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THE UK'S FIRST EVER MULTIPLE WATER BARRIER PACKAGE

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ABSTRACT

International Nuclear Services (INS) is a wholly owned subsidiary of the Nuclear Decommissioning Authority (NDA) who specialise in providing a complete nuclear transport system. INS' engineering department have a wealth of experience in the design and licensing of Radioactive Material (RAM) Transport Packages.

This paper describes the engineering challenges associated with producing a Package Design Safety Report (PDSR) for the first ever UK Multiple Water Barrier Package Licence application and discusses how INS and its stakeholders overcame them. The main technical challenges faced by the project were:

- Automatic site closure welding process development
- ALARP non-destructive testing techniques to justify closure weld as a containment boundary
- Demonstration of compliance with regulatory Accident Conditions of Transport (ACT) impact tests

A paper has been produced that discusses the licensing strategy that was applied in order to achieve a 'right first time' safety case [1]. Another paper has been produced that discusses the challenges encountered in demonstrating criticality safety during the design [2].

BACKGROUND

The M4/12 package was designed for delivery of fresh Light Water Reactor (LWR) Mixed Oxide (MOX) fuel from Sellafield MOX Plant (SMP) to European customers. The package was initially licensed as a Type B(U)F Package in the UK in 2006, followed by validation in Germany.

Operational use comprised two tandem deliveries of Pressurised Water Reactor (PWR) MOX fuel to the Grohnde NPP in Germany. However, operational issues with SMP and reverses in German nuclear policy combined to limit further use of the two M4/12 Packages.

INS performed a feasibility study in 2011 in an attempt to find an alternative use for the package, beyond its design intent. Following the study INS secured a contract for a number of shipments involving an array of different contents. The M4/12 Package was suitable to carry this material as:

- The M4/12 basket was capable of being adapted to fit contents equivalent to, or smaller, than a PWR fuel assembly
- Pu enrichment of the new contents was significantly higher than the LWR MOX fuel however the quantities being transported were much less
- The activity and thermal load of the new contents was significantly less than the M4/12 design base line

