The Multi-Purpose Canister: A Bulwark of Safety in the Post-9/11 Age

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Abstract–*A structurally competent all-welded canister made of corrosion resistant alloys that is equally suitable for on-the-pad storage, for long distance transport and for long-term storage in a repository – the multi-purpose canister – was proposed by the U.S. Department of Energy in the early 1990s to help standardize the packaging of spent nuclear fuel at nuclear power plants. The rise of the MPC has been instrumental in increasing the safety and security of dry storage at ISFSIs around the world. The performance imperatives of the multi-purpose canister (MPC) to satisfy the thermal and structural requirements for storage and transport under federal regulations are presented. In particular, the consequences of incorporating the MPC into cask design, particularly in fortifying the confinement boundary and strengthening the fuel basket, are explained. Analyses performed to evaluate the structural reserve in the MPC against design basis as well as beyond-the-design basis accident events are used to quantify the robustness of a state-of-the-art MPC. Bereft of environmentally fragile materials (such as carbon steel) in its internal or external body and constructed to the highest pedigree of the ASME nuclear code, a modern MPC is shown to be a competent waste package that should be readily stored in the long-term repository without additional processing.*

I. INTRODUCTION

In the early 1990s, the technology for storing and transporting spent nuclear fuel underwent a major change as the notion of the multi-purpose canister (MPC), initially espoused by the Department of Energy (DOE), gained acceptance as a meritorious concept among the cask designers. Before the advent of the MPC, the spent fuel storage systems came in two varieties: (i) the metal cask that contained a fuel basket, and (ii) a ventilated cask with a welded canister containing the fuel basket.

The metal cask genré featured a bolted lid with two concentric gaskets as the sole barrier between the fuel and the external environment. The sealworthiness of a bolted joint, as is well known in the literature [1-4], is severely derated by pressure and temperature cycles. In a cask, situated outdoors, incessant pressure and temperature variations with changing weather and the consequence adverse effect on the joint reliability is unavoidable. Furthermore, because metal casks, in order to be handled by the nuclear plant's crane for fuel loading, were restricted in their weight to 125 tons (max.), which limited their radiation shielding capability. Because of the above shortcomings, the metal casks with "bare" baskets have received limited industry acceptance. Frequent leakage alarms at Dominion's Surry Station (which has the largest metal cask array in the U.S.) have further dampened the industry acceptance of metal casks with "bare" baskets.

The ventilated cask concept relied on a "transfer cask" to fetch the fuel from the fuel pool and, therefore, it was not constrained by the plant's crane capacity and could be made suitably massive to block radiation. The ventilated casks sought to provide a welded confinement barrier against the release of radioactivity to the environment. However, storage-only welded containers used in the ventilated casks were not subject to exacting structural strength requirements by NRC's regulations, resulting in designs that were often guided by economy rather than considerations of structural ruggedness. Use of carbon steel in the fuel basket is an historically recognized example of the consequence of non-rigorous requirements imposed on the storage-only fuel canisters designed and licensed in the pre-MPC era.

The metal cask design requirements until the mid-90s suffered from a similar lack of consistency in criteria and performance expectations, leading to the use of heavy steel forgings (with their poor low-temperature fracture strength properties) and other structurally detrimental design decisions.

The concept of the multi-purpose canister premised on a set of rigorous structural requirements was the first step in elevating the plateau of structural performance of fuel-bearing canisters. These requirements were later codified and reinforced with the publication of well-written NUREGs (such as NUREG-1536) and numerous Interim Staff Guidance documents (ISGs) by the Nuclear Regulatory Commission's Spent Fuel Project Office (SFPO).

