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ABSTRACT

DOE manages over 300 types of spent nuclear fuel (SNF), many of which are located at the Idaho National Laboratory (INL) site. Managing this large variety of SNF for storage, transportation, and disposal poses a challenge to DOE. The Idaho Cleanup Project and INL are collaborating on the DOE SNF Road-Ready Demonstration ("Road-Ready Demonstration"), which will develop and demonstrate the designs, technology, processes, and regulatory framework for packaging DOE-managed SNF for "road-ready dry storage." Road-ready dry storage is an SNF management concept in which SNF is packaged into dry, sealed canisters that are then placed in onsite storage in anticipation of later transport and disposition. The forward-looking goal of the Road-Ready Demonstration is to establish the foundation for a large-scale road-ready dry storage program at the INL site.

In support of establishing a large-scale road-ready dry storage program at the INL site, the Road-Ready Demonstration will first package Fort St. Vrain SNF currently in dry storage at INL into several DOE Standard Canisters (DOESCs). These DOESCs will in turn be loaded into another containment similar to commercial multi-purpose canisters. This multi-purpose canister will then be compatible with a transportation or storage system, such as a storage cask for interim storage or transportation package for offsite transport. These DOESCs will remain sealed over the course of their storage, transportation, and applicable disposal functions. The closure process for the DOESC will include fuel and basket loading, welding, inspection, leak testing, and, if needed, repair. As a follow-up to previous discussions on the design of the DOE Closure Leak Test Assembly (LTA), this report describes recent fabrication and testing efforts performed at INL.

DOESCs are sealed by two sequential gas tungsten arc welds, both of which are performed by remotely operated and semiautomatic welding systems. The first weld is a circumferential pipe weld that completes the assembly of the canister body and lid assembly. The second and final closure weld attaches the vent plug to the vent socket via a butt joint. After the second weld is performed, the welds are helium leak tested using an evacuated envelope technique. The LTA was designed for both remote and manual operation. This report describes the fabrication and performance testing associated with the evacuated envelope technique.

INL staff designed, fabricated, and tested the LTA at INL facilities. This testing included establishing technique and system sensitivities in accordance with ASME and American National Standards Institute N14.5 requirements. Forthcoming work will cover such areas as design optimization, process and personnel qualification, and implementation in Road-Ready Demonstration operations.

INTRODUCTION

The U.S. Department of Energy (DOE) manages over 300 types of spent nuclear fuel (SNF), many of which are located at the Idaho National Laboratory (INL) site outside Idaho Falls, Idaho. One management concept is to package the DOE-managed SNF at the INL site into dry, sealed canisters, which are then placed in onsite storage for later removal [1]. The canisters and associated packaging are designed to facilitate SNF removal from the intermediate SNF storage facility and allow long-term dry storage before shipment to alternative storage or eventual disposal when an appropriate facility becomes available. This management concept is known as “road-ready dry storage” (RRDS).

In support of establishing a large-scale RRDS program at the INL site, the DOE SNF Road-Ready Demonstration (formerly known as “DOE SNF Packaging Demonstration”, referred to as “Road-Ready Demonstration” hereafter) will demonstrate the capability to implement RRDS by packaging DOE-managed SNF into DOE Standard Canisters (DOESCs), packing the DOESCs into over-canisters, placing the over-canisters into storage overpacks, and placing the storage overpack on a cask pad. Additional detail regarding the Road-Ready Demonstration may be found elsewhere [2, 3]. This paper will focus on the fabrication and testing progress of the DOESC Closure Leak Test Assembly (LTA) since previously reported [4].

BACKGROUND

The DOESC was originally designed under the National Spent Nuclear Fuel Program and Office of Environmental Management as a sealed containment for the wide variety of DOE-managed SNF [5, 6] (Figure 1). The DOESC design was included in the license applications for the Idaho Spent Fuel Facility and Yucca Mountain geological repository, which were not realized as operational facilities [1, 7]. The Road-Ready Demonstration is the most recent effort to use the DOESCs [2, 3, 8, 9].

