# Behavior of Spent Fuel and Safety-Related Components in Dry Cask Storage Systems

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## ABSTRACT

A Castor-V/21 cask containing 21 spent PWR rods (burnups in the 30-35 GWd/MTU range) has been in storage at the Idaho National Environmental and Engineering Laboratory (INEEL) since 1985. This cask represents one of the longest storage periods in the current fleet of licensed dry storage containers in the United States. Given that current dry storage cask licenses are only for 20 years, and several cask systems are approaching the end of the initial license period, it is necessary to establish a technical basis for extended storage. Consequently, the Nuclear Regulatory Commission, the Electric Power Research Institute, and the Department of Energy have embarked upon a cooperative research program to assess the integrity of this cask in order to establish a partial basis for extended dry storage in existing licensed casks. The Castor cask has been reopened and the cask internals, fuel assemblies, and selected rods from one fuel assembly have been visually inspected at the INEEL. The cask, and the stored fuel rods appeared to be unchanged by the long storage duration.

## INTRODUCTION

Most nuclear power plants in the United States were not originally designed with a storage capacity for the spent fuel generated over the operating life by their reactors. Utilities originally planned for spent fuel to remain in the spent fuel pool for a few years after discharge, and then to be sent to a reprocessing facility. Since reprocessing has been eliminated, and no other option for spent fuel disposition currently exists, utilities expanded the storage capacity of their spent fuel pools by using high-density storage racks. This has been a generally short-term solution with many utilities having reached, or soon will reach, their spent fuel pool storage capacity [1]. Utilities have developed independent spent fuel storage installations as a means of expanding their spent fuel storage capacity on an interim basis until a geologic repository is available to accept spent fuel for permanent storage.

The U.S. Nuclear Regulatory Commission (NRC) promulgated 10 CFR Part 72 [2] for the independent storage of spent nuclear fuel and high-level radioactive waste outside reactor spent fuel pools. Part 72 currently limits the license term for an independent spent fuel storage installation to 20 years from the date of issuance. Licenses may be renewed by the Commission at or before the expiration of the license term. Applications for renewal of a license should be filed at least two years prior to the expiration of the existing license.

In preparation for possible license renewal, the NRC Office of Nuclear Material and Safeguards, Spent Fuel Project Office, is developing the technical basis for renewals of licenses and Certificates of Compliance for dry storage systems for spent nuclear fuel and high-level radioactive waste at independent spent fuel storage installation sites. These renewals would cover periods from 20 to 100 years, and would require development of a technical basis for ensuring continued safe performance under the extended service conditions. An analysis of past performance of selected components of these systems is required as part of that technical basis.

In the 1980s through the early 1990s, the Department of Energy (DOE) procured four prototype dry storage casks for testing at the Idaho National Engineering and Environmental Laboratory (INEEL): Castor-V/21, MC-10, TN-24P, and VSC-17. The primary purpose of the testing was to benchmark thermal and radiological codes and to determine the thermal and radiological characteristics of the casks.

The Castor-V/21 cask was loaded in 1985 with irradiated assemblies from the Surry Nuclear Station and then tested in a series of configurations using a variety of fill gases. Since the tests were not intended to be fundamental fuel behavior tests, the fuel prior to the tests had undergone only minimal characterization consisting of visual examination of the outside of the assemblies and ultrasonic examination to ensure no breached rods would be included. During the tests, the temperature at various locations was monitored and the cover gas was periodically analyzed to determine if any leaking rods had developed. No leaking rods were found. The details of these tests have been reported in a number of documents. Since the conclusion of the testing in 1985, the Castor-V/21 cask containing the Surry fuel assemblies remained on the storage pad at INEEL.

