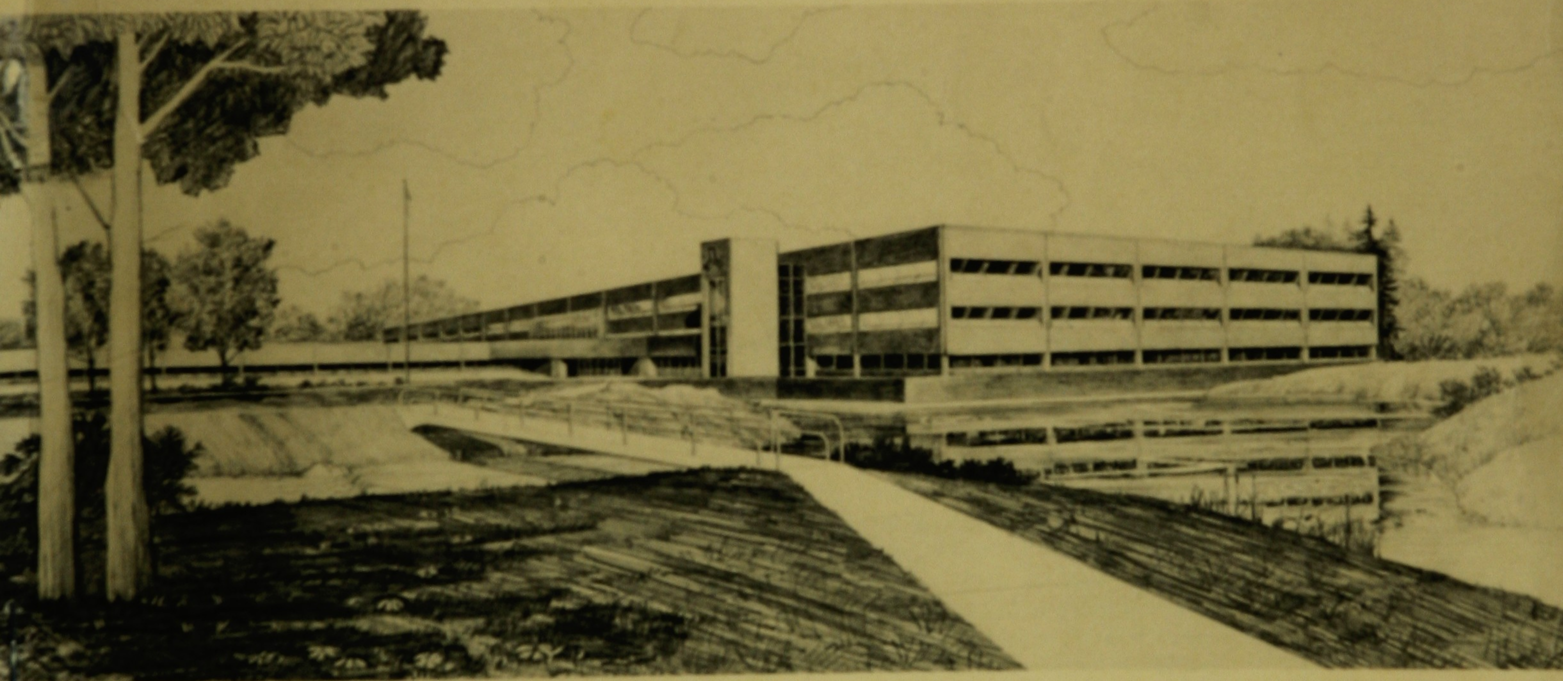
EGG-TMI-6304

DESIGN ANALYSIS REPORT:
HIGH-INTEGRITY CONTAINER FOR DISPOSAL OF EPICOR-II PREFILTER LINERS

Ray L. Chapman
Harley W. Reno

Idaho National Engineering Laboratory

Operated by the U.S. Department of Energy



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Prepared for the
U.S. DEPARTMENT OF ENERGY
Under DOE Contract No. DE-AC07-76ID01570

EG&G Idaho

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Published June 1983

EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

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ABSTRACT

A container design that satisfies requirements established for disposal of EPICOR-II prefilter liners from TMI Unit-2 is described. The requirements set forth in Specification ES-50652B by EG&G Idaho, Inc., for the container are summarized, and design features are compared with design requirements. Decisions made in the design process are explained. A complete set of design drawings is included as an appendix. Other appendices contain detailed analyses performed in the course of design development.

SUMMARY

A high-integrity container has been developed to (a) immobilize the EPICOR-II prefilter liners from Unit-2 of the Three Mile Island (TMI) Nuclear Power Station, and (b) protect possible future, inadvertent intruders from damaging radiation. The container is designed for disposal depths to 90 feet in either wet or dry subsurface conditions. A built-in vent system for each container will permit the release of gas and function as a water barrier at pressures reaching 45 psig. The container has outside dimensions of 62.5 inches diameter by 84 inches high, and is designed to ensure a 300-year functional life. Its design features multiple barriers that prevent corrosives from penetrating container walls. The multiple-barrier approach provides a 1,204-year mean time to total failure, based on an assumed single-event-failure probability of 20%.

The multiple-corrosion-barrier concept is supplemented by aluminum hydroxide, which reduces the chemical activity of corrosives potentially arising from chemical decomposition of organic resins in the EPICOR-II prefilter liner. Aluminum hydroxide, an effective amphoteric material, tends to neutralize both acids and bases.

An epoxy seal between the lid and container body functions as a barrier against any loss of container contents. Two separate epoxy materials fill the space between the lid and container body; they form a seal, mechanically bonding the lid in place. After curing, this epoxy material has a greater strength than the concrete; thus, the concrete has to fail in order for the lid to loosen.