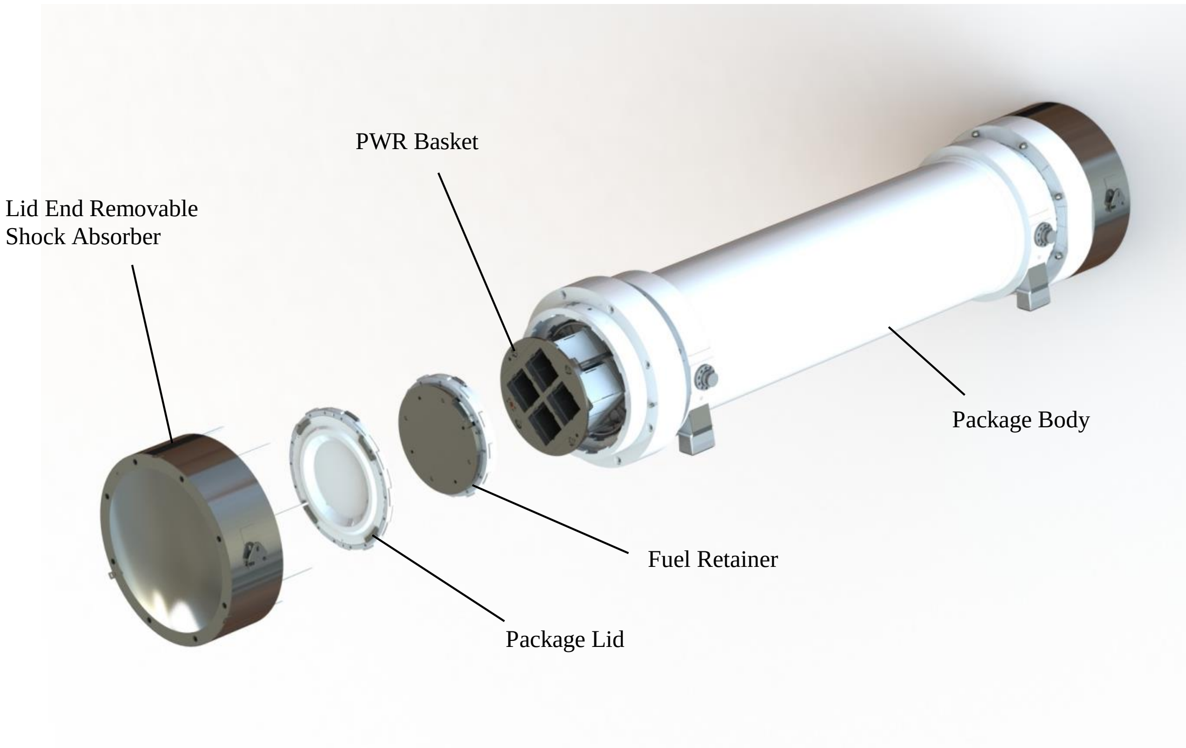


Figure 1 - M4/12 Package

REASON FOR MWB

The material to be transported had been in storage for an extended period of time, circa 30 years. The fuel was inspected in an attempt to justify the assumption that it could still be considered 'fresh'. The inspections discovered the fuel in various degrees of cleanliness – the best looked as if the fuel was new whereas the worst had large regions of corrosion with some areas of pitting.

An inability to justify the integrity of a large quantity of the material to be shipped meant unlimited break-up had to be assumed in accident conditions. Unrestricted break-up of fuel material in the M4/12 cavity combined with water ingress increases content reactivity unacceptably. Consequently, INS deemed the most achievable solution to meet the shipment programme was to overpack the contents within a secondary boundary which has been substantiated to maintain containment during accident conditions. This additional boundary is called the Mk III Unirradiated Fuel Container (UFC) which acts in parallel with the M4/12 containment boundary to provide a high standard Multiple Water Barrier (MWB) system.

REGULATORY REQUIREMENTS

The requirements for the use of multiple high-standard water barriers are summarised in [3], paragraph 680:

> ***Assessment of an individual package in isolation***
>
> 680. For a package in isolation, it shall be assumed that water can leak into or out of all void spaces of the package, including those within the containment system. However, if the design incorporates special features to prevent such leakage of water into or out of certain void spaces, even as a result of error, absence of leakage may be assumed in respect of those void spaces. Special features shall include either of the following:
>
> - Multiple high standard water barriers, not less than two of which would remain watertight if the package were subject to the tests prescribed in para. 685(b), a high degree of quality control in the manufacture, maintenance and repair of packagings, and tests to demonstrate the closure of each package before each shipment

Notable from the regulations is that both the outer container (M4/12 Package) and the inner container (UFC) must remain leak-tight under the IAEA test regime. The M4/12 has not been subjected to a full scale physical fire test, however, as the shipments were made under Special Arrangement, the terms of which include mitigation of a fire scenario, the absence of demonstrating leak-tightness following a fire accident was considered acceptable.

A further requirement relates to the need for the establishment of leak-tightness to be error proof. This had major implications for the operational testing regime and the equipment required.

STRATEGY

INS' adopted strategy for justifying a MWB approach was:

1. Define and have accepted what constitutes 'leak-tightness' relating to the inleakage of water i.e. specify a test criteria expressed in Standardised Leakage Rate (SLR) below which it is known water cannot leak. An acknowledged leak tightness criterion below which water leakage can be assumed not to take place is $\boldsymbol{1 \times 10^{-5}\ Pa.m^3.s^{-1}}$ [4]
2. Confirm the M4/12 has been demonstrated to meet the leak tightness requirement
3. Specify a test procedure for both the M4/12 and UFC that will demonstrate the leak tightness requirement is met, with a 'single-error-proof' procedure supported by adequate personnel training to develop experience and appropriate oversight
4. Design a UFC physically compatible with the unmodified dimensions of the M4/12 lodgements and with the dimensions of the different contents
5. Design and develop a UFC to the level required to satisfy the definition of a high-integrity water barrier in both normal and accident conditions of transport

UFC DESIGN

The basis of the UFC design is a length of seamless 8-inch schedule 40S pipe of 316L stainless steel (UFC Body). A heavy machined closure system (UFC Base) is welded to the base end, and a short machined cylindrical extension (UFC Neck) welded to the top end. The UFC Neck is machined with features that allow handling operations and also the weld preparation required to mate with the UFC Lid.

