Operational/Preshipment Leak Testing of Large Transport Packages

I.J. Hunter[1], R. Gowing[2], L. Jones[1]

[1]*Nuclear Transport Ltd., Risley, Warrington*
[2]*British Nuclear Fuels, plc, Risley, Warrington, United Kingdom*

Introduction

The "Excellox" type flask is operated by Pacific Nuclear Transport Ltd (PNTL) and Nuclear Transport Limited (NTL) for transporting irradiated fuel from PWR and BWR reactors to reprocessing plants. The combined fleet total more than 80 and include the following types:-

Excellox 3
Excellox 3B
Excellox 4
NTL 3
NTL 11
NTL 14

This range of flasks vary in weight from 50 to 94 Tonnes and they are described in detail in another paper at this symposium (Gowing). The NTL 11 flask, illustrated in Figure 1, transports fuel in the wet mode, the cavity water providing both shielding and a heat transfer medium. It has a payload of 7 PWR fuel elements or 17 BWR fuel elements.

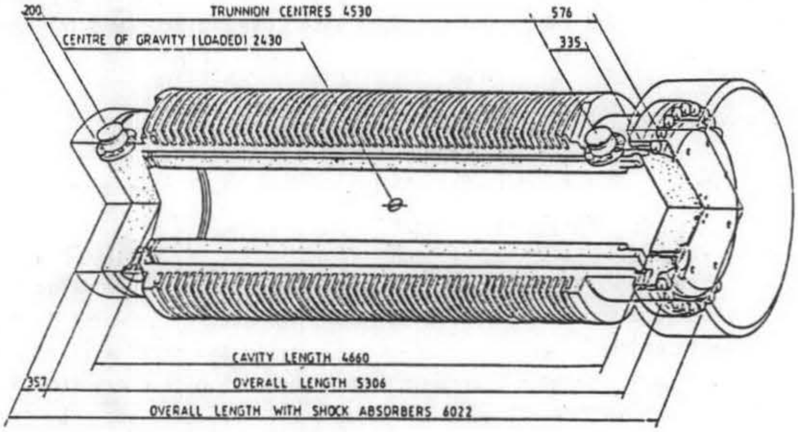


Fig 1. THE NTL 11 FLASK

The flask body provides a high degree of impact protection together with bolt on impact limiters at the lid and base end. A system of elastomer seals forms a containment system for the contents as shown in Figure 2.

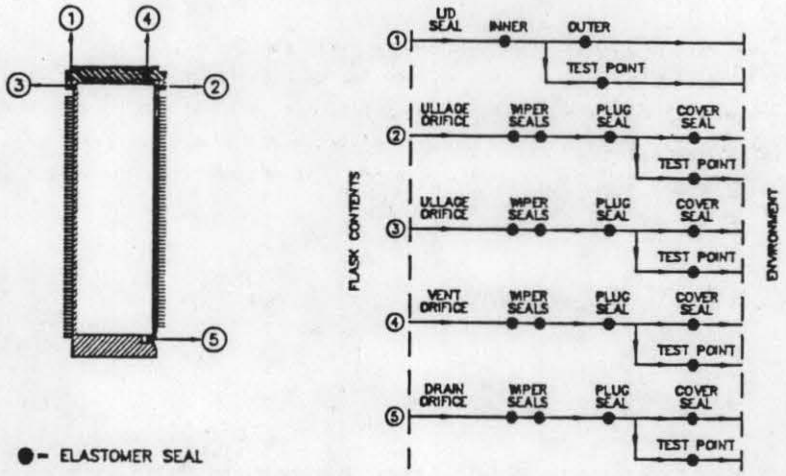


Fig 2. THE CONTAINMENT SYSTEM OF THE NTL 11

The sealed penetrations in the flask are used for loading/unloading operations at the reactors and reprocessing plant and they have a facility for leak testing;

Flask lid - for access to the fuel contents
Ullage orifice - for adjustment of internal water levels
Vent orifice - for venting during filling, flushing or draining
Drain orifice - for complete draining or water circulation

ACTIVITY RELEASE LIMITS

The IAEA regulations, (IAEA 1985), impose limitations on the activity release from transport packages. These limits are expressed in terms of A_2 values, each radionuclide being allocated such a value in curies taking into account its potential radiological hazard. For example, a particularly hazardous material will have a low A_2 value. The "Excellox" type flasks have been approved to the 1973 IAEA regulations as type B(M) packages and the maximum allowable releases of activity are as follows:-

Normal transport conditions: $10^{-6}A_2$ per hour

Post accident conditions: $10A_2$ of Krypton 85 per week and A_2 per week of all other nuclides

