Used Nuclear Fuel Dry Storage Cask Materials Monitoring System: A Proof of Concept to Deploy and Retrieve Monitoring Equipment – 15504

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ABSTRACT

The cask materials monitoring system is a proof-of-concept to deploy and retrieve monitoring equipment. The system is an airlock-type system that is bolted to the cask fill/drain port. It consists of the following major components: (1) a monitoring module that contains the equipment for monitoring the cask environment, (2) a sliding shield plug that provides radiation shielding throughout the deployment and retrieval of the monitoring equipment module, (3) a primary seal flange that is permanently installed on the cask that provides cask boundary confinement, and (4) a containment tube that provides the airlock function providing cask confinement when the primary seal is broken.

In this proof-of-concept development, corrosion coupons were selected as the monitoring equipment for deployment into a spent nuclear fuel cask. However, the system has the potential for a variety of uses. The integration of a camera deployment system into the cask materials monitoring system will permit inspection of used nuclear fuel while maintaining cask atmosphere.

INTRODUCTION

Objective and Scope

In the “Gap Analysis to Support the Extended Storage of Nuclear Fuel,” Rev. 0 (PNNL-20509, 2012), several technology needs were identified to close the technology gaps to allow extended storage in existing transportation and storage casks. The cask materials monitoring system addresses three of the gaps identified; (1) develop systems for early detection of confinement boundary degradation, monitor cask environmental changes, and transmit data without compromising cask or canister boundary; (2) measure temperatures within the cask; and (3) develop systems for early detection of corrosion.

Cask Selection

Of the current casks located at the Idaho Nuclear Technology and Engineering Center (INTEC) at the U.S. Department of Energy’s Idaho Site, the CASTOR V/21 cask was chosen as the test cask for the project due to previous inspection data and the various materials of construction.

In the mid-1980s, the DOE procured three prototype dry storage casks for testing at the Idaho Site: MC-10 TN-24P, and CASTOR V/21. The primary purpose of the test was to benchmark thermal and radiological codes and to determine the thermal and radiological characteristics of the three casks. The CASTOR V/21 cask is loaded with irradiated assemblies from the Surry Nuclear Power Plant.

In 1999, a project was jointly funded by NRC-Office of Nuclear Regulatory Research (RES), Electric Power Research Institute (EPRI), DOE-Office of Civilian Radioactive Waste Management (RW), and DOE-Office of Environmental Management (EM) to examine the Surry spent fuel in dry storage at the Idaho Site. The project consisted of a detailed examination of the CASTOR V/21 cask and provided confirmatory data used for license applications for continuing dry storage beyond the original 20 years.

CASTOR V/21 Cask Description

The CASTOR V/21 cask is a one piece cylindrical structure composed of ductile cast iron in nodular graphite form. The overall external dimensions of the cask are 4.89 m (16 ft) high and 2.4 m (8 ft) in diameter (see figure 1). The external surface has 73 heat transfer fins that run circumferentially around the cask and is coated with epoxy paint for corrosion protection and ease of decontamination. The diameter of the inner cavity is 1.53 m (5 ft) and the overall inner cavity length is 4.15 m (13 ft - 7 in). The inner cavity surfaces, including sealing surfaces, have a galvanic-applied nickel plating (INEEL/EXT-01000183, 2001).

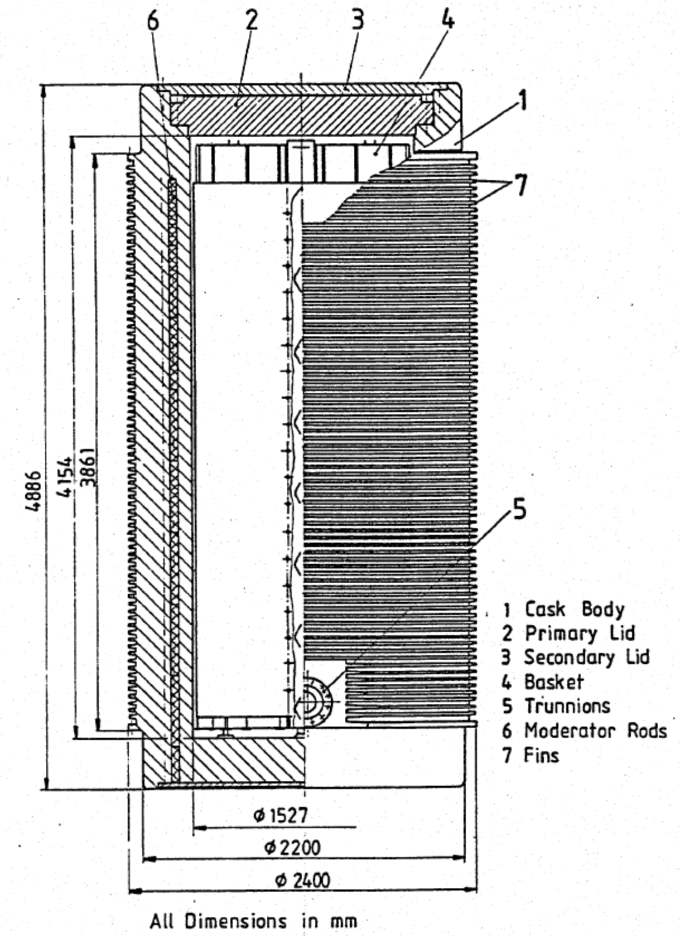


Fig 1. CASTOR V/21 cask (GNSI, 1985)

