

**In-Situ Visual Inspection of the CASTOR V/21 Used Nuclear Fuel Dry Storage Cask:  
A Demonstration of Camera System Capabilities – 15505**

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**ABSTRACT**

On June 11, 2014 the Gesellschaft für Nuklear Service (GNS) CASTOR V/21 spent fuel dry storage cask was inspected in-situ at the Idaho Nuclear Technology and Engineering Center (INTEC). The purpose of this inspection is to demonstrate and document the technology necessary to perform inspections of spent fuel dry storage casks. The inspection includes internal temperature measurement, internal radiation measurement, and a visual examination using a bore-scope type camera system inserted through the cask fill/drain penetration. It is concluded from this inspection that in-situ inspections of bolted lid spent fuel storage containers is possible using current camera technologies. Using 3D Phase Measurement Technology, measurements of entities such as cracks or corrosion are possible. The internal surfaces of the CASTOR V/21 cask that were inspected were free of corrosion and exhibited no evidence of degradation. One crack identified in previous inspections was examined and appeared the same as in the previous inspections.

**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. In-situ cask camera inspection addresses two of the technology needs identified in the gap analysis: (1) “develop systems for early detection of confinement boundary degradation, monitor cask environmental changes, and transmit data without compromising cask or canister boundary” and (2) “develop systems for early detection of corrosion of metal reinforcement.”

**Previous Inspections**

In the mid-1980s, the U.S. Department of Energy (DOE) procured three prototype dry storage casks for testing at DOE’s 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 provided confirmatory data used for license applications for continuing dry storage beyond the original 20 years.

### 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).

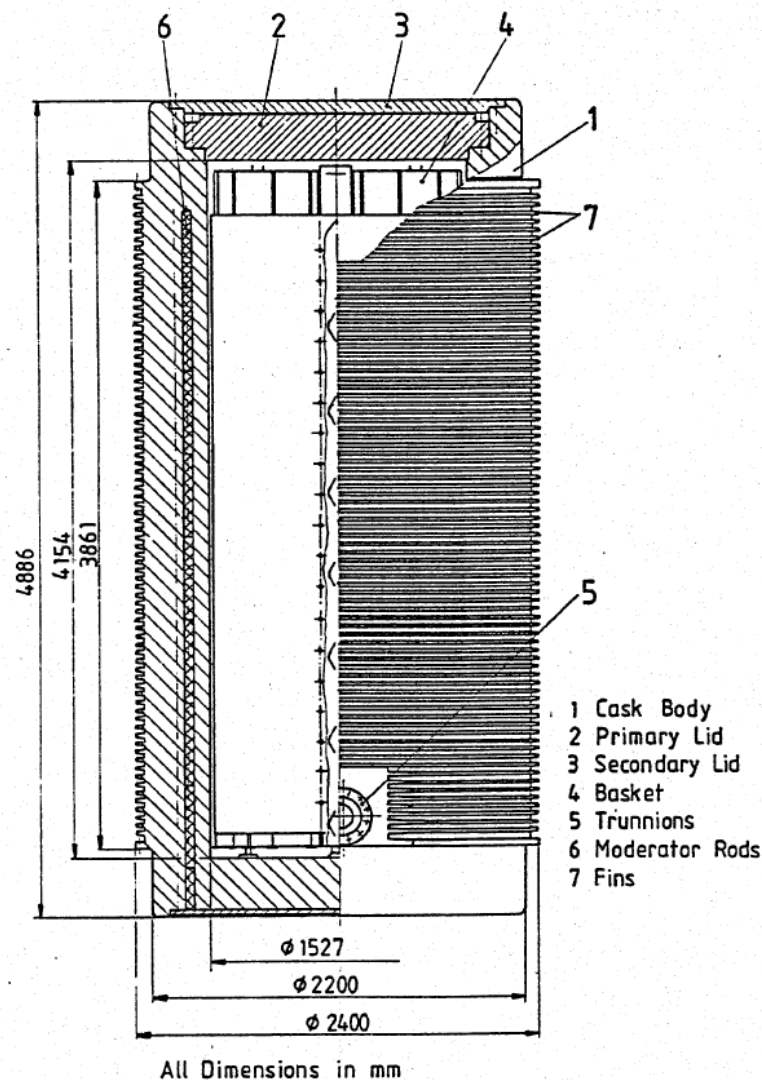


Fig 1. CASTOR V/21 Cask (GNSI, 1985)

The spent fuel basket (see figure 2) is a cylindrical structure of welded stainless steel plate and borated stainless steel plate. 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 55 mm (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). The inspection described in section 2 utilized this primary lid penetration to access the cask internals.