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1. INTRODUCTION

This report describes the design and presents supporting analyses for the High-Integrity Container (HIC) developed in response to EG&G Specification ES-50652B.[1] The purpose of the report is to demonstrate that all features and requirements of that specification are reflected in the design of the HIC developed by Nuclear Packaging (NuPac), Inc., (Tacoma, WA) under EG&G Subcontract No. K-9063.

The introductory section presents a brief description of the HIC system and a summary of HIC performance under prescribed operational and environmental conditions. The remainder of the report, organized to provide an overview of the system, emphasizes considerations leading to design decisions. Section 2 contains a complete description of the HIC system. Section 3 summarizes the detailed design and selection rationale. Section 4 presents recommended changes based on experience during fabrication of the prototypes. Detail design drawings are presented in Appendix A. All analyses are collected in Appendices B through K. Those appendices are organized along functional lines, namely, stress, thermal environment, shielding, and material selection.

1.1 The HIC System

The HIC is a reinforced-concrete container designed for use in disposal of EPICOR-II prefilter liners from the TMI Unit-2. The container is designed to ensure safe, reliable, belowground disposal of the radioactive waste for a minimum period of 300 years (~10 half-lives of predominant isotopes).

Figure 1 illustrates the HIC design configuration. Appendix A contains detail drawings for the HIC. Corrosion resistance is provided by redundant corrosion barriers, supplemented by aluminum hydroxide to reduce

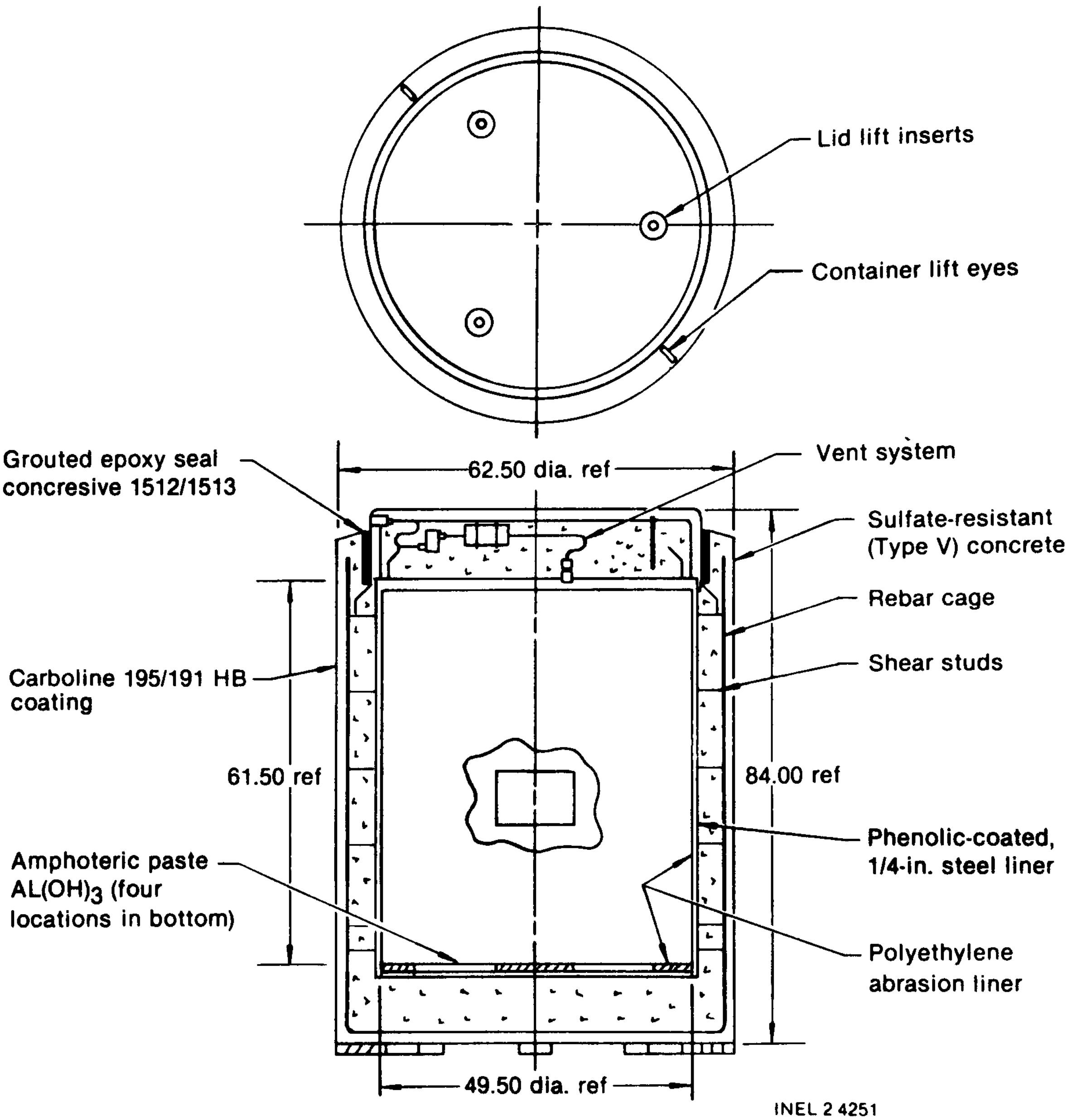

Figure 1. Design configuration of the High-Integrity Container.

the chemical activity of corrosives.[a] Each corrosion barrier provides adequate containment for the 300-year life of the container. Summed together, the collective barriers give a HIC life in excess of 1,200 years based on reliability analyses of Appendix B. The container lid is attached to the body by two separate materials, both of which form permanent seals. Those materials are installed independently, by different techniques and processes.

