DEVELOPMENT OF METALLIC HIGH INTEGRITY CONTAINERS

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ABSTRACT

This paper presents the development program for metallic high integrity containers (HIC's). The need for a high strength, thin walled HIC became apparent with the implementation of 10 CFR 61 in late 1983. The existing containers that were in use at that time were made of either low strength material (polyethylene) or bulky, heavy material (concrete). Neither of these materials met the need for a high strength , volume and weight efficient container that could survive the deep burial environment of sites such as Hanford, Washington.

Various alloys were considered for corrosion resistance for a 300 year life, high strength and toughness, and elastic stability to meet the requirements of 10 CFR 61. The alloy allowed for great flexibility in design to accommodate various waste forms. The containers were developed in various sizes with several different closures designed to minimize operator exposure during the loading operation. These design features provide the industry with efficient, disposable packages for a wide variety of waste forms.

The paper describes the analytical methodology and prototype test program. The analytical methods included finite element modeling of the burial conditions, prediction of drop performance, and elastic stability analysis. Prototype testing included leak tests and drop tests at various container orientations from heights of up to 25 feet.

BACKGROUND

A family of metallic High Integrity Containers (HIC's) have been developed for the disposal of low level radioactive waste. These packages (covered by a patent application) meet all regulatory performance criteria and provide an efficient transport package with a minimum of operational constraints.

With the advent of Title 10 Part 61 of the United States Code of Federal Regulations (10 CFR 61), the generator of relatively large volumes of low level radioactive waste has only two choices for disposal: he can either solidify the waste or place the waste in a High Integrity Container (HIC). Both of these options have their drawbacks. Solidification systems that have been "grandfathered" (that is, were qualified prior to 10 CFR 61 being in force) inherit a variety of practical and economic problems, such as processing difficulty, low transportation efficiency, and uncertainty of the quality of the solidified product. The existing high integrity containers also include some problems. The polyethylene containers used extensively at the Barnwell, South Carolina disposal site have relatively low strength, are very susceptible to damage from chemicals and still have less than optimum transport efficiency. High Integrity Containers fabricated from steel and concrete suffer the same poor transport efficiency as the solidification systems, although they are probably less susceptible to chemical degradation than polyethylene.

The polyethylene containers, like any product made from polymeric materials, are very susceptible to degradation from other organic compounds. Organic solvents are difficult to detect and even more difficult to quantify. Adding to the confusion, in many cases it is not knowing how much a particular organic compound will weaken the container over its full design life. The only operationally clean solution to this is to exclude all chemicals that are known to cause any damage. This puts a significant burden on the user to control a wide variety of difficult to detect chemicals.

The transportation efficiencies of a package, defined by the ratios of the net volume to the gross volume and the net weight to the gross weight, are critical to the economics of HIC usage. This is particularly true when the generator of the waste is located far from the disposal site. The usable volume within a transport cask is costly. The lowest total disposal costs may be achieved when this usable volume is filled to the greatest extent possible with actual waste. Likewise, because all transport casks have a payload weight limit, heavy containers as well as solidification media reduce the efficiency when the entire available volume cannot be used to transport waste without exceeding regulatory weight limits on the cask. HIC's of shapes other than right cylinders (such as domed containers, etc.) are especially hard on the transportation efficiency.

DEVELOPMENT

Because of these constraints, as well as the regulatory requirements of a 300 year life, the ability to withstand drop events, the ability to withstand burial environments up to depths of 45 feet, and positive closure, a program was put together to develop a better family of containers using a more suitable material, if one could be found. Several materials were examined. Ceramics were rejected because of impact properties and their inability to resist bending loads. Plastics were rejected due to the chemical constraints that would have to be placed on the container. Concrete was rejected due to the thickness and weight requirements of that material, which destroy the transportation efficiencies previously mentioned.

It was felt that a metallic HIC held the greatest potential for providing an efficient container. A metal container would be ductile enough to survive the various impacts. It could be fabricated into any shape or configuration required with sufficient strength to withstand the burial load. A highly efficient container could be designed due to the high strength to weight ratio of the material. The biggest problem associated with a metallic container would be corrosion resistance.