The design and functional imperatives of the MPC envisioned by the DOE may be summarized as three discrete requirements, namely, to serve as a competent container for three distinct scenarios: (i) to store fuel on-site under 10CFR Part 72, (ii) to transport fuel under 10CFR71, and (iii) to serve as a high-integrity radiological barrier in the repository. In the post-9/11 age, a fourth mission, namely, serving as a robust barrier against a missile, should be added to the list of the MPCs functional objectives. In fact a case can be made that the ability to maintain radiological confinement under all potential terrorist actions should be a paramount consideration in a storage and transport package design. That the MPC is positioned to excel in meeting the fourth mission is a direct result of the goals set down in the DOE's program a decade ago. It is indeed reasonable to speculate that transportation of spent nuclear fuel under the threat of a terrorist attack in the post-9/11 age would have forced the development of the MPC today, if it had not been developed earlier. Fortunately for the nation's repository program, the U.S. nuclear plants have been increasingly using MPCs to package their fuel for (presumably short-term) storage at on-site ISFSIs, which hardens the storage facility as well as the transport package against fire, missiles, projectiles, and the like. The benefits of the MPC technology, however, have come about because of the significant change that it demanded on the art and science of cask design. To appreciate the significance of the consequences of the MPC concept on the physical embodiment of casks, we begin by discussing the design repercussions stemming from the multi-purpose canister concept.

II. EFFECTS OF THE MPC CONCEPT ON CASK DESIGN

The MPC concept seeks to make the waste package an autonomous component by housing it in a cylindrical pressure vessel. The cylindrical vessel with the fuel basket installed in it constitutes the multi-purpose canister. We refer to the cylindrical pressure vessel surrounding the fuel basket as the "Enclosure Vessel". The Enclosure Vessel must be a high integrity container with absolute assurance that its internal environment is hermetically isolated from the external environment. In most contemporary MPC designs, this design objective is achieved by designing the Enclosure Vessel as an all-welded ASME Section III Class 1 pressure vessel [5] with a stipulated "design pressure" and by ensuring that there are no flanged or screwed joints (penetration of the pressure boundary). The requirement of an impregnable encapsulation of the fuel basket through the means of an all-welded Enclosure Vessel is central to the concept of the multi-purpose canister.

The role of the fuel basket within the MPC design remains unchanged from its classical function. The fuel basket is equipped with vertical cell openings (also called "fuel cavities"), each one of which holds one spent nuclear fuel assembly. The storage cells are suitably "poisoned" to ensure that the stored fuel array will remain subcritical ($k_{eff} < 0.95$) under the most adverse conditions. Even though the MPC is engineered to be an unbreachable barrier, the criticality analysis is predicated on the assumption that the canister is filled with water at a temperature to produce optimal reactivity moderation. All manufacturing tolerances, biases, and uncertainties are also assumed to aggregate in the most adverse manner, defying the expectations of classical statistics, to maximize the margin for criticality safety.

Ideally, one would weld the fuel basket to the Enclosure Vessel to realize maximum structural rigidity. However, thermal stress considerations intrude to make any physical connection between the Enclosure Vessel and the fuel basket unacceptable. The decay heat generated by the fuel assemblies produces considerable thermal expansion in the basket. The basket must be free to expand radially and axially, else the thermal stresses will reach unacceptably high levels. Inasmuch as the ASME Code categorizes thermal stresses due to "constraint of free-end expansion" as primary stresses, a constrained basket (welded to the Enclosure Vessel) is a non-starter as a design concept. The fuel basket, in short, must be physically decoupled from the Enclosure Vessel. In other words, in an MPC concept-based dry storage system, a physical gap must exist between the fuel basket and the Enclosure Vessel as well as between the MPC and the overpack inner surface. (The massive structural weldment that absorbs the neutron and gamma fluxes emanating from the fuel in the MPC is referred to as the "overpack".) The gap between the overpack and the MPC must be large enough such that any MPC out of a large number manufactured would fit into any overpack within a like population of overpacks. Inasmuch as the MPC and the overpack are both fabricated components, the effects of weld-induced camber, bow, twist, and machining tolerances, must figure in prescribing the nominal MPC/overpack gap.

To summarize, the incorporation of the MPC concept in the cask design has two geometric consequences: (i) The fuel basket is isolated from the cask (overpack) through a high integrity pressure vessel (the Enclosure Vessel). Physical gaps between the fuel basket and the EV and between the EV and the cask inner surface are introduced, and (ii) The MPC-to-overpack gap must be large enough that all MPCs and overpacks can be assembled in interchangeable combinations.