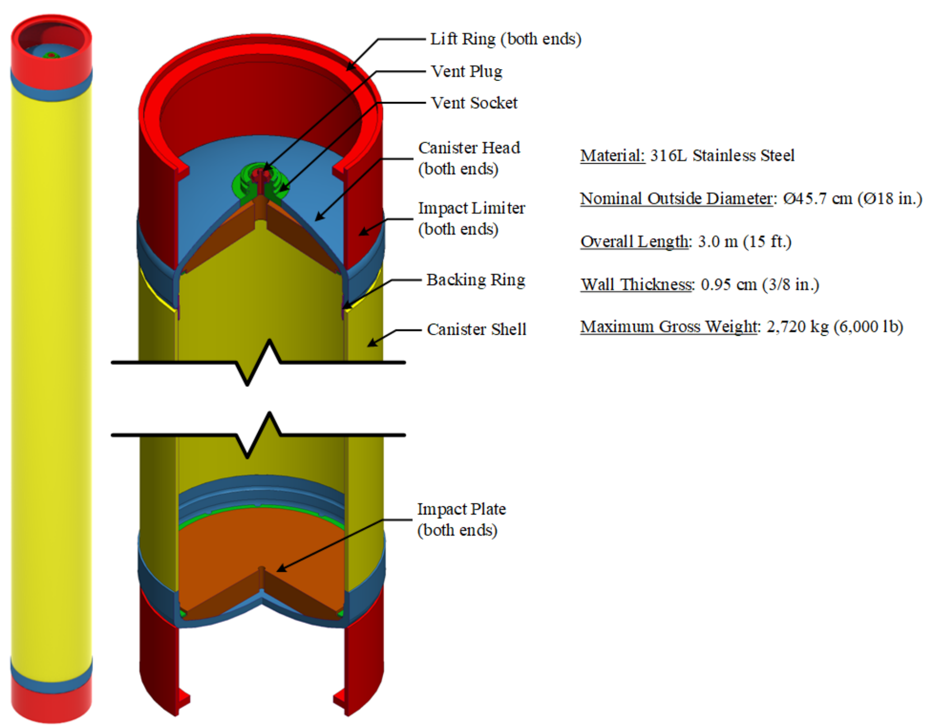

Figure 1: DOESC (Ø45.7 cm × 4.6 m variation).

Within the Road-Ready Demonstration, DOESC closure activities range from SNF loading to leak testing of the DOESC seal (Figure 2). Except for SNF loading, closure activities will be executed predominately manually (i.e., by hand). Some equipment may be operated remotely (e.g., welding, inspection, leak testing). DOESC closure will occur in the Irradiated Fuel Storage Facility at the Idaho Nuclear Technology and Engineering Center. The DOESC has two closure welds: one circumferential ("pipe") weld that joins the main shell to the torispherical head and another vent port weld that joins the threaded vent plug to the vent socket (Figure 1). Once welding and inspection are completed, The LTA is placed on the top of the DOESC to locally isolate the closure welds for leak testing.

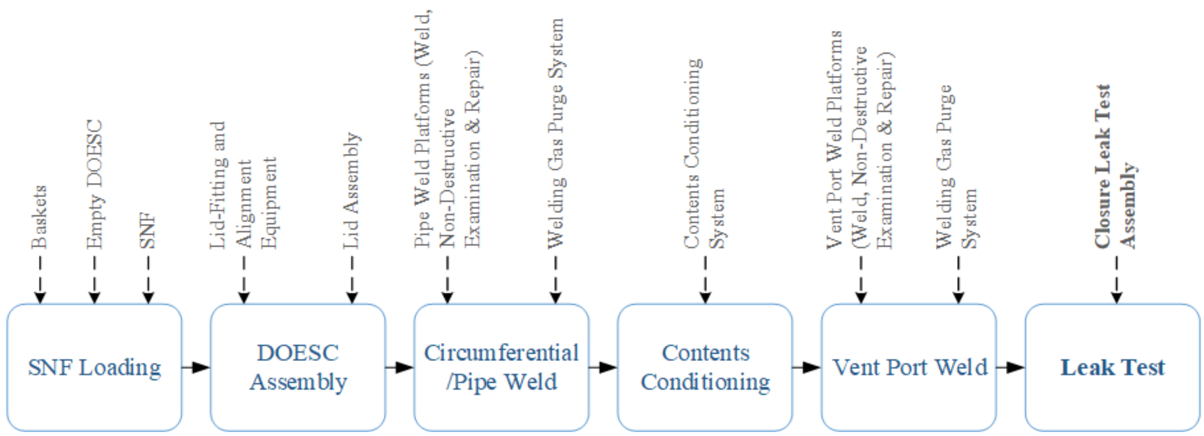

Figure 2: DOESC Nominal Closure Process Flowchart adapted from [4] (bolded text indicates equipment discussed in this paper).