The spent fuel basket is a cylindrical structure of welded stainless steel plate and borated stainless steel plate (see figure 2). The basket comprises an array of 21 square fuel tubes/channels that provide structural support and positive positioning of the fuel assemblies. The basket overall height is 4.11 m (13.5 ft) including the four 125mm (5-in) diameter pedestals that support the basket and fuel weight on the bottom of the cask cavity. The basket outside diameter of 1.53 m (5 ft) fits tightly in the cask cavity. A spacing of approximately 55mm (2.3-inches) is present between the top of the fuel assemblies and the underside of the primary lid (INEEL/EXT-01000183, 2001).

A pipe with an inner diameter of 40 mm (1.6-inches) and a lead-in funnel at the top are welded to the side of a fuel tube near the outer circumference of the basket. The pipe location corresponds to a penetration in the primary lid and low side of the slope in the cask cavity bottom. The pipe provides a path for a flanged pipe used to fill and drain the cask (INEEL/EXT-01000183, 2001).

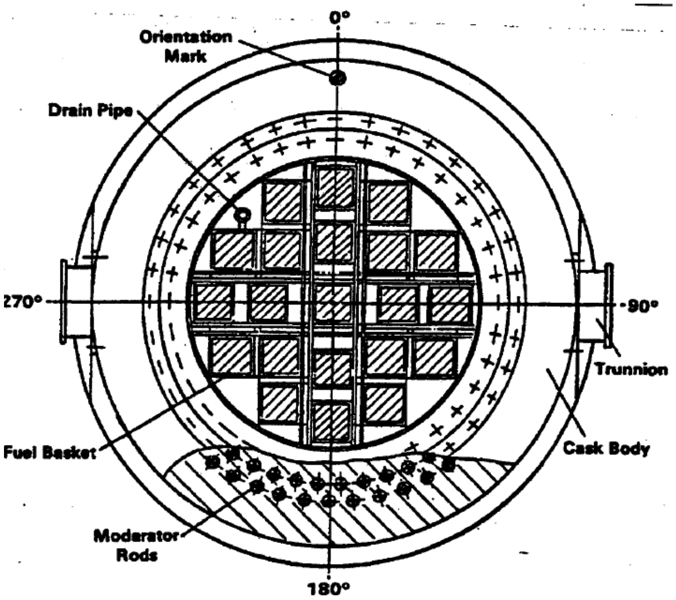


Fig 2. CASTOR V/21 Cask Cross Section (INEEL/EXT-01000183, 2001).

The CASTOR V/21 cask has a stainless steel primary lid that is approximately 1.8m (6 ft) in diameter and 0.29 m (1ft) thick. A secondary lid, used in commercial application, is not used on the cask located at the INL because of interference with thermocouple lances, pressure monitoring, and gas sampling activities (INEEL/EXT-01000183, 2001)

Three penetrations through the primary lid are provided for various cask operations. A 35 mm (1.37-inch) straight-through penetration is used for water fill/drain operation and is located near the perimeter of the lid. This penetration is normally sealed with two flanges; the inner equipped with a shield plug extending the thickness of the primary lid and sealed with an elastomer O-ring. The outer flange is equipped with a metal “C” shaped O-ring. This fill/drain penetration will be used for the the cask materials monitoring system deployment. The other two penetrations, spaced next to each other and covered by a single flange, are also located near the lid perimeter, but 180 degrees from the fill/drain penetration. The through lid penetration at this location is equipped with a quick-disconnect fitting used for pressure monitoring, vacuum drying, and backfilling with gas (INEEL/EXT-01000183, 2001).

The primary lid on the CASTOR V/21 cask located at the INL is not a standard lid and has 10 additional penetrations for thermocouple lances (see figure 3).