The above-mentioned, unavoidable gaps are the chief distinguishing features of an MPC-based system. These gaps alter the physics of the thermal and structural problem in the cask design/analysis in a profound manner, as we discuss later in this paper.

III. THE MPC ENCLOSURE VESSEL

The Enclosure Vessel (EV) in the MPC serves as the guarantor of leaktightness. The EV is a cylindrical pressure vessel with flat bottom (baseplate) and top (top lid) closures. The EV is designed and manufactured as an open-ended container (the top lid is installed after the fuel is loaded) to the highest pedigree of the ASME Code [5]. The top lid is typically a thick stainless plate or forging stock, also manufactured to the quality requirements of [5]. The top lid is joined to the shell through a "J" or "V" groove joint. Figure 1 shows the essentials of the EV design used in Holtec International's HI-STAR/HI-STORM MPCs. The joint between the shell and the baseplate, and the seams internal to the EV shell, are all full penetration, volumetrically examined welds as required by [5]. The top lid-to-shell joint, on the other hand, is a partial penetration weld that, because of the limitations in the state-of-the-art of volumetric imaging technology for austenitic stainless steel, can only be inspected using surface flaw detection methods (viz., liquid penetrant examination). Although NRC regulations require multiple (staged) liquid penetrant examination of the lid-to-shell weld mass [6-11], the absence of the means to perform volumetric examination on a gross structural discontinuity renders the top lid-to-shell joint structurally the most vulnerable location in the MPC EV. To compensate for this perceived vulnerability, a secondary lid is provided (not shown in Figure 1) that serves as a second independent barrier against leakage.

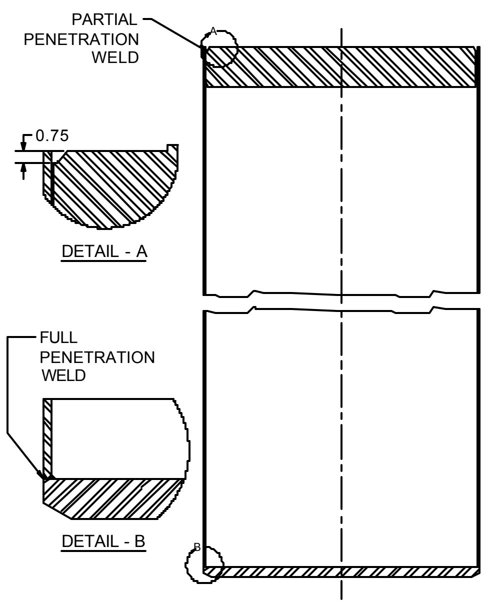

FIG 1; GEOMETRY OF THE HOLTEC INTERNATIONAL MPC ENCLOSURE VESSEL

The EV serves all of the four vital functions required of an MPC mentioned in the foregoing: (i) As a high integrity pressure vessel capable of withstanding the maximum possible internal pressure that can develop during its operation (the maximum internal pressure would be produced if all of the fuel rods in the MPC are assumed to be breached), liberating all of the plenum gas contained in the fuel claddings; (ii) As a structurally competent pressure vessel capable of meeting the Code stress limits under postulated mechanical accident events of 10CFR72 (storage) and 10CFR71 (transport) [12]; (iii) As a leaktight enclosure for maintaining fuel confinement when subject to large impactive or impulsive loads (Design Basis Threat (DBT) loadings); and, (iv) As a thermal barrier to retard the inflow of heat to the stored fuel during a fire event.

IV. EVOLUTION OF FUEL BASKET DESIGNS FOR APPLICATION IN THE MPC

In essence, a fuel basket is an assemblage of square prismatic cavities arrayed in a grid. The basket designs used in the industry can be placed in three discrete categories, namely: (i) the box-and-disk (B&D design originally developed in the 1970s [13]), (ii) the patented plug welded box (PWB) design [14]; and (iii) the coplanar cell wall honeycomb (Holtec patented) design [15,16].

From the designer's standpoint an MPC fuel basket must be structurally capable of withstanding the Part 71 and Part 72 loadings and must overcome the "thermal problem" induced by the gaps (discussed before), that is intrinsic to the MPC design.