DOESC Closure Welds

The circumferential weld geometry resembles a butt joint between the canister head and shell with a u-groove (Figure 3). The canister shell is a Schedule 40S Ø45.7 cm (Ø18 inch) 316L stainless steel pipe with a nominal 9.5 mm (.375") thickness, which will require some restraining hardware to correct its ovality for fit-up with the canister head during closure. The torispherical canister head is machined to match the shell's diameter. The 1.5 mm faying surfaces are aligned during the lid assembly placement using a series of funnels that allow a running fit of the lid assembly. The welding technique is a gas tungsten arc weld in the vertical position, performed with 5–7 weld passes.

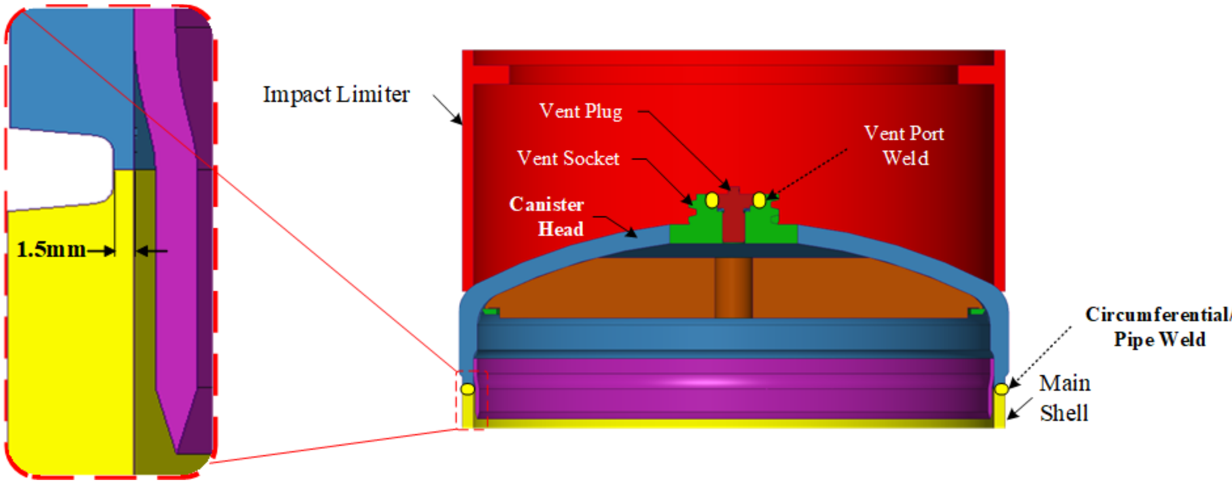

Figure 3: DOESC closure welds.

The DOESC vent port consists of a vent socket welded into the top canister head and a vent plug that is installed after canister conditioning (Figure 3). When fully torqued, the plug and socket form a u-groove butt joint similar to the circumferential weld.

LTA

Leak testing is a common method to demonstrate the required containment and confinement of SNF containers within transportation packages and storage casks, respectively [10-13]. Separate from *pressure* testing (i.e., hydrostatic and pneumatic pressure tests), *leak* testing relies on a tracer gas (usually helium) to determine whether potential leak paths (e.g., welds) exceed an allowable leakage rate. Helium leak testing is used because of helium's inert properties, relatively low background concentration, and high diffusion through small leaks. There are several helium leak test techniques available based on the system to be tested, allowable leakage rate, and other factors [14].

Evacuated Envelope Technique

The Evacuated Envelope leak test technique was originally selected for the DOESC closure leak test. This technique is well-suited for leak tests using test items sealed with a tracer gas and requiring high sensitivity. Both factors are applicable because the DOESC will be a sealed container and the acceptance criteria for the DOESC closure welds is 1E-07 std-cc/sec. Further details regarding the acceptance criteria and other techniques are described elsewhere [4]. When applying the Evacuated Envelope Technique, the evacuated envelope usually contains the entire test item. Due to the DOESC's large size, an evacuated envelope could also take a prohibitively long time to draw a sufficient vacuum for testing. It is not required to contain the entire test item (i.e., DOESC) if the potential leak pathways can be adequately isolated from the atmosphere's background concentrations of helium. The ASME Boiler and Pressure Vessel (B&PV) Code recommends locally testing these welds instead of the entire test volume [15]. The LTA employs an open-ended enclosure that sits on the top of the DOESC and seals on the outside diameter of the canister's shell to isolate the closure welds for leak testing (Figure 4).

