Scale-up and Leaktightness

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INTRODUCTION

Many years ago ENEA and the University of Pisa developed a research program to design a fissile material transport packaging manufactured with common and commercial materials. It was decided to use a small industrial packaging, a steel cylindrical drum filled with a mixture of concrete and vermiculite, with an inner cylindrical steel liner. The containment system, placed inside the thin cylindrical liner, was in this way protected from mechanical shocks and thermal input to withstand accidental conditions. To verify the characteristics of the mixture of concrete and vermiculite, kept wet between the outer and inner cylinders, many drop and thermal tests were performed. Finally it was possible to fix the better recipe for the mixture and get the Competent Authority approval certificate for a Type B fissile package denominated CF6.

Recently it has been necessary to have a larger packagings to move fissile materials between ENEA laboratories, so it was decided to design the CF66 packaging, scaling-up the CF6 1.5 times and taking into account the results of the previous tests on the latter. Besides the U and Pu in solid form allowed in the CF6, a small quantity of plutonium solution was considered as a new content also.

The Competent Authority was not completely satisfied with the design based on the previous tests on a smaller prototype and requested a complete test in agreement with the IAEA Transport Regulations, maybe, owing to the strong public concern about movement of plutonium. Due to the Competent Authority requirements and to the need to obtain versatile packaging a detailed test program was planned, exceeding the IAEA Transport Regulations, to allow new contents in the future changing only internal components, shielding and criticality calculations, on the base of a well-known behavior of the packaging in any conditions of transport.

DESCRIPTION OF THE TWO MODELS

CF6 model

Prototypes tested were manufactured using a steel industrial drum with removable head and a capacity of 60 l : a welded and riveted liner was placed inside to create a gap. The gap was filled with concrete and vermiculite mixture containing residual water in agreement with a detailed procedure, and then it was sealed to avoid the evaporation of the water (fig. 1). The water has an important role during the thermal test, so its quantity was well defined after several preliminary tests. The removable head has attached a shock absorber manufactured like the main body and the closure device is reinforced with six clamps pivoting on the drum and kept closed with a steel rope. The containment system has only one O-ring, and the content (36 kg) was simulated with small lead pieces. All the approved CF6 packagings were manufactured completely with stainless steel to avoid frequent inspections on steel thickness, in compliance with the approval certificate.

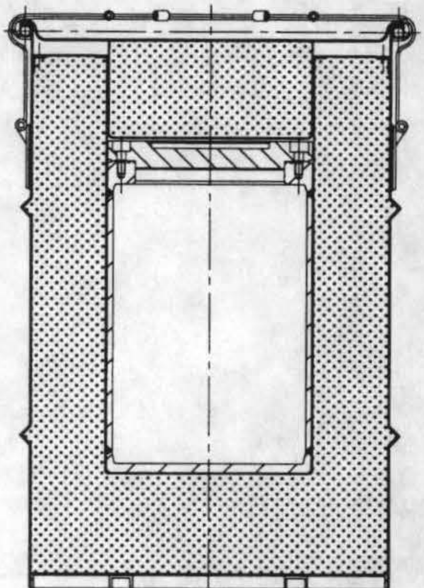

Figure 1. CF6 Section

CF66 model

The two CF66 prototypes tested were similar to the CF6 with few modifications due to lack of commercial components and all dimensions enhanced 1.5 times (table 1). Stainless steel was used for every part and the external drum was manufactured with the bottom welded; two rolling hoops were added to reinforce the structure and to facilitate the handling (fig. 2). The closure of the removable head has two semi-rings tied with a screw-threaded device; the six hold-down clamps were closed with a circular steel bar. The containment system has three O-rings, and the dummy content was constituted by 121 kg of lead for most of the tests. A dummy load of 220 kg was used for the last part of drop and fire tests, since the safety margins turned out to be very high, and a larger content could be useful in the future for different radioactive sources.

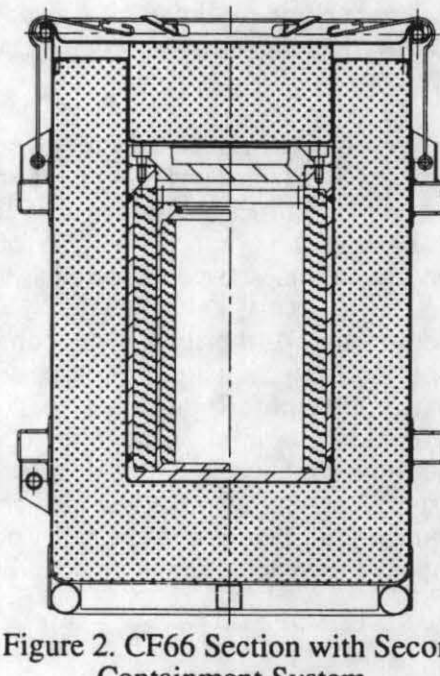

Figure 2. CF66 Section with Second Containment System.