The NRC, the Electric Power Research Institute (EPRI), and the DOE Offices of Civilian Radioactive Waste Management (DOE-RW) and Environmental Management (DOE-EM) are participating in a cooperative research program (Dry Cask Storage Characterization Program) to determine the long-term integrity of dry cask storage systems and spent nuclear fuel under dry storage conditions. The program objectives are (1) determine the long-term integrity of dry storage cask systems and spent nuclear fuel under dry storage conditions, and (2) provide data to augment the technical bases and criteria for evaluating the safety of spent-fuel storage and transportation systems, and for extending dry cask storage licenses. The Castor-V/21 cask at INEEL was selected for study under this Program. This cask represents the "lead" storage cask in the United States - the cask with fuel assemblies stored inside for the longest amount of time. A summary of the scope of work performed on the Castor-V/21 cask and fuel can be found in [3].

## CASTOR-V/21 CASK DESCRIPTION

### Cask Body

The cask body is a one piece cylindrical structure composed of ductile cast iron in modular graphite form. This material exhibits good strength and ductility, as well as providing effective gamma shielding. The external dimensions of the cask body are 4886 mm (16 ft.) high and 2385 mm (7.8 ft.) in diameter. 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 cask body wall, excluding fins, is 380 mm (15 in.) thick. Incorporated within the wall of the body are polyethylene moderator rods to provide neutron shielding. Two concentric rows of these 60 mm (2.4 in.) nominal diameter rods are distributed around the cask perimeter. Two lifting trunnions are bolted on each end of the cask body.

### Spent Fuel Basket

The spent fuel basket is a cylindrical structure of welded stainless steel plate, and borated stainless steel plate, having a boron content of approximately 1% for criticality control (Figure 1). 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 4110 mm (13.5 ft.) including the four 130 mm diameter (5 in.) pedestals that support the basket and fuel weight on the bottom of the cask cavity. The basket outside diameter of 1524 mm (5 ft.) fits tightly in the cask cavity inner diameter of 1527 mm (5 ft.).

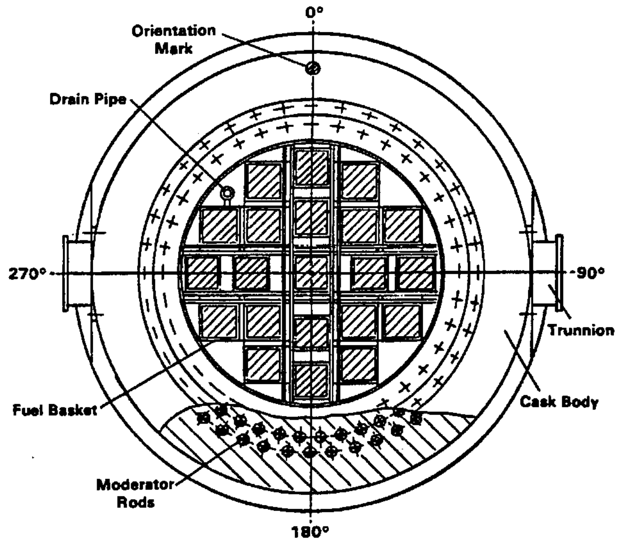


Figure 1. Castor-V/21 Cask Cross Section

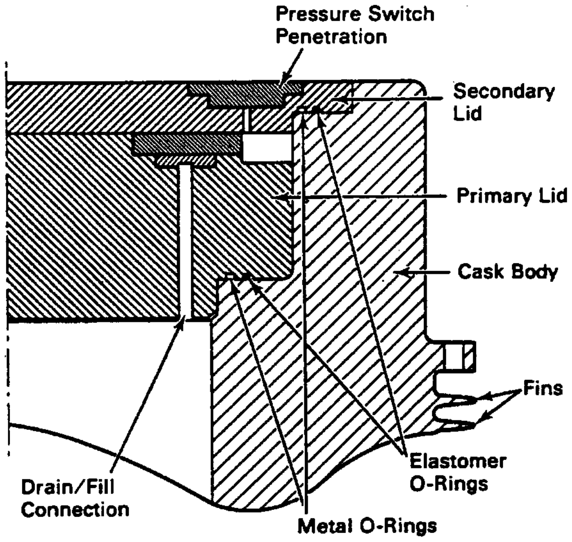


Figure 2. Castor-V/21 Seal System
(the secondary lid was not used - see text)

