FABRICATION AND OPERATIONAL EXPERIENCE WITH THE INTERIM STORAGE CASK

R. M. Grenier (1), M. A. Koploy (1), P. L. Scott (2)

(1) General Atomics, PO Box 85608, San Diego CA 92186-5608, USA
(2) B & W Hanford Company, PO Box 1200, Richland, WA 99352, USA

SUMMARY

This paper discusses the fabrication and operational experience of the Interim Storage Cask (ISC). The ISC is a dry storage cask which is used to safely store a Core Component Container (CCC) containing up to seven Fast Flux Test Facility (FFTF) spent fuel assemblies at the United States Department of Energy's Hanford Site. Under contract to B & W Hanford Company (BWHC), General Atomics (GA) designed and fabricated thirty ISC casks which BWHC is remotely loading at the FFTF facility. BWHC designed and fabricated the CCCs.

As of December 1997, thirty ISCs have been fabricated, of which eighteen have been loaded and moved to a storage site adjacent to the FFTF facility. Fabrication consisted of three sets of casks. The first unit was completed and acceptance tested before any other units were fabricated. After the first unit passed all acceptance tests, nine more units were fabricated in the first production run. Before those nine units were completed, GA began a production run of twenty more units. The paper provides an overview of the cask design and discusses the problems encountered in fabrication, their resolution, and changes made in the fabrication processes to improve the quality of the casks.

The paper also discusses the loading process and operational experiences with loading and handling of the casks. Information on loading times, worker dose exposure, and total dose for loading are presented.

INTRODUCTION

The United States Department of Energy owned, Fast Flux Test Facility (FFTF) is one of many facilities located on the Hanford Site in southeastern Washington State. The FFTF is a 400 MWt liquid metal-cooled research reactor which operated from 1980 until 1992. The reactor had an outstanding performance and safety record throughout its operation. However, in March 1992, the DOE concluded that justification to support continued operation did not exist and ordered that the FFTF be placed in a standby condition.

Following a concerted effort to find a combination of compatible missions that could make the reactor financially self-supporting, the DOE directed that a phased shutdown process of the FFTF be initiated on December 15, 1993. The resulting shutdown schedule projected that approximately seven years would be required to transition the FFTF to a long-term surveillance and maintenance configuration, pending final decommissioning.

One of the critical path activities of the phased shutdown process was to offload the inventory of highly radioactive spent reactor fuel assemblies from an oxygen-free molten sodium storage environment to dry storage in Interim Storage Casks. Since the casks were expected to be long-lead items, a competitive contract for design, analysis, fabrication, and performance testing was awarded to General Atomics in September 1993. Delivery of the first ISC occurred in June 1995 and an extensive acceptance testing program was initiated to demonstrate the ability to safely transfer irradiated fuel to the ISC for dry storage using the new, existing, and modified equipment and facility stations.

The initial "cold" phase of the acceptance testing used simulated assemblies in place of spent fuel. This phase of testing consisted of performing all operations required to receive, load, handle, transfer, and unload the ISC using the new interfacing equipment and several new operating procedures developed for the spent fuel offload process. This phase was also used to provide hands-on training for the hot cell operators prior to proceeding with remote "hot" testing with irradiated fuel.

After acceptable completion of the "cold" testing phase, "hot" testing was performed to verify shielding on all new components and to conduct final operating procedure validations in preparation for operation. The "hot" phase of the testing program was successfully completed in January of 1996 with the transfer of the first loaded ISC to the designated outdoor Interim Storage Area located adjacent to the reactor. During 1996, a total of 77 spent fuel assemblies were transferred to 11 ISCs as part of the FFTF shutdown process.

However, in January 1997, the DOE ordered the FFTF to remain in standby and discontinue irreversible shutdown activities pending reevaluation of potential missions. Based on a potential restart, fuel assemblies available for offload were re-evaluated resulting in releasing only 49 additional spent fuel assemblies for dry storage. These assemblies were offloaded to 7 additional ISCs from January to November of 1997. Currently, spent fuel offload is on hold while FFTF is in standby. Prior to the hold, General Atomics completed fabrication of thirty ISCs, of which 18 have been loaded with spent fuel.