Most people who have had experience with rusting steel might consider a 300 year design life unattainable. Yet there are many cases of buried metallic items surviving that period of time and being recovered, especially in dry environments such as deserts. To attempt to solve the corrosion problem, stainless steels were examined. Although they do not have the same kind of generalized corrosion problems as carbon steel, they will still corrode in some environments and are susceptible to pitting, crevice corrosion and stress corrosion cracking. A closer examination demonstrated that these problems were mainly associated with the lower alloy stainless steels such as the 300 and 400 series.

Even within these steels a wide range of corrosion resistance performance exists. The common 304 stainless steels are far more susceptible to all forms of corrosion than 316 stainless. Yet even 316 in many environments has very high corrosion rates and is very susceptible to pitting and crevice corrosion. It also has the difficult characteristic of becoming sensitized and losing much of its corrosion resistance.

These problems have forced the development of highly corrosion resistant alloys for service in the pulp and paper industry, the marine industry, the oil industry and the chemical industry where 300 series stainless steels, 316 included, have proven to be inadequate. There are a number of these alloys available today that have high percentages of nickel, molybdenum, chromium and other alloying elements. These are known by such names such as C-276, Alloy 625, Alloy 29-4, and Ferralium Alloy 255. They have been tested in various environments and have demonstrated excellent corrosion resistance. Unfortunately, in most cases these high alloy steels are considerably more expensive than the more common stainless steels. Additionally, many are not available in appropriate forms adaptable HIC fabrication, e.g., plates.

When examining the corrosion resistance of these very high alloy materials, one material, Ferralium Alloy 255, consistently ranked near the top in all corrosion tests and yet was relatively low in alloy content. This patented duplex alloy produced by the Cabot Corporation (under license from Bonar Langly of the United Kingdom) was readily available in various plate sizes. This material, besides having excellent corrosion resistance, had very high strength (80 ksi yield) compared to that of more common stainless steels (20-30 ksi yield). Due to cost considerations many other duplex stainless steels were also investigated. Although many of them were excellent in their respective ways, none of them had the corrosion resistance coupled with the physical properties, strength and impact resistance exhibited by Ferralium Alloy 255.

This material was selected as the key element in the development of the Nuclear Packaging, Inc. Enviralloy series of High Integrity Containers. Extensive examinations of the various waste streams that these containers would be exposed to were performed and compared to the known information on the types of chemicals that would cause corrosion of the Ferralium Alloy 255. This led to a detailed analysis of the corrosive effects of ion-exchange media. The analysis and testing indicated that the corrosiveness of the media could be compared to some of the acids that had previously been tested. Although these medias were extremely corrosive to carbon steel and some stainless steels, it had little affect on Ferralium Alloy 255.

A big advantage to this material is that although similar to materials commonly found in power plants, it is far superior to them in corrosion resistance. Hence, the compounds that could create a problem for this material, strongly acidic solutions with high concentrations of halides (such as chlorides and fluorides) are normally controlled at a plant. Additionally, these conditions are easy to measure and control when compared with controlling the many different organic compounds which affect polyethylene, where there is no simple monitoring methodology.

With the chemical compatibility question answered and an acceptable corrosion thickness determined for the environment the container would see, the physical design was addressed. The design goal was to meet all of the regulatory requirements (drop tests, burial loads, etc.) with the minimum amount of material encompassing the largest possible volume in the shape of a right cylinder. This design goal was accomplished. (see Fig. 1)

Fig. 1. Completed Enviralloy Container.

Because the container geometry is important to the HIC's ability to meet many of the requirements of 10 CFR 61, and therefore only those configurations which have been approved by either the NRC or an Agreement State with a disposal site can be used, it became apparent that it would be beneficial to have an entire family of containers, including in the family all configurations which might have some practical value. Three main configurations were finally settled on, differing only in closure geometry: one with a 24 inch center opening, one with a fully open bolted top, and one with a fully open welded top. Each of these configurations were adapted to both the type A and type B families of Nupac casks. Then, the three main configurations were supplemented with smaller designs, including 55-gallon HIC drums and overpacks for both one and two 55-gallon drums. The fully open welded design was created to act as an overpack for other HIC's or solidified waste that may be unable to meet the requirements of Part 61 due to damage or improper processing.

