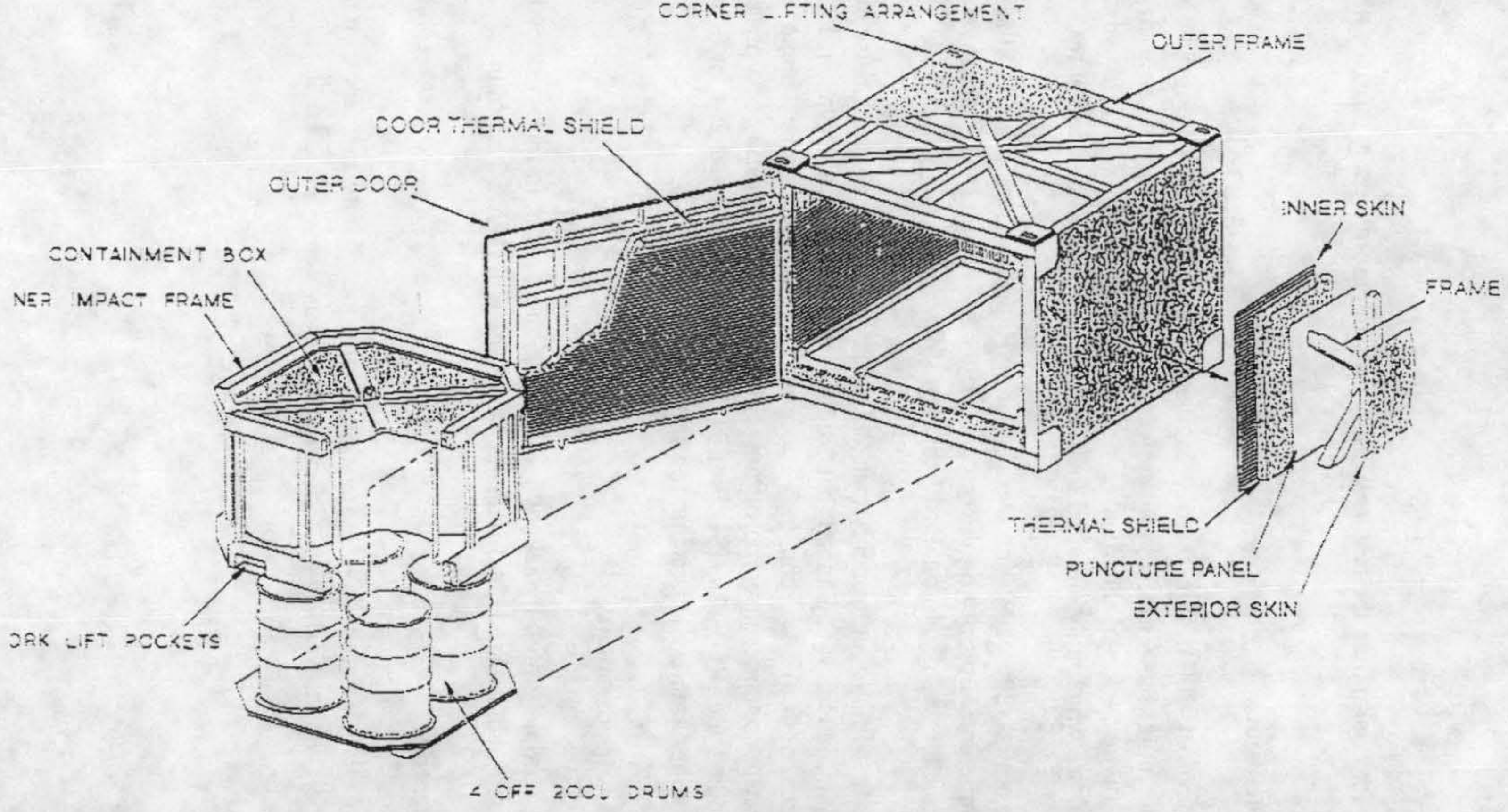
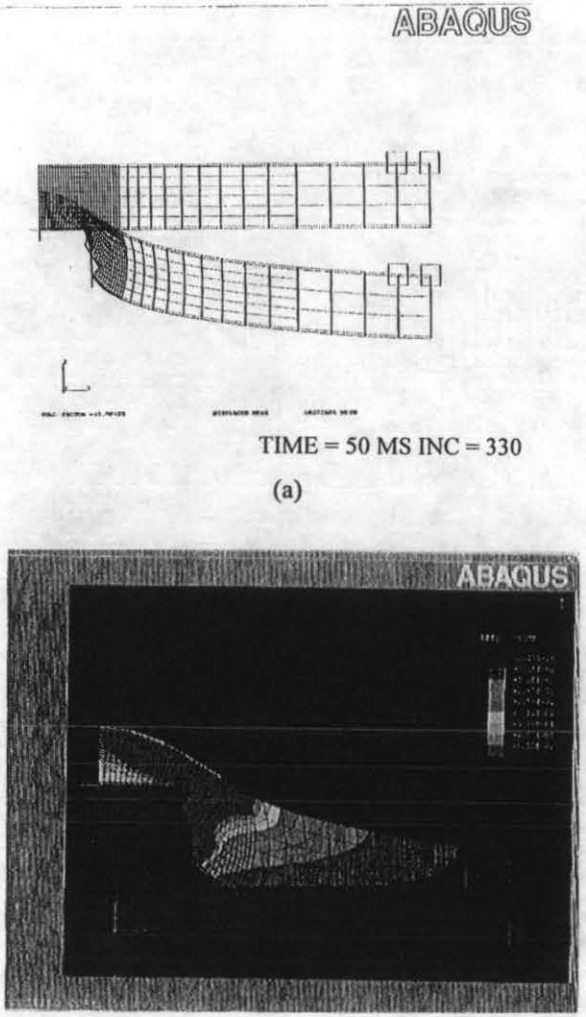