The UFC has a removable threaded Internal Cap that is loaded following packing of the UFC. The UFC Lid incorporates a centrally located Quick Release Coupling (QRC) seal welded within the profile of a machined lifting pintle.

The UFCs contain 'Inner Furniture' when carrying the different contents. The furniture comprises aluminium extrusions or items of welded stainless steel construction to support the various containers of materials, fuel pins and uranium bar material.

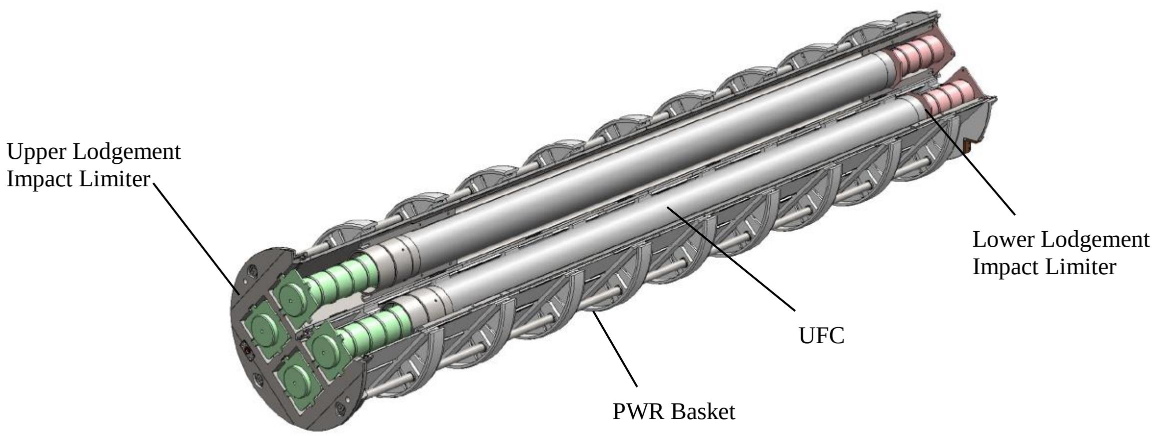
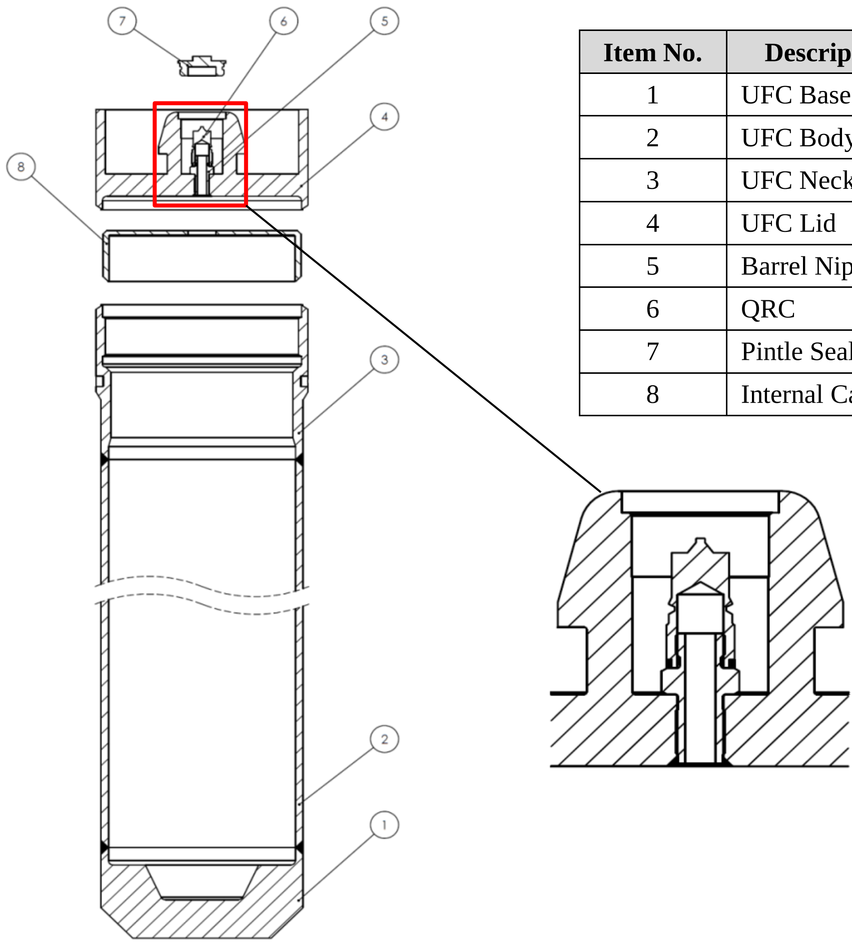