(Figs. 1 and 2 from [4]. Permission to use this copyrighted material is granted by the EPRI)

### Primary and Secondary Lids

The stainless steel primary lid is 1785 mm (5.8 ft.) in diameter and 290 mm (12 in.) thick. Forty-four bolt holes are machined near the lid perimeter to secure the lid to the cask body. Two grooves machined around the lid underside, inside the bolt circle, are provided for O-ring gaskets (Figure 2). The inner groove accepts a metal O-ring, which serves as the first barrier between stored fuel and the environment. The outer grove accepts an elastomer O-ring. A 10 mm diameter (0.4 in.) penetration through the lid provides access to the annulus between the two seals to perform post-assembly leak testing. This penetration is plugged when not in use.

The stainless steel secondary lid is 2007 mm (6.6 ft.) in diameter and 90 mm (3.5 in.) thick (Figure 2). Forty-eight bolt holes are machined near the lid perimeter to secure the lid to the cask body. Two concentric grooves located inside the bolt circle on the underside are provided for a metal O-ring/elastomer O-ring sealing system of the same design as that used on the primary lid. Three normally sealed penetrations are provided for various cask operations. A 10 mm diameter (0.4 in.) penetration through the lid provides access to the annulus between the two seals for post-assembly seal testing. A gasketed seal plug is used to close this penetration.

The secondary lid was not used in this particular cask because of interference with fuel assembly instrumentation leads that were installed during the Castor-V/21 cask performance test conducted in 1985.

## VISUAL INSPECTIONS OF THE CASK COMPONENTS AND FUEL ASSEMBLIES

Inspections were performed on the cask exterior, primary lid bolts, primary cask lid seals, cask interior, and fuel assemblies to assess if degradation occurred, and if applicable, the mechanisms of the degradation such as, corrosion, wear, or accumulation of crud.

### Cask Exterior

It appeared that the cask exterior had not undergone any real damage, although some small superficially corroded areas were noticed where the epoxy paint had peeled. The epoxy may contain UV inhibitors, which would not have been uniformly mixed, and the densification of which may have cause peeling of the exterior layer. Alternatively, the paint loss could be due to abrasion by chocks during the handling of the container when it was previously moved.

### Primary Lid Bolts

The 44 bolts of the primary lid were individually inspected visually for their physical condition, specifically for evidence of cracks, pitting corrosion, general corrosion, thread damage, and any discoloration. All bolts were in satisfactory condition. None had any indications of pitting or general corrosion, cracks, thread damage, discoloration, or any defects or indications of potential failure.

### Primary Lid Seals

Approach. The accessible surfaces of the primary lid O-rings were inspected immediately after the cask was opened. In early 2000, at the end of the cask and fuel assembly inspections, the original O-rings were replaced and the entire surface of the original O-rings was subjected to a direct visual examination.

The objectives of the inspection were to evaluate the condition of the seals for potential degradation due to (1) oxidation of the elastomer and metal seals; (2) thermal degradation of the elastomer seal; (3) embrittlement or hardening, including cracking, crazing and evidence of loss of elasticity or ductility; and (4) physical damage to the seals, such as scratches across the seal surfaces, dents, and seal deformation.

The remote inspection used three video cameras mounted on a work stand (work platform) at 120° intervals around the top perimeter of the cask. The resolution and color rendition of the cameras were checked daily with a resolution chart. The magnification and resolution of the remote cameras were sufficient to discern fine defects. For example, in the initial inspection immediately upon opening the cask, it was possible to clearly identify a long fine hair (presumably human hair) that was looped across the two O-rings of the primary lid.

Observations - Elastomer O-Ring Seal. The O-rings in the primary lid were in excellent condition. The remote visual inspection immediately upon opening the cask and removal of the primary lid indicated that the compression area of the elastomer and the metal O-rings were free of breaks, cracks, crazing, delamination, pull-outs, oxidation or other evidence of degradation of the O-rings.