The thermal problem in a cask consists of rejecting the decay heat produced by the spent nuclear fuel such that the temperature of the fuel cladding remains below the threshold value at which long-term temperature effects would not degrade the cladding. Elementary heat transfer instructs us that for a given ambient temperature, the temperature of the fuel cladding would rise as the resistance in the path of heat transmission is increased. Recognizing that the resistance to conductive heat transfer offered by a 1-inch gap filled with air is equal to nearly 2,000 inches of steel, it is quite apparent that introducing even a small gap (say, 0.25 inch), would greatly magnify the thermal resistance to heat transmission. In other words, the gaps exacerbate the thermal performance of a cask in a most direct and significant manner.

In the pre-MPC era, the cask designer was able to persuade himself that the basket-to-cask gap would be closed or greatly diminished by a tight manufacturing tolerance and by the thermal growth of the basket during operation. The only location where a designer had to contend with an undiminished physical gap was the spacing between the stored fuel and the storage cell cavity.

The assumed absence of a serious gap barrier elsewhere in the cask enabled the designers to utilize the so-called "box-and-disk" design described in [13]. In this design, each storage cell is defined by a box; an array of boxes is arranged in a square grid pattern maintained by a number of transverse discs. Square holes burned in the discs provide lateral support to the boxes; an array of discs reduce the unsupported longitudinal span of the boxes and provide the path of heat transmission to the overpack. The designers often utilized a strong, but poor, heat conductor alloy material such as SA240-304 S/S, and highly conductive, but weak, aluminum discs in an alternating pattern to respectively provide structural support and heat transfer path.

In addition to its poor heat transmission characteristics, caused by the extensive gaps between the boxes and the discs, the B&D basket lacks the structural ruggedness required of an MPC because of the absence of a physical connectivity between the boxes that would strengthen the assemblage. The plug-welded basket [14], extensively utilized by the Transnuclear Company [17], makes an improvement in this respect by making the basket from a box assemblage wherein boxes are attached to each other through a number of tungsten fusion welds in the shape of a "dime". The neutron absorber panel is sandwiched between facing walls of the boxes. A patented fusion welder process connects the cylindrical stainless stub to the box panels at its two extremities. This process is said to produce typically 1/2 inch diameter "nuggets" with shear strength on the order of 3,000 psi. A review of previous topical safety analysis reports available in the public domain indicates that in PWR baskets two plug welds, transverse to the box, are made with approximately 5-inch spacing. The pair of plug welds is made every 8 to 10 inches along the box length [17]. In all, less than 2.5% of the facing surfaces of the boxes are joined together by welding.

In addition to a weak box-to-box connectivity, the PWB design, however, has other drawbacks that limit its thermal and structural capacity during a drop event. For example, (i) The rounded corners of the boxes cannot be practically supported and, therefore, must transfer the load from the box above through cantilever action during a horizontal drop event. The greater the box corner radius, the greater is the cantilever arm and the associated bending moment; (ii) The plug welds must withstand lateral shear and bending as the adjacent box walls tend to bend under the fuel loading under a horizontal or oblique drop event; and (iii) The potential for gaps in surface-to-surface contact between the boxes, with only the plug welds providing metallic connectivity, make the resistance to the transmission of heat across the boxes mathematically uncertain.

The internal gap within the basket (thermal problem) and structural ruggedness issues germane to their use in MPCs are reconciled in the coplanar cell wall honeycomb basket design [15,16] used in all Holtec MPCs (Figure 2). The Holtec honeycomb basket illustrated in Figure 2 has the following essential attributes: (i) The storage cells are connected to adjacent cells at all common corners; (ii) The cells' walls are completely coplanar, i.e., there is no offset between the walls of the successive cells; (iii) The neutron absorber is removed from the load path, eliminating the potential of damage to the neutron absorber during lateral impact events; and (iv) There is no "corner radius" at cell corners. The corner radii in the boxes in the PWB design, as we stated earlier, is the central cause for high stresses in the box walls under lateral impact events.