Figure 2 - UFC in M4/12 Basket

UFC MANUFACTURE

The manufacture of the UFC took into account the need to produce a high integrity containment vessel and was assured by:

- Use of seamless, hot drawn 316L stainless steel schedule 40S pipe for the body section – this material has the advantages of being ductile, not crack sensitive and an extensive history of successful weldability in a highly regulated industry.
- Application of full penetration circumferential welds for the UFC Base to UFC Body and the UFC Body to UFC Neck connections
- 100% radiography of the circumferential welds with a rigorous acceptance standard
- Helium leak testing of the completed UFC Body assembly and the UFC Lid assembly to the same acceptance criteria to that applied to the UFC prior to despatch from site
- Use of a supplier with a proven track record and appropriate qualifications / accreditations in the manufacture of similar products
- Application of Sellafield Ltd 'Quality Grade 01' with a Suitably Qualified Experienced Personnel (SQEP) Sellafield employee nominated as independent inspection authority



Item No.	Description
1	UFC Base
2	UFC Body
3	UFC Neck
4	UFC Lid
5	Barrel Nipple
6	QRC
7	Pintle Seal Plug
8	Internal Cap

Figure 3 - UFC Design / Manufacture

UFC CLOSURE WELD DEVELOPMENT

The UFCs were manufactured off site and delivered as a UFC Body assembly with Inner Furniture fitted and UFC Lid assembly. Following packing of the UFCs and installation of the Internal Cap the UFC Lid is fitted and two closure welds are applied. The first is a circumferential weld securing the UFC Lid to the UFC Body whilst the second is a sealing weld applied to the Pintle Seal Plug.

