A NEW TYPE C PACKAGING FOR AIR TRANSPORT OF FRESH MOX FUEL ASSEMBLIES

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SUMMARY

With the aim to transport fresh MOX fuel assemblies by air starting in 2001, COGEMA asked Transnucléaire to develop a global transportation system based on the use of a totally new packaging concept. The concept study was made in accordance with the new type C packaging requirements defined in the 1996 revision of the IAEA regulations and with the requirements set forth by the NRC in 10 CFR Part 71. This type of packaging must, in particular, be demonstrated to withstand high speed impact tests of 90 m/s for the IAEA and 129 m/s for the NRC regulations. A new drop test onto a truncated cone-shaped punch was also introduced.

In order to comply with operational and transport constraints, new principles have been considered in the design of this packaging. A large number of numeric simulations were carried out to define the basic concept and to assess its behavior under variable impact angles. The numeric models, some of which included more than 100,000 elements, were readjusted by means of real impact tests performed on scale models throughout the whole development period. This preliminary study allowed to define the impact angle for the qualification test which will be performed at the end of 1999.

INTRODUCTION

In view of the increased production of MOX fuel assemblies planned by COGEMA and of the corresponding growth of international movements by 2001, Transnucléaire has undertaken the development of a new system allowing the transportation by air of these fuel assemblies.

This transportation system relies upon the use of a special type C packaging, whose concept takes into account the following requirements:

Contents

The packaging has been designed to accommodate one of the 3 following contents:

- one PWR 900 MOX assembly
- two BWR MOX assemblies
- canistered fuel rods

In this respect, the feasability of a multi-content packaging, as already demonstrated through the development of the FS 65 container, has been maintained.

Safety justification

Justifications must be prepared in accordance with IAEA 1996 regulations, which are, in particular, applicable to future type C packagings designed for transportation by air. The NRC regulations 10 CFR part 71 were also taken into account in the packaging concept.

The new definition of the Neutron Quality Factor given in the ICRP 60 regulations were taken into acount. For MOX fuel, these regulations dictate the shielding requirements, since 80% of the dose rate results from neutron sources.

Specific dimensioning constraints were introduced by COGEMA in addition to the applicable regulatory requirements. Resistance to deep immersion was required and external pressure testing has recently demonstrated the ability of the containment vessel to withstand immersion to a depth of 10,000 meters.

Fuel integrity

In order to guarantee fuel integrity, in particular with respect to mechanical resistance and geometrical criteria, strict prescriptions concerning vibratory and thermal issues had to be taken into account.

REGULATORY CONSIDERATIONS

One of the main innovations of the 1996 revision of the IAEA Regulations is the creation of this new type of packaging (type C), which must be used in all cases for the transportation by air of material whose activity exceeds 3000 A2.

The corresponding series of tests are defined, including in particular an impact test onto an unyielding target at a speed of 90 m/s (paragraph 737) which is obviously predominant for dimensioning. The punch test in which the packaging falls from the height of 1 meter onto a cylindrical punch bar for type B packagings has been upgraded with the use of a more aggressive truncated cone shaped punch and a drop height multiplied by three (paragraph 735).
The NRC regulations (paragraphs 71-74) as applicable to the transportation of plutonium by air impose a far more severe sequence of testing. This sequence starts with an impact test at a

speed of 129 m/s, followed by other mechanical tests including a drop test onto a truncated cone-shaped punch and ends with a fire test.

According to the well known philosophy of the Regulations, each type of test must of course be carried out in the most damaging configuration for the containment, which leads to a large number of possible scenarios.

THE FS81 CONCEPT

See figure 1

To remain compatible with different operational and transport constraints and in view of the need to withstand the new regulatory tests, innovative principles have been introduced in the packaging design. One of the basic principles is to consider that a substantial part of the kinetic energy at the moment of impact is absorbed by the containment components of the packaging and by the content itself. This leads to assume controlled local plastification of these differents elements.

Therefore, a new containment concept excluding any mechanical assembly was used. The containment vessel is provided by a leaktight welded capsule without any orifice. This cylindrical capsule is of uniform thickness and is closed at each end by a hollowed hemisphere. This containment vessel has no opening/closure arrangement. Closure is performed by welding one hemispherical end after introduction of the internal arrangement and of the contents. Opening is carried out by mechanical cutting of the same end.