In summary, the fuel basket design for use in an MPC must have a high structural rigidity and should minimize internal gaps that reduce its heat transfer capability. Because the mechanical accident events can load an MPC in any conceivable direction, the fuel basket must possess high structural strength with respect to all loading directions (axial, oblique, and lateral). The only means to accomplish the requisite structural strength is to maximize the extent of the connection between the contiguous storage cells through welding.

V. ENCLOSURE VESSEL INTEGRITY UNDER HYPOTHETICAL ACCIDENT EVENTS

As mentioned in the foregoing, the lid-to-shell (LTS) weld, which is of the "partial penetration" type, is the most vulnerable location in the Enclosure Vessel confinement boundary. We shall evaluate the ruggedness of the LTS weld under two hypothetical accident scenarios, which we label as (a) bottom down drop, and (b) top down drop scenarios, respectively. In both cases, the fall is assumed to occur pursuant to 10CFR71 from 9 meters onto an essentially rigid surface; the fall of the cask is cushioned by a suitably engineered impact limiter, which limits the inertial acceleration to 60g's.

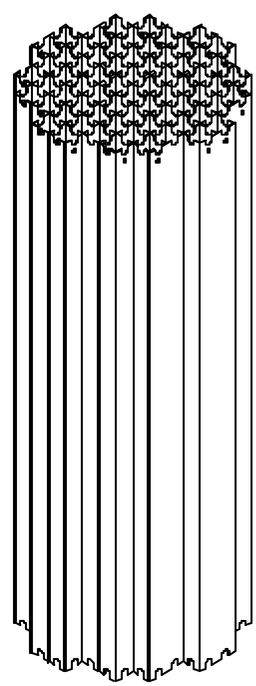

FIG 2; HOLTEC MPC FUEL BASKET
(FOR BWR SNF)

Recognizing that the Holtec MPC lid is quite thick, it is readily deduced that the most likely fracture failure mode for the LTS weld is through shear failure, formally known as the Mode II crack propagation in the fracture mechanics literature. We should, therefore, assume a flaw shape and configuration that would synergize with the Mode II failure model. The shape of the weld joint and the nature of the applied loading (axial) indicates that the flaw should be assumed to be rectangular with sharp corners, oriented with its long side parallel to the MPC shell axis. Further, we assume that the flaw extends 360 degrees circumferentially, i.e., it is seamless. Such an adversely oriented cylindrical flaw, albeit entirely hypothetical, helps maximize the potential for crack growth. Finally, we will assume that the flaw is 50% of the height of the weld, i.e., a = 0.375" (the weld, as shown in Figure 1, is 0.75" deep; b = 0.75").

Our object in this analysis is to compute the margin of safety against through-thickness crack propagation under τ using principles of Linear Fracture mechanics. A critical flaw size is assumed to exist if the Stress Intensity Factor (SIF) equals the materials' fracture toughness.

In the bottom down drop, the MPC lid, magnified to 60 times its dead weight, W_L, would tend to shear the LTS weld. This case, using the data for Holtec MPC presented in Table I, is found to result in a shear stress of 4,717 psi (by assuming conservatively that "lugs" directly underneath the lid do not provide any resistance).

The "top down" drop, in principle, would produce little shear stress in the LTS weld, because of the "hard" support surface provided by the overpack lid forging. However, to bound the problem, we will assume that the weight of the MPC shell and MPC baseplate magnified by 60g's will act to shear the MPC shell past the lid. Conservatively ignoring the mitigating effect of internal pressure, the shear stress, τ, in this event is computed by using the Table I data as 26,331 psi. Thus, the top down drop event is governing.

In computing the above value of shear stress, τ, we have completely ignored the support provided by the overpack lid to the MPC lid (a wholly improbable and physically non-credible situation).

For conservatism, we will analyze the consequences of τ on crack propagation for the LTS weld. Moreover, we will further assume the nominal τ to be increased by the ratio (b/a), even though classical fracture mechanics principles do not require the nominal shear stress to be magnified by reason of the flaw. Therefore, the applicable shear stresses for fracture analysis are τ = 52,662 psi (for the 0.75" weld), say 53 ksi.

