

## **A High Integrity Can Design for Degraded Nuclear Fuel**

**P. A. Holmes**

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**A High Integrity Can Design for Degraded Nuclear Fuel**  
**Patrick A. Holmes**  
**Lockheed Martin Idaho Technologies**  
**Idaho National Engineering and Environmental Laboratory**  
**PO Box 1625**  
**Idaho Falls, Idaho 83415-5106**  
**Phone: 208-526-4107 Fax: 208-526-3535 E-Mail: patrick@inel.gov**

**ABSTRACT**

A high integrity can (HIC), designed to meet the ASME Boiler and Pressure Vessel Code (Section III, Div.3, static conditions) is proposed for the interim storage and repository disposal of Department of Energy (DOE) spent nuclear fuel. The HIC will be approximately 5 3/8 inches (134.38mm) in outside diameter with 1/4 inch (6.35mm) thick walls, and have a removable lid with a metallic seal that is capable of being welded shut. The opening of the can is approximately 4 3/8 inches (111.13mm). The HIC is primarily designed to contain items in the DOE SNF inventory that do not meet acceptance standards for direct disposal in a geologic repository. This includes fuel in the form of particulate dusts, sectioned pieces of fuel, core rubble, melted or degraded (non-intact) fuel elements, unclad uranium alloys, metallurgical specimens, and chemically reactive fuel components. The HIC is intended to act as a substitute cladding for the spent nuclear fuel, further isolate problematic materials, provide a long-term corrosion barrier, and add an extra internal pressure barrier to the waste package. The HIC will also delay potential fission product release and maintain geometry control for extended periods of time. For the entire disposal package to be licensed by the Nuclear Regulatory Commission, a HIC must effectively eliminate the disposal problems associated with problem SNF including the release of radioactive and/or reactive material and over pressurization of the HIC due to chemical reactions within the can. Two HICs were analyzed to envelop a range of can lengths between 42 and 101 inches. Using Abacus software, the HIC's were analyzed for end, side, and corner drops. Hastelloy C-22 was chosen based upon structural integrity, corrosion resistance, and neutron absorption properties.

**INTRODUCTION AND BACKGROUND**

Within the Department of Energy (DOE) complex there is a need for a small diameter, high integrity dry spent fuel-repackaging can (HIC).

Two groups within the DOE complex have an identified need for the HIC and have been working toward its development. These groups are the DOE National Spent Nuclear Fuel Program (NSNFP) and the Idaho National Engineering and Environmental Laboratory (INEEL) Spent Nuclear Fuel (SNF) program.

The NSNFP desires a HIC to encapsulate damaged or degraded spent fuel for storage at the Monitored Geologic Repository (MGR). The HIC will minimize the need for characterization will be very corrosion resistant.

The HIC is needed by the INEEL SNF Program, which is actively accepting repackaged spent fuel. Fuel is received in a variety of repackaging cans and put in interim dry storage at the INEEL's Irradiated Fuel Storage Facility (IFSF). The cans, made primarily of stainless steel, are various sizes and shapes, and have various lifting features and closure mechanisms.

Each individual facility that ships spent fuel to the INEEL must meet the INEEL fuel receipt criteria (Ref.1). From this criteria a variety of spent fuel repackaging cans have evolved, each of which must be reviewed and approved by the INEEL. This has resulting in a long review and approval process.

The HIC will help expedite this process for the INEEL because it will be offered to all facilities as a "pre-approved" INEEL can with a screw type closure lid. The costs associated with the review and approval of many different designs will be avoided.

Eventually all spent fuel currently stored at the INEEL IFSF will be moved to the MGR. Spent fuel in the HIC will not have to be repackaged prior to shipment, thus avoiding repackaging costs.

Should the spent fuel in the HIC need to be inspected before to shipment to the MGR, the screw top design of the HIC allows it to be re-opened. Prior to shipment to the MGR, the HIC will be welded shut. The HIC will be fabricated from Hastelloy C-22 and is expected to meet or exceed MGR storage requirements.