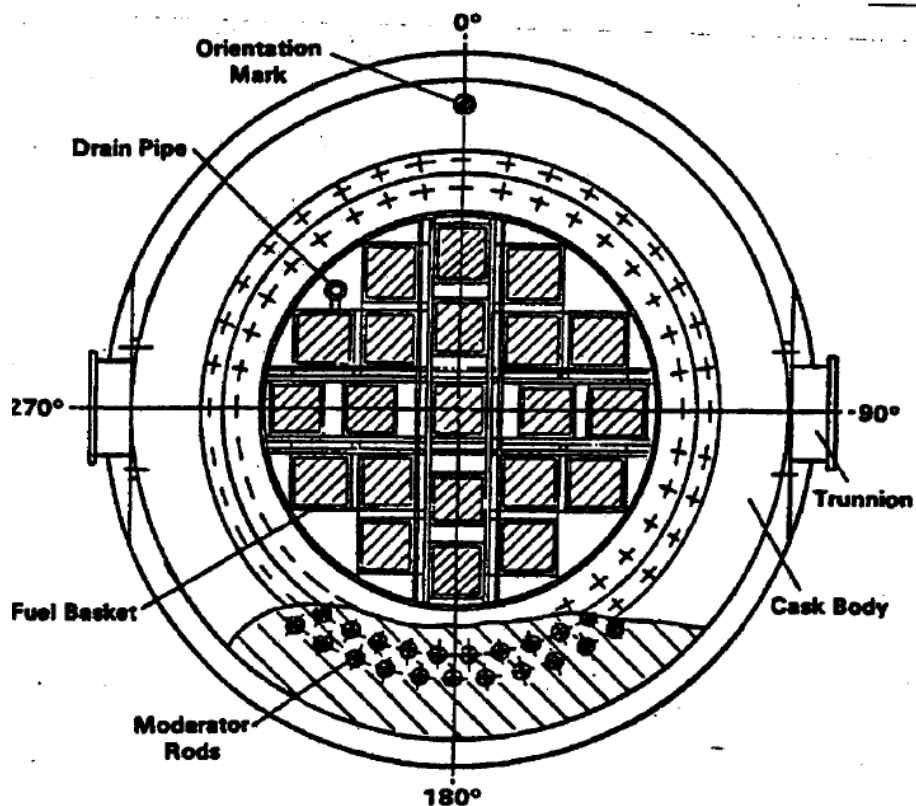


Fig 2: CASTOR V/21 Cask Cross Section (INEEL/EXT-01000183, 2001).

The CASTOR V/21 cask has a stainless steel primary lid that is approximately 1.8 m (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 inspection. 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).