Model	Drum		Containment system		Content
	Diameter mm	Height mm	Diameter mm	Height mm	kg
CF6	380	580	216	335	36
CF66	570	932	322	525	121
Ratio CF66/CF6	1,5	1,61	1,49	1,62	3,36 (1.5^3)

Table 1. Comparison of the Two Models

RESULTS OF DROP TESTS

Thirteen prototypes of the CF6 model were tested not only to comply with the IAEA Transport Regulations but also to understand the behavior of the shock absorber with different quantities of water, concrete, and vermiculite. Some models were dropped twice on different positions to save time and to know the margin of safety, since it was always easy to remove the containment system after every drop test. Table 2 shows a summary of some drop tests of prototypes with the shock absorber composition very close to the final one (Forasassi 1985).

Position	Drop test number / prototype	Acceleration max - g (Hz= 1600)	Deformation mm	Content mass kg
Vertical axis- bottom	1/3	350	40	36
Vertical axis- bottom	1/2	300	55	"
Vertical axis- lid	1/6	400	55	"
Horizontal axis	2/2	320	40	"
Horizontal axis	1/5	320	38	"
Horizontal axis	1/11	390	30	"
Horizontal axis	1/13	380	33	"
Lid corner	1/7	140	90	"

Table 2. 9-m Drop Test Result for CF6 Model

Two prototypes of the CF66 model were tested to verify compliance with transport regulations and the effects of scale factors. Since the safety margin was high as shown by the acceptable deformations of the shock absorber measured after three drop tests on the same prototype, the last drop test was carried on with a heavier content. Table 3 shows the result of all drop tests and points out that the accelerations were ≈1.5 less than CF6 ones in agreement with scale factors, but the horizontal drops, where the rolling hoops produced a different impact onto the unyielding target (Forasassi and Aquaro 1990).

Position	Drop test number / prototype	Acceleration max - g (Hz= 1600)	Deformation mm (+= drum)	Content mass kg
Vertical axis	3/1	240	10+55	121
Horizontal axis	1/1	285	10+9	121
Horizontal axis	1/2	330	8+10	121
Lid corner	2/1	103	60+d	121
Lid corner	2/2	225	80+d	220

Table 3. 9-m Drop Test Result for CF66 Model

In no case was a deformation of the containment system measured, and it was always easy to remove the containment system to verify its leaktightness.

RESULTS OF THERMAL TESTS

Many prototypes of the CF6 model underwent to the open fire test as required by the transport regulations, while only two final prototypes were tested in a furnace after one drop test. For the open fire the temperatures were measured with thermo-fusible gauges while the temperatures recorded for the last test, outside and close to the O-ring, are shown on figure 4 .

Both CF66 prototypes were tested in a furnace, and figures 5 and 6 show the temperature recorded in the most significant positions. The O-ring temperature of the containment system for the second prototype (fig. 6) is lower than the first one due to the larger mass of the content (220 kg instead of 121 kg) .

It is evident, looking at all the temperatures recorded, that the presence of the residual water in the shock absorber keeps the temperature of the containment system always below 100°C: the lower temperature recorded inside the CF66 model is due to the scale factor, since the surface increased by 1.5^2, and so the thermal input, while the mass increased by 1.5^3.