## **SCOPE**

This paper will discuss the functions of the HIC, the current design status, design features, upcoming challenges, user responsibilities, cost estimates, and conclusions.

## **HIC FUNCTIONS**

The HIC has several functions. It will be used to repackage dry spent fuel at various DOE sites. It is not considered an integral part of the transport package because the transport package configuration is not known (and may vary from shipment to shipment). Transport packages must protect the HIC, unless additional analyses are done which qualify the HIC as part of the transport system. The HIC will also function as part of an interim storage container (in the INEEL IFSF) and as an inner container (within a short, 18 inch diameter DOE Standardized Canister, Ref. 1) for transport to the Repository Surface Facility (RSF) located at the Monitored Geologic Repository (MGR).

At the MGR, the HIC, contained within the Standardized Canister, will be placed in the dry storage system. At this point, the HIC becomes a component of the dry storage package within the MGR. For long-term repository use, the HIC will help maintain fuel in its configuration and provide some neutron absorption to help mitigate a criticality (along with spacing and loading) within the Standardized Canister. The HIC will also perform as a long-term corrosion barrier at the MGR due to the high corrosion resistance of Hastelloy C-22.

At the IFSF or the RSF (within the DOE Standardized Canister), the HIC must meet handling and potential drop requirements. The drop scenarios at other DOE facilities will either be enveloped by the limits given in the HIC Design Input Document (Ref. 2) or controlled to within limits of the design input.

## **CURRENT STATUS OF DESIGN DOCUMENTS, REVIEWS, AND TESTING**

### **Completed Documents**

Many documents have been completed in support of the HIC design. Some of the documents are briefly discussed below.

The Design-Input Document for the HIC (which is essentially a design specification) has been written. Many DOE sites, including the MGR, and others have reviewed it. The document has been approved by the DOE NSNFP.

Based on the Design-Input Document, extensive structural analysis (Ref. 3) was performed using I-DEAS (for modeling) and ABACUS (linear/non-linear analysis) software. Analytically, the HIC met or exceeded all design input requirements. A large portion of the analysis consisted of drop calculations.

ASME Section III, Division 3, calculations were also completed for the specified static load conditions. As specified in Design Input Document, the HIC meets the specified design pressure of 250psi.

Criticality calculations (Ref. 4) were performed using deflected shapes from the drop analyses. The HIC was determined to be critically safe alone or arranged in the standard canister (U235 loading of 20.9 g/in or U239 loading of 11.8 g/in.) with 6 HIC's nested in a standard canister around a central empty can).

Software verification and validation reports were completed to meet DOE quality requirements (Ref.5). These reports were completed for ABACUS and I-DEAS, as well as for the criticality software.

A HIC materials selection report specifying the use of Hastelloy and a cost estimate were also completed as part of the design package (Ref. 6 and 7).

A set of envelope drawings was produced to show the overall design features of the HIC and an inspection/weld review document is currently being completed.

### **Design Review and Testing Status**

External design reviews and an independent internal review have been completed. Comments resulting from these reviews have been or are being incorporated.

The HIC is undergoing testing to assure that the mechanical seal system performs as desired. Preliminary tests indicated that the metallic seals were not performing as intended. These seal problems are being resolved (seal surface polishing).

The remote operability of the HIC, using standard remote manipulators, will also be checked. Thread galling of Hastelloy on Hastelloy is also a concern. However, preliminary testing at low torque values indicates that galling will not be a problem.

Additionally, drop testing mock-up HICs is anticipated to be performed in the future to further validate analysis results.

## **HIC DESIGN FEATURES**

The general HIC features are discussed below; followed by a detailed discussion of specific features and desired operational aspects.