DRY STORAGE CASK SYSTEM

The requirements considered when developing the FFTF dry cask storage system included: capability to implement the storage system within the short time-frame required by the shutdown schedule, consistency with the requirements established for U.S. commercial nuclear spent fuel storage as specified in 10 Code of Federal Regulations (CFR) 72 *Licensing Requirements for Independent Storage of Spent Fuel and High-Level Radioactive Waste*, ability to demonstrate a safe storage configuration, capability to interface with the facility's existing equipment, flexibility to relocate the storage system to a central Hanford storage complex at a future date, and retrievability of the fuel at any time during its storage life.

Consistent with U.S. commercial spent nuclear fuel storage, the primary functions of the dry storage system are passive removal of decay heat, criticality control, shielding, and confinement. In addition to preventing the release of radioactive material, the leak-tight cask confinement boundary also provides a benign storage atmosphere via an inert gas blanket (helium) and prevents the in-leakage of air and moisture. This feature limits fuel cladding degradation and fuel oxidation reactions such that the condition of the spent fuel assemblies is expected to be preserved for the duration of the storage life.

The schedule and economic needs of the FFTF shutdown schedule, combined with the existing fuel handling equipment interface requirements, resulted in the development of a vertical top-loading ISC that is smaller in size than a typical commercial dry storage cask. The smaller cask size eliminated the need for extensive and time consuming facility modifications.

The requirement to allow for future relocation of the storage system to a central Hanford storage complex resulted in imposing additional site-specific transport-related design loadings on the Interim Storage Cask. These design features, along with administrative limitations that can be imposed and controlled on-site, will accommodate future plans to consolidate the FFTF spent fuel storage system with other Hanford spent fuel.

CORE COMPONENT CONTAINER

The Core Component Container (Figure 1) was designed by B & W Hanford Company. The CCC is unshielded, provides storage positions for up to seven spent fuel assemblies, and is designed for remote handling and dry transfer capability. It is fabricated from stainless steel and nickel alloy materials to ensure long-term corrosion resistance. The storage tubes and supports of the CCC provide the physical spacing to ensure criticality control during handling and storage of the spent fuel, even in the unlikely case of full water moderation.

A single CCC is loaded into each Interim Storage Cask. The spent fuel is loaded into the CCC in an argon inerted hot cell. A single full-length spent fuel assembly can be stored in each of the six outer storage tubes of the container. The central seventh tube can also store a spent fuel assembly if it is shortened by removing a non-fuel portion of the assembly. The handling interface for the container is an integral part of the bolted closure which is designed for remote assembly in the hot cell. The closure also provides a metallic seal which is leak tested in the hot cell.