Fracture toughness of austenitic stainless steel is known to be quite high. According to [18, p. 20-9], the value of Charpy energy, C, at -50°C is well in excess of 130 lb-ft. Therefore, a Charpy impact energy value of 130 ft-lb at -40°F is a most conservative lower bound value. The Charpy value C is related to the fracture toughness K by a relationship of the form [17, p. 300].

$$\left(\frac{K}{s_y}\right)^2 = 5\left(\frac{C}{s_y} - 0.05\right)$$

where:

$K \; is \; ksi\sqrt{inch}$, σ_y is yield stress, ksi, and C is Charpy energy in ft-lb.

Using a conservative value of C = 130, σ_y = 30 (yield strength), we obtain $K = 138.8\, ksi\sqrt{inch}$

To determine the "Stress Intensity Factor", we utilize the solution for a Mode II cracking of a plate width b [19, Table 7.1]. The value of b in our case is the longitudinal dimension of the weld, i.e., 0.75 inch.

Let us assume that the crack is 0.375 inch long, i.e., a = 0.375". The stress intensity factor K_{II} under τ in this configuration is given by

$$K_{II} = t\sqrt{0.5pa}\,F(x)$$

where:

$$F(x) = \{1 - 0.1x^2 + 0.96x^4\}\sqrt{\sec px}$$

$$x = \frac{0.5a}{b} = 0.25$$

τ = 53 ksi

By substituting for x, we obtain; F(x) = 1.186. Then, for τ = 53 ksi, we have K_{II} = 48.3 <<K, i.e., a large margin of safety against crack propagation is indicated (138.8/53 = 2.62).

Table I: Data for LTS Weld Fracture Analysis Under Postulated Drop Events

Shell I.D.	68.375 inch
LTS Weld Groove Depth	0.75 inch
Lid Weight	10,400 lbs.
Design Internal Pressure	100 psi
Weight of Enclosure Shell and Baseplate	8,900 lbs.
Weight of SNF, Fuel Basket and MPC Internals	70,700 lbs

VI. MPC INTEGRITY UNDER A BEYOND-THE-DESIGN BASIS IMPACTIVE EVENT

The ability of the HI-STAR/HI-STORM MPC to withstand a large impactive loading event is evaluated by considering the free fall of a loaded MPC (weight = 90,000 lbs) from an elevation of 25 feet onto an extremely stiff concrete slab (a semi-infinite reinforced concrete space with 6,000 psi minimum compressive strength (concrete)).

The LS-DYNA finite element model developed for simulating the postulated MPC drop event is based on the actual configuration of a representative Holtec MPC Enclosure Vessel design (Figure 1). Only a quarter of the structure is modeled to take advantage of the symmetry. The thick MPC lid is modeled by solid elements with fine grids along the periphery of the lid for capturing the stress concentration at the lid-to-shell weld connection, which is also modeled by solid elements. Shell elements are used to model the relatively thin MPC shell and MPC base plate. The MPC shell is discretized using very fine grids, especially at the connection regions with the lid and the baseplate. The MPC contents, namely, the fuel basket and the stored fuel assemblies, are conservatively modeled as a rigid solid (i.e., no energy dissipation capacity) with a small gap to the MPC shell. The impact target concrete model spans sufficiently far away from the impacted region and the element size in the impacted region are smaller than that of the remote region in order to simulate the expected large gradients. Non-reflecting boundary conditions are applied at proper boundary surfaces of the concrete model to simulate the target as an infinite half-space. The automatic surface-to-surface contact is defined at each of the potential contact interfaces among all modeled components. The concrete material is simulated using the model incorporated within LS-DYNA. Finally, the stainless steel used to manufacture the MPC Enclosure Vessel is modeled as a bi-linear elasto-plastic material with its properties conservatively defined based on the design temperature for each component and with a failure strain established at 0.38. The material behavior of the weld joint is assumed to be the same as the MPC shell material. Table II lists the material properties of the MPC components.

The LS-DYNA model determines the failure of any structure element based on the specified ultimate stress/strain of the material.