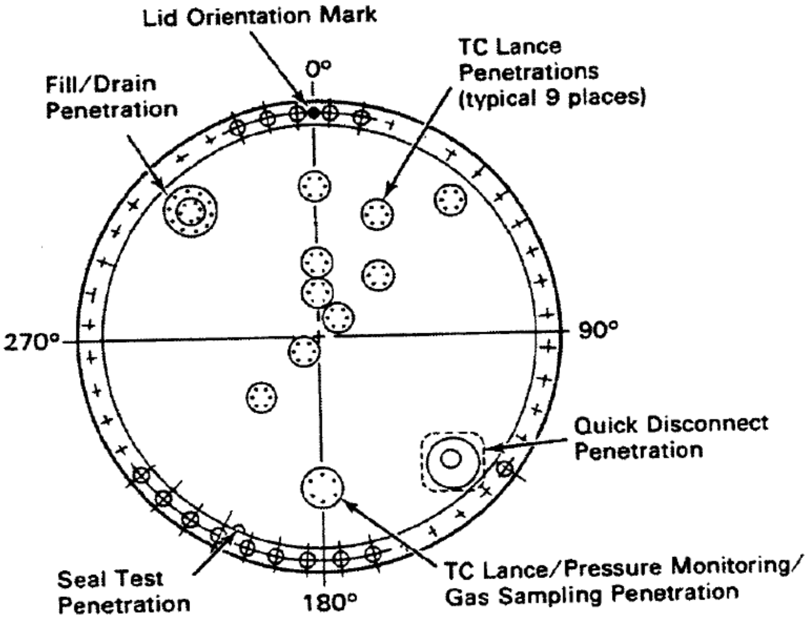


Fig 3. CASTOR V/21 Primary Lid (INEEL/EXT-01000183, 2001)

DESIGN

The cask corrosion monitoring system consists of the major components as discussed below and as shown on figure 4:

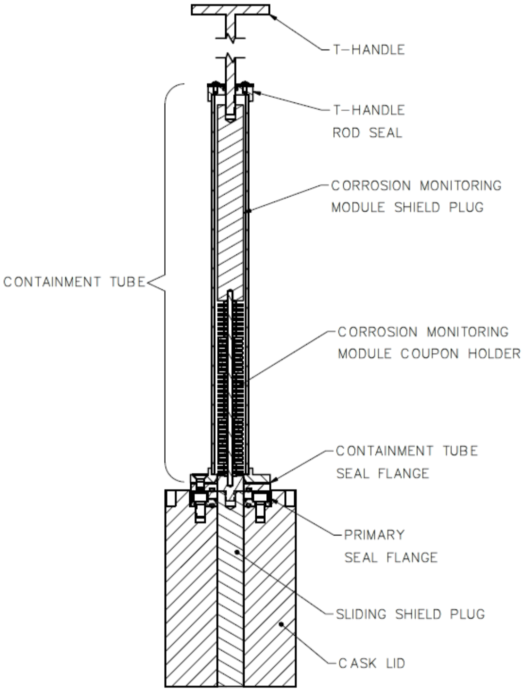


Fig 4. Cask Materials Monitoring System

The sliding shield plug provides shielding when the cask materials monitoring system is not deployed. It also can be attached to the monitoring system and moved out of place when the system is being deployed. The monitoring system has an upper seal flange that replaces the shield plug through the port when the monitoring system is deployed.

The primary seal flange is bolted onto the cask lid and serves multiple functions. When the system is in its deployed position for long term storage the seal flange maintains cask confinement and holds the shield plug in place. When the system is being retrieved the seal and clamp around the shield plug is released allowing the system to slide. At this time the cask confinement is not entirely contained by the seal flange, but the containment tube will be deployed to maintain complete confinement.