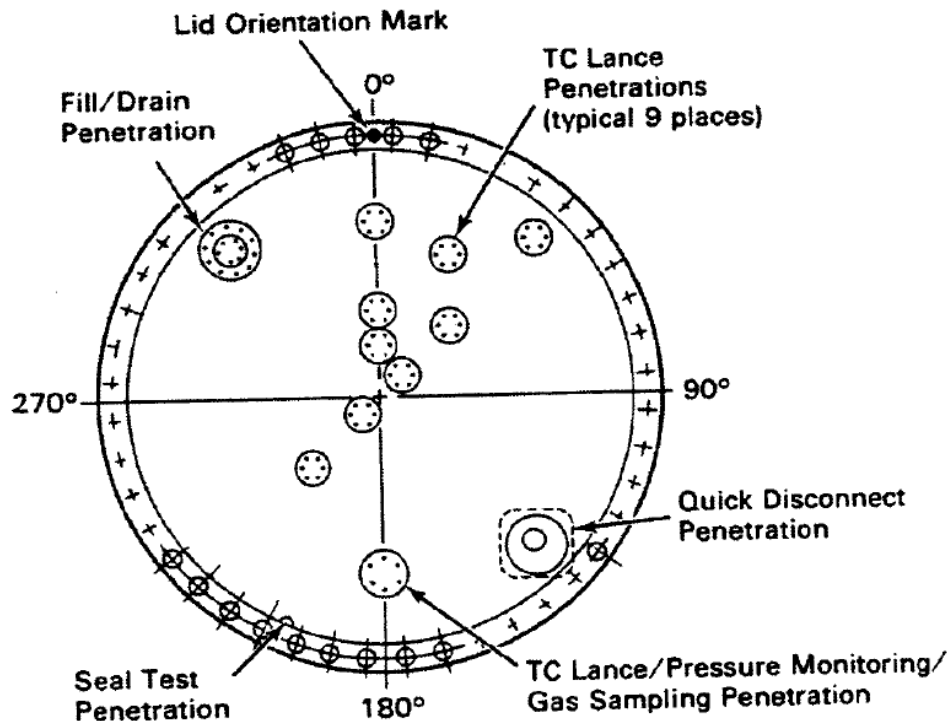


Fig 3: CASTOR V/21 Primary Lid (INEEL/EXT-01000183, 2001)

## TEMPERATURE MEASUREMENT

The temperature inside the cask was of interest in order to quantify the environment in which the camera system would be operating. Spent fuel storage systems are designed to withstand and shed the decay heat. This decay heat decreases with time.

The thermocouple temperature was measured using a Fluke 87 multi-meter with a Fluke 80TK thermocouple module. A type K thermocouple was inserted through the fill/drain penetration in

the primary lid and slowly lowered into the fill/drain tube within the cask. In one foot increments, the thermocouple was held in place to wait until it came to equilibrium. The temperature along the fill/drain port was a uniform 84°C (182.9°F) showing no variation. The external cask temperature was not documented, but was not much greater than the ambient outside air temperature approximately 27°C (80°F).

In 1999, the CASTOR V/21 was opened and temperatures measured. The highest internal temperature recorded at that time was 154°C (309°F) (INEEL/EXT-01000183, 2001). The external cask temperature was measured in both 1999 and 1985 after the cask was originally loaded. These both sets of temperatures were recorded in the INEEL 2001 report. In 1999 the highest external temperature recorded was 60°C (141.0°F) and in 1985 the highest external temperature recorded was 105°C (221.5°F). Both of these were measured on the top of the cask.

It was expected that the temperatures in 1999 were considerably higher than they are today as decay heat decreases with time.

### **Radiation Measurement**

The radiation fields within the cask were of interest in order to quantify the environment in which the camera system would be operating. An Area Monitor Probe (AMP)-200 was used to measure the gamma dose rates within the cask. The probe was slowly lowered through the fill/drain penetration in the primary lid and the dose rate recorded in 1ft increments measured from the top of the primary lid. At each foot the probe was held in-place and allowed to equalize prior to recording the data. The dose rates within the cask ranged from 251 R/hr to 7404 R/hr (see TABLE I for complete results).

It is noted that the 2001 INEEL report does not indicate any measured internal cask dose rates for the 1999 inspection.

**TABLE I. Gamma Dose Rate Along Fill/Drain Tube**

<b>Distance from top of cask primary lid (feet)</b>	<b>Radiation dose rate (R/hr)</b>
1 (just below lid)	251
2	2330
3	5462
4	6699
5	6908
6	7157
7	7157
8	7404
9	7404
10	6888
11	7349
12	6894
13	5842
14	1412