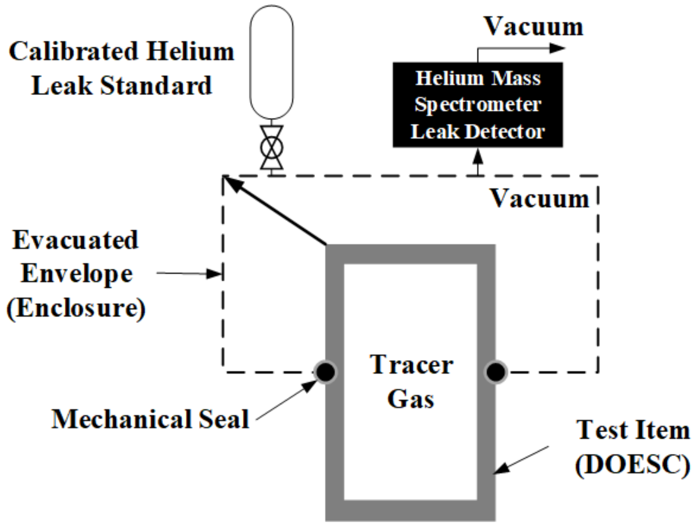

Figure 4: Evacuated Envelope Leak Testing Technique Adapted for DOESC closure (figure adapted from American National Standards Institute N14.5 [14]).

The overall process for performing this leak test is based on the Helium-Filled Container (Cup Test) specified in the ASME B&PV Code [15]. The test begins with opening the calibrated helium leak standard and placing the enclosure on top of the DOESC (Figure 5).

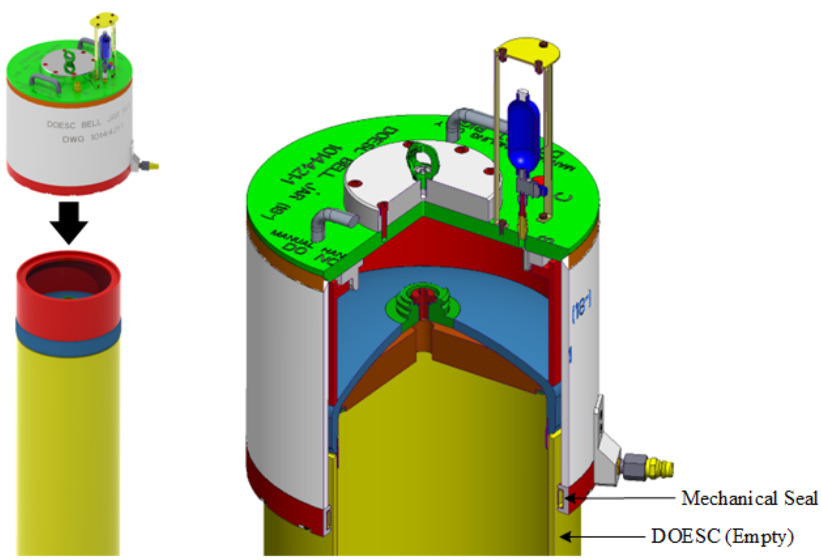

Figure 5: LTA installed on top of empty DOESC.

After making the mechanical seal with the DOESC, the volume within the enclosure is pumped down to a vacuum. This initial signal measured by the helium mass spectrometer leak detector (MSLD) is the stable leakage rate R_1. The calibrated leak is then closed, and the next stable signal observed by the MSLD is recorded as R_2. The calibrated leak is then reopened, and the resultant stable MSLD signal is recorded as

R_3. The R_1 and R_3 values include helium from the natural background, apparent leakage from the test item, and leakage from the calibrated leak. R_2 only includes helium from natural background and apparent leakage from the test item. If R_2 > 1E-07 std-cc/sec, the DOESC closure welds are considered beyond the acceptance criteria and would fail.