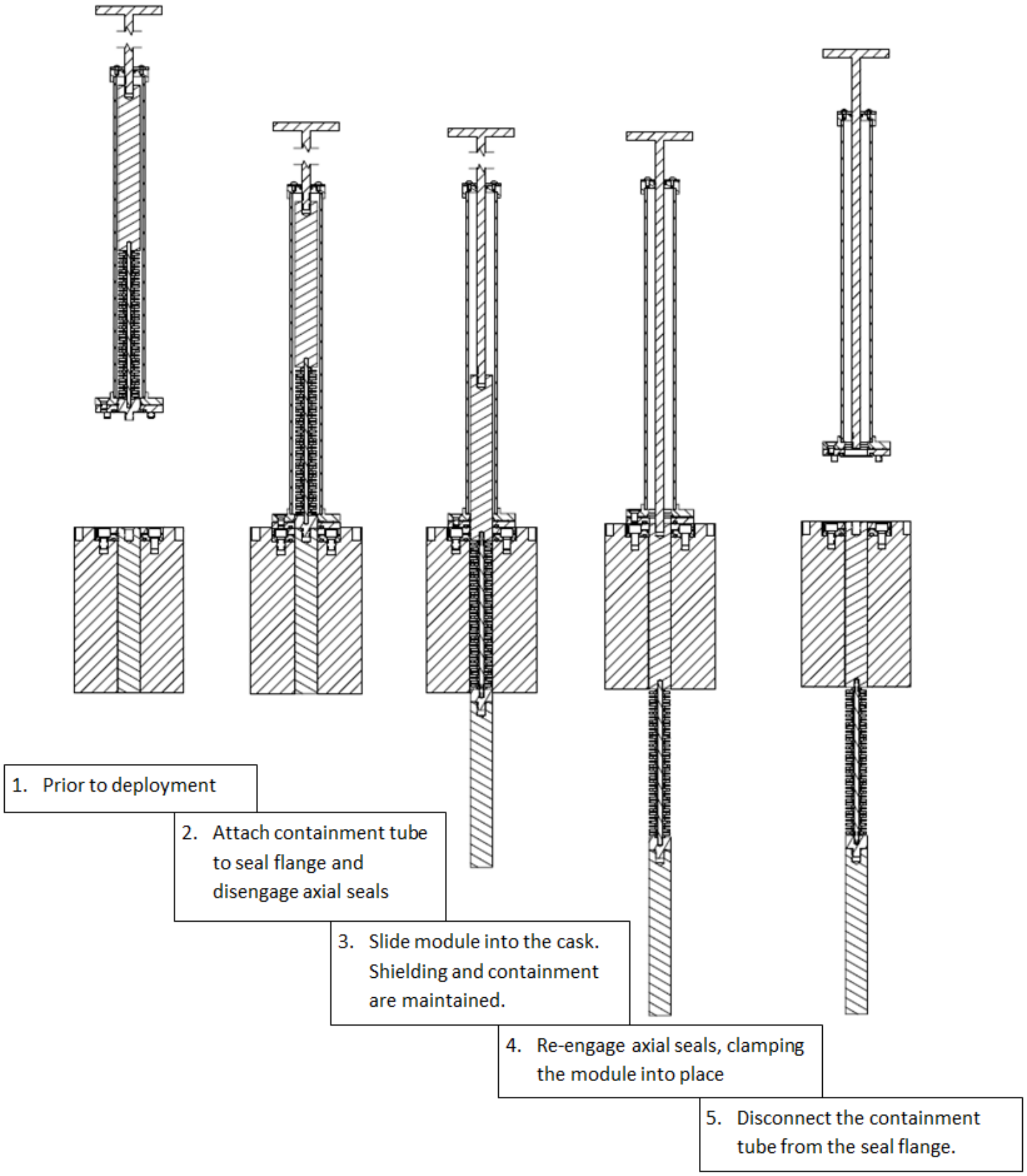
The containment tube allows the monitoring system to be deployed and retrieved without loss of confinement. The containment tube is attached to the top of the primary seal flange acting as confinement when the primary seal flange is disengaged from the shield plug. The containment tube is constructed of standard stainless steel pipe with a type of seal flange on the bottom and a rod seal at the top to allow the T-handle rod to pass through.

The cask materials monitoring system is designed so that different modules could be installed into the cask using the same deployment system. So far within the scope of this project, only a corrosion monitoring module has been designed. This module consists of a shaft in which disc-like corrosion coupons can be attached. The corrosion coupons would be constructed of various materials that would represent the materials within the cask. The coupons are attached to the shaft by a ceramic insulator to prevent galvanic corrosion effects among the dissimilar metals.

Deployment Sequence

The following is a sequence of steps for deployment of the cask materials monitoring system. These steps were used during the testing of the CMMS. Figure 5 shows the general deployment sequence.

1. ATTACH the corrosion monitoring module to the bottom shield plug
2. ATTACH the containment tube (containing the corrosion monitoring module) to the seal flange
3. LOOSEN the axial seals on both the containment tube
4. ENSURE the monitoring module is securely threaded into the bottom shield plug by turning the T-handle
5. LOOSEN the axial seals on the seal flange while keeping a hold of the T-handle.
6. SLIDE the corrosion monitoring module into the cask
7. TIGHTEN the axial seal on the seal flange
8. ENSURE the monitoring module is securely clamped into position by trying to move the T-handle after the axial seal is engaged
9. DETACH the T-handle from the corrosion monitoring module
10. DETACH the containment tube (now empty) from the seal flange



1. Prior to deployment
2. Attach containment tube to seal flange and disengage axial seals
3. Slide module into the cask. Shielding and containment are maintained.
4. Re-engage axial seals, clamping the module into place
5. Disconnect the containment tube from the seal flange.

Fig 5. Deployment of the CMMS

Retrieval Sequence

The following is a sequence of steps for the retrieval of the cask materials monitoring system. These were used in the testing of the CMMS. In general the retrieval sequence is the reverse of the deployment sequence.

1. ATTACH the containment tube (empty) to the seal flange
2. ATTACH the T-handle to the corrosion monitoring module
3. LOOSEN the axial seals on both the containment tube and seal flange
4. SLIDE the corrosion monitoring module into the containment tube

5. TIGHTEN the axial seals on the seal flange
6. ENSURE the bottom shield plug is securely clamped into position by trying to move the T-handle after the axial seal is engaged.
7. TIGHTEN the axial seals on the containment tube
8. DETACH the containment tube from the seal flange
9. DETACH the corrosion monitoring module from the bottom shield plug

Clamping Seal Design

The clamping seal provides a positive gas seal for atmospheric containment and also serves as a clamp to hold the module in place. Figure 6 identifies the detailed components of the seal flanges.