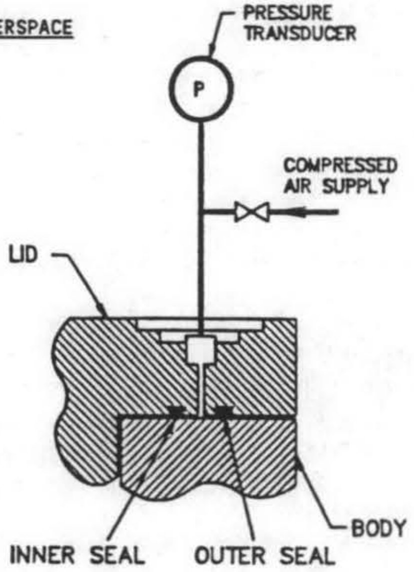
The vast majority of the activity within the flask is locked up within the fuel elements with no potential for direct release. Some activity will be present in the flask water from fission products or activated corrosion products. This activity in the water will include crud particles in the 20 μm range. Gases are present within the fuel pins - Krypton 85 and Tritium. Rupture of the fuel cladding releases these gases but it has been shown by Gowing and Williamson (1979) that more than 90% of the gas is retained within the ceramic fuel matrix.

Fuel pins occasionally experience cladding failure in reactor operations and it has been an established practice to incorporate an allowance of up to 1.5% pin failures in the fuel presented for transport. For accident conditions it is assumed that 100% pin failure occurs.

Having established the source of activity within the package it is possible to define the effective A_2 value and investigate the two potential release modes - gaseous and liquid.

An allowable gaseous leak rate can be derived from the A_2 limit and the active gas concentration of the package. The original safety cases for each Excellox type flask examined each penetration individually and calculated the release potential from an operational test leak rate. The operational leak test is performed after flask assembly and involves pressurising the seal interspace with air and measuring the rate of pressure loss with time, as illustrated in Figure 3.

Fig 3. A TYPICAL PRESSURE TEST SEAL INTERSPACE



A limit is set on the operational test and this is equated to a laminar flow leak through a single cylindrical leak path. Using the Hagen Poiseulle Law it is possible to convert the test leak rate to the conditions of normal transport and accident conditions. Established formulae are readily available to the flask designer for this task (ANSI N14.5 1977).

REVIEW OF LEAK TIGHTNESS ANALYSIS

The Excellox fleet have been operated safely for nearly two decades and there has never been a recorded incident of a flask leaking during transport. As more flask types were brought into service it became established practice to try and standardise on the operational leak test for each penetration. The volumes of individual interspaces range from 28cc for an orifice up to 410cc for a lid and the pressure drop test sensitivity is a function of the test volume. Consequently there was no standard degree of regulatory compliance throughout the fleet. In 1988 a study was undertaken to increase the proportion of failed fuel pins for a specific flask type. This study showed that the operational leak test for this specific transport needed to be increased in sensitivity, putting it on the limit of the current equipment and the resulting operational difficulties led to the operators requesting the designers for a fresh look at the problem. Subsequently a joint BNFL/NTL group was set up to review the leak tightness safety case for the full range of Excellox type flasks.

The primary objective of the group was to derive a standard analysis method across the full range of flasks. Recent work by the United Kingdom Atomic Energy Authority (AECP 1068, 1988) recommended the use of standardised leak rate (SLR). The SLR is the leak rate normalised to reference conditions of air at 25°C leaking from an upstream pressure of 1 bar (absolute) to a downstream pressure of 0 bar (absolute). This value can be converted to operating, test or accident conditions using the same formulae as in existing safety cases.

The allowable leak rates for each packaging were calculated in terms of SLR and were found to be in the range 10^{-5} to 10^{-6} bar cc/s. This is the total volumetric leak rate from the package and in the case of the NTL 11, it must be split 5 ways if the operational test is used to demonstrate compliance. The nominal sensitivity of the gas pressure drop method is quoted to be in the range 10^{-1} to 10^{-6} bar cc/s (AECP 1068 1988) and a study of the equipment showed no scope for significant improvements.

A new approach was needed and the group turned to the principle of fabrication verification and containment system assembly verification (ANSI N14.5, 1977). Using this philosophy, a leak test is performed after fabrication to demonstrate compliance with the regulations. As part of the preparation for each actual shipment the containment system is checked and tested to demonstrate correct assembly. Hence a much more stringent test can be applied after fabrication and during periodic maintenance. Unfortunately, no such data existed for the Excellox fleet as the original manufacturing specifications relied on the operational leak test method. Some practical testing was called for.

FLASK LEAK TEST MEASUREMENTS

It was decided to perform a leak test on a fully assembled flask using a mass spectrometer. This technique, illustrated in Figure 4, is known as the gas filled envelope method and requires the flask to be surrounded by a blanket of helium with a mass spectrometer connected to the cavity.