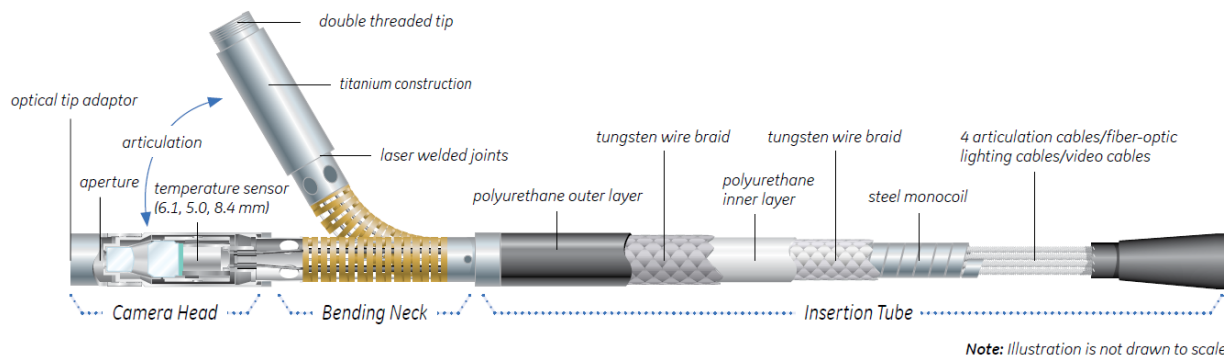
15	511
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## REMOTE CAMERA INSPECTION

### Camera Description

The internals of the CASTOR V/21 were visually inspected using General Electric’s XLG3TM VideoProbe® which provides both qualitative (video and photos) and quantitative (3D Phase Measurement Technology) inspection capabilities. The 3D Phase Measurement creates a 3D surface scan of the viewing area and can measure all aspects of surface indications using a 3D scan (GE, 2010). See Figure 4 for a general diagram of the camera used for the inspection.

The published camera tip manufacture’s recommended operating temperature is  $-25^{\circ}$  to  $80^{\circ}\text{C}$  ( $-13^{\circ}$  to  $176^{\circ}\text{F}$ ) (GE, 2010). With the measured cask internal temperature of  $84^{\circ}\text{C}$  ( $182.9^{\circ}\text{F}$ ) slightly higher than the camera manufacturer’s recommended operating temperature, there was some concern about how well the camera would perform. The camera system provided a temperature warning as indicated by the yellow and red triangles in the top right corner of the video; however, the camera did not cut-out and performed adequately at the elevated temperatures.