CORNER LIFTING ARRANGEMENT
OUTER FRAME
DOOR THERMAL SHIELD
OUTER DOOR
CONTAINMENT BOX
NER IMPACT FRAME
INNER SKIN
FRAME
THERMAL SHIELD
PUNCTURE PANEL
EXTERIOR SKIN
ORK LIFT POCKETS
4 OFF 200L DRUMS

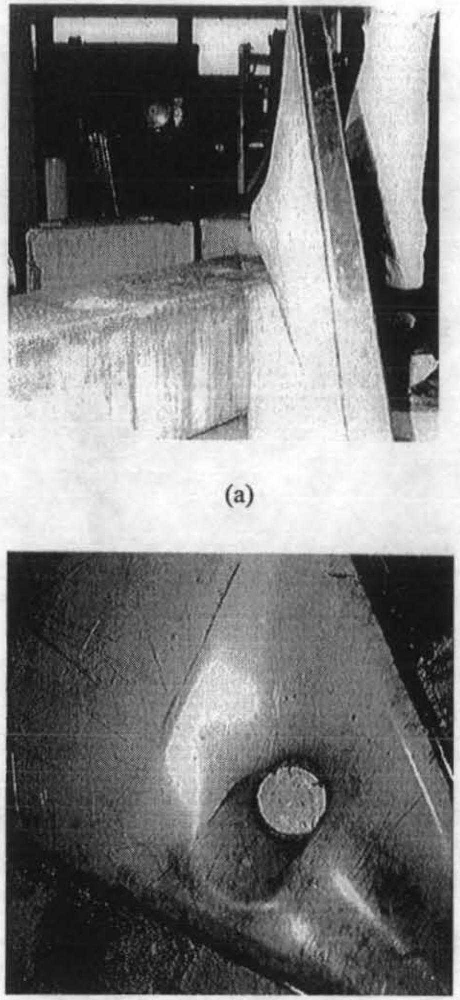
Figure 1



(a)

(b)