Evaluation of EPICOR-II Prefilter No. 16 confirms that the EPICOR-II radioactive waste materials evolve significant quantities of gas.[2] As a result, the HIC is equipped with a venting system for excess gas removal. The vent is cast into and protected by the reinforced concrete lid assembly. The container possesses sufficient burst strength to contain all gases without venting (see Appendix C).

Lifting, loading, and handling features are designed for quick disconnect to facilitate remote operations, thereby minimizing personnel exposure to radiation.

1.2 Key Findings

1.2.1 Fabrication

The container is fabricated primarily of concrete, which must be protected against freezing and high-impact loading during curing. Once the concrete is cured, it is no longer susceptible to damage from freeze/thaw cycles. The container has sufficient impact strength to permit handling by conventional means, such as crane or forklift. Lifting inserts in the concrete provide a means for safely moving the cured container.

---

a. Many corrosion-resistant materials have been developed in the past 30 years. As a result, long-term experience with the durability of such materials is lacking. That absence forces one to rely on experimental data derived from material testing and mathematical extrapolation from measured trends to estimate corrosive durability of materials over long periods of time.

1.2.2 Loading

A funnel-shaped interface collar is used to center the liner as it is placed in the HIC. The interface collar protects the epoxy seal bead around the top of the container. As an added precaution, a high-density polyethylene liner is installed permanently in the HIC before loading. The plastic liner acts as a buffer between the EPICOR-II liner and wall of the HIC, thereby preserving the integrity of the phenolic corrosion barrier.

1.2.3 Sealing

The epoxy seal bead is placed manually around the rim of the container; the EPICOR-II liner is inserted; then the lid is lowered into place. An epoxy grout is poured remotely into the annular space between the lid and body of the container. Remote grout placement, necessary because of the excessive radiation levels produced by the EPICOR-II liner, is facilitated by the self-leveling characteristic of the epoxy grout. The epoxies cure to a permanent, high-strength bond in 48 hours and will endure for the requisite 300-year life of the container.

1.2.4 Transport

DOT regulations require that significant quantities of radioactive material be sealed inside a Type-B shipping cask for transport over public roads, and that the shipment not pose an explosive risk. To satisfy those requirements, EPICOR-II liners are vented for several weeks before being sealed in a HIC. That will permit a shipping window of at least 37 days after insertion in the HIC, since it takes longer than that to generate enough hydrogen to form a combustible mixture in the HIC.[a] Temperatures during transport may range from -40 to +170°F (see Appendix D).

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a. H. M. Burton letter to Dr. W. W. Bixby "EPICOR-II Shipping Safety Assessment Document Cask Insertion Requirement," Hmb-511-82, EG&G Idaho, Inc., November 4, 1982.

1.2.5 Disposal

The most critical nonthermal conditions occur after disposal of the HIC and its contents. Externally applied pressures of 150 psi will induce compressive stresses on outer surfaces of the container. Internally, gases generated primarily by dissociation of water will escape through the vent system in the lid at an estimated maximum rate of 0.052 mole/day, or 0.049 liter/hour. That flow-rate will maintain internal pressure of the HIC well below design maxima.

Once a HIC is disposed, internal and external chemical environments will have little or no effect upon the container during its 300-year life. However, permeable, acidic soils rich in oxygen are to be avoided, because degradation of protective coatings could be accelerated.

1.2.6 Test Evaluation

The first prototype HIC, S/N001, was subjected to a series of vendor evaluation tests (see Appendix E), which focused on the mechanical and structural integrity of the container as specified in design requirements. All design requirements and required containment of contents for handling events (accidents) were demonstrated.

2. SYSTEM DESCRIPTION

The HIC consists of a right circular cylinder made of reinforced concrete, and a permanently sealed lid. A vent system cast in the lid continually effects passive venting of the container and prevents passage of liquid or solids from the outside environment to the inside of the container. Operational support equipment provided to facilitate handling and loading of the container consists of lifting gear for the lid and container, and a loading interface collar. The relationship of HIC components is depicted in Figure 2.

2.1 Design Requirements

Design requirements for the HIC are either taken from EG&G Specification ES-50652B or established by analyses included in appendices of this report. Table 1 contains a brief statement of significant requirements and presents corresponding design goals established by the vendor. That table also shows results attained in the HIC design. The final product meets all design requirements, based on a combination of technical analyses and tests.

2.2 Physical Description

2.2.1 Structural Features

The HIC is a right circular cylinder of reinforced concrete (Figure 1). Its dimensions are: 62.5 inches, outside diameter; 84 inches, height; 6 inches, thickness of cylindrical walls; and 11 inches, thickness of ends.

Concrete Structure. The reinforced concrete is capable of withstanding all specified internal and external loads. Recessed eyes and precast inserts provide for convenient handling and stacking of containers.