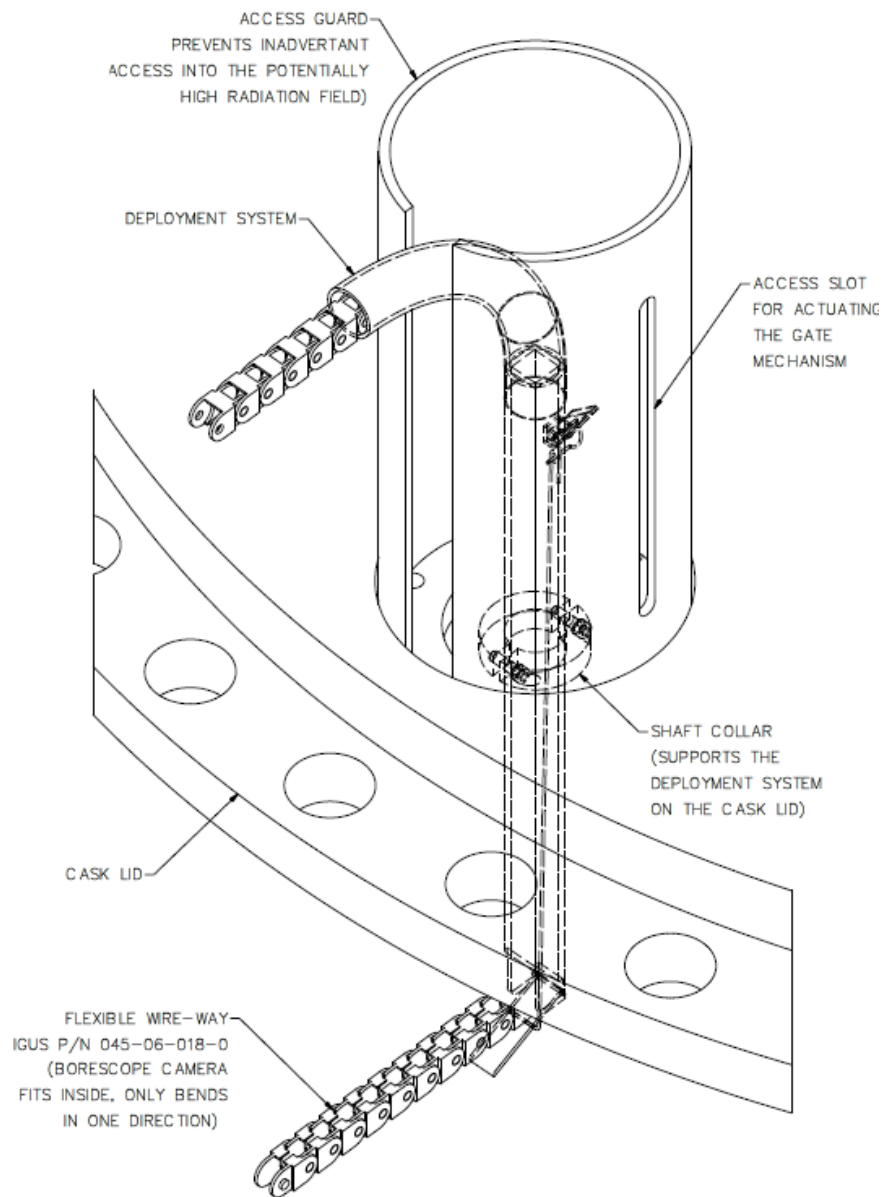


**Fig 4. Inspection Camera Technical Specifications (GE, 2010).**

### Camera Deployment Method

The camera is deployed using a custom system designed and built by the remote systems group at INTEC. It consists of a tube that fits through the CASTOR V/21 primary lid fill/drain penetration in which a flexible cableway that only bends in one direction can slide down. The flexible cableway houses the borescope camera and guides the camera horizontally within the space between the top of the spent fuel basket and the bottom of the cask primary lid (see figure 5).

The camera deployment system is designed in such a way so it can be operated outside of any direct radiation stream that would penetrate through the fill/drain penetration. An access guard prevents inadvertent access into the potentially high radiation field.



**Fig 5. CASTOR V/21 Camera Inspection Deployment System**

### **General Conditions**

The general conditions in the CASTOR V/21 cask were observed while the camera was deployed. Figure 6 shows a photo taken in the 1999 inspection showing the general conditions of the fuel storage basket. Figure 7 shows a photo from the 2014 inspection showing similar conditions. The stainless steel fuel basket in both inspections appears to be reflective and corrosion free.



Fig 6. Photo from 1999 Inspection (INEEL/EXT-01000183, 2001)