The only observed defect in the elastomer O-ring was an imperfect splice joint that was slightly misaligned and partially open. The glue did not completely fill the gaps in the joint; however, the joint still had good strength, and could not be pulled apart manually. Furthermore, this imperfection was not significant enough to cause air ingress during the 15 years of storage.

The elastomer O-ring was still firmly resilient in consistency, flexible, and limber, with no evidence of embrittlement, stiffness, or depolymerization. Bending, pulling, twisting, and coiling the elastomer into a 300 mm (12 inches) diameter coil did not cause fracture or stress failure.

The elastomer O-ring did exhibit random, crisply-delineated patches of light surface discoloration, appearing gray against the black color of the elastomer. These patches were not associated with surface relief or differences in flexibility, resiliency, or firmness of the polymer and had a 'graphitic' sheen, suggesting that they are probably caused by excess anti-seize lubricant that was used on the lid bolts. These 'graphitic' patches were much more numerous on the back side of the elastomer, which contacted the seat of the O-ring groove in the lid, suggesting that the anti-seize lubricant was used as an aid to hold the seal in place during lid assembly.

Observations - Metal O-Ring Seal. The metal O-ring compression surface did not show any evidence of breaks, scratches, dents, distortion, or corrosion. The compression area of the metal O-ring was textured due to the impression of the machining marks from the mating metal seal surface of the cask body. The metal O-ring was still ductile, as indicated by a few slight kinks, bends, and fresh surface scratches imparted by handling during removal from the lid.

The compression sealing area of the metal O-ring was, in general, quite reflective, glinting in the natural illumination in the hot shop, indicating that no significant corrosion or oxidation had occurred. The discolorations on the compression surface of the metal O-ring were usually associated with similar gray discoloration on the elastomer seal and with deposits/films of material on the metal flange of the bolt circle. It seems possible that excess fluid anti-seize compound may have run off the lid bolts onto the solid sealing surface of the cask body, and wicked onto the elastomer and the metal O-rings before the bolts and the lid were torqued down.

## Cask Interior

Approach. The objectives of the cask interior examinations were to inspect the exposed, accessible, internal surfaces of the cask structure for evidence of cask and/or basket degradation caused by long-term storage. For the cask cavity, the visual inspection focused on evidence of corrosion and crack formation in the sidewalls and the bottom of the cask, particularly in the bottom corner, as well as the failure of the nickel coating by blistering, delamination, corrosion, or discoloration. For the fuel basket, the inspection focused on evidence of new cracks in welds or in walls of fuel tubes (cracks had been identified during the initial thermal testing conducted in 1985), propagation of existing cracks in welds, corrosion and discoloration of fuel tube walls, and accumulations of oxide particles on bottom support brackets and at the bottom of cask in each fuel tube.

The inspection of the inner wall at the top of the cask was performed by remotely using three video cameras mounted on a work stand (work platform) at 120° intervals around the top perimeter of the cask. The floor and the bottom corner of the cask were examined with a radiation-tolerant miniature (pencil) camera and light mounted at the end of a 4.5 m (15 ft.) pole. As with the video cameras, the pencil camera resolution was checked daily with the resolution and color charts.

Most of the cask inner wall and bottom was not accessible to visual inspection due to the size and tightly fitting characteristics of the basket. At the top of the cask, only approximately 80 mm (3 in.) of sidewall was exposed above the top of the basket and the rebate below the seal area of the cask body (i.e., the sidewall area between the top of the basket and the bottom of the lid), the 50 mm (2 in.) step of the rebate, and approximately 250 mm (10 in.) of sidewall between the primary and secondary seal seats. The floor of the cask was accessible only through the 21 fuel tubes. The bottom corner and 20 - 50 mm (1 - 2 in.) height of cask sidewall was partially accessible through a few of the larger flux traps (approx 90 mm [3.5 in.] at the widest) at the periphery of the basket.

Because of the tight clearances for access to the bottom corner and sidewall of the cask, the examination was attempted initially with a borescope, but failed because of the narrow field of view, short working distance, short depth of field, and poor dynamic response of the borescope camera.