Seals. Redundant seals bond the lid securely and permanently to the container. The interior, or primary seal, is formed from Concresive AEX-1513, a product of Adhesive Engineering Company (San Carlos, CA). A

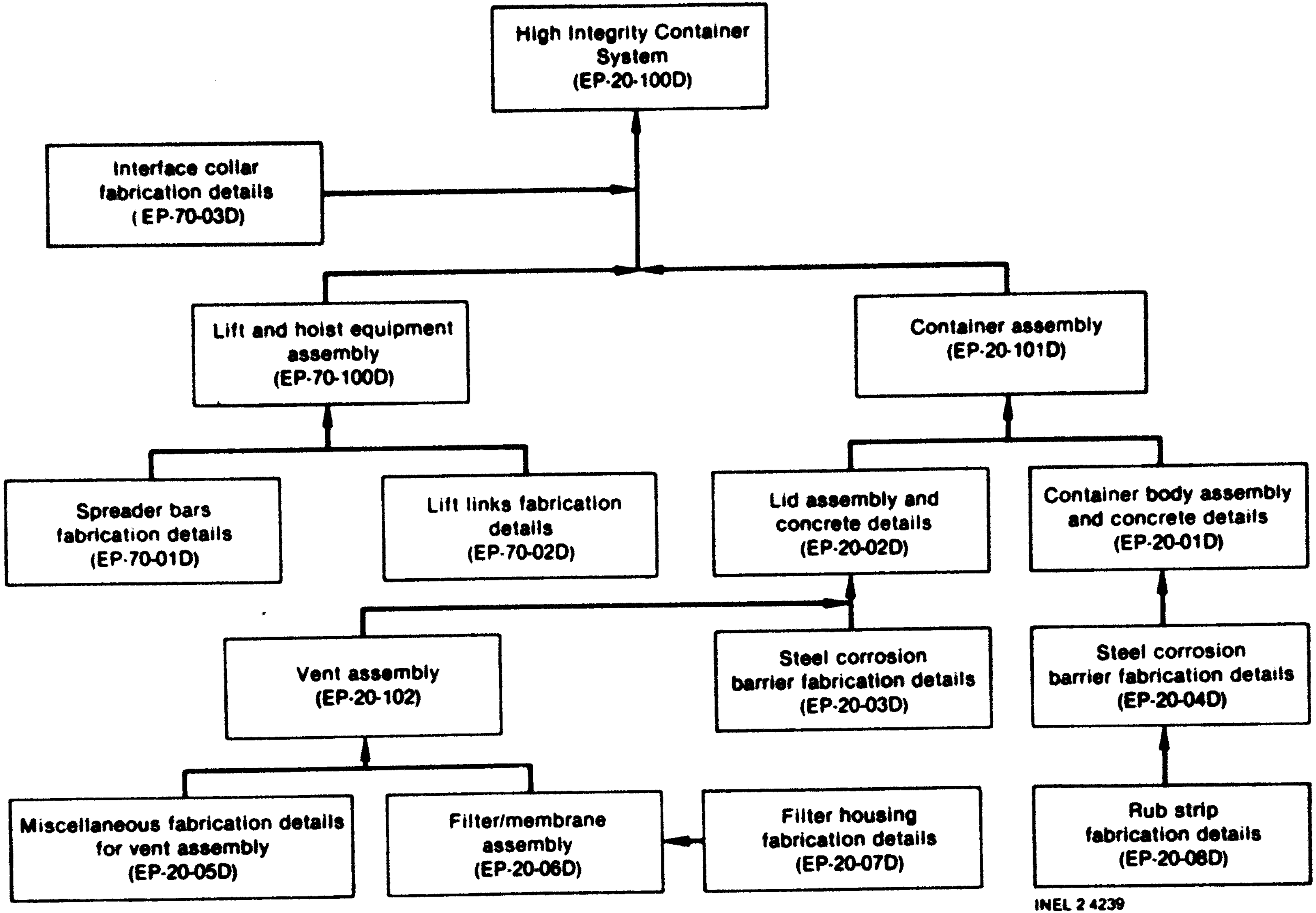


Figure 2. Relationships of design components of the High-Integrity Container (parenthetical numbers correspond to drawing numbers in Appendix A).

TABLE 1. SYSTEM DESIGN REQUIREMENTS FOR THE HIGH-INTEGRITY CONTAINER

Function	Requirement	Parameter	Design Goal	Design Result
Life	300 years	Mean time to failure	300 years	1,204 years
Vent	Prevent pressure buildup	Gas release	>0.052 mole/day	>0.15 mole/day
Vent	Prevent release of liquids	Fluid in-filtration	Groundwater will not fill container in 300 years ($<1 \times 10^{-4}$ cm^3/s)	Goal demonstrated for hydrostatic heads of at least 55 ft
Vent	Prevent release of solids	Particulate exit	Retain particulates >5 microns	Multiple 1- and 5-micron filters
Corrosion allowance	Adequate for 300 years retention of waste	--	300 years	--
Lift provisions	Vertical load, 3 g	Factors of safety	Factors of 3 on yield and 5 on ultimate	Minimum margin of safety = +0.03
Stacking	Design for stacking	Surface flatness	Top and bottom surface flush and flat	Top and bottom flush and flat
Stacking	Stack six high	Vertical pressure	19.7 psi	Designed for 150 psi external pressure
Weight	Legal transport (no overload)	NA	Transport option of NuPac proposal (para. 2.2 and 3.1.1) not exercised	NA
Contour	Avoid water entrapment in voids/pockets	Contour	Smooth vertical sides; no pockets	Goal attained
Bulk density	Container shall not float; density >1.2	--	--	Bulk density = 1.8
Transport type	Design for Type-A or Type-B, as applicable	Transport type	Transport integrity and shielding provided by a reusable package	Type-A package conditions are satisfied

TABLE 1. (continued)