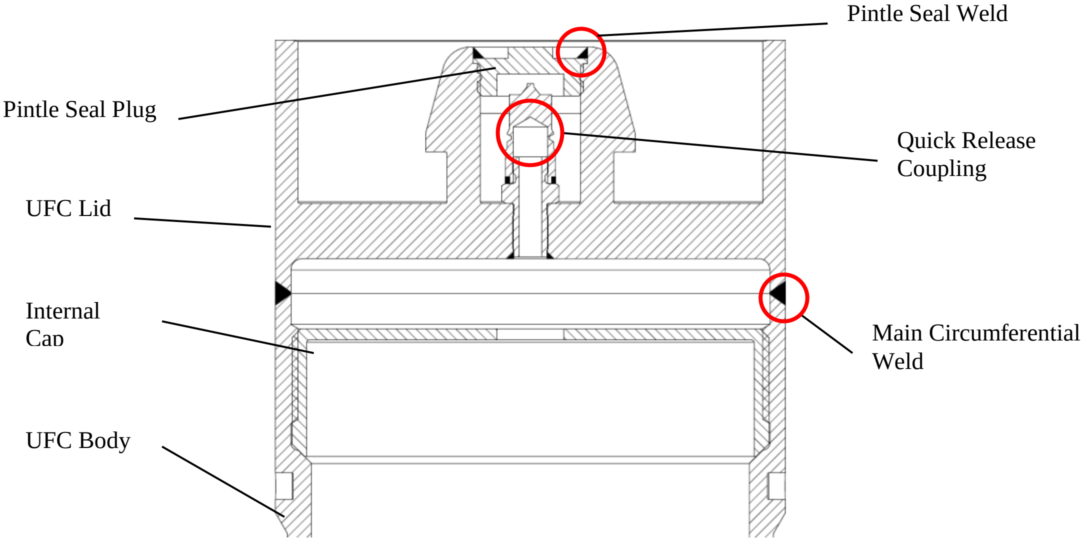


Figure 4 - UFC Closure Detail

Main Circumferential Weld

The Main Circumferential Weld (MCW) is a full penetration butt weld performed using a fully automated Tungsten Inert Gas with filler wire process. The internal volume of the UFC is purged through the QRC using Helium which is subsequently used for leak testing following completion of welding operations.

Pintle Seal Weld

The Pintle Seal Plug is a small threaded disk that is screwed into the UFC Lid lifting pintle following completion of the MCW and subsequent leak testing. The Pintle Seal Weld (PSW) is a 3mm manual fillet weld where the depth requirement has been defined by long term storage requirements.

Quick Release Coupling

A QRC is seal welded into the UFC Lid. The QRC provides a number of functions during UFC packing operations and during transport. The QRC includes a seal that has a maximum operating temperature of 204°C which, if exceeded, would compromise the QRC's ability to maintain leak tightness. Trials were performed that determined this maximum operating temperature is not reached during welding operations.

Weld Repeatability

It was agreed early on in the project that weld repeatability trials would be performed to build confidence in the process before it was deployed on site. Full scale Weld Test Qualification Units, which replicate the top end of the UFC, had both MCW and PSW completed before undergoing the testing requirements defined in Table 1. A total of 6 Qualification Units were completed and all tests were successful.

Table 1 - UFC Closure Weld Inspection Requirements

MCW	PSW
Visual	Visual
100% Digital Radiography	Pressure Rise Leak Test
Helium Leak Test	Dye Penetrant Test
Dye Penetrant Test	

LEAK TESTING

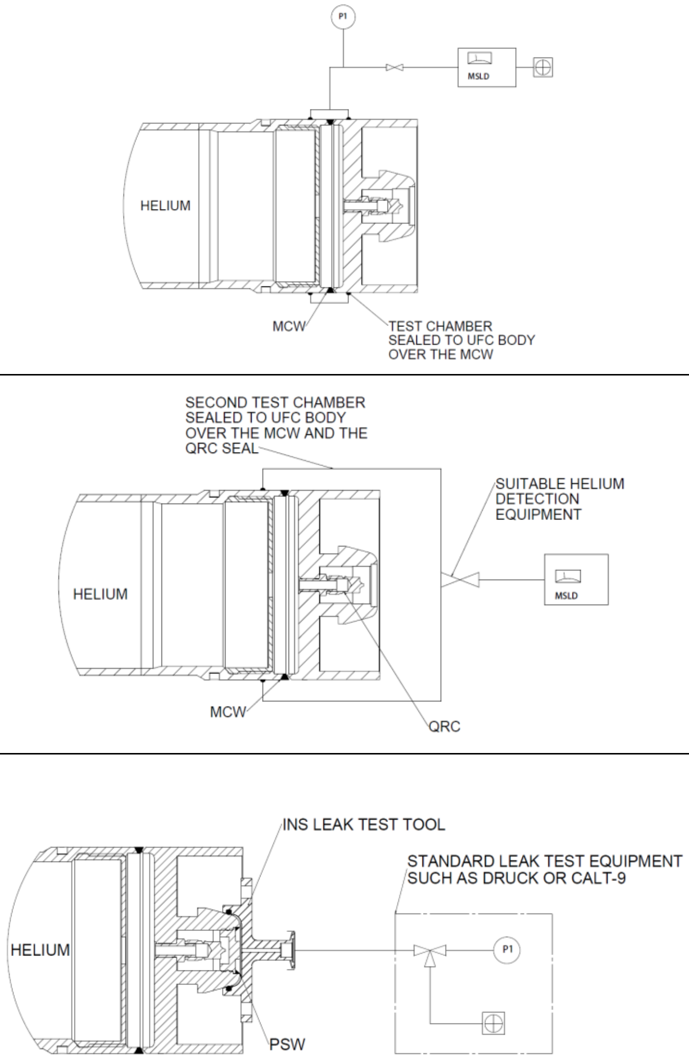
A key component of the strategy was to specify a test programme for both the M4/12 and the UFC that demonstrated the leak tightness requirement was met using a 'single-error-proof' procedure. The following testing processes ensured the UFC and the M4/12 were tested by two independent methods using suitable resource with appropriate oversight.