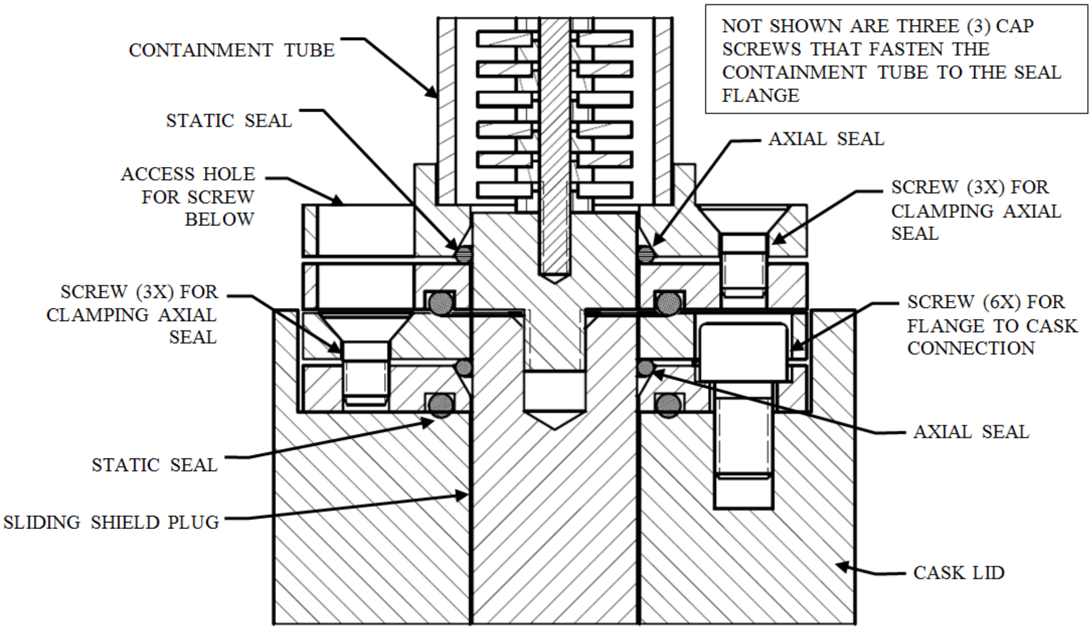


Fig 6. Seal Design

The axial seals provide both sealing and clamping capabilities. As the two flanges are brought together by tightening the three countersunk screws, the axial seal is compressed against the shield plug because of the angled groove cut into one of the adjoining flanges. The static seals provide positive gas seal between the flanges faces.

Recommended Seal Design Change

When the seal flange is dis-engaged to allow the shield plug to slide the seal is also broken between the two flanges. One possible solution is to add an additional seal that will still allow the two flanges to separate slightly but still maintain the seal, see figure 7 below.

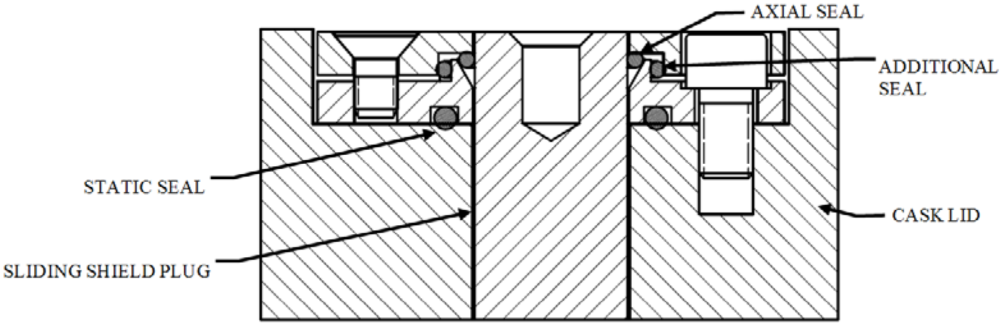


Fig 7. Seal Flange Recommended Change

CORROSION MONITORING MODULE

In the "Gap Analysis to Support the Extended Storage of Nuclear Fuel," Rev. 0 (PNNL-20509, 2012), one of the approaches to closing the technology gaps is to "develop systems for early detection of corrosion of metal reinforcement." This section discusses the approach to monitoring corrosion within the CASTOR V/21 spent nuclear fuel storage cask and includes, 1) coupon material selection based on the materials of construction for the CASTOR V/21 cask; 2) determination of the expected forms of corrosion; and 3) determination of the preferred coupon geometries.

Materials Selection

The materials of interest for coupon testing are those materials that are in direct contact with the casks inner atmosphere. The Topical Safety analysis report of the Castor V/21 spent nuclear fuel cask (GNSI, 1985) lists the cask construction materials. US equivalent will be used in testing the corrosion rates within the cask. The Materials that are in direct contact with the inner cask environment are 1) the fuel basket, which has a standard stainless steel type as well as a borated stainless steel type; 2) the fuel cladding made from Zircalloy; 3) the inner cask walls that are plated with a corrosion resistant nickel plating that also extends to the primary lid and sealing surface; and, 4) the cask seals (one is a metallic aluminum seal and the other is a elastomer seal). The metallic seal creates a galvanic couple between the soft outer aluminum and the nickel plating. This material combination should be galvanically tested within the cask.

