HIGH INTEGRITY CONTAINERS

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ABSTRACT

Based on a development program with DOE, KLM Technologies (KLM) has advanced the concept of the high integrity container. The initial HIC concept considered the use of engineered fiberglass to develop a waste package which is explicitly engineered for the waste contained within the package, as well as the conditions experienced by the outside of the packaging. The engineered reinforced fiberglass construction guarantees the long life and integrity of the unit as well as the public safety. KLM has designed, fabricated and successfully tested an engineered fiberglass container that has design qualities that meet or exceed recent design criteria for HICs. Available in 55-gallon to 300 cubic feet designs, high integrity containers can be applied to spill clean-up, radioactive waste transport and disposal, chemical transport, hazardous industrial waste transport and disposal, as well as on-site storage of hazardous and/or toxic materials. This is a technically superior and economically justifiable container to handle low-level radioactive waste and possible Type A and Type B TRU waste from defense, DOE, and commercial waste activities, as well as toxic substance orginating from chemical non-nuclear wastes.

The concept of a "high integrity" container (HIC) has been approved by the Department of Health and Environmental Quality of the State of South Carolina and the Nuclear Regulatory Commission. The objective of the high integrity container is to provide an additional environmental barrier for waste disposed at low-level radioactive waste disposal facilities.

The problem of clean-up, handling, transportation and disposal of hazardous, toxic and radioactive substances is complex and poses many challenges. Radioactive and other hazardous wastes are packaged in various kinds of containers, ranging from 55-gallon (210-liter) drums to large disposable liners having volumes of 50 to 300 cubic feet. The problems with traditional methods of waste disposal are seen every day in the form of container leakage, environmental contamination and litigation.

BACKGROUND

Each of the steps in the nuclear fuel cycle generates radioactive waste (radwaste) products which, because they are radioactive, must be managed in a way that will assure they do not enter the biosphere in amounts and concentrations which can pose a hazard to living things. The problem is formidable and affects a wide spectrum of activities.

In 1976, a KLM principal developed the concept of an improved low-level waste container to be used instead of the mild steel (with its inherent corrosion tendencies) and wooden boxes. Basically, a concept was developed whereby the entire waste package--waste, solidification/immobilization agent, if any, and waste container--would be evaluated as an integrated system and design and mitigation credit given for not only the solidified waste form but also the waste container. In a paper entitled "Is the Steel Drum the Answer?" presented at the "Management of Low-Level Radioactive Waste" symposium held in Atlanta, Georgia, May 23-27, 1977, the predecessor to the "high integrity container" was introduced.

The use of advanced fiberglass material specially engineered to the waste stream and burial environment was suggested. This concept was new and only received interest from several Department of Energy (DOE) facilities. The concept was further developed with an actual design engineered for two DOE facilities.

During the 1970s, some radioactive waste was shipped for burial in the form of liquids or liquids absorbed on a porous medium. This type of packaging is allowed today for only very small quantities of low-activity waste or waste samples; this practice is not allowed for normal power plant wastes. Some wet solid wastes, particularly ion exchange resins, have been shipped by first "dewatering" them (i.e., pumping away all drainable liquid) and then putting them into standard containers. At present (1986) the disposal of dewatered resins is allowed only if they are packaged in a high integrity container (HIC) and satisfy certain criteria.

The concept of a "high integrity" container was subsequently adopted by the Department of Health and Environmental Quality of the State of South Carolina and is encompassed by the U.S. Nuclear Regulatory Commission in 10CFR61. The objective of the high integrity container is to provide an additional environmental barrier for waste disposed at low-level radioactive waste disposal facility.

Currently, radioactive waste materials from power reactors, research, and medical facilities are containerized for transportation and buried in engineered trenches. The combination of the geological formation of the site and the engineered trench design ensure no significant off-site migration of radionuclides will occur. Estimates of migration times for radionuclides in typical site geology are on the order of one thousand years well beyond the lifetime of the radioactive material being disposed. This, however, has not been the case at several of the closed burial sites.