UFC

As shown in Figure 4 the MCW and the PSW represent two potential avenues for leakage following closure welding that must be tested. The QRC combines in series with the PSW to provide a containment boundary for transport.

Table 2 - UFC Leak Testing Procedure

Test 1:	Following UFC packing the Internal Cap is fitted and the MCW is completed using Helium as a purge gas. A test chamber is installed around the region of the MCW that is sealed off. The Helium gas inside the UFC is increased to a pressure above atmospheric whilst the test chamber is evacuated. A Mass Spectrometer Leak Detector (MSLD) is attached to the test chamber that will detect any Helium passing through a defect in the weld.
Test 2:	Following completion of test 1 a second test chamber is installed that encloses the top end of the UFC, capturing both the MCW and the QRC. A suitable, independent method to detect Helium leakage shall be employed. This test demonstrates the integrity of the QRC seal has not been compromised during welding operations and provides an independent second test of the MCW.
Test 3:	The Pintle Seal Plug is screwed in place and the PSW is completed. After a thorough cleaning a temporary leak test tool is clamped into place above the Pintle Seal Plug, seating with an O-ring seal on the tapered profile of the pintle. A small interspace volume is created above the PSW, this is evacuated and the leak rate is calculated using conventional pressure change techniques.



TEST 1

Primary test on MCW

Success Criteria:
SLR ≤ 1 x 10^{-6} Pa.m^3.s^{-1}

TEST 2

Test on QRC Seal
Secondary test on MCW

Success Criteria:
SLR ≤ 1 x 10^{-6} Pa.m^3.s^{-1}

TEST 3

Test on Pintle Seal Plug Weld

Success Criteria:
SLR ≤ 5 x 10^{-6} Pa.m^3.s^{-1}

Figure 5 - Pre-despatch UFC Leak Testing Strategy

M4/12

During the original development of the M4/12 Package it was demonstrated that the Package Lid seals were capable of achieving a level of leak-tightness that effectively precluded the need to consider a leakage of water into the Package. As such, there was a high confidence that operational leak testing would not challenge the current working practice. However the 'single-error-proof' philosophy used for the UFC needed to be adopted for the M4/12 Package as it forms the outer part of the MWB system.

Table 3 - M4/12 Leak Testing Procedure

Test 1:	Initial Pressure Drop test using CALT-9 equipment and a nominal 2 bar absolute test pressure is carried out on the lid seal interspace and the cavity plug interspace.
Test 2:	A second Pressure Drop test is performed on the two test points using DRUCK equipment and a nominal 7 bar absolute test pressure.

PHYSICAL TESTING

The M4/12 Package was subject to a full scale physical testing programme in support of its original licence. A new M4/12 FEA model was produced by INS that was validated by comparing analytical predictions with physical test results.