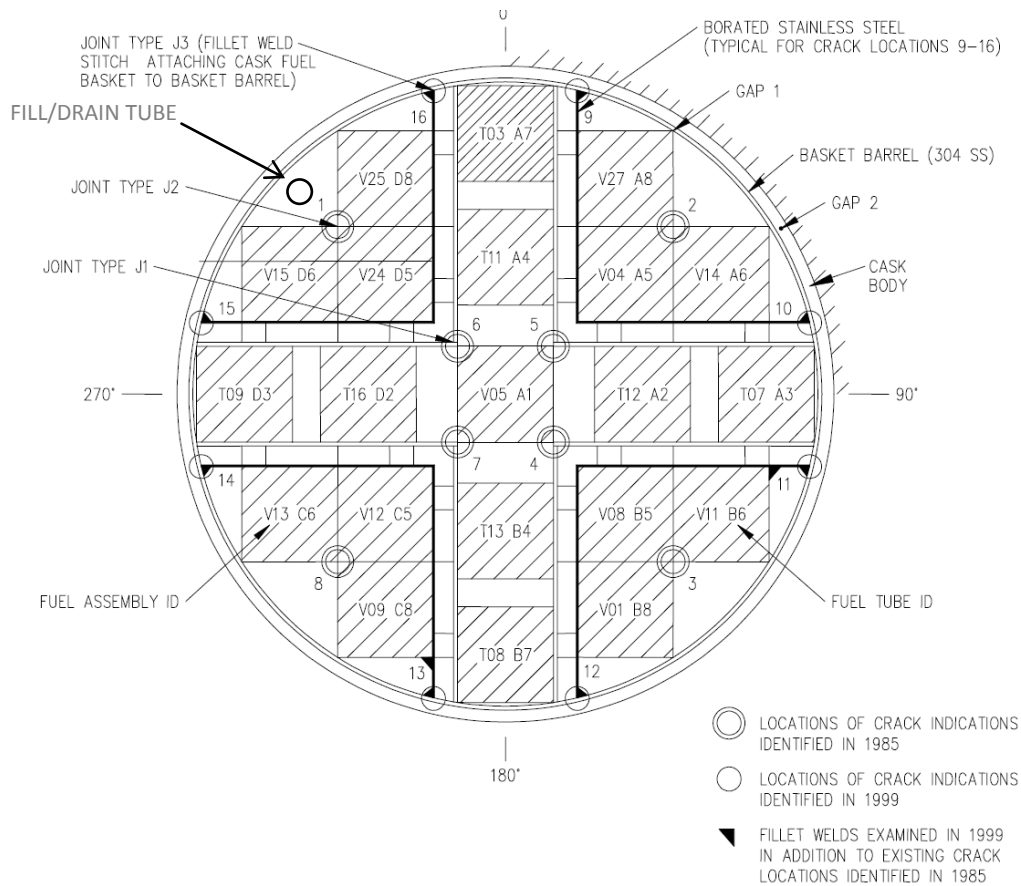
Fig 7. Photo from 2014 Inspection



### Cracked Weld Inspection

The 1985 inspection of the basket after the completion of the heat transfer performance tests identified eight broken welds in the top of the basket (EPRI NP-4887, 1986). The welds cracked as a result of the stresses created by the differential thermal expansion of the tightly fitting basket within the cask during the testing (INEEL/EXT-01000183, 2001). One objective of the 2014 inspection was to determine if the cracked welds could be reexamined and to examine any other accessible welds in the basket structure for cracks or corrosion.

Figure 8 shows the locations of the previously identified cracked welds. For the 2014 inspection, weld location #1 was inspected because of its close proximity to the fill/drain penetration. The crack width of weld location #1 was measured at 0.48 mm (0.019-inch) and 0.38 mm (0.015-inch) as shown in figures 9 and 10 respectively. Figure 11 shows the crack at weld location #1 from the 1999 inspection. Although there was no measurement taken in the 1999 inspection, it does not appear that the weld has changed in size or appearance since that inspection.