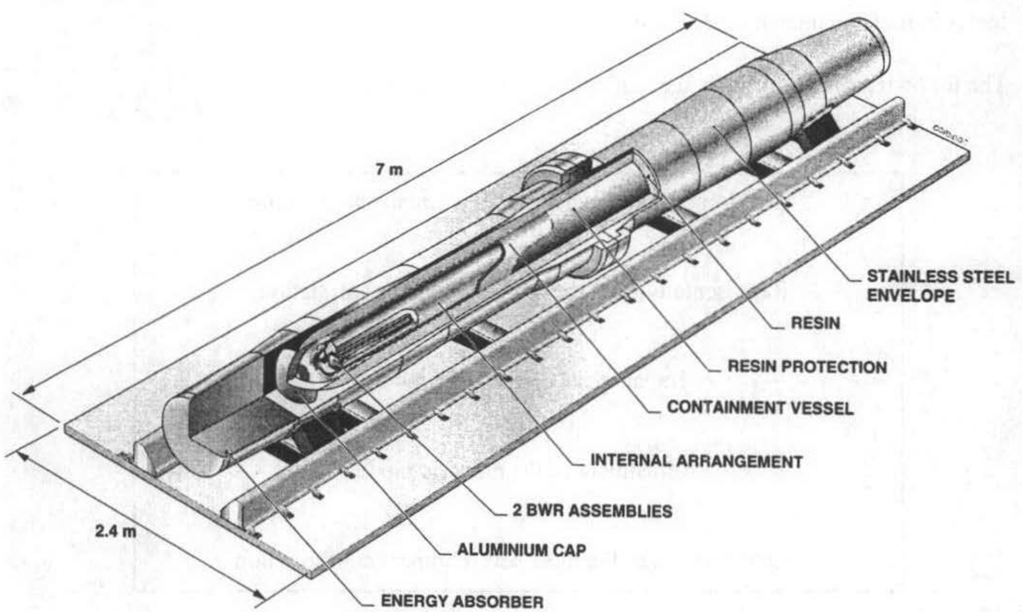


Figure 1: Main components of the FS81 packaging

The packaging body is designed to protect the containment vessel during the different mechanical and thermal regulatory tests. It contains a layer of efficient neutron absorbing resin which contributes primarily to the radiological protection but also acts as fire protection. The two ends of the body are protected by special devices designed to absorb a large part of the kinetic energy during impact. These devices absorb more than 50% of the kinetic energy during an axial impact at more than 130 m/s and remain efficient during angled impacts. Their efficiency is still approximately 35% at an impact under a 19° angle.

The body consists of two almost identical parts which can be separated to provide access to the containment vessel during loading and unloading of the fuel assemblies. Two aluminium caps have been designed to protect both ends of the containment vessel, and "operate" at precise moments during impact.

Since the possibility to transport different types of contents with the same packaging was one of the initial goals, only the internal arrangement is specific to the content transported. These internal arrangements are designed to prevent damage to the internal wall of the containment vessel from shocks imposed under normal and accident transport conditions.

The packaging body is connected to an aluminium frame by means of an anti-vibration system (AVS) to ensure fuel integrity.

STUDY OF BEHAVIOR DURING IMPACT

For impact resistance, the design has been elaborated by means of numeric simulations as well as by impact tests on representative scale models. The simulations are carried out using the inelastic finite element calculation code LS DYNA3D.

The following diagram shows the main development sequences:

Creation of the numeric models / Impact simulations

⇩

Representativity of the scale models for correlations

⇩

Impact tests on the scale models

⇩

Adjustment of the numeric models

⇩

Determination of the most severe impact configuration

The following figures show deformations of the packaging body and its energy absorbers during the simulation of an impact at 140 m/s under a 19° angle.