Possible Forms of Corrosion

The CASTOR V/21 Cask has a gaseous backfilled environment. The cavity atmosphere consists of helium as an inert heat-conducting medium as well as for corrosion protection of the fuel cladding. This inert atmosphere will greatly reduce corrosion. However expected forms of corrosion will be, uniform, galvanic, pitting, crevice, and stress crack corrosion. Uniform corrosion also known as general, is expected to the large surface areas within the cask producing even amounts of metal loss. The galvanic is expected with the couple between the aluminum seal and nickel plated surface. This will be due to the fact that these two metals are electrically connected to each other through contact and have an electrical potential difference between them. The difference in potentials is the driving force where the less noble material will corrode at an increased rate. Pitting corrosion is highly localized, where pits form and may grow into the material. Pitting can attack imperfections in the material surface or can be associated with geometry. Pitting is expected in the fact that there are most likely imperfections in materials that are within the cask. Stress crack corrosion is produced when a material has an induced stress where the material begins to crack. The CASTOR V/21 Cask is constantly under an environmentally driven cyclic temperature loading. This varying temperature from winter to summer and night to day produces tensile stresses within cask materials that may allow for the initiation of stress crack corrosion. Intergranular corrosion is a mechanism where metals grain boundaries are attacked. This usually occurs when an element such as chromium precipitates into the grain boundaries reducing the corrosion resistivity characteristics of the metal at the boundaries. This then produces an anodic and cathodic region where the precipitate meets the original metal thus the grain boundaries are attacked because the grains are in a sense protected cathodically. This is not necessarily an expected corrosion type but it is possible that it may be seen on the corrosion coupons.

Corrosion mechanisms that are not expected are, erosion, and selective leaching. Erosion corrosion is where an increased rate is experience due to the movement of a corrodent over the material surface. The inner cask environment is an inert atmosphere that is also stagnant therefore there are no moving corrodents over a material surface. The other type is selective leaching; this is where specific elements are removed from an alloy. The element within the material is removed due to reactions with the environment.

Preferred Coupon Geometries

Disc corrosion coupons are standard industry coupons to measure corrosion. A typical disc that would be used is shown in figure 8. This disc coupon can be stacked on a rod with insulating corrosion coupons and deployed with the CMMS, see figure 9.

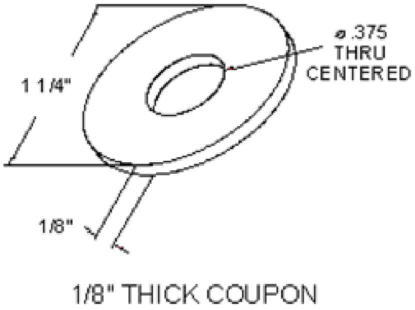


Fig 8. Disc Corrosion Coupon

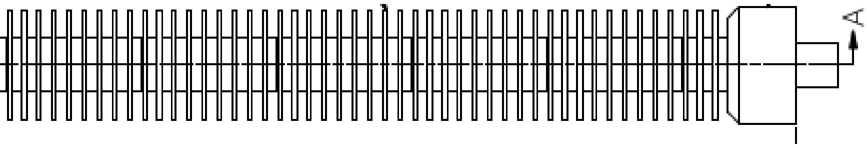


Figure 9. Standard Disc Corrosion Coupon on the CMMS Deployment Rod

The stress crack corrosion coupons require the coupon to be placed under a stress. This is most commonly accomplished by bending a flat coupon into a ‘U’ shape and fastening it to stay under this stress with a bolt and a nut at either end (see figures 10 and 11).

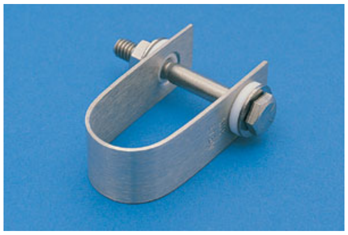


Fig 10. Stressed Corrosion Coupon, courtesy of Metal Samples Company (www.metalsamples.com)