LTA Mechanical Design Modifications

The LTA design has been modified since last reported [4]. The enclosure weldment (i.e., Pipe and Head) was constructed with 6061-T6 aluminum, which has been changed to 316L stainless steel due to supply chain disruptions. This increased the LTA weight to approximately 136 kg (300 lb). The larger lifting bale was replaced with a commercial lifting point given a change in location of DOESC closure. However, manual operation has not affected the leak testing techniques considered for DOESC closure. A 6061-T6 Bearing Plate is bolted to the underside of the head to interface with the DOESC's Lifting Ring (Fig. 6). Further details on the LTA are reported elsewhere [4].

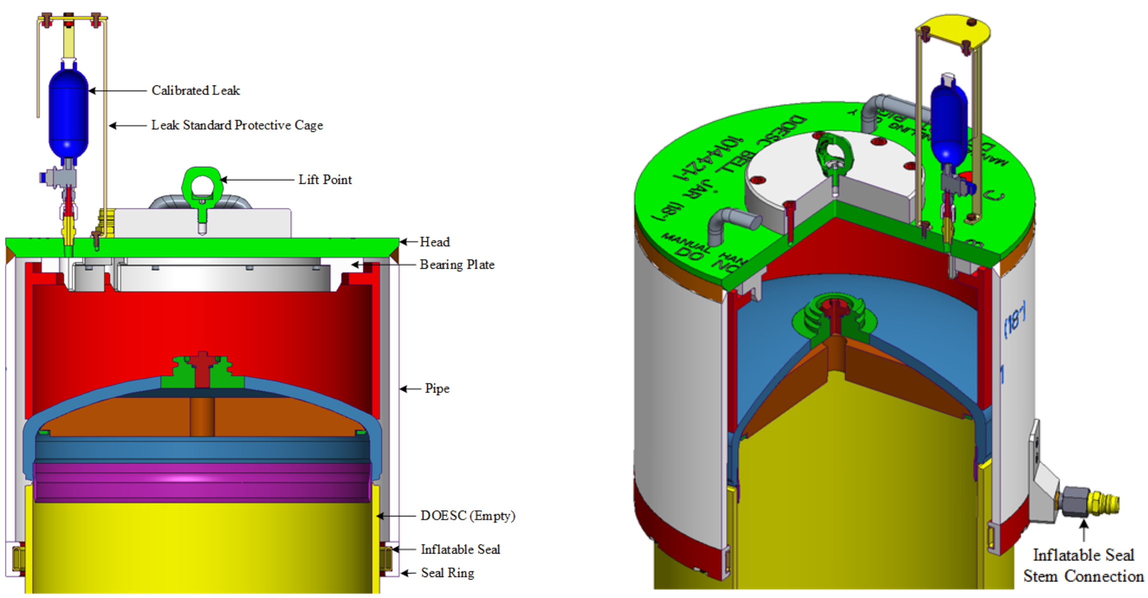

Fig. 6: LTA

INFLATABLE SEAL TESTING

Static mechanical seals were originally considered, but scale testing could not demonstrate an ability to hold an adequate vacuum required for an MSLD [4]. Ethylene Propylene Diene Monomer (EPDM) rubber inflatable seals were selected and tested at INL using a full-scale prototype in a laboratory setting. The prototype was fabricated at INL (Figure 7).

Figure 7: Full-scale LTA prototype during fabrication testing.

The LTA was leak tested in two phases: first during fabrication of the enclosure without the inflatable seal and then in the laboratory setting with the inflatable seal.

Enclosure Leak Test

The first leak test was performed using a standard hood technique of the entire enclosure, except for the inflatable seal. This involved bagging the enclosure and filling that bag with helium while vacuum pumping the volume within the enclosure. This technique was selected because it would simulate air flow in the same direction as would occur in operation during DOESC closure. This first test omitted the inflatable seal because several kinds of inflatable seals were going to be tested, and it was more practical to qualify the leak tightness of the overall LTA before different inflatable seals were interchanged with the LTA. This first leak test included the pipe threads on the enclosure Head, circumferential weld, and gasket-maker seal between the seal ring and bottom of the enclosure Pipe. The bottom surface of the seal ring was sealed with a vacuum compound during the test (Figure 8). The acceptance criteria for the hood test were no helium leaks larger than 1E-04 std-cc/sec and a ≤50 mTorr vacuum.