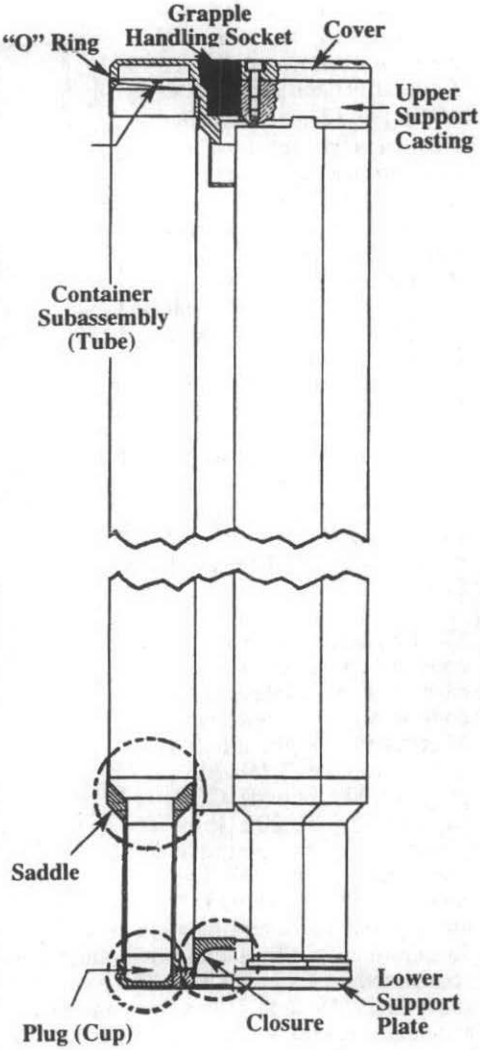

Fig. 1. Core Component Container

Even though the leak-tight seals of the ISC control dry storage atmosphere such that cladding degradation or fuel oxidation is expected to remain extremely limited, a conservative decision was made to include a metallic seal in the CCC design. The function of this seal is to provide enhanced contamination control of particulates during any future retrieval operations. Additionally, the actual condition of the storage atmosphere within the ISC cavity must be assessed prior to removing the cask's closure bolts for CCC retrieval. Assessment of the cask cavity atmosphere is required to limit radiological exposure to personnel during the retrieval operation. The ISC closure is therefore designed with a penetration port with a quick-connect fitting that is used to perform this sampling.

INTERIM STORAGE CASK

The Interim Storage Cask (Figure 2) is an aboveground storage cask designed to protect the public, the environment, and personnel from exposure during handling and interim storage of the FFTF spent fuel. As such, the ISC is designed to meet the applicable requirements (e.g., shielding, thermal loading, pressure, seismic and wind-loading events) as defined in

Department of Energy Order 6430.1A, *General Design Criteria*, and 10 Code of Federal Regulations (CFR) 72, *Licensing Requirements for Independent Storage of Spent Fuel and High-Level Radioactive Waste*. The design was performed by General Atomics, a qualified vendor with previous U.S. Nuclear Regulatory Commission licensing experience, and was modeled after approved U.S. Nuclear Regulatory Commission designs for spent commercial fuel, although formally not licensed by the Nuclear Regulatory Commission for the DOE-owned FFTF spent fuel.

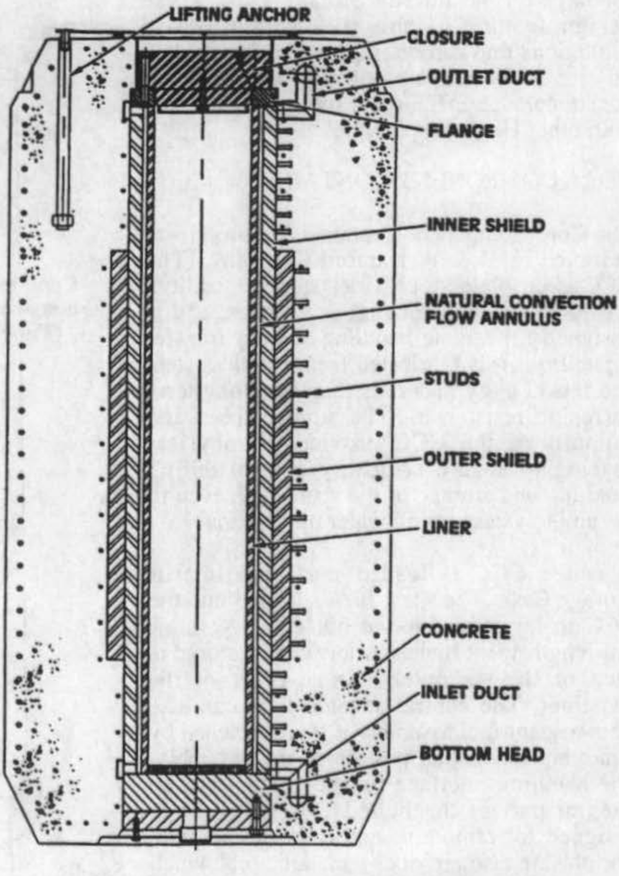

Fig. 2. ISC Has Concrete and Steel Components

The ISC design consists of a concrete and steel shielded cask with a stainless steel confinement boundary. Maximum weight of the cask, with the 2,268 kilogram (5,000 pound) CCC payload, is 52,000 kilograms (114,200 pounds). The outside diameter of the cask is 216 centimeters (85 inches) and the overall length is 462 centimeters (182 inches). The internal cavity is 53 centimeters (21 inches) in diameter and 373 centimeters (147 inches) in length to accommodate a single CCC. The cask provides structural integrity and protection for the spent fuel. As such, it has been analyzed to safely withstand all normal, off-normal, and accident conditions associated with handling and storage of the spent fuel. An aluminum honeycomb impact limiter is located at the bottom of the internal cavity of the cask to protect the CCC if an unlikely drop of the CCC were to occur during vertical loading or unloading of the ISC. This impact limiter would reduce the impact load to the CCC such that it would remain intact.