Interior Cask Sidewall Observations. The upper exposed area of the inner sidewall of the cask was in very good condition. The galvanically-applied nickel coating was still intact and did not show any evidence of blistering, peeling, cracking, delamination, or corrosion.

The nickel-plated sidewall was free of significant defects. However, a few isolated minor, superficial features or imperfections were visible in the visual inspection; these appeared to be light scuff and faint scrape marks that were most likely created during the initial installation of the basket in the cask. Adjacent to fuel tube D3 (Figure 3, at the 270° position), the sidewall had an imperfection that initial inspection identified as a blister or dimple. However, close examination of the illumination shadows indicated that the feature was a shallow depression (dimple) about 2 cm in diameter and probably only approximately a millimeter deep, with the nickel coating still intact. The visible surface of the sidewall also had several isolated, randomly-oriented superficial lines that could be surface deposits (from abrasion by a softer material) or superficial scrapes. These features are quite faint, with no discernible vertical dimensions, burrs, ridged edges or plow marks that usually are associated with scratches that penetrate coatings or gall a surface.

Considering the tight fit of the basket within the cask body, the nickel coating on the upper sidewall shows little evidence of damage due to insertion of the basket. The only discernible feature that might constitute significant coating damage was a black mark on the sidewall at the level of and coincident with the corner of fuel tube D3. However, the black surface mark appeared to be superficial, and did not have any burrs or dimensional relief indicative of substantial abrasion damage, corrosion product formation, or cracks. While the feature is coincident in location with the corner of fuel tube D3, it cannot be the result of abrasion by the corner of the fuel tube (by vibration from cask handling), for the fuel tube is separated from the wall by the thickness of the steel barrel plate comprising the outer rim of the basket. Instead, this feature may be the result of abrasion during insertion of the tightly-fitting basket into the cask or from vertical thermal expansion of the tightly-fitting basket barrel wall during the 1985 thermal tests. The upper sidewall has several similar, less distinct blemishes that could be construed as light scuffing or abrasion of the nickel coating from contact during the insertion of the basket into the cask body. These features consist of black 'scuffs' and spots on the nickel surface, as if the nickel plating was lightly abraded from the high points of the rough as-machined surface of the cask body. These features have no discernible relief, implying negligible superficial damage at worst, and have no evidence of more than possibly superficial surface corrosion, as might have occurred prior to sealing the cask in 1985. Furthermore, there was no evidence of delamination and peeling of the nickel layer around these features, or of subsurface corrosion or blistering in the areas surrounding the features, which could be the expected effect from a corrosive, oxidizing environment.