This acceptance criteria may appear to be at odds with the 1E-07std-cc/sec acceptance criteria for the DOESC closure welds. However, the larger 1E-04 std-cc/sec leak rate on the LTA is limiting the amount of *background* helium from the closure area entering the LTA enclosure during the test. Helium background is nominally 5 ppm [16]. If the MSLD signal observed from the LTA enclosure is less than the 1E-07 std-cc/sec acceptance criteria, then the LTA is adequately leaktight. Using the guidance of ANSI N14.5 [14]:

(Eq. 1)

Where L_m is the measured leak signal in the LTA, L is the volumetric leak rate of the LTA's mechanical seal, P_t is the LTA's partial pressure of tracer gas outside the LTA (i.e., 5 ppm is equivalent to 1E-06 atmospheric pressure), and P_m is the total pressure of the tracer gas outside the LTA. Based on this approach, a 1E-04 std-cc/sec volumetric leak rate is proportional to a 5E-10 std-cc/sec MSLD signal – far smaller than our DOESC acceptance criteria. Therefore, assigning a 1E-07 std-cc/sec maximum leak rate for the mechanical seal would be unnecessary. The 1E-04 std-cc/sec leak rate is equivalent to "water tight" and is therefore an achievable leak rate while keeping background helium low during closure. The 50 mTorr vacuum was defined based on previous mechanical seal testing that showed how sensitive MSLDs are to a low (i.e., >1 Torr) vacuum [4]. The enclosure passed both acceptance criteria during the first leak test.

Figure 8: LTA Prototype prepared for first leak test with vacuum compound on bottom surface (top-left); Bearing plate bolted to inside surface of top plate (bottom-left); Rigging the LTA for testing (right).

Inflatable Seal Leak Test

The inflatable seal was tested during the second leak test with another hood technique and identical acceptance criteria as the first test. A large aluminum test plug simulated the DOESC shell sealing surface during this leak test (Figure 9). The first inflatable seal was a circular tube cross section totally constructed of EPDM (i.e., not fiber-reinforced) that required a 25–30 psia inflation pressure.

With an adequate vacuum pump, the inflatable seal achieved a 50 mTorr vacuum in less than 15 minutes. While the inflatable seal was able to achieve and hold a 50 mTorr vacuum, it was unable to pass the 1E-04 std-cc/sec leak rate with the same outside-in hood technique. Leakage appeared to be predominately coming from the hole in the seal ring where the stem penetrates (Figure 9) and the seam where the inflatable seal is joined together.

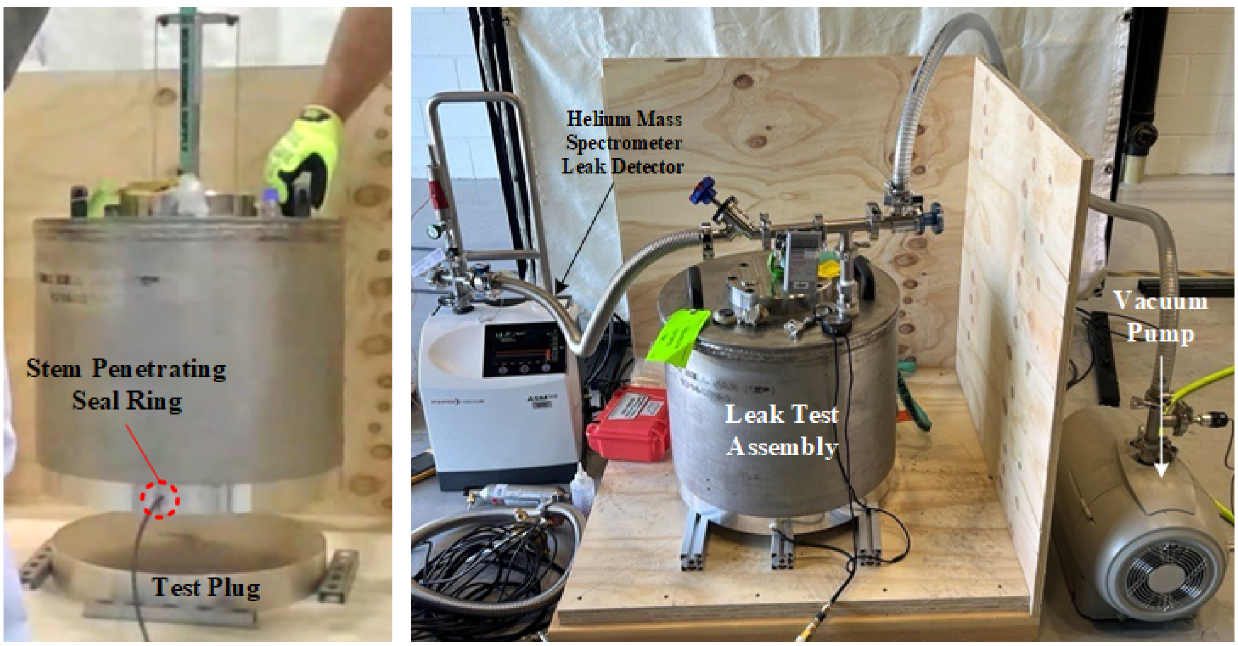

Figure 9: Second inflatable seal leak test.