The ISC confinement boundary consists of a liner and flange assembly with a bolted closure. The bolted closure has redundant metal seals and a penetration port with a quick disconnect to access the cask cavity for helium inerting and sampling. The ISC confinement boundary is required to remain leak-tight during long-term storage of the spent fuel. The confinement boundary provides radiological protection, maintains the high purity inert gas atmosphere, and eliminates any oxygen and moisture in-leakage that could cause degradation of the spent fuel. Subsequent to loading the ISC with spent fuel, the bolted closure is installed and the cask cavity is backfilled with helium. Confinement of the closure is then verified by performing 1 x 10^{-7} atm cm/s helium leakage tests on both metal closure seals and installing redundant metal covers, which are independently seal welded and dye penetrant tested, over the penetration port quick disconnect. Confinement of the liner and flange assembly is verified during fabrication by a combination of inspection techniques which includes full radiographic or ultrasonic inspection of each weld and helium leak testing to 1×10^{-7} atm cm/s.

Decay heat removal capacity for the spent fuel without active cooling systems is also provided by the ISC. Heat removal occurs via natural convection of air through a ventilation annulus located between the steel shielding and the exterior of the confinement boundary and by conduction through the steel and concrete shielding to the external environment. A 250 watt decay heat limit per assembly and a design requirement to maintain the cladding temperature less than 482°C (900°F) was imposed for dry storage of the FFTF spent fuel. This temperature limit was based on preventing stress rupture of the most limiting type and condition of fuel clad material for the 50-year storage life. The ISC thermal analysis predicts a maximum fuel clad temperature of less than 390°C (736°F) during the hottest summer day. Even for the accident case, where no credit is taken for the passive ventilation system of the cask, there are no storage system components that exceed any normal condition limit. Based on these results, which were confirmed by thermal testing of the cask, a high margin of safety for passive decay heat removal is demonstrated and there is no safety requirement to monitor the ventilation ducts. However, surveillance is still performed to ensure that the ventilation ducts remain open to maintain storage temperatures as low as possible.

The ISC shielding was conservatively designed to maintain radiation exposure as low as reasonably achievable. Administrative radiological design guidance resulted in a requirement to limit occupational exposure for the spent fuel offload activity to less than 5 mSv/year (0.5 rem/year) which is 10% of the DOE annual limit of 50 mSv/year (5 rem/year). Based on this requirement and examining the amount of time a worker would be near the cask during loaded cask handling, performing surveillance, and conducting maintenance, a dose rate limit of less than 0.02 mSv/h (2 mrem/h) was imposed at the cask surface. Additionally, a dose rate limit at the Interim Storage Area fence perimeter, located approximately 23 m (75 ft) from the stored casks, of less than 0.0005 mSv/h (0.05 mrem/h) was also established. This limit ensures that the non-radiation worker receives less than 1 mSv/year (100 mrem/year) assuming 2,000 hours/year occupancy in an area immediately beyond the fence.

FFTF SPENT FUEL OFFLOAD PROCESS

After irradiation, the Fast Flux Test Facility spent fuel is transferred via fuel handling machines from the reactor to sodium pool storage vessels for continued decay heat removal and storage in an oxygen-free molten sodium environment. Once the fuel has decayed to less that 250 watts (requires approximately 4 years), the fuel can be transferred to dry storage. The process time to transfer seven spent fuel assemblies to dry storage in an ISC averages approximately 13 days. Fuel washing and drying is a 24 hour process for each assembly. As such, it is limiting to the cask process time. The main activities to transfer the spent fuel to dry storage consist of: (1) utilizing the existing fuel handling machines to transfer the spent fuel from sodium storage to a hot cell for residual sodium removal; (2) loading the cleaned and dried spent fuel assemblies into a CCC; (3) transferring the CCC via a shielded and sealed transfer cask from the hot cell to the cask loading station for placement into an ISC; (4) transferring the ISC from the cask loading station to an outdoor Interim Storage Area (Figure 3) designated for dry cask storage.