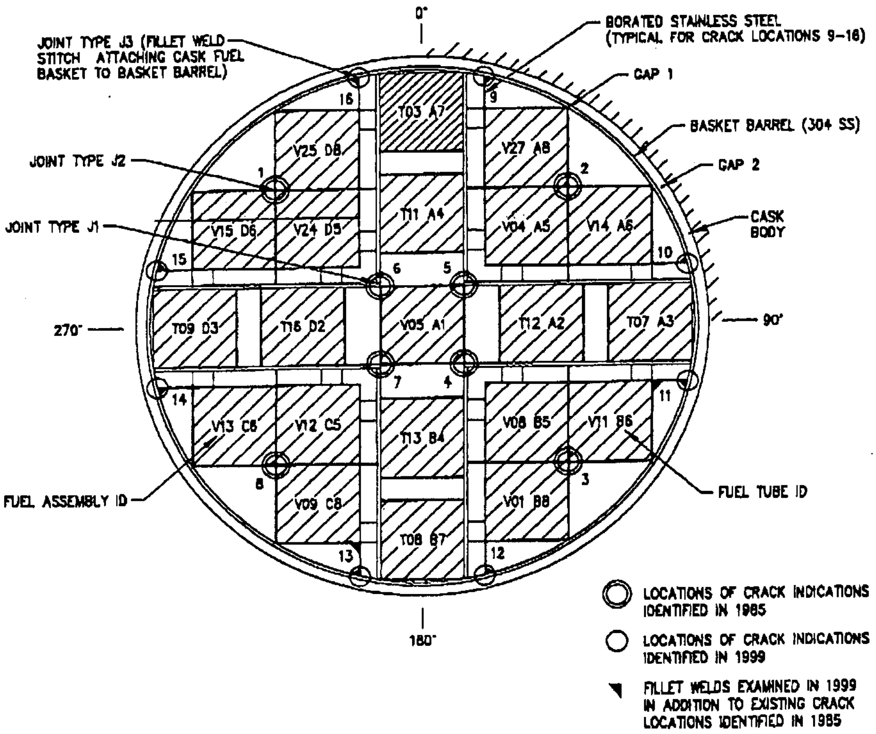


Figure 3. Castor-V/21 Cask Basket Crack Indications Locations

Interior Cask Bottom and Bottom Sidewall Observations. The cask bottom and bottom sidewall could be inspected only to a limited extent by access through the 21 fuel tubes and the eight channels at the perimeter of the basket. Access via the remaining flux traps was prevented by the tight dimensions of the traps and the structural gussets and spacers in the cavities of the traps. In addition, the inspection of the whole area of the cask floor was hampered by the small clearance (approximately 3.8 cm [1.5 inches]) between the bottom of the basket and the cask floor.

The floor of the cask was of roughly-grained as-cast texture, overcoated with the nickel plating. The floor of the cask turned smoothly up into the sidewall, so that the first centimeter or two of sidewall was also generally of rough as-cast texture. The sidewall above the bottom corner radius was smoother than the floor, as if it had been machined to remove the as-cast texture prior to nickel plating.

The nickel plating on the floor and bottom sidewall was generally clean and quite reflective despite the as-cast texture. There was no evidence of any corrosion, cracks, or flaws in the nickel plating, such as blistering or delamination, in the floor, corner, or sidewall of the cask. In general, the bottom sidewall was quite clean and reflective, particularly those areas that were machined prior to nickel plating. There were, however, isolated areas that appeared to be covered with light-colored spots of material that were not reflective and had no relief. These patches appeared to be mineral spots, as if deposited from residual water in the cask (as from evaporation of residual plating solution or rinse water). These flat, light-colored spots did not appear to contain much material as they had no relief (depth); neighboring areas were free of these deposits. They did not appear to be caused by corrosion or oxidation, nor was the integrity or adherence of the nickel plating affected by them.

Small grains of debris were thinly scattered over most of the cask floor. The debris ranged from sandlike particles of submillimeter to several millimeter size, to long slivers of material several millimeters in length. These generally appeared to have been deposited after the nickel plating of the surface, since the larger particles were dark in color and not reflective. Similar material had accumulated on the horizontal bars at the bottom of each fuel tube, on which the fuel assemblies rested. Much of the sand-like debris probably consists welding slag or grinding swarf from the basket. However, some of the debris appeared to consist of slivers of metal, and may be slivers of stainless steel gouged from the fuel tube walls by insertion and extraction of the fuel assemblies, since the fuel tube walls exhibited much evidence of scraping by the fuel assemblies.

**Fuel Assembly Basket**

Approach. The fuel basket was examined for evidence of further corrosion of the plate surface, the welds and associated heat affected zone, the junction between stainless steel and borated stainless, and contact points between the stainless steel structure and the zircaloy fuel assembly structure, such as on the steel brackets at the bottom of each fuel tube that support the weight of the fuel assemblies. In addition, the welds in the basket structure were inspected for failure, both for propagation of the cracks in the known broken welds and for initiation of new cracks in other welds.

The accessible portions of the fuel assembly basket inside the cask were inspected visually, using the three remote video cameras positioned around the top rim of the cask, and the pencil camera used to inspect the floor.