Recent efforts to reduce the volume of reactor waste being buried is resulting in higher specific activity of solidified liquids and ion exchange materials. The inevitable presence of liquid in these waste forms and the longer times required for complete decay of these materials could further increase the possibility of some migration of radioactive materials occurring. Given the high level of environmental concern in the U.S. associated with safe disposal of radioactive waste, a policy of insuring no movement of buried radioactive material is prudent.

Two approaches for increasing the stability of the buried waste have been proposed: improved stability of the waste form (solidification agent) and the use of high integrity containers. Improved stability of the waste form would include solidification of ion exchange material, development of improved solidification agents, and the development of standards for the "leachability" of the waste form. Several problems exist with efforts to improve the stability of the waste form:

- Solidification of ion exchange material will increase the volume of material requiring transportation and disposal.
- The most prevalent solidification agent, cement, has generally low leach resistance, and even the more sophisticated agents will leach a portion of the longer-lived radionuclides. Some radionuclide migration would still occur.
- The standardization and control of leach rates would be an extremely difficult undertaking. Leach rates are sensitive to the actual chemistry of the waste and analysis would be required for each batch of waste processed at each plant. Scaling between small samples and the numerous commercial-sized containers is difficult and depends on a number of process parameters that may make sample analysis meaningless.

The use of high integrity containers to provide an environmental barrier offers several advantages over "improved" waste forms:

- The waste is completely isolated from the soil environment.
- The environmental barrier is not sensitive to individual waste chemistry.
- Concern for detection and measurement of small quantities of liquid in solidified material or ion exchange materials is eliminated.
- There is no increase in the waste volume disposed of.
- Regulatory standards can be more uniformly enforced.

The State of South Carolina requires that high concentration waste forms be buried either completely solidified or in a high integrity container. These containers should be designed to be used in conjunction with existing Type A and Type B specification shipping containers to meet the U.S. Department of Transportation and NRC requirements.

KLM - DOE PROJECT

In 1983, a survey by KLM Technologies revealed that several HIC designs based on polyethylene were being licensed by South Carolina. This material is considered inferior to the flexibility of engineered fiberglass where the container can be "engineered" to the application, be it reactor low-level waste, TRU contaminated waste, or unique DOE waste. When the U.S. Department of Energy's (DOE) Small Business Innovative Research program was announced, it was decided that the need for an "engineerable" container provided the proper basis for the Phase I program.

KLM developed the following key tasks for its successful proposal which resulted in a DOE-approved Phase I project:

1. Review container design criteria; adapt resins and laminate structure; produce drawings; order materials and supplies.
2. Construct appropriate molds.
3. Fabricate molded components.
4. Construct containers for testing and test.
5. Develop TRU waste and Type B waste container criteria.

This program was successful and in August 1984 a $460,000 Phase II program was funded by DOE. The Phase II project is well into its development stage and includes the following objectives:

- <u>Objective 1</u>. Design, fabricate, and test a DOT Type A box container of a nominal 100-125 ft^3 size.
- <u>Objective 2</u>. Design, fabricate, and test a number of DOT Type B waste containers including a nominal 55-gallon drum and large box.
- <u>Objective 3</u>. Develop a waste container design compatible with waste form and burial environments featuring both permanent and reopenable container seals which are compatible with waste handling equipment and practices and which complies with or exceeds all DOE, NRC, and DOT criteria and regulations.
- <u>Objective 4</u>. Assure cost-effective design and manufacturing features while providing superior performance, chemical resistance, earth burial effects, radiation resistance, and overall strength.

KLM HIC Design

The development of a fiberglass laminate for a HIC must meet numerous design criteria. Review of the experimental and design data for existing stainless steel and polyethylene HICs reveals areas where problems have been identified. For example, NUREG/CR-3168, "Technical Considerations for High Integrity Containers for the Disposal of Radioactive Ion-Exchange Resin Waste" identifies several problems:

"Localized corrosion observed in the studies of irradiated ion-exchange resins and stainless steel may extend to the oxidation of polyethylene in similar experiments."

and

"Containers made from organic polymeric materials are of particular concern since organic materials are susceptible to radiation damage. The radiation chemistry of polymers including polyethylene has been reviewed. Low density polyethylene when irradiated generates hydrogen gas. Additionally, the mechanical strength of the material is degraded.