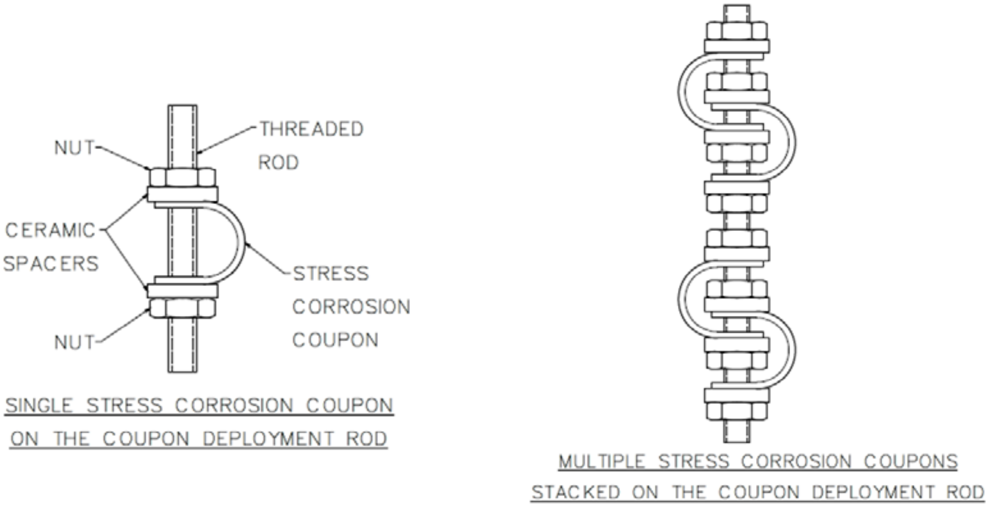


Fig 11. Stressed Corrosion Coupons on the CMMS Deployment Rod

The crevice corrosion coupons consist of a coupon in which an insulator is pressed against the coupon that has areas of flush contact and raised areas above the coupon (see figure 12). This will produce aerobic and nonaerobic environments which will induce the crevice corrosion. This does not require a special geometry coupon, only a special geometry insulator.

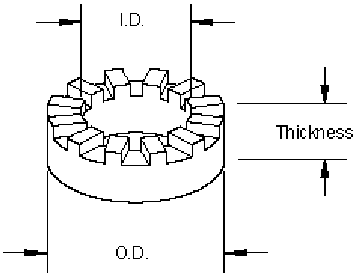


Fig 12. Crevice Insulator Washer, courtesy of Metal Samples Company (www.metalsamples.com)

Corrosion rates can vary between welded and non-welded metals. Studies involve examination of the parent material, the heat-affected zone, the weld metal, and the interfaces between all metals involved. The surface effects produced by welding, heat-tint formation or oxidation, fluxing action of slag, and the deliquescence of slag can be important factors in the corrosion behavior of metals. Welded corrosion coupons would be deployed in a similar manner as the standard disc coupon (see figure 13).

Fig 13. Welded Corrosion Coupon, courtesy of Metal Samples Company (www.metalsamples.com)

All corrosion coupons require insulation from the metal on the CMMS, ceramic washers are used for this purpose. Shoulder washers provide insulation from both the CMMS deployment rod and the adjacent washer (see figure 14).

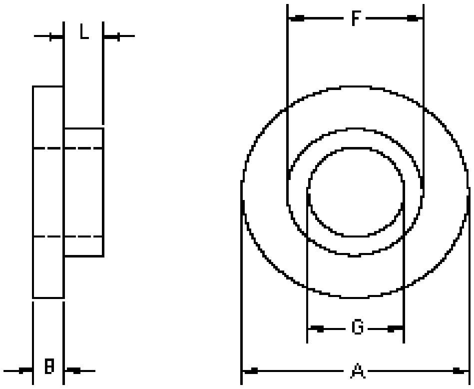


Fig 14. Shoulder Washer, courtesy of Metal Samples Company (www.metalsamples.com)

ADDITIONAL MODULE CONCEPTS FOR FUTURE WORK

Integration of Camera Inspection System and the CMMS

The current camera inspection system does not maintain the cask atmosphere. By integrating the camera system with the cask materials monitoring system, it would be possible to develop a system to deploy a camera while maintaining cask atmosphere.

Sample Cylinder, Coupons to Absorb Specific Gases, Active Gas Sampling

The CMMS system provides the model for additional monitoring equipment that may be utilized in the place of the corrosion coupons. A gas sample cylinder or gas absorbing coupons could be periodically retrieved and analyzed providing accurate cask atmosphere data. It has also been conceptualized to use a type of desiccant coupon to measure moisture content within the cask. The CMMS system could also be designed to provide the pathway for active sampling if other penetrations were not available. See figure 15 for these concepts.