Following the failure of the inflatable seal's leak test against the 1E-04 std-cc/sec acceptance criteria, the enclosure was tested for its background helium signal during operation while under vacuum and its response and cleanup times using the guidance of Section V of the ASME B&PV Code [15]. As previously mentioned, there is a calibrated helium leak standard attached directly to the enclosure that permeates helium at a fixed rate of 2.4E-08 std-cc/sec. This calibrated leak is normally used during operation to establish the system sensitivity against the acceptance criteria (i.e., 1E-07 std-cc/sec for the DOESC closure welds). During a hood test, the response time is the time it takes for the MSLD to register a signal after opening the calibrated leak. The cleanup time is the time it takes for the MSLD to register a steady signal after the calibrated leak is closed.

After pumping the enclosure down to 40 mTorr and with the calibrated leak closed, there was a background helium signal of 1.1E-07 std-cc/sec. The calibrated leak was then opened, and there was helium signal of 1.4E-07 std-cc/sec after 3 minutes. The calibrated leak was then closed, and the background signal of 1.1E-07 std-cc/sec was again achieved after 4 minutes and 30 seconds.

DISCUSSION AND PATH FORWARD

The failure of the inflatable seal against the 1E-04 std-cc/sec acceptance criteria should be considered against its function during operation. The enclosure must provide a vacuum environment necessary for the MSLD to enter its testing mode and prevent the in-leakage of background helium from the operating area into the enclosure. As noted previously, the enclosure could achieve a vacuum <50 mTorr, which allows the MSLD to obtain a steady signal. Preventing the in-leakage of significant background helium is important. If a helium signal (i.e., R_2) larger than the acceptance criteria (≥1E-07 std-cc/sec) is observed from the natural background, it would be impossible to separate the natural background from a leaking DOESC.

Therefore, the background signal of 1.1E-07 std-cc/sec is inadequate because, at that level, the MSLD is unable to distinguish test item leakage from the natural background. The background signal must be ≤1E-07 std-cc/sec. While the inflatable seal is superior to the static seals previously tested, additional testing is required to identify a reliable mechanical enclosure seal. In addition, the effects of factors on seal performance need to be tested. Such factors include the ovality of DOESC shell and head and length of vacuum tube on cleanup times.

This excessive leakage could be due to the total EPDM construction, which limits the pressure the inflatable seal can be inflated with. Additional inflatable seals with fiber reinforcement will be tested, which have a higher inflation pressure (up to 45 psi). Increasing the inflation pressure would constrict leakage pathways. In addition, other inflatable seals designed for higher pressure differentials will be tested. Additional mechanical sealing concepts may be considered if inflatable seals are shown through testing to be incapable of providing the required vacuum and helium background.

CONCLUSIONS

Under the Road-Ready Demonstration, DOESCs will be loaded with SNF and sealed for RRDS. These DOESCs will remain sealed over the course of their storage, transportation, and applicable disposal functions. The LTA performs the critical function of verifying the leak tightness of each DOESC's containment boundary after SNF closure. The LTA mechanical design has been modified based on scope changes within the Road-Ready Demonstration. The mechanical sealing mechanism of the LTA has been tested to achieve the required vacuum and background helium concentration using inflatable seals. While these inflatable seals are superior to previously considered static seals, testing to date has still shown an inability to prevent in-leakage of natural background helium into the enclosure. A background of 1.1E-07 std-cc/sec within the enclosure was observed during hood leak tests of the inflatable seal, which exceeds the 1E-07 std-cc/sec "leaktight" acceptance criteria. Additional testing of more robust inflatable seals will be performed, and other factors that affect performance will be investigated (e.g., vacuum tube length). All this testing will inform the final design of the LTA that will be critical to Road-Ready Demonstration success.

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