Only the surfaces of the basket directly accessible to the video and pencil cameras were inspected. The basket was inspected while in place within the cask. The extremely tight diametral clearance between the basket and cask wall (approx. 3 mm [0.1 in.]) prevented the unloading and extraction of the basket from the cask. The top surfaces of the basket were inspected by the three video cameras mounted around the top of the cask. With the fuel assemblies removed, the interior surfaces of the 21 fuel tubes and eight ungussetted air channels were inspected with the pencil camera system. The interior surfaces of the flux traps and the triangular air spaces at the perimeter of the basket could not be inspected with the pencil camera, for these spaces were obstructed by welded spacers and gussets, or were too narrow to permit insertion of the pencil camera.

General Observations. The fuel basket was in good condition, comparable to the surface condition observed in 1985 [4]. In fact, some of the images of the tops of the basket in 1985 looked worse (more oxide scale) that in the 1999 inspections, an effect of the difference in lighting conditions. The basket structure showed no evidence of corrosion beyond the mill surface finish and the heat tarnish in the heat affected zones of the welds. The fabricator of the basket had left the mill surface finish on the steel plate components of the basket; no attempt had been made to remove the native oxide, stencils, construction layout marks, or environmental stains on the as-supplied steel stock.

Therefore, most of the surfaces of the basket structure had a light-gray non-reflective surface, as well as superficial oxide tarnish in the region of many of the welds. However, some of the interior surfaces of the fuel tubes bore the marks of spot (rotary) surface grinding that 'skinned' the flat surfaces; these ground surfaces were still brightly reflective under the camera illumination, indicating that neither significant air oxidation nor corrosion had occurred since the fabrication of the basket. There was no evidence of corrosion due to incompatibility between the stainless steel and the borated steel, nor was there evidence of corrosion or degradation at the contact between the zircaloy bottom nozzle of the fuel assemblies and the bottom support plates in the fuel tubes. No cracks or similar degradation was seen in the steel plate components, except for some of the welds as noted below.

Basket Weld Observations. The 1985 inspection of the basket after the completion of the heat transfer performance tests identified eight broken welds (Figure 3, welds 1 - 8) in the top of the basket [4]. The welds cracked as a consequence of the stresses created by the differential thermal expansion of the tightly-fitting basket within the cask during the tests.[1] An objective of the 1999 inspections was to reexamine the affected welds for any changes in configuration, and to examine other accessible welds in the basket structure for cracks or corrosion. Unfortunately, the stitch welds of the structure are located in the flux trap and spacer channels, not inside the 21 fuel tubes. Therefore, the only accessible welds were the welds visible at the top of the basket and a few others.

Welds numbered 1 - 8 in Figure 3 appeared to be the same as in the 1985 inspection. The four welds in the corners of the central fuel tube A1 (welds numbered 4 - 7) involved welds of stainless steel to borated stainless steel, whereas the four welds joining the fuel tubes in other locations (welds numbered 2, 3, 8, and 1) involved only stainless steel. The 1999 inspection confirmed that five welds were broken clear through (as initially observed after the 1985 thermal testing), and three had substantial cracks that propagated partially through the top stitch weld. The narrowness of the flux traps and the supports within blocked the views of the stitch welds below the top welds from the top-side video cameras, and prevented the insertion of the pencil camera assembly. Therefore, the condition of those welds could not be determined.

The top stitch welds throughout the top of the basket were inspected, as well as the welds of the top-most struts within the flux traps. Except for the eight known cracked welds, the remaining welds were in good condition.

The stitch welds in the triangular air channels at the perimeter of the basket (fillet weld stitch attaching the cask fuel basket to the cask barrel) were examined with the pencil camera system. The gusset- and strut-free channels were just large

[1]The basket used in these tests was specifically designed to be more tight-fitting than those used in all other Castor casks. Thus, the weld cracking observed in the 1985 INEEL tests is not expected to be indicative of the performance of other Castor casks.

enough to permit insertion of the pencil camera for viewing the stitch welds attaching the fuel basket partition plates to the basket barrel.

The inspections found that all eight of the top stitch welds were cracked, and seven of the eight bottom welds. The intermediate welds did not appear to be cracked.

Additional cracks in basket welds were associated with stainless/borated steel junctions welds in fuel tubes.