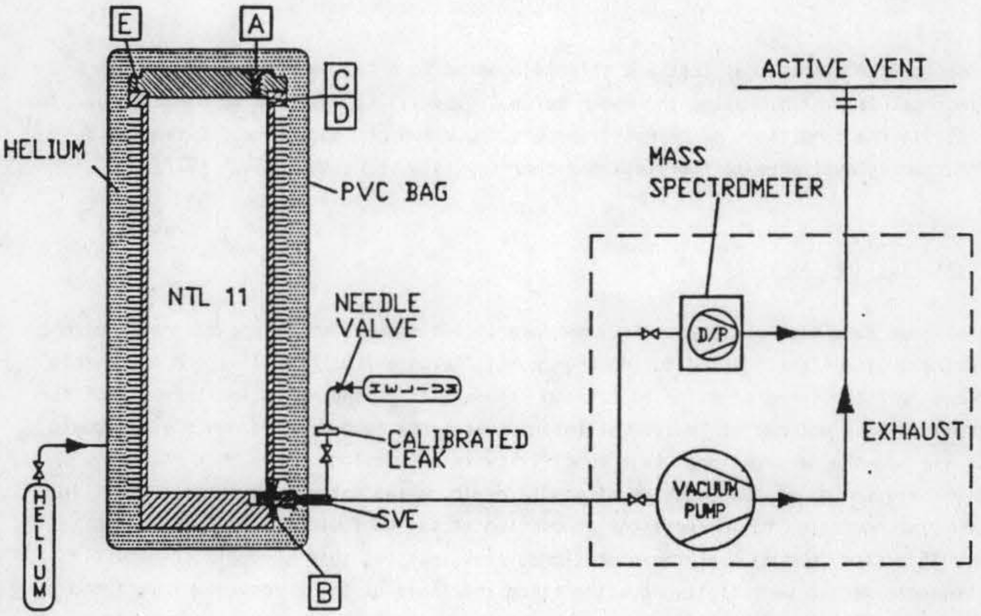


Fig 4. TESTING THE NTL 11 FLASK USING THE GAS FILLED ENVELOPE METHOD

The first test was carried out in April 1988 using a newly fabricated Excellox 4 flask at the manufacturers works, BSC Cumbria Engineering in Workington. A reference leak is included in the equipment for calibration and to determine system response times. The containment system must be accessed to the mass spectrometer via one of the flask orifice connections and, to ensure the full system was tested, the test was repeated via a second orifice. The results of this test together with the results of another flask test are shown in Table 1. The second test was performed on an NTL 11 flask at the COGEMA La Hague maintenance facility in France. Additional filters and operational controls were necessary as the flask had been used for fuel transports and the cavity was contaminated but the basic test method was identical to the Excellox 4 test.

Table 1 Results of Mass Spectrometer Tests

Measured leak rates in bar cc/s

	EXCELLOX 4	NTL 11
Test via Orifice A	$< 1 \times 10^{-9}$	$< 4 \times 10^{-8}$
Test via Orifice B	$< 1 \times 10^{-6}$	$< 1 \times 10^{-7}$

The differences in results for the two Excellox 4 flasks can be explained by equipment problems. A limit of 10^{-6} bar cc/s was set for the test and the orifice B test was terminated when this value was reached. It was concluded that a much lower value could have been achieved if time had permitted a repeat test. In general, the total leak rate measured by the mass spectrometer method was one or two orders of magnitude lower than that indicated by the gas pressure drop interspace tests. The possible reasons for such a difference are listed below:-

1. The interspace test measures the leak rate of two seals in parallel but the fully assembled flask has a sealed plug in the interspace test point which results in the two seals acting in series.

2. The gas pressure drop tests rely on calculated interspace volumes and in practice the measured volume is probably lower.

3. The gas pressure drop tests are sensitive to small variations in temperature.

4. The sensitivity of the test is approaching the limit for the transducers.

REVISED SAFETY CASE

Having established by practical testing that the leak tightness performance was much better than indicated by normal operational tests the safety case for the NTL 11 flask has been revised as follows:

1. The design leak tightness was based on a value achievable by demonstration using the helium mass spectrometer.

2. All the safety analysis was based on the design leak tightness value.

3. Operational tests were to continue using established methods which included turnround maintenance and inspection of all components in the containment system.

4. The design leak tightness test would be repeated during periodic maintenance.

FURTHER DEVELOPMENTS

The leak tightness analysis is based on laminar flow theory for a single cylindrical leak path. In reality there are likely to be a large number of small leak paths through a seal. The theory also assumes that the cylindrical leak does not change shape with increasing pressure. Development work in these two areas could reduce some of the inherent pessimisms in the current analysis methods. The ability of small capillaries to transmit active liquids could also reduce pessimisms as a significant part of the activity is in the form of suspended particles which may actually block the capillary and prevent release. A development programme on the leakage of aerosols through capillaries is currently being undertaken by the United Kingdom Atomic Energy Authority (Burgess, 1989).

CONCLUSIONS

Practical testing of large spent fuel flasks has demonstrated their containment system to be well within regulatory limits for activity release. The adoption of a two tier test system gives operational flexibility whilst maintaining adequate safety margins. Further development work could help to reduce some of the pessimisms in existing analysis.

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