Table II: MPC Material Properties

Structural Component	Design Temperature (°F)	Young's Modulus (psi)	Yield Stress (psi)	Ultimate Stress (psi)
Lid	550	2.555×10^7	1.88×10^4	6.33×10^4
Shell	450	2.615×10^7	2.005×10^4	6.4×10^4
Base Plate	440	2.65×10^7	2.07×10^4	6.44×10^4

After undergoing a free fall for 25 feet, the MPC hits the target with an initial impact velocity of 481.5 in/sec, (i.e., $\sqrt{2gH}$, where, g is the gravity acceleration and H is the drop height). The dropped MPC is subject to a peak rigid body deceleration of 695 g's, and starts to bounce back 0.003 seconds after the initial impact with the target. The stress time history results demonstrate that, during the impact process, the MPC Enclosure Vessel experiences a maximum Von Mises stress of 45,994 psi at the lower end of the MPC shell near the baseplate, where the shell is plastically deformed due to local bending. Being consistent with the stress results, the maximum plastic strain occurs at the same location with a peak value of 0.174; the plastic strain distribution result shows that the shell-to-lid region also experiences a less severe plastic deformation. It is important to note that the maximum stress of the MPC Enclosure Vessel is less than the ultimate stress of the material (6.4×10^4 psi), and the maximum plastic strain is only 45.6% of the failure strain. Deformation results of the MPC drop simulation also confirm that no through-wall cracking occurs (Figure 3). Therefore, it can be concluded that the postulated 25' drop accident of a loaded MPC will not result in the breach of MPC confinement.

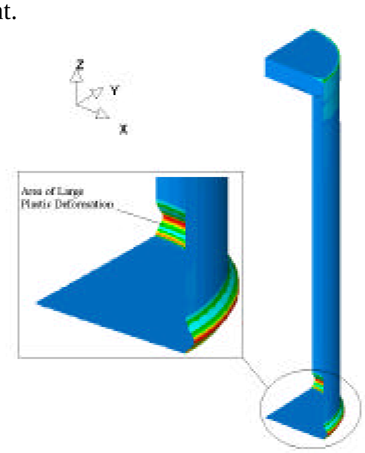

FIG 3 Deformed MPC Enclosure Vessel after a Postulated 25' Vertical Drop Accident

Because MPC handling operations are normally carried out using single-failure-proof devices, free fall of an MPC is not postulated as a design basis accident event in the NRC regulations. The analysis and results presented in the foregoing, therefore, should be viewed as a beyond-the-design basis accident event. The absence of breach of the confinement boundary despite the severity of the drop event (695g maximum deceleration) speaks to the structural robustness of the multi-purpose canister as a pressure retention device.

VII. THREAT OF LOSS OF CONFINEMENT

The USNRC and the Pacific National Laboratories have conducted extensive probabilistic assessment studies to quantify the probability of an Enclosure Vessel leakage. The results of this work, summarized in [20-21], assert that the probability of loss of confinement in an MPC is less than 1E-11. Additional work, conducted using test data collected from a Holtec MPC deployed at a nuclear plant, corroborate the theoretical work. NRC's work in the MPC confinement boundary integrity is expected to culminate in an ISG that would give regulatory imprimatur to the MPC pressure vessel essentially immune to leakage. A formal regulatory acceptance of the MPC's leak tightness would alleviate the burden on the away-from-the-reactor ISFSIs, or ISFSIs at decommissioned plants, by not requiring them to maintain an expensive MPC leak remediation facility.

VIII. CLOSURE

The analyses and evaluations presented in this paper show that a state-of-the-art MPC is a high integrity waste package whose structural ruggedness capabilities, valuable in the post-9/11 age, easily surpass the requirements of 10CFR72 and 71 [12]. Because the Waste Acceptance Criteria for the Yucca Mountain repository have not yet been promulgated, it is not possible to assert that the MPC will meet them. However, in light of its austenitic stainless steel EV, a pressurized inert gas internal environment, absence of degradable internals such as carbon steel, and a substantial structural strength reserve, should suggest that a repackaging of the fuel to create a new waste package would be technically unwarranted and indefensible. DOE's developers of the Waste Acceptance Criteria would be well advised to consider the robustness of the MPC in devising the strategy for interring the nation's SNF in the permanent repository.

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