These experiments suggest that care be used when testing polymeric high integrity container material. It may not be assumed at this time that a desired mechanical strength is maintained at a given dose (i.e., 10^8 rad) based on high dose rate laboratory experiments. The material used for a waste container will be irradiated from radionuclide decay in the waste at a much slower dose rate than normally used in laboratory irradiators, and the results of Clough and Gillen indicate that mechanical strength of polymeric material may degrade to a design level at a much smaller total accumulated dose."

These and other problem areas further support the need for an "engineerable" solution.

Fiberglass Technology

Fiberglass reinforced plastic (FRP) technology has reached a level of sophistication and reliability where its commercial applications are no longer questioned. A wide variety of fiberglass reinforcements with polyester or epoxy resin matrices options are available to the designer.

Four basic glass compositions are presently used in plastics reinforcement. The lowest-cost type is "A" (alkali) glass, similar in composition to ordinary window or bottle glass. Several firms make mats from A glass, but its use is not widespread. The most common reinforcement is "E" glass, a boroaluminosilicate containing normally small percentages of calicia and magnesia. The alkali metal (sodium and potassium) content is kept very low. The product's combination of good water resistance and reasonable cost has not been excelled in its 40-year existence. "C" glass, a calcium aluminosilicate has exceptional acid resistance and is useful in surface mats, glass flakes for coatings, and yarns for acid-resistance cloth. "C" glass has poor water resistance and has not been used as a major reinforcement. "S" glass is used in high-strength aerospace applications. It is several times costlier than E glass. Although there are no known applications of S glass in the corrosion market, it has exceptional resistance to acids (approximately equal to C glass) and excellent resistance to water.

Selection of glass reinforcement: The physical properties, chemical composition, and the diameter of the glass fibers as well as the finish and sizing treatments applied by the glass manufacturer all greatly influence the properties of the glass reinforcement. There are many combinations of weaves, weights, and finishes as well as wide variations in price.

Other factors which affect glass reinforcement selection are strength, bulk, and wettability. These properties, together with glass-to-resin weight ratio, the reinforcement orientation, and the laminate sequence of resin and reinforcement all contribute significantly to the composite's properties.

Forms of glass reinforcement: Fiberglass normally consists of filaments--slender fibers of glass manufactured in diameters form 0.05 to 25 micrometers which are produced by drawing molten glass through bushings of the desired diameters. The various forms of glass listed in order of relative cost (low to high) are: continuous strands; roving and chopped strands; reinforcing mats; woven roving and milled fibers; yarns; surfacing and overlay mats; and woven fabrics. Less expensive forms tend to produce lower strength FRP because of the lower glass content and random orientation of the filaments.

FRP Resins: There are four major classes of resins used in FRP--polyester, vinyl ester, epoxy, and furan. Each of the four classes exhibit chemical resistance strengths and weaknesses which are correlatable to their molecular structures. The acid/base resistance of a given resin system is related to the weakest link in the polymer chain and the total content of and the extent of protection to that weak link. In polyester resins and in vinyl esters, the ester linkage is where attack can occur. In amine cured epoxies, attack can occur at the tertiary nitrogen. With anhydride cured epoxies, the ester linkages represent the weakest link. In furan resins, addition to the ring followed by deterioration are suspect. In most of these resins, however, molecular modifications exist that minimize the number of weak links and/or provide shielding to that chain weakness. Solvent resistance varies directly with cross link density (permeation resistance) of the resin and its chemical dissimilarity to the solvent.

Generally, theoretical predictive behavior of polymers is useful in assessing expected FRP performance. These predictions, however, may not in all instances predict FRP performance in an actual field condition. It is difficult, for example, to quantify the effect of trace solvents on acid/base resistance or the effect of a short term temperature excursion or other upset on FRP life. In these instances, composite testing and/or case histories developed in similar environments provide the most reliable prediction of suitability. Molecular predictions coupled with these observations are then used to choose the right FRP resin(s) for a given application.