CASK FABRICATION EXPERIENCE

Since the ISC is a composite structure of steel and reinforced concrete, GA subcontracted to a steel fabricator for the steel portion and to a concrete casting supplier for the concrete work. The steel fabricator machined, fit, assembled, welded, inspected and tested the steel structure which was then shipped to the concrete casting yard for assembling the reinforcement and pouring the concrete.

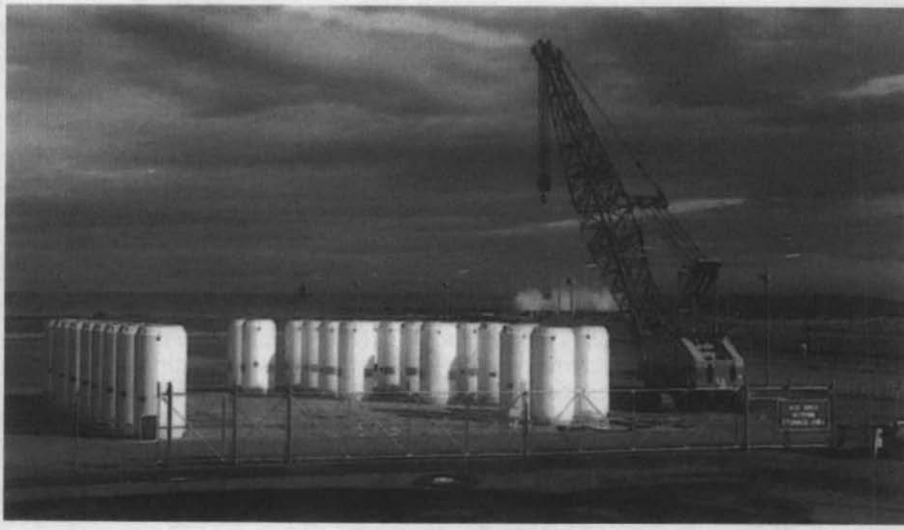

Fig. 3. FFTF Interim Storage Site

There were relatively challenging concentricity and verticality tolerances for the composite cask structure which were necessitated by the interface requirements of the remote loading station. Features on the closure of the steel structure and a centering feature on its bottom surface were used to center and align the concrete form with the steel structure. Although this method required close coordination with both suppliers to assure that the tolerances were achieved, the system worked very well and all casks met the specified dimensional requirements and interfaced as planned in the cask loading station.

During the course of the project, two manufacturing problems arose with threaded connectors. One of the problems was the failure of a closure bolt that occurred after the cask was delivered but prior to its use. The bolt had been under tension for approximately six months after it had been torqued as part of the final acceptance leak test of the closure. The bolt failed at the junction of the hex head and the shank. Chemical and mechanical testing verified that the bolt's material properties and its composition met the specification. Metallographic examination of the failure surface, however, indicated that the failure was caused by hydrogen embrittlement initiated at the location of a manufacturing defect, or crack. Although the integrity of a cask would not have been compromised by the failure of an isolated bolt, GA decided, and BWHC concurred, that it would be prudent to replace all of the closure bolts with a lower strength material that would not be susceptible to stress-corrosion cracking. In addition, each of the new replacement bolts was inspected using ultrasonic and wet magnetic particle techniques and electrocoated with zinc for enhanced corrosion performance. During the replacement of the bolts on nine loaded casks, it was determined that none of these 154 bolts had failed in-service.