### **General**

The HIC will be constructed of Hastelloy C-22, has an outside diameter of 5.375in. (136.5mm), within a minimum inside diameter of 4.375in. (111.1mm). The overall HIC dimensions range from 42in. to 101in. (1.07 to 2.57m). Inside HIC dimensions are 36 to 95 inches (0.914 to 2.41 m). These dimensions encompass all spent DOE fuels anticipated to be repackaged (See Fig. 1).

The HIC will have a removable screw-on lid. The lid allows for relatively easy inspection and/or repackaging at a variety of facilities. The lid has a mechanical seal for confinement of spent nuclear fuel (to meet INEEL criteria, Ref. 8). The HIC can be opened, if needed, for later inspection at the IFSF. The HIC lid will be welded shut prior to shipment to the MGR. If the HIC spent fuel needs to be purged with an inert gas, a "purge" lid will be added at the IFSF and welded shut.

### **Specific Criteria**

**Lifting Fixture.** The HIC's lifting fixture meets the DOE Hoisting and Rigging Standard (minimum factor of safety of 5:1 with respect to the materials' ultimate tensile strength and 3:1 with respect to the materials' yield tensile strength). It is

relatively short and designed to be engaged by a hook or lifting tool.

**Design Pressure.** The pressure design meets the requirements of the ASME Boiler and Pressure Vessel Code Section III, Division 3 (static loading conditions only). The Maximum (internal) Normal In-Plant handling Pressure (MNIP) is 250 psig. The Maximum Normal Operating Pressure (MNOP) is 211 psig. These pressure requirements allow the HIC to be used for temporary management of SNF that is essentially dry but containing some very small amounts of water.

The HIC design also meets a maximum external design pressure (occurring during the IFSF drying operation, if needed) of 14.7 psig with zero internal pressure. During this process there will be a gradual increase in temperature from ambient temperature to 572 °F. Note that in actual use, the HIC lid will be removed or loosened prior to drying.

**Stacking and Storage Loads.** The HIC design meets the allowable stress requirements of ASME Section III for loads encountered while the HICs are stored in a cask, in an IFSF canister, or in a DOE Standardized Canister (within a basket, bucket, loading guide, etc). A minimum stacking arrangement (load) of 3 tiers of HICs was considered the basis for IFSF storage.

**Shipping Requirements.** For this design effort, the HIC was not considered part of the transport package.

**Seismic Requirements.** IFSF facility: The HIC meets performance category PC-3 as defined by DOE STD 1020 and the INEEL site-specific criteria (Ref. 10 and 11). The HIC maintains its geometry when subjected to an earthquake in the IFSF storage facility.

Other facilities: Other facilities using the HIC for interim storage must assure that the loads imposed from their seismic criteria produce loads on the HIC which are equal to or less than the loads imposed by PC-3 at the IFSF. Alternatively, the loads imposed on the HIC shall be recalculated and reviewed to determine if acceptable.

**Drop Analysis.** The HIC was analyzed and has successfully passed the following criteria. The selected bounding drop scenarios are divided into three categories: IFSF interim storage, Repository Surface Facility (RSF), and Other Drops. Each of these drop calculation categories was performed with and without the 250 psig specified design pressure. Temperatures for the drops were between -20 °F to 100 °F.

- **IFSF Drops (HIC Lid screwed shut)**

An individual HIC was successfully analyzed and has passed the criteria for the worst vertical drop accident (top, bottom, side, top edge, and bottom edge) from a 30ft.(9.14m) height. Fuel confinement was ensured within the HIC interior cavity by limiting crack width openings to no greater than 0.05in (1.27mm). Note that material failure, which does not compromise fuel confinement, was allowed. Any material shown to reach the full ASTM ultimate strain was considered to have failed. Current INEEL practice graphically connects (in a straight line) the

material strength from the ASTM value at 67% of ultimate strain to zero material strength at 100% ultimate strain.