Fiberglass Reinforced Plastic HIC

Fiberglass reinforced polyester or epoxy resins are currently used in a wide range of underground storage tank applications. They can also be employed in transport containers for hazardous or toxic materials. A variety of fabrication techniques can be applied for the glass reinforcement: spray application of chopped fiber, layup of woven mats, and filament winding. The design and engineering options are considerably more flexible than the high density polyethylene. Lids, caps, and closure devices would be manufactured from equivalent materials.

Design, fabrication, and testing specifications are required.

- Manufacturing must have a quality assurance program to ensure a consistent, uniform product.
- Materials of construction for the vessel must be polyester or epoxy resins and grade C or E glass fiber. Lids, closure devices, and bolting materials may be selected from acceptable corrosion resistant metals (e.g., 316L S.S., 317 S.S., Alloy 20, etc.).
- Chemical and physical analyses of the resins are required to ensure consistent quality and acceptable shelf life.
- Documentation of all process controls including mixing ratio, application rates, and curing temperatures, and times.
- Fabrication must be in conformance with appropriate NBS, ASTM, and ANSI standards for glass reinforced resin tanks.
- Documented stress analyses or hydrostatic pressure and vacuum tests performed to ensure meeting the burial loads for each different container size or configuration.
- All additional tests and analyses required to meet current DOT and NRC regulations for the type and quantity of waste transported.
- Each container fabricated should be subjected to hydrostatic pressure and vacuum tests to ensure structural stability and leak tightness.

The current KLM high integrity container concepts have evolved from their inception in 1976 to take advantage of improved fiberglass and other composite material technology and to comply with the more stringent requirements of the state burial sites, NRC, and DOT. A preliminary fiberglass HIC specification was developed in 1977 and served as the basis for subsequent design activities.

In the U.S., the KLM HIC design as presently evolving is an alternative container design utilizing fiberglass but having dimensions compatible with existing waste transportation casks from Hittman-Westinghouse, Chem-Nuclear Systems, Inc., Nuclear Packaging, and NUS Corporation as well as casks utilized by DOE. KLM is developing HIC designs for the following:

- 55-gallon drums
- 55-gallon drum overpacks
- 69 ft^3 - 300 ft^3 liners
- 80 ft^3 - 120 ft^3 boxes

KLM HIC Design

The actual design of the KLM HIC encompasses several interrelated factors including:

- o Material of Construction
- Design Standards
  - In-plant factors
  - Transportation factors
  - Burial site factors
  - Other regulatory requirements
- Closure
- Vents
- Coating
- Size and Weight Limits
- Inspection Testing
- Quality Assurance/Quality Control

The KLM HIC is a unique engineered fiberglass container utilizing a multi-laminate structure. The HIC designs include a 55-gal container, 55-gal overpack, and a variety of large liners. Extensive experience is available with DOT-7A fiberglass-coated plywood boxes involving TRU waste. This is potentially useful for disposal of Class A waste in a stabilized trench. In addition, a unique fiberglass box design is under development for TRU-contaminated and low-level radioactive dry wastes.

The KLM fiberglass container concept has a vastly improved life-span, shows superior corrosion and acid resistance, has high strength-to-weight ratios, and good radiation resistance, as well as numerous other features which make the use of fiberglass very attractive. The benefits and performance properties of a fiberglass container are superior to other materials and are expected to provide an improved waste container at reasonable prices.

The following discussion is a review of the status of the KLM HIC development. This initial program involves a 55-gallon HIC. Other types being developed in the series include larger liners and boxes as described above. KLM has designed and manufactured several prototype proof of concept fiberglass HICs. The initial container design was for Type A waste and extensive supporting information makes up KLM's proprietary HIC data base. Criteria for TRU waste and Type B waste are developed and prototypes under development.

Historically, DOE packaging requirements have been similar to those of the NRC and DOT. Two classes of packaging are potentially available for TRU waste and under current regulations--Types B and A. Packages in each of these categories must meet specific performance tests. All packagings are limited to their use by the quantity, physical form, and isotopic content of the materials to be carried.

Type A TRU packages must demonstrate their integrity after being subjected to a series of tests and environmental conditions considered to be representative of normal transportation and handling conditions. Type B packagings are designed to withstand more severe environments.