It is not possible to unequivocally state these stitch welds cracked during the 1985 thermal testing since no visual inspection of these welds was performed at that time. However, stress analyses undertaken to assess the weld cracks that were observed immediately after the 1985 thermal testing suggest that the yield strength of these stitch welds was also exceeded during the thermal testing [4]. Thus, it is probable that these weld cracks also occurred during the initial thermal testing and not during the subsequent years of dry storage.

### Fuel Assemblies

Approach. The Surry PWR fuel assemblies in the Castor-V/21 have burnups in the range of 30-36 GWd/MTU. The assemblies were out of the reactor for a total of 26 or 46 months at the time of initial loading and testing in 1985. Thus, the initial decay heat at the time of initial loading was estimated to be 28kW. While these burnup levels are now more indicative of 'medium' burnup fuel, the relatively short decay time at the time of loading means that the initial thermal output for this cask is also roughly representative of higher burnup fuels with longer initial decay times prior to dry storage. Thus, the peak temperatures experienced by this cask are broadly representative of what would be experienced by a cask containing higher burnup fuel assemblies with longer out-of-reactor times prior to dry storage.

The inspection searched for evidence of change in the structure and integrity of the fuel assemblies: changes in corrosion and crud deposits on nozzles, grid spacers, rod cladding; additional corrosion, loose or lightly adherent corrosion product or crud; evidence of spallation or flaking; physical degradation or damage to nozzles, spacers, fuel rods; cracks, bowing of rods, or distortion.

The visual inspection required the removal of the fuel assembly from the basket. Once the assembly was lifted out of cask basket, the inspectors identified the assembly serial number and its orientation with respect to basket. They checked the relative uniformity of fuel rod lengths by clearance between tops of rods and top nozzle, then scanned the four sides using the three remotely operated cameras with zoom capabilities. After the visual inspection, the fuel assembly was returned to its original channel in the cask, maintaining the original orientation.

Observations. The measured force required to start lifting each fuel assembly is almost the same as the fuel assembly weight indicating little 'sticking' of the assemblies and that no significant bowing of the assemblies or development of corrosion products causing adherence to the cask floor occurred.

The assemblies were in a generally good condition, which had not changed since the 1985 inspection. The general visual survey revealed a dark gray oxide layer under ambient cell lights, and light tan by video. The inspection found no increase in the oxide layer thickness. There was no formation of a loose oxide scale or particles between the fuel rods of the grid spacers or on the bottom nozzles.

## GAS SURVEY

One of the primary concerns of the study of the Castor V-21 cask was whether degradation of the spent fuel cladding due to the initial thermal testing or long term storage would lead to the release of gaseous fission products. In addition, it is important to maintain a low oxygen environment inside the cask to minimize oxidation of the cladding and spent fuel. Thus, the cask internal cavity was backfilled with helium after completion of the thermal testing in 1985.

In 1985, the cask cover gas was sampled several times during performance testing, to evaluate the integrity of the spent fuel rods and the cask lid seals.

In August 1999, a mass spectrometric analyses of the Castor-V/21 cask gas samples were performed. Radiochemical analyses were performed on approximately 10 std-cc of gas from each bomb. In addition, the analytical procedure followed also checked for the presence of Ne, Kr and Xe; measurable quantities were not detected. A separate scan for organic species was also run on each sample, none were detected.

It appears that no major leakage of air into the cask occurred between 1985 and 1999. It also appears that none of the fuel rods in the stored assemblies have leaked over the same time period.

## CONCLUSION

A series of examinations in 1999 and early 2000 to investigate the integrity of the Castor V/21 cask were undertaken. There is no evidence of significant degradation of the Castor V/21 cask systems important to safety from the time of initial loading of the cask in 1985 up to the time of testing in 1999. Supporting evidence for this lack of significant degradation are (1) gas analyses show neither signs of air ingress into the container nor signs of cladding failure leading to fission product release, (2) visual examination of the cask lid O-rings suggest they were in adequate condition to maintain a seal; (3) there was no evidence of major crud spallation from the fuel rod surfaces; and (4) all materials inside the cask, including the assemblies, appeared the same as they did in 1985.

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