- **RSF Drops (HIC Lid welded in place)**

The HIC (placed six to a layer around a central "empty" HIC in the DOE Standardized Canister), was successfully analyzed and has passed the criteria for the case where the DOE Standardized Canister is dropped horizontally from a height of 30ft (9.14m). Fuel containment was ensured within the HIC interior cavity by allowing no material cracks. This calculation helps assure that the HIC will survive a Standardized Canister drop with or without the DOE Standardized Canister being in a cask. See note regarding current INEEL analysis practice in previous paragraph. Note that deformed can shapes were considered by Criticality Safety personnel in their analyses.

- **Other Drops (HIC Lid Welded)**

The HIC was successfully analyzed for other drops. Dropping the HIC horizontally from 17ft (5.18m) onto a blunt (1/2in or 12.7mm wide by 3in or 76.2mm tall) edge. This simulates dropping a HIC onto an object such as a brace holding up a DOE Standardized Canister. Another drop scenario considered was dropping the HIC (vertically) onto another HIC from 30ft (9.14m). Lastly, a case was considered for dropping a HIC vertically 30ft (9.14m) to determine if a ½ in (12.7mm) square object is able to penetrate the base of the can.

**Materials.** The HIC will be constructed of Hastelloy C-22 (Ref. 6 & 9). Note that the HIC, although specified to meet ASME Section III Division 3 criteria, uses material which is not currently specified for this section of the ASME code (but is expected to be approved).

**Mechanical**

**HIC Lid.** The HIC top is a removable screw-on design with a mechanical c-ring type seal. The seal is Hastelloy and is coated with silver for a minimum of 50 years under interim storage conditions including radiation, pressure and temperature. The HIC lid incorporates features that allow it to be gripped, closed and sealed, and removed (and exchanged with a helium purge lid) in the future at interim storage facilities such as the IFSF. The lid will be remotely welded shut prior to shipment to the MGR.

The lid is flush with the HIC body outside diameter; inside the HIC, the transition from the lid to the body is tapered to facilitate loading and unloading contents.

**HIC Envelope Testing.** For normal (non-accident) operations, the HIC envelope testing requirements are as follows. The HIC must withstand hydrostatic pressure testing to 1.50 times the design pressure at standard temperature and pressure (STP) and the HIC envelope must be tested to assure a leak rate of no greater than  $10^{-4}$  cm<sup>3</sup>/sec STP (external) using helium at the design pressure.

**General Process Requirements**

The HIC user will specify their required length (between a 36in [0.914m] length and a 95in [2.14m] interior cavity length) to fit the "short" 18in (457mm) diameter DOE Standardized

Canister length), considering the lengths of the IFSF canister and the DOE Standardized Canister.

For stacking purposes, when the HIC lengths are chosen, the lengths shall be optimized for stacking in the DOE Standardized Canister

**Weight/Loading Considerations.** The design of the HIC considered the total weight of the DOE Standardized Canister and contents limit of 5005 lb. The design also considered the weight limit of the IFSF canisters of 2000 lbs.

The HIC was designed for an internal contents weight of 4.7lb./inch (84g/mm), or roughly equivalent to a solid steel 4in (101.6mm) diameter bar. For example, a 36in (.914m) internal length can has a capacity of approximately 170lbs (7.7kg).

**Can Surface Finish.** The surface finish for the HIC material is the standard finish from the mill for Hastelloy C-22.

**Marking Requirements.** Each HIC will be marked with a unique number specified by the NSNFP and shall be shown on the fabrication drawings.

**Corrosion and Design Life Requirements.** Hastelloy C-22 shows virtually no general corrosion or pitting of concern in extended testing using expected repository water compositions (Ref. 9).

The design life for interim storage is 50 years; the design life for MGR storage is 300 years (Ref. 3).

**Temperature, Humidity Conditions.** The analyses considered conditions at the IFSF for interim storage and canning.

At IFSF (Interim Storage) the environment is ambient desert conditions in a dry storage environment, where temperature and humidity extremes range from -20 to 100°F, and 10 to 100 percent relative humidity, respectively.