Function	Requirement	Parameter	Design Goal	Design Result
Corrosive environment	Container thick enough to provide 20% margin based upon projected corrosion rates	Redundancy	Multiple corrosion-resistant barriers	Selected barriers not subject to failure by corrosion; multiple barriers
Neutralizing agent	Permitted	Neutralizing agent	Neutralize all corrosives	0.83 lb $AL(OH)_3$ required for neutralization; 20 lb furnished
Decay heat	8 W	--	--	Waste temperature less than 8°F higher than soil temperature
Internal atmosphere	Saturated air with H_2, SO_x, Co, CO_2, NO_x, and $^3H_2$	Gas generation	Detail predictions in Appendix C	Compatible coating and vent materials selected
Chloride content	2-200 ppm in free-standing liquid	--	--	Compatible coating materials selected
pH	2 to 11	pH	Neutralized to pH 7-9; coating design requirement, pH 6-10	Amphoteric material added to control pH
Internal gas pressure	10 psi maximum	Internal pressure	Vent flow rates at 10 psi	Vent flow at 10 psi, $\geq$0.15 mole/day
Internal gas pressure	10 psi maximum	Internal pressure	25 psi for structural integrity evaluation	Container margin of safety = +8.84 vent; margin of safety = +0.60 (test)
Contact dose	Specific estimate = 2000 rads/h	Initial contact	Internal coating = 3276 rads/hr	HIC materials selected for >10^9-rads exposure capability
Curie deposition	80% of Ci in 18 ft^3 at top	Curie deposition	Uniform deposition over top 6 in. of resin, or top half as applicable	HIC materials capable of >10^9 rads exposure

TABLE 1. (continued)

Function	Requirement	Parameter	Design Goal	Design Result
Integrated dose	Specific estimate $1 \times 10^9\ R_\beta < 1 \times 10^9\ R_\gamma$	Integrated dose	Varies with location: 930-Mrad-coating; 9-Mrad-vent, etc.	HIC materials have greater than 10^9 rads exposure capability
Soil temperature	68 ± 18°F	--	--	Boundary conditions: thermal analysis
Soil physicals	O_2 = 0 to 3 mg/L; Cl = 0 to 300 ppm; pH = 4 to 9; water = 0 to sat.	Soil physicals	Eastern and western conditions separated	Corrosion of rebar cannot occur; chloride ion threshold low by factor of 15
External pressure	150 psi hydrostatic, lithostatic, and stacking	--	--	Container minimum margin = +0.23 (lid shear)
Soil chemistry	Sulfate compounds present	--	--	Sulfate-resistant concrete
Transport thermal conditions	Ambient air: -40 to 130°F insolation per NRC Reg. Guide 7.8	--	--	Design capable of withstanding transport temperatures of -40 to 165°F
Temperature conditions	Six freeze-thaw cycles before transport	--	--	Materials of construction not sensitive to freeze/thaw cycle
Seal function	10 psi at 58 to 66°F; life at elevated temp., 60 days at 180°F; $10^9 R_\gamma$ dose	Integrated dose	Detail analyses, Appendix B, reduce dose to 175 Mrads	Seal materials were selected to satisfy the requirements
Geometry and finish	No retention of water; corrosion-resistant materials; surface can be decontaminated	--	--	Nuclear-qualified coatings; ANSI N5.12 tests; coatings can be decontaminated

TABLE 1. (continued)

Function	Requirement	Parameter	Design Goal	Design Result
Lift devices	Furnish and protect from corrosion, hang within 2 degrees of plumb.	--	--	Corrosion-resistant lugs employed (316 SS)
Liner clearance	Must receive an EPICOR-II liner. (44-in. OD x 60.63 in. high)	--	--	50.5-in. ID x 61.5 in. high
Lid closure	Self-aligning during remote installation ($\leq$60 mrem dose/person)	--	--	Self-alignment spacers on lid; remotely pourable grout seal
Lift eyes	Hookup via crane	--	--	Conventional lift eyes provided
Transport features	Interface with Type-B transport package	Transport cask	No Type-B cask exists	--
General interfaces	60-degree entry angle preferred	--	--	60-degree entry angle
Marking	Permanent markings	--	--	Provided on all components
Welding	Fabricate and inspect per ASME, Section IX	--	--	Provided on all components
Concrete properties	f'_c = 6000 psi, strength ρ >140 pcf, density	--	--	f'_c = 6000 psi ρ = 145 pcf
Reliability evaluation	Quantitative assessment	--	--	Provided
Failure analysis	Single-failure analysis	--	--	Provided

custom-formulated epoxy gel, it is compatible with the phenolic coatings on the HIC liner. The primary seal is applied to the mating metal surface of the container body before the EPICOR-II prefilter liner is inserted. The four-hour pot-life of the primary seal is long enough for insertion of the EPICOR-II liner and realignment of the lid should the lid not seat properly after the first attempt.

The external, or secondary seal, is formed from Concresive AEX-1512 (also a custom-formulated epoxy), which fills the 1-inch gap between the lid and container body. That grout, containing rounded aggregate to effect self-leveling, is custom-formulated as a flowable material. The grout is catalyzed to provide rapid curing, thereby minimizing curing time. The self-leveling characteristic of the grout permits pouring at two locations diametrically across on the container. That is viewed as an advantage, since pouring must be done remotely.

Postcure aging of both seals increases their collective strengths through radiation-induced cross linking of polymers in the sealants. Of course, continued irradiation eventually will reduce the strength of both seals; but that will not occur until more than 900 Mrads of exposure (total anticipated exposure ~175 Mrads).