Requirements for Type B containers to transport TRU wastes are that they meet applicable Type A standards and hypothetical accident conditions without a radioactive material release (10CFR71). Hypothetical accident conditions for Type B packages are applied sequentially and consist of: (1) A free drop through a distance of 9.1 meters (30 feet) onto a flat and essentially unyielding horizontal target surface; (2) A free drop through a distance of 1.0 meter (40 inches) striking the top end of a vertical cylindrical mild steel bar that is 15 cm (6 inches) in diameter; (3) Exposure to a thermal test in which the external heat input to the package which would result from exposure of the whole package to a thermal radiation environment of 802°C (1,475°F) for 30 minutes; and (4) Water immersion (for certain limits only).

KLM has engineered, fabricated, and tested a low-level, Type A, nuclear waste container for potential use by the DOE, and the commercial nuclear sector. The container met and exceeded the container performance criteria specified for Type A wastes.

The design for the container project included a proof of concept configuration for the 55-gallon container, drawing production, and creation of the male plug from which the female container molds will be produced. The laminate construction and resin composition were adapted during this phase. The design phase considered an optimized container in terms of strength, weight, and molecular stability when buried. Several designs have been developed for various HIC configurations.

The construction phase produced a prototype fiberglass waste container and lid for testing and potential certification purposes. KLM developed design criteria necessary for TRU waste and Type B quantity containers as well as Type A containers. Future efforts will consist of additional testing and certification of other prototype fiberglass containers.

The container was to be a multi-layer dual walled unit, with a separate lid designed for easy and rapid bonding to the container after filling. The original walls were to have an outer laminate of fiberglass adapted to fracture upon severe impact and to dissipate a substantial portion of the energy of impact. Behind the outer layer would be a medial layer of cellular material adapted to distribute the remaining impact energy throughout the container. The container was also to have an inner laminate of fiberglass adapted to resist the energy of impact without fracture. The layers would be bonded together with selected resins to form an integral structure. The container's dual wall construction was to provide for high compressive loading strength.

The actual prototype contained each of the features identified as well as other features which allowed for alternative designs to be tested. The actual prototype consisted of a multi-laminate design. This design utilized "bump" end caps which illustrated the dual wall concept and utilized a polyurethane foam medial layer which served to dissipate impact energy.

The fiberglass laminate is built up with successive layers of fiberglass roving, woven roving (WR), and chemical resistant vail glass. High quality Class I fire retardant resins, with 5 percent antimony trioxide could be employed. This resin composition provides a flame spread rating of 25, and is highly resistant to acids and decomposition when buried. A yellow pigmented gel-coat employing the same resin base was to provide a bonded outer finish to the container for ultra-violet protection and ease of decontamination. A combination of yellow and white gel-coat was utilized. Further, the design also utilized chopped mat glass to test capabilities in the bump end caps.

Quality control of the resin composition will be insured by subjecting the containers to a 30,000 volt holliday and pinhole detector test. This test and other quality control steps in material and construction techniques will be assured by detailed procedures, training, and inspection.

KLM - DOE PROJECT - PHASE II

KLM is working in the second year of a program entitled "Development of Prototype Fiberglass Containers for DOT Type A and Type B Radioactive Waste." Pursuant to the contract, KLM will design, fabricate and test a DOT Type A box container of a nominal 100 - 125 ft^3 size; design, fabricate, and test a number of DOT Type B waste containers including a nominal 55-gallon drum and large box (100 - 125 ft^3); develop a waste container design compatible with waste form and burial environments featuring both permanent and reopenable container seals which are compatible with waste handling equipment and practices and which comply with or exceed all DOE, NRC, and DOT criteria and regulation; and assure cost-effective design and manufacturing features while providing superior performance, chemical resistence, earth burial effects, radiation resistance, and overall strength.

The technical approach taken to each Phase II objective follows.

Objective 1

The design, fabrication, and testing of a Type A box container requires that a design basis be established. A box design was initiated to address this basis as well as utilize the features of FRP to ensure the product is acceptable. Important elements of this effort include:

- Structural design of walls, corners, and lid.
- Design of various lid seals to meet particular needs for permanent or reopenable container closures.
- Manufacturing techniques which will assure cost-effectiveness.
- Development of computer models to evaluate performance of the containers during handling and test conditions.