At the IFSF Canning Station, should the HIC contents require drying in the IFSF Fuel Canning Station, the mechanically sealed HIC lid will be removed or loosened. The maximum temperature (gradually applied) in the canning station is 572°F (300° C). A maximum change of temperature, through the can wall thickness, of 100°F, for one drying cycle was used for design/analysis purposes.

The HIC considered the design temperatures of the DOE Standardized Canister. The maximum design temperature of the Standardized Canister is 350°F (in calm air) and 650°F when inside another container (Ref. 2).

The maximum anticipated heat loading from the hottest fuel is 4.25 watts/inch.

It is important to note that all temperature change cycles were applied gradually. No extreme or rapid temperature changes are expected. For thermal and stress analysis purposes the following was used: 20 cycles with the design pressure and a maximum change in temperature, through the wall thickness, of 75°F.

**Radiation.** For design purposes, the HIC considered nominal radiation fields of 1500 R/hr (for the life of the HIC), which is not a concern for Hastelloy.

## **CHALLENGES**

Additional work will be performed to finalize the design. Issues remain concerning remote welding and inspection,

remote operability, seal effectiveness, galling, drop testing, and pressure testing.

Originally the Design Input Document specified that the final closure weld (for the repository) would be remotely welded with continuous visual inspection (with no volumetric inspection). This was deemed necessary because of the difficulties involved with radiographing welds with spent fuel in a HIC. However it is extremely unlikely that this would be acceptable to the ASME. Ultrasonic inspection is being developed at the INEEL as an option for inspecting final closure welds.

Remote use and operability of the HIC was considered during design. These features will be tested prior to finalizing the can design.

Further testing will be performed to test the metallic seal effectiveness. Currently the seal and/or sealing surfaces are not providing the seal desired.

Testing to determine the torque necessary to seal the pressure lid will be performed. Friction and galling of the Hastelloy will be addressed. Preliminary testing indicates that galling will not be a concern at lower torque values.

Actual drop testing of HIC's is anticipated to be performed to validate analyses. HIC's from 42 inches to 101 inches are expected to be dropped.

Pressure testing of the vessels must be addressed. Vessels that contain spent fuel and then are welded shut and pressure tested pose a hazard should they fail.

Lastly, because the HIC will be an ASME pressure vessel, and will be fabricated and stamped as such, there is a challenge to address who will be responsible for, and who will perform the final closure weld. The HIC may be in interim storage for a number of years before this final weld is made.

## **HIC USER RESPONSIBILITIES**

The HIC user must understand the design parameters of the can and demonstrate that these parameters are met. For example, the maximum expected pressure generated from the can contents must be shown to be less than the can pressure limit. The HIC user must also select the desired can length for their fuel

## **COST ESTIMATES**

Cost estimates (Ref.7) have been completed assuming 1000 HIC's will be fabricated and are summarized below.

- ASME Code Certified, Hastelloy C-22 material: \$5173 ea.
- Non-ASME Code Certified, Hastelloy C-22: \$4793 ea.
- ASME Code Certified, 316L Stainless steel: \$2298 ea.
- Non-ASME Code Certified, 316L Stainless Steel: \$2099 ea.

These estimates assume a die set for 5.38in (136.53mm) diameter seamless tube is purchased by the NSNFP program and used for all tubing fabrication. Costs may be considerably less for a rolled and welded plate product.

## **CONCLUSIONS**

The HIC is expected to fulfill many functions. It will act as cladding for defective spent fuel, and will be physically very strong and corrosion resistant. It will be able to be mechanically sealed for transport to interim storage. The HIC will be able to be opened (should the spent fuel need to be re-inspected) prior to shipment to the MGR. The HIC can be welded shut and will withstand pressures up to 250psi.