2.2.2 Corrosion Barriers

Amphoteric Material. An amphoteric material neutralizes both acids and alkalies. Such a material (viz., aluminum hydroxide) was chosen for use in the HIC, because acids or bases may be produced during degeneration of EPICOR-II resins. The amphoteric material, placed in cutouts at the bottom of the polyethylene liner, will reduce the corrosion capability of degraded materials, once they are outside the enclosed EPICOR-II liner. That neutralization of corrosives will extend the life of the container. Twenty pounds of aluminum hydroxide, divided equally among four locations, are placed in the bottom of the container (see Dwg. EP-20-08D of Appendix A). That amount is more than sufficient to neutralize all acids or alkalines that could be produced by degradation of EPICOR-II ion-exchange media.

Steel Liner Coatings. The HIC steel liner serves primarily as a substrate for corrosion-resistant coatings and secondarily as the inside form for casting of the concrete. The phenolic coatings of the steel liner consist of one layer of Phenoline 300 Orange primer and two layers of Phenoline 302 finish, both materials being manufactured by Carboline. Those coatings, qualified for both radiation fields and chemical environments, are applied to the interior and exterior of the steel liner. The coatings are applied by a vendor in accordance with the manufacturer's recommendations and are thoroughly examined by certified quality assurance personnel.

Since the coatings on the inner surface of the steel liner are the most important corrosion barrier, their inspections will be performed both by the painting contractor and an independent coating-inspection agency. The vendor will witness and certify the inspections performed by the inspection agency. A polyethylene liner protects the corrosion-resistant coatings during loading, handling, and transporting. Detailed rationale for using the coatings are given in Section 3.2.2.

Concrete. Composition of the concrete provides 6000-psi compressive strength and is resistant to deterioration by sulfates.

External Coating. Carboline-195 Surfacer and Carboline 191 HB are applied separately to the exterior of the concrete container in accordance with the manufacturer's recommendations. Those nuclear-qualified coatings are inspected and certified by both the applicator and vendor. Detailed rationale for use of the exterior coatings are provided in Section 3.1.3.

Consistent with good practice for application of nuclear-grade coatings to concrete, no oil-based release compounds may be used for the concrete forms. Those compounds could cause the surface coating of the concrete to partially lose adhesion. Concrete-curing compounds are prohibited to ensure escape of water from the concrete. Curing compounds also form a surface film that would endanger adhesion of the surface coating.

The concrete is cured for at least 28 days before the external coating is applied, so that most moisture will be evaporated from the concrete. The moisture remaining in the concrete, along with radiation or corrosion-induced gases, will exert minor pressures on the exterior coating. In order to minimize that pressure and ensure bonding of the grout, areas where the epoxy grout bonds the container body and lid together are left uncoated to allow the concrete to breathe.

2.2.3 Venting Features

The vent system of the container consists of the following components (proceeding from lid interior to the outer surface as shown in Dwg. EP-20-102D of Appendix A):

1. A stainless steel, inline filter element with a 5-micron pore size. The filter ensures that resin beads will not escape from the container to the external environment.

2. A nonmetallic (polyethylene) filter assembly consisting of three filter elements. That assembly restricts infiltration of liquids into the container.

3. A PVC water trap that self-purges any water by means of gases generated within the container.

4. A 70-micron polyethylene external filter, with large surface area. That filter, located in a recessed PVC pocket at the lid edge, functions as a screen against mud and debris.

The vent system can accommodate a flow rate (0.15 mole per day) nearly three times greater than the design basis (data presented in Appendix F). Although the vent system could be plugged by a single event, it has been designed to circumvent that possibility through incorporation of the external filter, internal metallic filter elements, and large excess capacity. If the vent plugs, even at the beginning of life, the maximum pressure that would build up (see Appendix C) is insufficient to cause container failure.

If the vent blows out, the top-mounted vent system provides little possibility of material escaping from the container, since the container would be buried in the upright position.

The inlets and outlets for the vent also are situated and designed to prevent plugging during grouting of the lid to the container. Prototypes of the vent system have been tested; they satisfy design requirements and functions as specified. Results of those tests are presented in Appendix F. Detailed rationale for the design of the vent system is provided in Section 3.4.

2.2.4 Biological Shield

The concrete container attenuates radiation from the enclosed EPICOR-II liner by a minimum factor of 9--not enough shielding to permit hands-on operation, but enough to simplify handling procedures and safety precautions. Calculations of surface dose rate are presented in Appendix G.

2.2.5 Weights and Center of Gravity

Presumably, the center of gravity of the HIC is the geometric center of the body. Weights of the container and its ancilliary paraphernalia, based on calculations in Appendix H, are summarized in Table 2. The bulk specific gravity of the package is:

$$\frac{17,126}{(\pi/4)(62.5^2)(84)(62.4/1728)} = 1.84 \ . \qquad (2\text{-}1)$$

Thus, the container will not float, exceeding the minimum bulk specific gravity requirement of 1.2, as specified in Paragraph 3.2.2.6 of EG&G Specification ES-50652B.

2.2.6 Mechanical Properties of Materials

Mechanical properties of materials for the HIC are listed in Table 3.

TABLE 2. SUMMARY OF HIC WEIGHTS

Components	Weights (lb)
Container body	11,096
Lid	2,531
Payload (EPICOR-II liner)	3,250
Seals	110
Rub strips and amphoteric material	139
	17,126

TABLE 3. MECHANICAL PROPERTIES OF MATERIALS USED IN THE HIC

Material	Yield Stress (psi)	Ultimate Stress (psi)	Young's Modulus (10^6psi)
ASTM A-36	36,000[a]	58,000[a]	29[d]
ASTM A-615 GR 60 REBAR	60,000[a]	90,000[a]	29[d]
Concrete	--	6,000[c]	4.42[e]
Studs (A-100)	50,000[b]	60,000[b]	29[d]

a. Data obtained directly from ASTM standards.

b. Data reported in Reference 3.

c. Specified reinforced-concrete design parameter, f_c'.

d. From Reference 4.

e. From ACI 318-77 formula: $E = 57,000 (f_c')^{1/2}$.