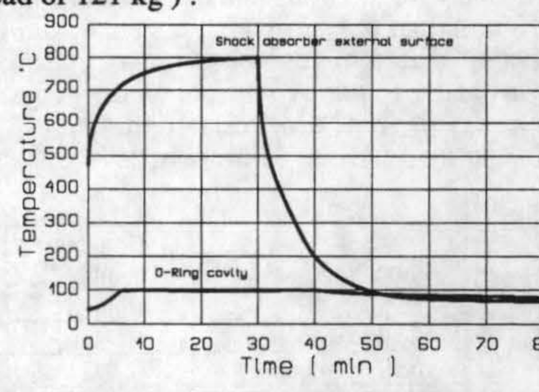

Figure 4. CF6 Thermal Test Results

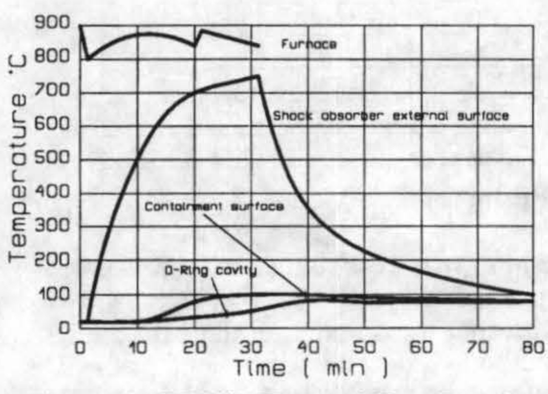

Figure 5. CF66/1 Thermal Test Results

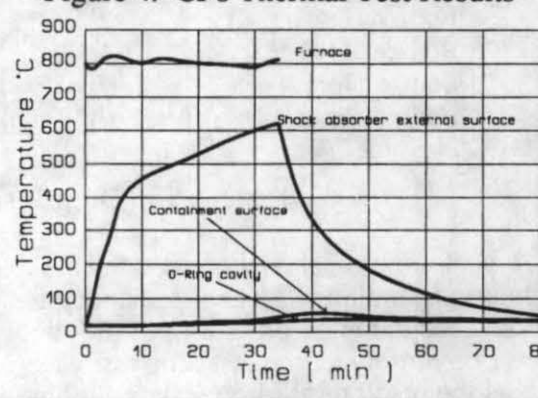

Figure 6. CF66/2 Thermal Test Results

FINAL DESIGN OF CF66 AND LEAKAGE TESTS

The transport regulations require that in normal conditions of transport the loss of radioactive contents should be restricted to no more than 10^{-6} A2 per hour and in accident condition to no more than A2 in a period of one week. This requirement, although very stringent in the case of plutonium , was complied with, since the prototypes were leaktight, in agreement with the ANSI N. 14.5-1987, after severe tests (tables 4 and 5). Viton is not recommended at low temperature however; silicone has high helium permeability and characterics not compatible with foreseen content.

N	Condition	3 O-rings	Test time	Leakage (atmxcm^3/s)	Notes
1	Initial	Viton	2h 20'	7,0x10^{-8}	He outside
2	Initial	Viton	4h	1,6x10^{-8}	He inside
3	Drop test	Viton	1h	1,6x10^{-8}	He inside
4	Thermal test	Viton	1h 50'	4,0x10^{-8}	He inside
5	After inspection	Viton	3h 45'	2,0x10^{-8}	He outside
6	After inspection	Viton	3h 30'	6,7x10^{-8}	He inside
7	After heating (95°)	Viton	3h 15'	1,3x10^{-7}	He inside
8	After inspection	Silicone	3h 45'	3,9x10^{-6}	He outside
9	After inspection	Silicone	3h 30'	4,8x10^{-6}	He inside
10	After heating (95°)	Silicone	2h 45'	5,6x10^{-6}	He inside

Table 4. Leakage Test Results of CF66 Second Prototype

In Italy it would be easy to demonstrate that in no place on a road would the package temperature reach -40°C. Obtaining a derogation from the Competent Authority, however, means, if the case, to transport in special arrangement conditions. Since special arrangements, in any case, are not permanent and are difficult to accept psychologically as an equivalent level of safety, it was necessary to change Viton O-rings to comply with every statement in the IAEA S.S. N° 6. In agreement with ANSI standards, too, a leakage test was performed on the two manufactured packagings ready to be used in the transport of plutonium in liquid form, where a second containment system was added as it is requested in many national regulations.

First prototype	Second prototype
Preliminary leakage test	Preliminary leakage test
Horizontal 9-m drop test	Horizontal 9-m drop test content mass 121 kg
Leakage test	Leakage test
Corner 9-m drop test	Corner 9-m drop test - content mass 220 kg
Vertical 9-m drop test	Punch test
Leakage test	Leakage test
Thermal test	Thermal test
Leakage test	Leakage test
	Immersion test
	Penetration test

Table 5. Experimental Test List of CF66 Prototypes

In agreement with ISO standards, many leakage tests on the two containment systems were performed with only one O-ring. However two O-rings were tested to verify the possible improvements (Rapone 1993). The measured leakage in either case was small after few hours. In the first set of leakage tests, Viton O-rings were used to compare the result of tested prototypes. In the second set, special teflon-silicone were used: a teflon O-ring with a cavity filled with silicone (denominated fep-o-seal by Angst&Pfister) with a working temperature lower than -40°C and chemical characteristics compatible with the contents foreseen. The third O-ring installed on the packagings tested was necessary only to create the gap where the vacuum pump was connected to detect the helium released inside the containment system, by a small pressure vessels with an electronic timer, after the closure: practically, the mentioned 3rd O-ring is important for the containment system assembly verification. It could be possible to take into account the third O-ring as a reliable barrier, but the handling procedure to close the packaging became too complex. The results of leakage test show the influence of helium permeability through teflon and silicone. This phenomenon is more evident when second-hand O-rings were used as indicated in fig. 7, since helium was trapped in the small gap present between the teflon and the silicone and absorbed in the gasket itself.