The other significant manufacturing problem that occurred was the machining of non-conforming internal threads on the lifting anchors. These components, coated with zinc, are embedded in the concrete and serve as lifting points for handling the cask. The threads were machined oversize, which is standard practice to accommodate a coating on internal threads. However, field inspection of the threads revealed partial application of the coating and out of tolerance thread conditions beyond those allowed to accommodate the coating. Once the non-conforming threads were discovered, it was necessary to mechanically remove the zinc coating to reveal the full length of the threads and measure the characteristics of the threads. Many of the threads had varying degrees of oversized minor and pitch diameters and too wide a variation in pitch diameters. Based on field measurements, an enveloping oversize condition, acceptance criteria, and justification was developed. In addition to finite element analysis, a pull test with an anchor bar having oversized pitch and minor diameters and wide variation in pitch diameters was performed to verify that it could withstand its design load of five times the cask's weight. The test was conducted until a failure occurred in the mating part of the anchor bar at a load well in excess of the design load. This result demonstrated that any anchor bar with threads that fell within the envelope of the part tested was acceptable after recoating with zinc. For casks that had not been poured when the thread problem was discovered, new lifting anchors were fabricated and their threads were inspected before and after coating. For those anchor bars that already had been embedded in concrete and fell outside of the acceptable envelope, it was necessary to develop an acceptable repair. The easiest solution would have been to retap the holes and use a commercial thread insert. Unfortunately, there was no available insert for such a large thread. After analysis of the effect on the remaining anchor bar wall thickness, it was decided to drill and tap the holes with a larger thread size. As it was impractical to transport the casks to a machine shop, it was necessary to retap the anchor bars in the field. To accomplish the field repair, the steel fabricator built a platform with a portable drill mounted to it that could be adjusted to align with the existing tapped holes. An oversized tap was threaded into the hole and the drill was aligned to the tap. This process gave the best assurance that the new hole would be concentric with previous threads. More than 20 anchors were successfully retapped with this process without any problems. All of the new threads met the acceptance standards as demonstrated by inspection with appropriate go and no-go gages. The threads were slightly oversized to allow space for a final cold zinc coating. Finally, the threads were load test to meet site lifting and handling criteria..

CASK OPERATIONAL EXPERIENCE

Extensive radiation surveys were conducted during the initial cask loading which demonstrated the effectiveness of the cask shielding. Table 1 provides the estimated exposure times for various steps in the cask loading procedure and a conservative estimate of the worker doses received during the loading and cask handling process. The dose rates are more than an order of magnitude less than those for loading commercial spent fuel storage casks owing to the very low design dose rates for the ISC. The maximum dose rate at the Interim Storage Area boundary is 0.00013 mSv/h (0.013 mrem/h), well below the design value of 0.0005 mSv/h (0.05 mrem/h).

LEGAL DISCLAIMER

Table 1. Cask Loading Times and Maximum Estimated Personnel Doses

Work Activity	Number of Personnel	Estimated Exposure Time (h)	Dose Rate (µSv/h)	Exposure (µSv)
ISC Preparations for Loading				
Transfer empty ISC from transport trailer to below-grade cask loading station.	4	4	0	0
Remove the cask closure, clean sealing surfaces, inspect cask interior, install internal impact limiter, and replace metallic seals.	2	4	0	0
Install the cask loading station shield valve.	3	2	0	0
CCC Loading in Hot Cell				
Remove CCC closure, clean sealing surfaces, inspect interior, replace metallic seal, inert container with argon, install closure with gasket to protect seal, and transfer into hot cell with shielded transfer cask.	4	8	0	0
Transfer spent fuel from sodium pool storage into hot cell with refueling machines.	2	42	0	0
Individually wash sodium from spent fuel. After drying is complete, transfer to CCC.	2	168	0	0
Torque CCC lid bolts and test seal.	2	8	0	0
CCC Transfer to ISC				
Transfer full CCC to shielded transfer cask from hot cell.	2	1	5	10
Move transfer cask from hot cell to cask loading station.	5	4	10	200
Lower CCC into ISC using transfer cask hoist system.	2	1	5	10
Remove empty transfer cask.	5	1	1	5
Install cask closure.	3	1	20	60
Remove cask loading station shield valve.	3	1	5	15
Torque closure lid bolts, back-fill cask with helium, leak test seals, and seal weld port covers.	3	4	20	240
ISC Transfer to Interim Storage Area				
Vertically lift loaded cask with lifting fixture and facility crane. Survey for radiation and contamination.	5	2	5	50
Load cask on transport trailer and transfer to Interim Storage Area.	5	2	5	50
TOTAL ESTIMATED PERSONNEL EXPOSURE DOSE PER CASK LOADING				640 µSv (64 mrem)

SESSION 2.4

Spent Fuel Transport and Storage