2.3 Functional Description

Figures 3 through 5 depict operations involved in loading and disposing of a HIC. Operations illustrated involve two phases, which are described in the following subsections.

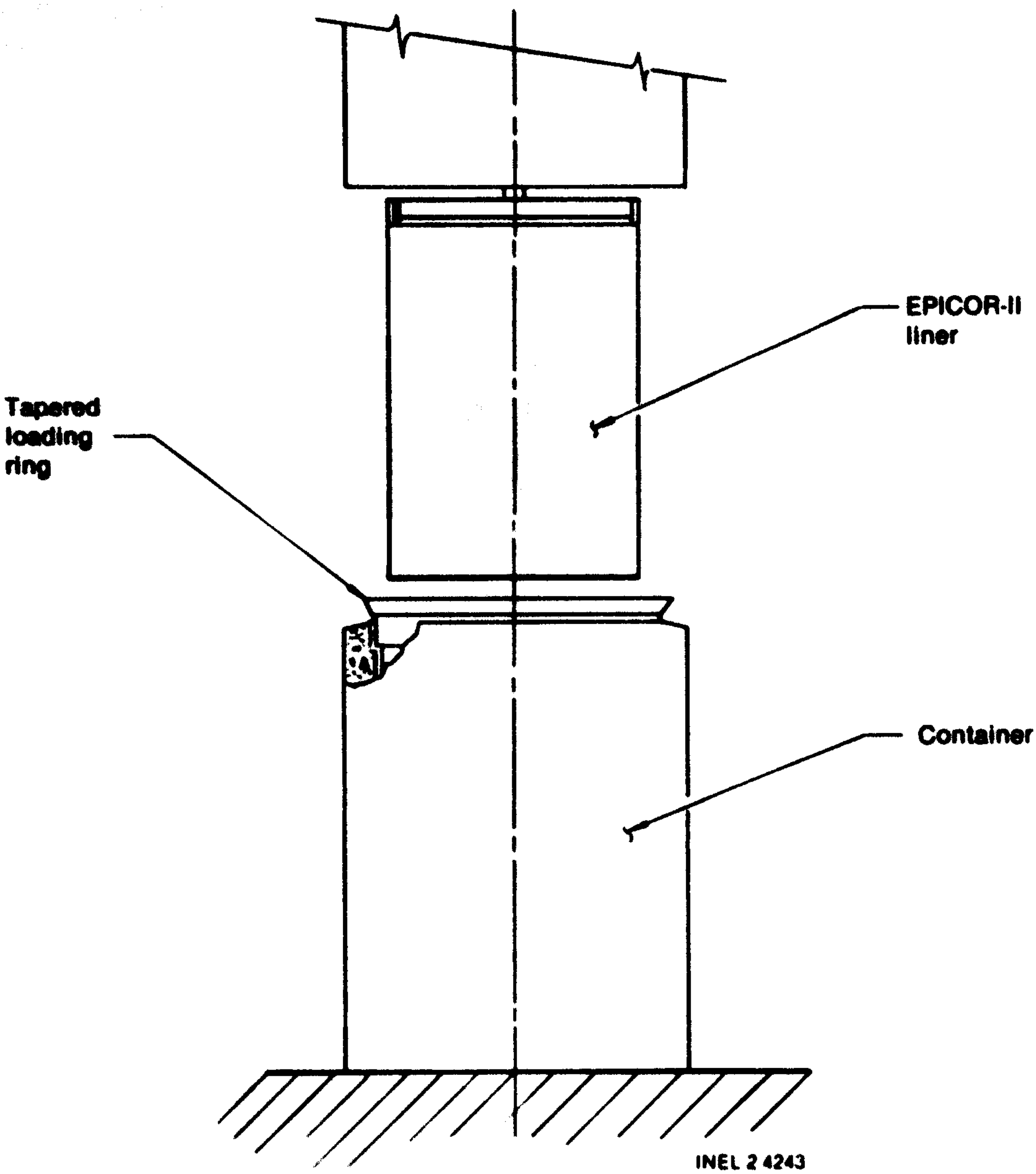


Figure 3. Placement of an EPICOR-II liner in the HIC.