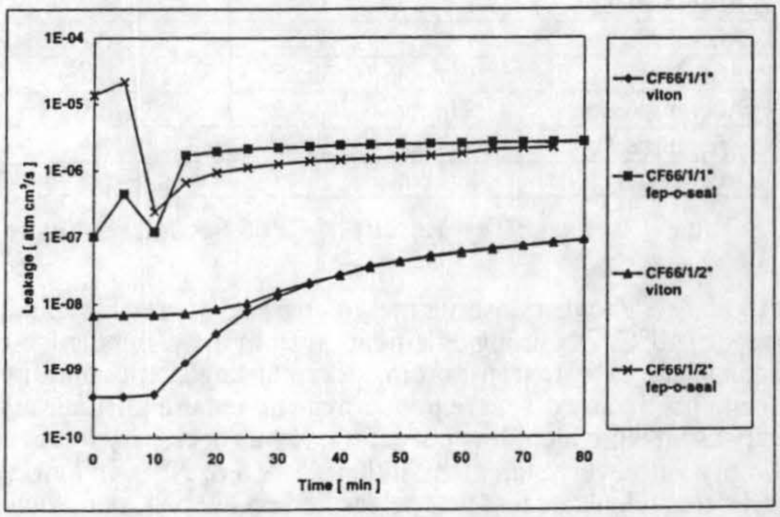

Figure 7. Leakage Test of CF66/1 Packaging

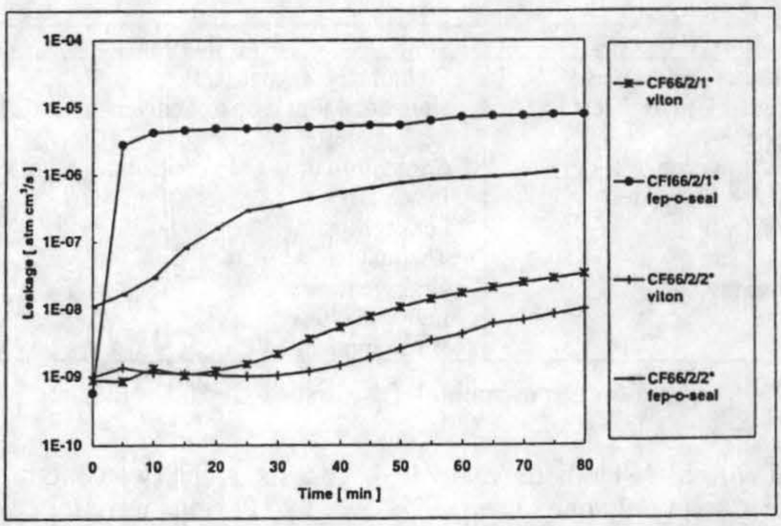

Figure 8. Leakage Test of CF66/2 Packaging

Although the leaktightness (10^{-7} atm cm^3/s ANSI definition) of the two containment systems was verified with the Viton O-rings, this was not possible with fep-o-seal O-rings, which gave a leakage rate of $\approx 10^{-6}$ atm cm^3/s (fig. 8).

Taking into account that:

· a new set of fep-o-seal O-rings will be installed for each transport,

· the measurements of leakage rate have been made with one O-ring and not two as present in practice,

· the pressure inside the containment system is very low in any conditions with a maximum temperature = 95°C after thermal test, and

· there are two containment systems,
the Competent Authority agreed on the compliance with IAEA Transport Regulations and issued the approval certificate for Type B(U)F packaging containing a Pu solution.

CONCLUSION

All tests performed on CF6 and CF66 models have shown clearly the possibility of using scale factors to design new packagings, although the safety margin can be high, particularly for the thermal test. As regards the allowable leakage rate, the limit becomes too stringent if the packaging is designed with elastomeric seals and compliance with IAEA Transport Regulations would be verified by the leaktightness of the containment system as suggested in ANSI N. 14.5-1987, especially when combined with -40°C. Leaktightness is a simple criterion that avoids calculations based on hypothetical assumption. It is more easily understandable for the public than the criteria based on A2 value.

REFERENCES

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