**Fig 8. Cracked Weld Locations (INEEL/EXT-01000183, 2001)**

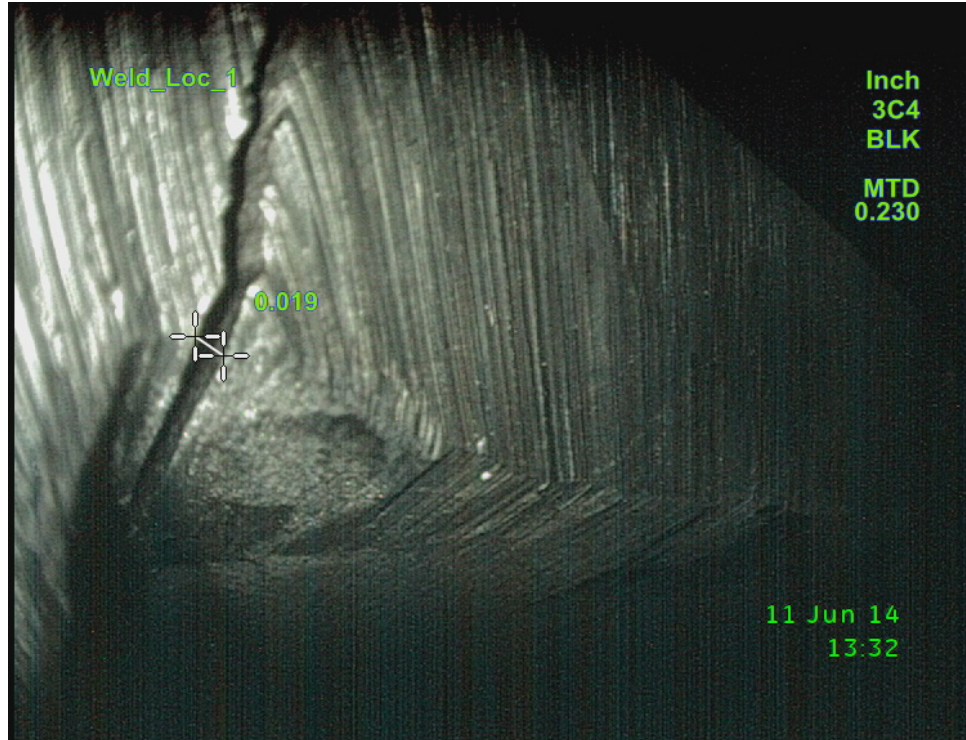


Fig 9. Weld Location #1 Measurement—2014 Inspection

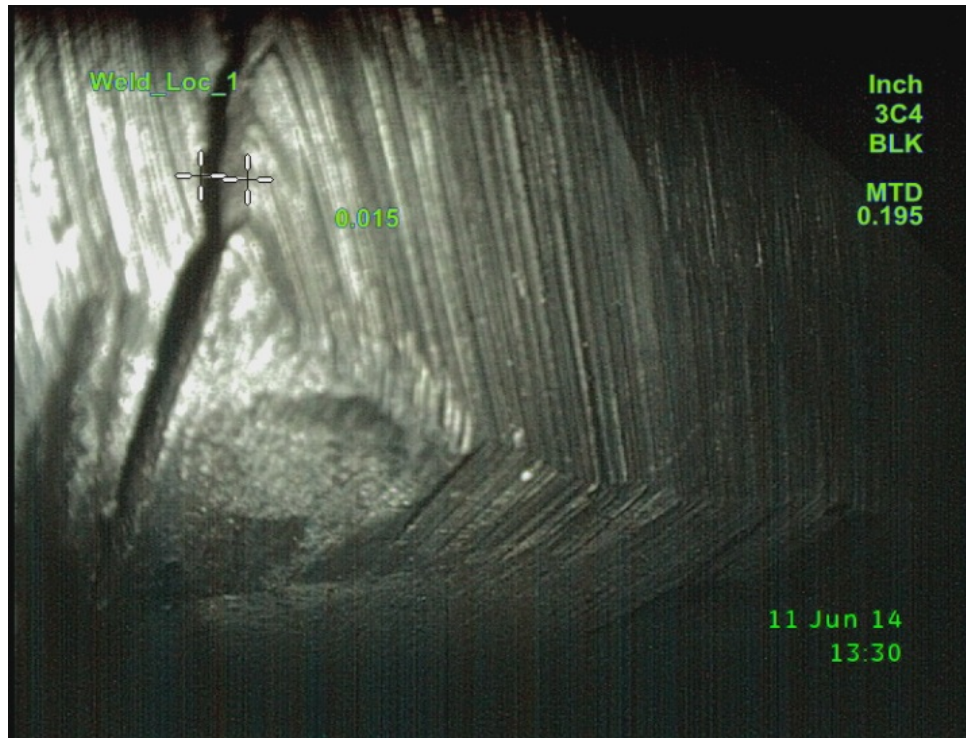


Fig 10. Weld Location #1 Measurement—2014 Inspection



Fig 11. Weld Location #1--1999 Inspection (INEEL/EXT-01000183, 2001)

### Intact Weld Inspection

Figure 12 shows an intact weld on the fuel storage rack. It is free of corrosion and in generally good condition.