Additionally, the HIC will be fabricated and certified as an ASME pressure vessel. The Hastelloy material and ASME certification/fabrication will also assure that the HIC will be suitable for long term repository storage, avoiding repackaging costs.

The HIC is not part of the transport package unless a shipper/cask owner decides to qualify the HIC for this function. The extensive analyses performed to date will help such an effort.

The HIC will meet the needs of the NSNFP, which is final repository disposal, and the needs of the INEEL SNF program, which are relatively easy can acceptance and interim storage.

The DOE at the INEEL is not an ASME stamp holder. The design documents generated (specifically the Design Input Document, Analysis, Envelope Drawings) would serve as the basis for direction to an ASME Design Owner. The Design Owner would cause the design to be developed, obtain a Certificate of Compliance, and demonstrate the adequacy of the containment system. At some point in time, the DOE may or may not become the Design Owner. Again, the extensive analyses and testing described herein is expected to significantly help such an effort.

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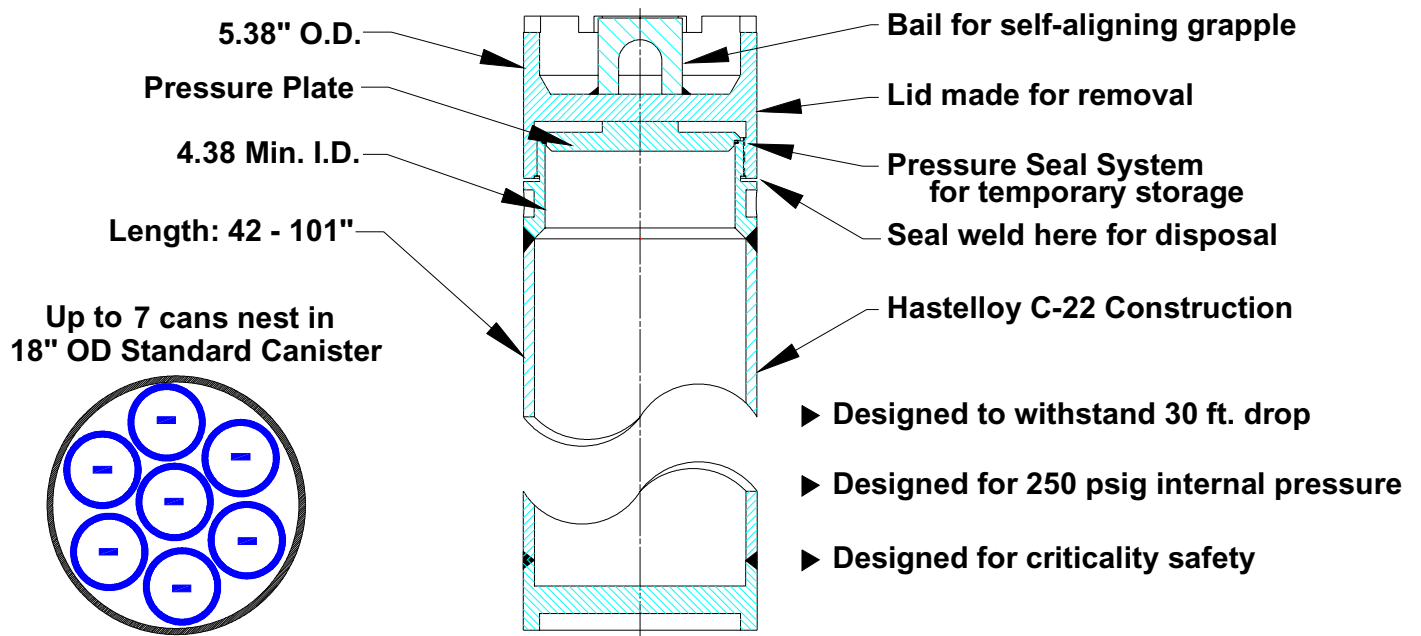


Figure 1  
High Integrity Can Cross Section