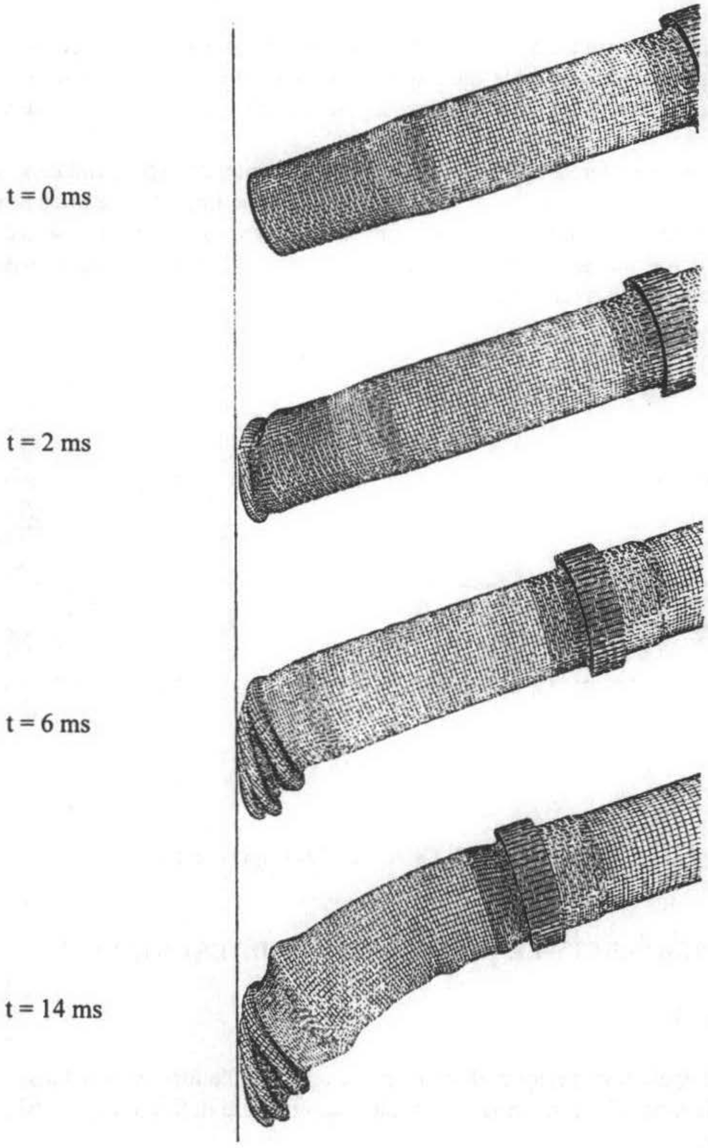


Figure 2: Impact simulation at various time sequences

IMPACT TESTS ON THE MODELS

The technical means of CEA-CESTA, near Bordeaux, and in particular a pneumatic gun with a 300 mm diameter, were used for the different experiments programmed during the development stage. The models were accelerated along the entire fifteen meter length of the gun and hit the target after a few meters of free flight.

For the angled impact tests, the model is placed in an elaborate wood and aluminium shoe which is propelled to provide the required acceleration. The shoe is stopped in flight by an appropriate device while the model crosses an opening before hitting the steel target.

The tests are registered by means of high-speed camera at approximately 8000 images per second used to analyze different time sequences of the impact. The image by image analysis of the films allows to measure the phenomena duration as well as to assess decelerations. For example, it was assessed that the duration of an axial impact was approximately 10 ms while for a 20° angle it was reaching 100 ms.