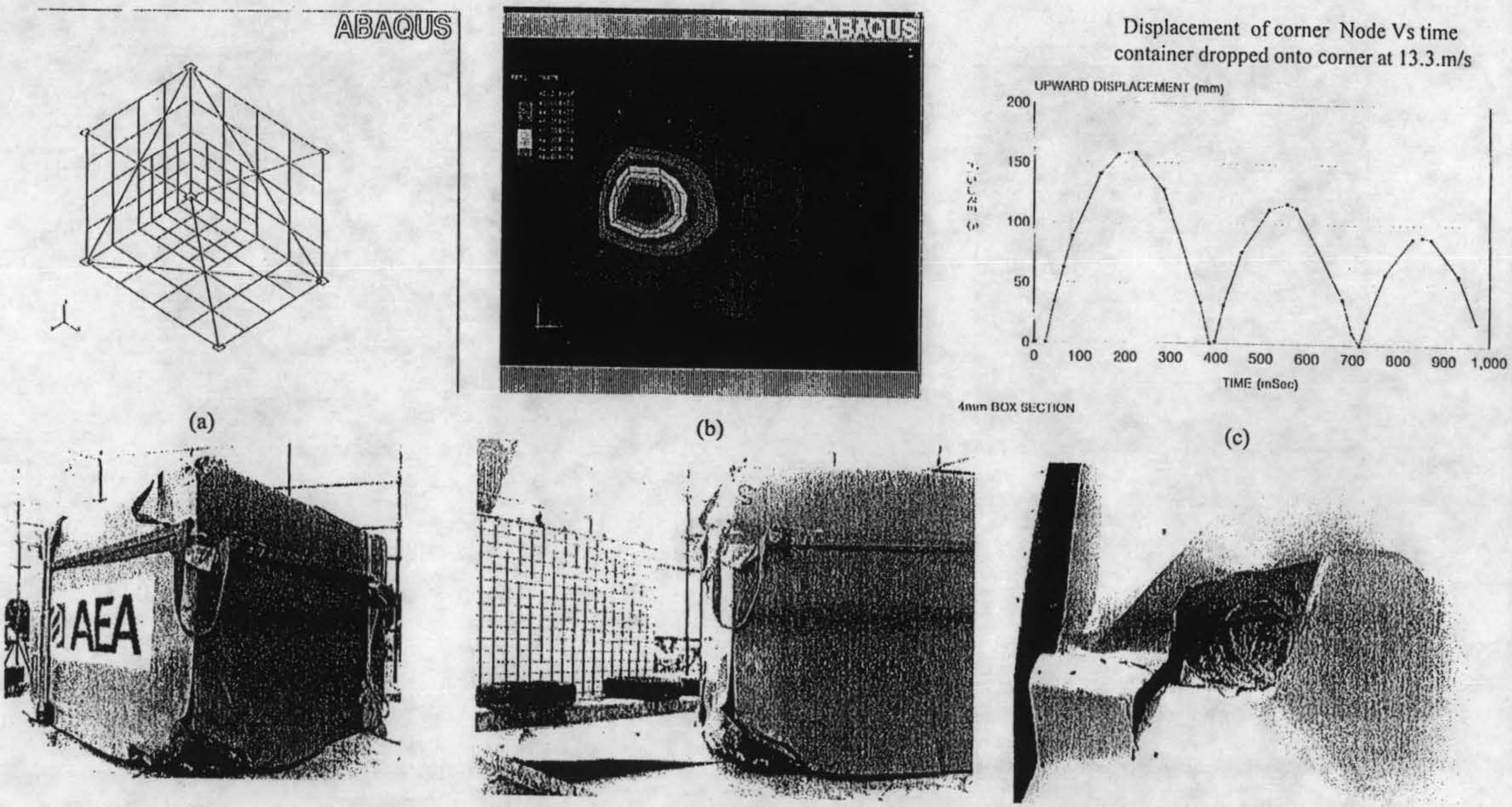
Figure 2



(a)

(b)

Figure 3



Displacement of corner Node Vs time container dropped onto corner at 13.3.m/s

(a) (b) (c)

(d) (e) (f)

Figure 4