Lodgement Furniture Validation

Additional Lodgement Furniture was designed to confine the UFC during transport (see Figure 2). The Lodgement Furniture has integrated Upper and Lower Impact Limiters designed to absorb energy in an impact scenario. A physical test was performed to demonstrate Impact Limiter performance by comparing FEA results with experimental data.

Figure 6 - Impact Limiter Validation Test

The test involved attaching an Impact Limiter to the underside of a 700kg mass (maximum mass of a laden UFC) and dropping it from 9m. The results showed excellent agreement:

Upper Lodgement Impact Limiters – FEA predicted stroke efficiency = 45.2%

– Actual mean stroke efficiency = 45.4%

Lower Lodgement Impact Limiters – FEA predicted stroke efficiency = 61.3%

– Actual mean stroke efficiency = 59.1%

Figure 7 - Actual vs Predicted

UFC Validation

INS required assurance that following ACT the UFC will remain leak tight. A test was designed that administered a known load to a critical area of a UFC Test Piece that exceeded the worst case predicted level of plastic strain from the FEA assessment of the UFC inside the M4/12.

The purpose of the test was to:

- Demonstrate that following the known load the UFC remains leak tight
- Validate the UFC FEA model by comparing predicted deformation with actuals

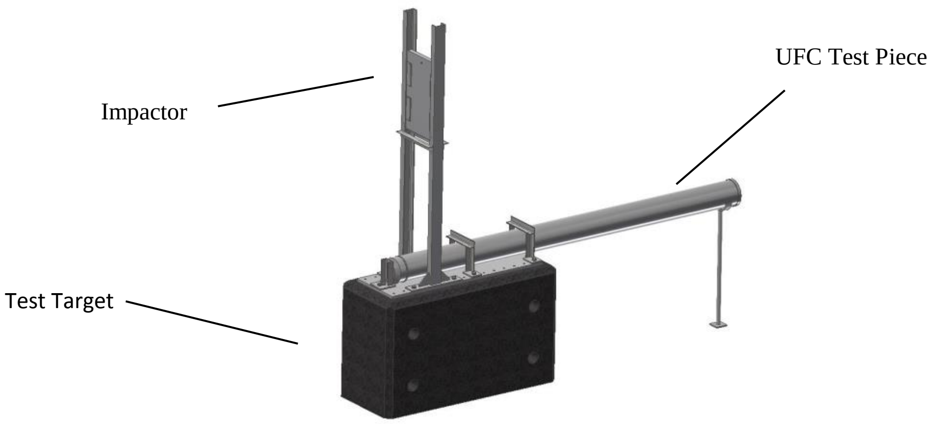


Figure 8- UFC Physical Test Rig Assembly

A total of 5 tests were performed. The test pieces were leak tested pre- and post-test and each unit achieved the required success criteria ($1x10^{-6}$ $Pa.m^3.s^{-1}$).

The FEA predicted an 8.1mm dent be created from the impactor striking the UFC Test Piece. The average dent created in the actual tests was 6.5mm giving a reasonable agreement.

CONCLUSIONS

A comprehensive weld development program was followed that resulted in qualified welding procedures for the MCW and the PSW.

A leak testing strategy for both the UFC and the M4/12 was developed and accepted by the Office for Nuclear Regulation as adhering to IAEA requirements.

The UFC was demonstrated to maintain leak tightness inside the M4/12 following ACT by validated FEA and supported by a number of physical tests.

REFERENCES

[1] V. Bhatti, *Licensing U.K's First Multiple Water Barrier Package*, INS, 2019.

[2] M. Nuttall, *Criticality Considerations Relating to the UKs First Licensed MWB Package (M4/12.UFC Mk III)*, INS, 2019.

[3] *Regulations for the Safe Transport of Radioactive Material - No.SSR-6*, IAEA, 2012 Edition.

[4] T Miyazawa et.al. , *Study on Water Leak-Tightness of Small Leaks*, 2002.