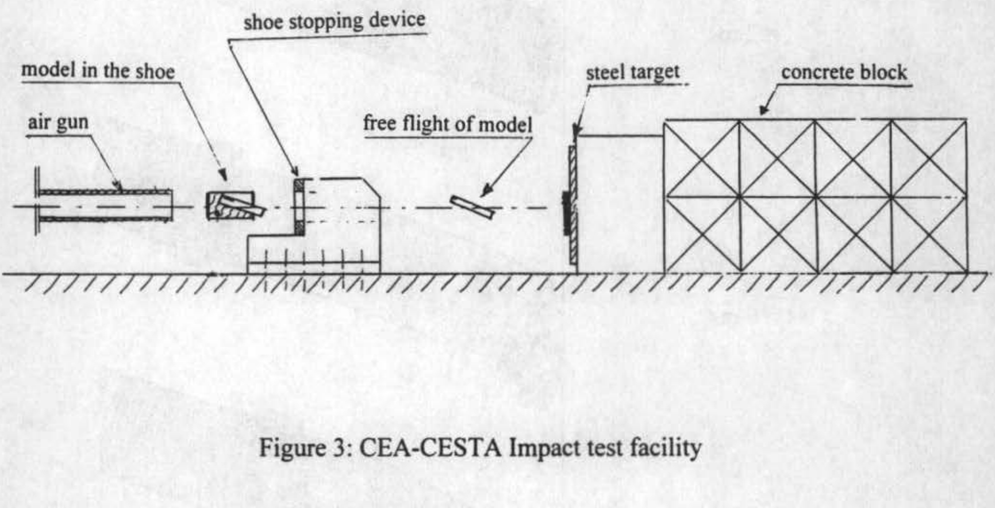


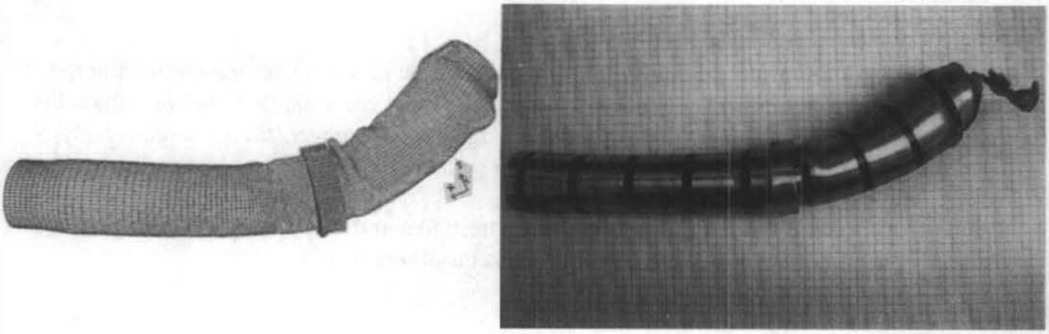
Figure 3: CEA-CESTA Impact test facility

COMPARISON BETWEEN SIMULATION AND TEST RESULTS

(See figure 4)

The first impact tests performed after the numeric simulations gave results extremely close to the calculations. The following views allow to compare deformations obtained by simulation and by testing.

The deformations also appear very similar for the energy absorber, which is quite remarkable. Moreover, Krupkowsky classical law ($\sigma = K(\varepsilon_0 + \varepsilon_\rho)^A$) was applied for the stainless steel in the simulation and no correction was necessary.



Simulation Test

Figure 4: Comparison between simulation and test results

SENSITIVITY STUDIES

A number of sensitivity studies were conceivable with the numeric calculation. These parametric studies allow to analyse the relative sensitivity of the various safety related parameters, e.g. mechanical caracteristics of the materials or operating temperature. These studies mainly dealt with the laws of the behavior of materials.

STUDY OF OTHER TESTS

Besides the high speed impact test, the other main innovation of the IAEA regulations is a drop test on a modified punch bar. For a model exceeding 250 kg, the drop is from a height of three meters on a truncated cone-shaped punch. This test is also required by the NRC regulations.

Thus, special tests have been carried out to calculate the minimum thickness allowable for the packaging body. This thickness has been determined considering that the external envelope must not be punctured during the drop. This assumption is very conservative in view of the expected damages on the containment vessel itself. The tests showed that for this design, a 25 mm thickness of stainless steel is sufficient.

The other mechanical tests have been evaluated and it has been shown that they are not dimensioning. On the other hand, since the containment is not provided by a conventional sealing arrangement, resistance to the fire test is easily achieved.

FUEL INTEGRITY

The packaging must protect the fresh fuel assemblies from shocks under the normal transport and handling conditions. For this purpose a special system has been designed to tighten the assemblies in the containment both axially and radially. Moreover, the packaging body is connected to the frame by means of anti-vibration systems.

To verify the maximum temperature of the hottest fuel rod, the thermal behavior of the packaging under normal conditions of transport was analyzed in detail.

CONCLUSION

A packaging designed to transport by air fresh MOX fuel assemblies has to take into account extremely severe regulatory requirements concerning, in particular, high speed impact tests. These requirements have already been taken into account for the development of packagings, whose contents differ from those now considered by COGEMA. To remain compatible with different operational and transportation constraints, Transnucléaire now develops a new packaging concept thanks to the efficient simulations provided by the numeric tools.

It should be noted that the French Safety Authorities (DSIN/IPSN) have been kept informed about the progress of this new concept at an early stage to allow updating their examination procedures. The packaging design is now virtually finalized, with qualification tests scheduled for end 1999 and the full transport system operational around year 2001.

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