Technical features which are being examined include:

- Choice of resins
- Laminate design
- Construction features of the corners
- Detailed lid and seal designs
- Container handling features
- Surface finishes
- Closure alternatives

KLM has established a data base which will allow resin choice, laminate design, and other FRP features to be determined as a function of waste form and burial environment. Computerization of this data base has been completed. A detailed review of resin performance was undertaken. Secrecy agreements have been exchanged with several companies to assist in developing an "optimized" "system" design. This also serves as the basis for computer design model which included materials of construction, special design features, structural and stress analyses, and analytical analyses to support and replace actual physical testing. Major efforts were directed toward identifying appropriate finite element, thermal, structural, and stress codes for use.

A decision was made to support the Type A and Type B HIC boxes development by using a quarter-scale box design. The molds design was initiated and prototypes have been constructed. A test program is continuing based upon establishing a DOT based test standard.

Objective 2

The design, fabrication, and testing of a Type B waste container is more difficult since Type B packaging criteria are more stringent. Type B packaging requires that packaging meet the standards for Type A packaging, and in addition, the standards for hypothetical accident conditions or transportation, including:

- Reduction of shielding is not enough to increase the radiation dose rate at three feet from the external surface of the package to more than 1,000 mrem/hr.
- No radioactive material is released. The allowable release of radioactivity from packages containing large quantities is limited to gases and contaminated coolant. The adoption of IAEA Standard will affect this standard.
- Test Conditions

  Free Drop: 30-foot drop onto a flat, essentially unyielding surface, for which maximum damage is expected.

  Puncture: free drop through a distance of 40 inches on a bar 6 inches in diameter.

  Thermal: exposure to 1475°F for 30 minutes.

  Water Immersion: immersion in 50 feet of water for 8 hours.

Based upon the results of Objective 1 efforts, a Type B design is continuing development for 55-gallon drum and large box container configurations. This effort is continuing with test coupon for thermal testing being developed and will continue work on various insulators. KLM's intention is to develop a waste container which will be suitable for transportation and cost-effective enough to bury. The design, fabrication, and testing of such a container requires several unique features for the HIC, including:

- A closure design suitable for easy use but capable of meeting the free drop, thermal, and water immersion tests.
- Multi-laminate design with a sacrificial outer layer capable of handling the free drop and passing the immersion and thermal tests.
- Choice of the thermal insulating materials and design bases for their use.

As with the Type A design, extensive computer modeling and analyses have been initiated to supplement or complement the actual testing requirements. Based upon the Phase I and limited Phase II tests, no problems are expected with testing, assuming that a suitable insulating material is found. This material and the closure design have been explored and numerous ceramic and spur minerals have been examined. Tests by the material vendors are available to support the decision-making process. Detailed efforts have been initiated and are being incorporated into the prototype box development program. Certain high temperature resins and insulation materials have been procured for the test program. However, these are not considered optimal. A box has been fabricated with high temperature insulation; however, this is not expected to be satisfactory given potential manufacturing limitations. A program based upon selected insulators appears promising.

Objective 3

The approach taken in support of the Type A and Type B containers included the development of a data base to support the design effort. This will serve as the major effort necessary to ensure that the designs are compatible with waste forms, burial environments, seal designs, handling requirements, etc. Substantial new information is available from the NRC and limited DOE programs. Several NUREGs were issued in the past nine months which are applicable. This effort will continue for at least one more quarter. Especially pertinent is testing required to comply with NRC criteria 10CFR61. Varied test results are being reviewed to ensure compliance.

Objective 4

Based upon the data base established above, the design bases will be reviewed and optimized to support the evaluation of actual product design. After assuring that all functional design elements comply with applicable criteria, the design will be reviewed for ease of fabrication, quality control, material handling, and cost reduction features.

Cost data is being obtained to support this effort. No significant effort has been initiated on this objective except to review various fabrication techniques, technologies and experience. Especially pertinent are certain tank and pipe fabrication technologies as well as extensive effort for non-destructive testing and evaluation. Several Department of Defense programs have been reviewed.

SUMMARY

There are no anticipated problems or changes to either the Phase II *objectives or* technical approach. The program will be completed in the third quarter of 1986.