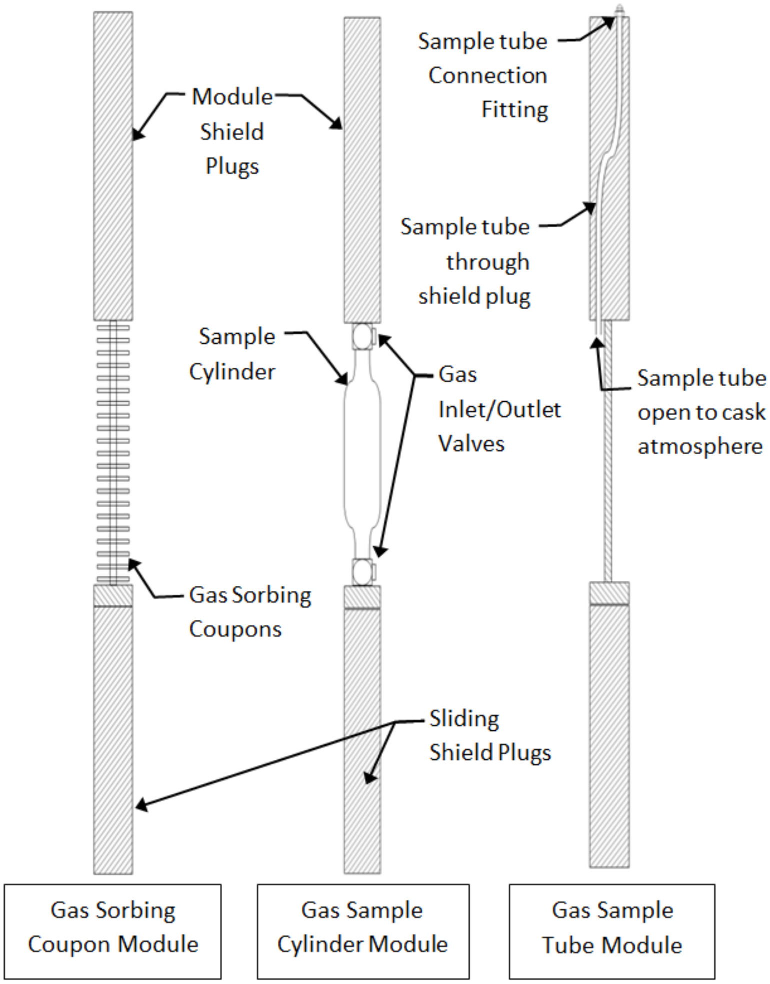


Fig 15. Additional CMMS Module Concepts

Temperature Monitoring

Cask temperatures are of interest, the CASTOR V/21 cask located at the INL already has a customized lid with penetrations for thermocouple lances. However, standard spent fuel storage casks do not. The CMMS could be used to deploy a temperature lance through the fill/drain penetration of a typical cask.

CONCLUSIONS

The CASTOR V/21 cask was procured for testing purposes. In 1999, a project to examine the cask and fuel provided confirmatory data used for license applications for continuing dry storage beyond the original 20 years (INEEL/EXT-01000183, 2001). The 1999 examination was very extensive and expensive requiring full removal of the cask lid. The facility where the 1999 examination took place no longer exists. The technology developed that is documented in this report has the capability of providing useful data to support the extended storage of spent nuclear fuel by helping to close the previously identified technology gaps to "develop systems for early detection of confinement boundary degradation, monitor cask environmental changes, and transmit data without compromising cask or canister boundary; measure temperatures within the cask; develop systems for early detection of corrosion" (PNNL-20509, 2012).

It is anticipated that by performing cask inspections and monitoring using technology as described in this report will be of great benefit while the cost would be a fraction of what an examination similar to that performed in 1999 would be, however it is recognized that there are limitations to performing in-situ inspection and monitoring as opposed to full fuel examination requiring removal of the cask lid. In summary, the capabilities and limitations are addressed in the following two sections.

Capabilities of In-Situ Inspections and Monitoring

The following capabilities are documented within this report.

- Corrosion monitoring: The cask materials monitoring system has the capability to quantify corrosion rates (or lack of corrosion) with actual corrosion coupons located within the cask environment.
- Inspection without disturbing the cask atmosphere: The capability of performing temperature, radiation, and detailed visual inspection without compromising the cask confinement barrier is of great potential.

Limitations to In-Situ Inspections and Monitoring

The CASTOR V/21 inspection that was performed in 1999 (INEEL/EXT-01000183, 2001) was used as a benchmark for what a desired full inspection would consist of. This section identifies the limitations to in-situ inspections as compared to the 1999 inspection.

- Limited access for fuel assembly inspection: In the 1999 inspection, the fuel assemblies were removed from the cask and inspected. Due to the tightly packed configuration of typical cask storage and fuel assemblies, there is virtually no access for inspection without removal. One option could be to load a test cask in such a way as to provide access to the fuel for in-situ inspection. This would take some upfront planning, design, and possibly cask modification prior to loading a cask.
- Limited to partial inspections of the fuel storage basket: In the 1999 inspection, the fuel storage basket was examined in depth. For in-situ inspections, only the top of the storage basket is accessible.
- Limited to partial inspections of cask body inner surfaces: For the CASTOR V/21 cask, the fuel storage basket conceals much of the cask inner surfaces. For an in-situ inspection, the inspection is limited to the bottom of the cask lid and the very top portion of the inner sides of the cask body that the fuel storage basket does not cover.
- Limited inspection of the cask lid seals: In the 1999 inspection the CASTOR V/21 cask lid seals were inspected. A full inspection of lid seals is not possible without removing the lid.
- In-ability to remove fuel for external examination: It is not feasible to remove fuel from a spent nuclear fuel cask using the technology presented in this report.

Future Possibilities

The camera technology and cask materials monitoring system presented in the report are viable options for closing the technology gaps identified. Future possibilities include integration of the camera inspection system and CMMS, development of a prototype CMMS for deployment on the CASTOR V/21 cask (or other similar cask), and development of additional monitoring modules to be used with the CMMS.

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