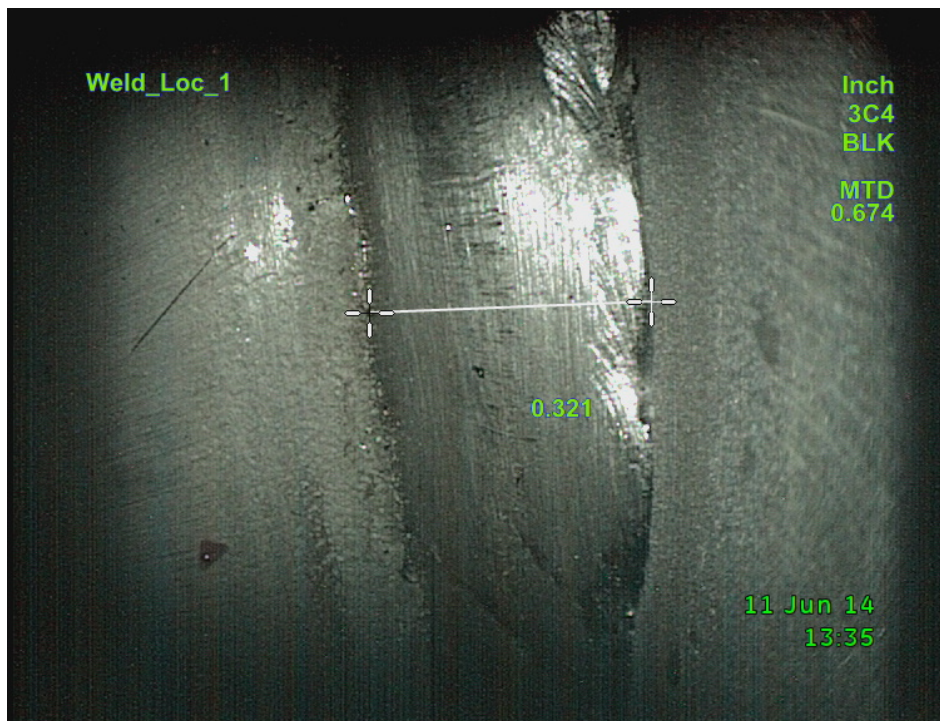


Fig 12. Intact weld inspection—2014

## GENERAL OBSERVATIONS

The primary objective of this project focuses on the inspection and monitoring of the internal state of the cask, however, there were other general observations that are noteworthy and described in this section. Since these observations were not the primary focus, little data (photos, measurements, etc.) was obtained.

### Fill/Drain Flange Seal Conditions

The CASTOR V/21 fill/drain penetration is equipped with an inner and outer flange. The inner flange is sealed by a silicone O-ring that is 42mm (1.65-in) inside diameter x 5mm (0.2-in) cross section diameter recessed in a dove-tail groove on the flange. The outer flange is sealed by a metal O-ring that is 124mm (4.88-in) inner diameter x 5.6mm (0.22-in) cross section diameter, Helicoflex type HN 200 with an aluminum jacket.

Upon removal of the fill/drain flanges the metal seal on the outer flange was in general good condition with no apparent degradation. The silicone O-ring on the inner flange, however, was no longer pliable and seemed to become hardened and brittle over the years. The inner seal was very difficult to remove from the dove-tail groove and had to be carefully scrapped out in pieces. It should be noted that the only seal that is credited in the Topical Safety Analysis report is the metallic seal (GNSI, 1985).

### Fill/Drain Flange Bolt Conditions

The CASTOR V/21 fill/drain flanges are attached with stainless steel A2-70 (18-8) M12 bolts. The outer flange equipped with ten and the inner with six. The bolts were in generally good condition. They were removed and re-installed without issue. There was no indication of corrosion or degradation of the bolts.

## CONCLUSIONS

The CASTOR V/21 in-situ inspection performed on June 11, 2014 to test the capabilities of camera inspection technology was successful. The following conclusions are reported:

- Temperature and radiation measurements can be made in-situ using the fill/drain penetration in a typical bolted lid cask.
- A portion of the internal surfaces of typical bolted lid casks can be visually inspected in-situ through existing ports, such as the fill/drain port.
- There is no evidence of degradation of the CASTOR V/21 cask systems important to safety that were inspected.
- The internal surfaces and general conditions of the CASTOR V/21 cask near the fill/drain port appeared the same as they did in 1999 showing no signs of corrosion or degradation
- The crack at weld location #1 appeared the same as it did in 1999
- Cracks are able to be measured using 3D Phase Measurement Technology in-situ.
- One intact weld was examined and appeared to be free of corrosion or degradation

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- The CASTOR V/21 fill/drain penetration flange metallic seal was in good condition with no apparent degradation.
- The CASTOR V/21 fill/drain penetration flange silicone O-ring seal has become hardened and brittle.
- The CASTOR V/21 fill/drain penetration flange bolts were removed and re-installed without issue and had no indication of corrosion or degradation.
- The selected camera system is able to withstand the temperature and radiation conditions of the CASTOR V/21 cask and may be viable for use in other dry spent nuclear fuel storage containers. However, the selected camera system would have limited capabilities in casks with higher temperatures.

## REFERENCES

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