Because the process of obtaining approval of a HIC design is a very lengthy one, an initial submittal was made with only a single design. This gave the Nuclear Regulatory Commission the opportunity to begin reviewing the container concept, especially the material performance, while the remainder of the family was developed.

A summary of the basic dimensions of the various members of the Enviralloy family is presented in Table I.

TABLE I

Enviralloy Family

	Outside		Weight	
Model	Diameter	Height	Tare	Gross
EA-210	75.25	78.5	3790	20000
EA-190	72.50	73.50	3455	20000
EA-142	64.00	70.25	2475	10000
EA-140	64.00	71.25	2500	15000
EA-7-100	73.50	39.00	2640	13000
EA-6-100	59.00	60.25	2100	12000
EA-50	46.50	50.75	1435	42000
EA-55 gal.	22.75	35.00	270	1400
EA-55 OP	25.50	36.25	340	1060
EA-55 2OP	25.50	71.00	540	2260

To maximize the utilization of the space within the transportation cask cavity, the 24 inch opening version had to be radically different from the fully open version. This design has four internal supports which aid in the support of the top and bottom. The full open versions have stiffeners on the ends which carry the loads to the walls. The center opening version internal supports are positioned and notched to allow for the installation of the Nuclear Packaging dewatering internals. The containers are also designed to allow the use of any approved dewatering process that can be adapted to the geometry of the container.

The design of the containers were analyzed for both the burial loads and the transportation loads. It was determined that the burial loads imposed at disposal sites like Hanford created the controlling design loads. To analyze these loads a finite element model of the container was constructed. This model allowed analysis of both the uncorroded and corroded container as well as detailed analysis of the effects of localized corrosion. In all conditions the containers were analyzed for elastic stability in both the axial and radial directions.

The large containers are designed to be lifted either by lifting slings or remote handling equipment. All of the lifting features meet the regulatory requirement of not exceeding the yield strength of the material when lifting three times the design gross weight.

A very efficient closure has been developed for the 24 in. opening version. This closure can be sealed within one minute manually or by a remote closure device. The seal has been proven through more than 30 days tests, and the container structure has withstood pressure in excess of 150 psig without any plastic deformation.

Although the design and closure structure has been tested to much greater pressures, the usual failure pressure of the seal has been around 60 psig. This is well in the excess of what is required by the regulatory standards. There is very little chance of pressure building up in the container for most waste forms. For those wastes for which there is concern for rapid and high gas generation, an optional vent is available for the lid.

TESTING

Each model of the container that has been put into use has been subjected to a series of prototype tests. This includes pressure testing until failure as well as a series of drop tests. The drop tests include drops from four feet onto an unyielding surface and from 25 feet onto compacted soil. The drop orientations include bottom down, center of gravity over bottom struck corner, side drop, center of gravity over top struck corner, and top down. A total of ten drop tests were performed on each model tested, one at each of the critical orientations from both four feet and from twenty-five feet. The maximum plastic deformation that was recorded was less than one-half inch. In all cases, the tested containers survived the impact events without compromising their continued usefulness as High Integrity Containers. This represents a new level of structural integrity for HIC's. Fig. 2, 3, and 4 demonstrate some of the drop testing performed.

CONCLUSION

A family of metallic High Integrity containers have been developed that meet all of the regulatory requirements and add a stepped increase in efficiency over past methodologies of handling waste. The containers allow for the disposal of a large variety of waste streams with few restrictions on the chemicals that can be disposed in them. These containers are providing the nuclear industry new options for its waste disposal.

Fig. 2. Twenty-Five Foot Flat Bottom Drop.

Fig. 3. Twenty-Five Foot Top Corner Drop.

Fig. 4. Four Foot Top Corner Drop on Unyielding Surface.