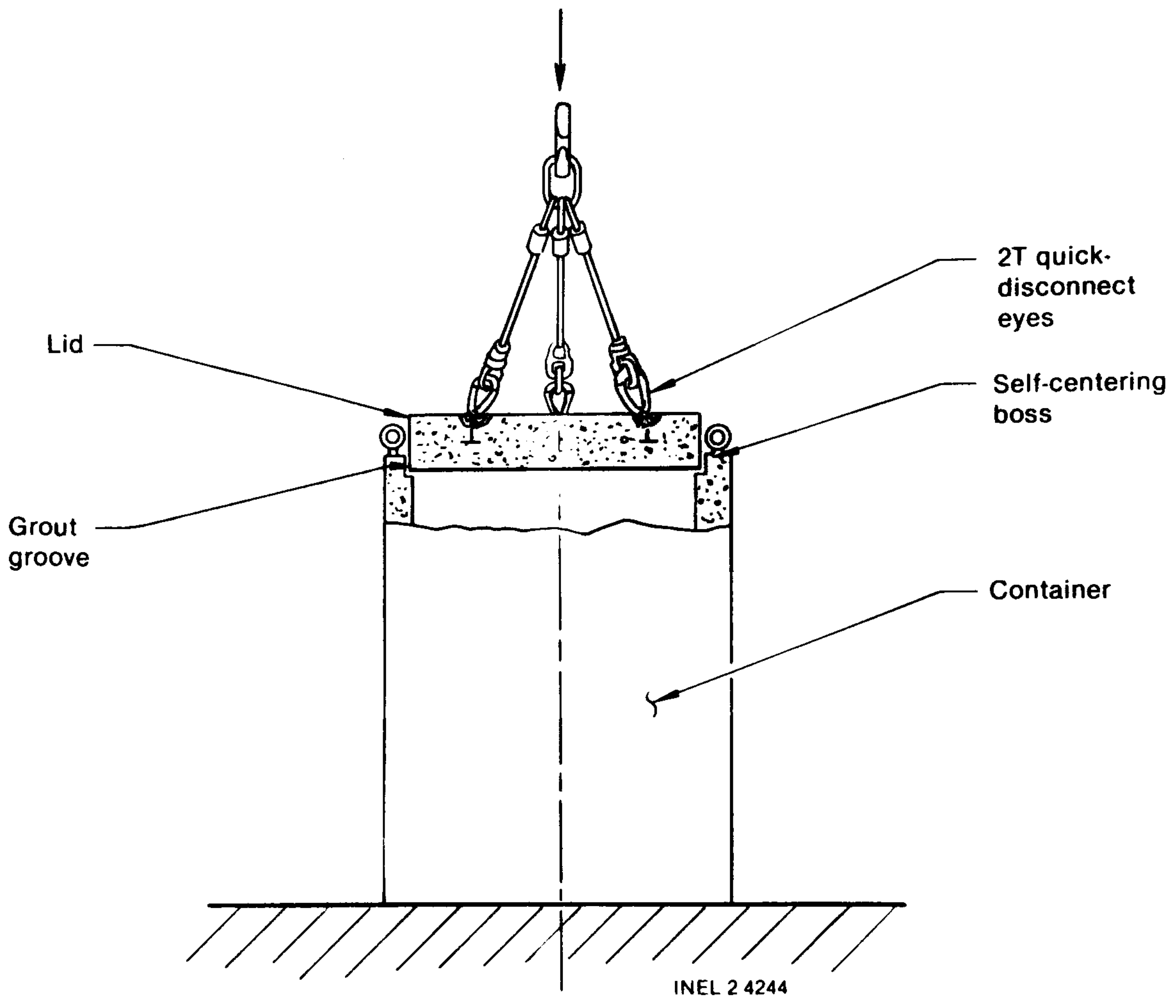


Figure 4. Placement of the lid on the HIC.

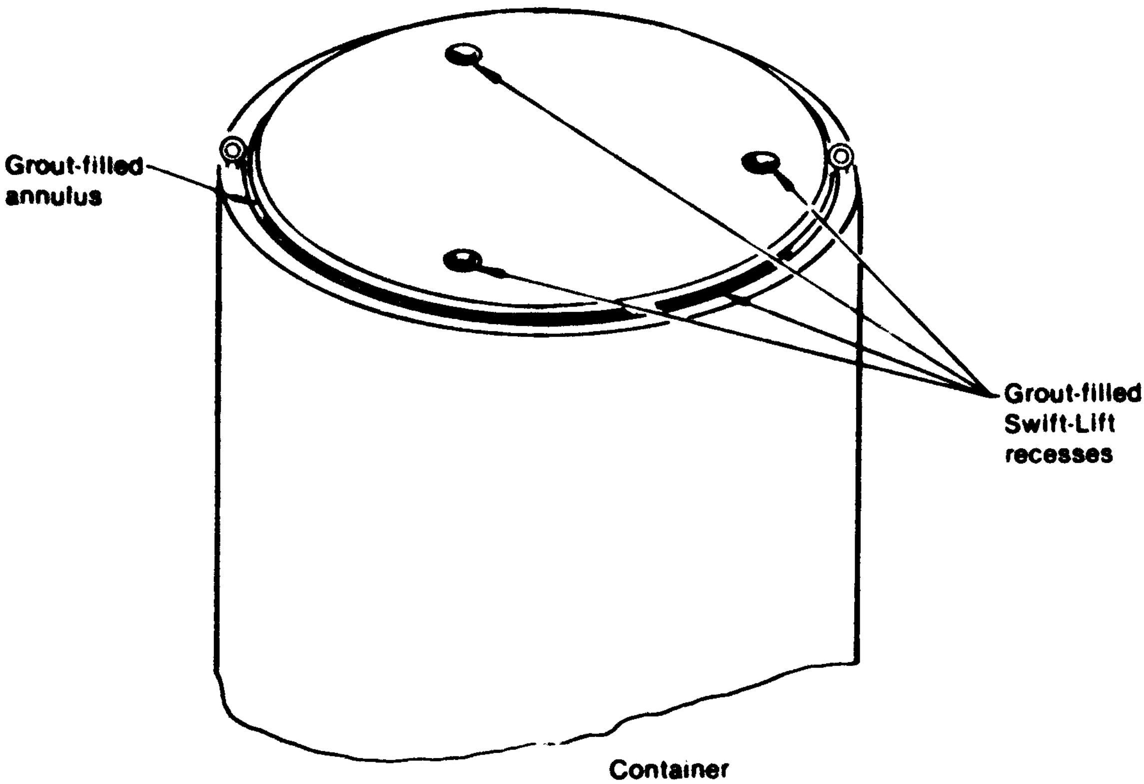


Figure 5. Final configuration of the HIC after being loaded and sealed.

2.3.1 Container Loading

The container body may be lifted and handled by two stainless steel lift eyes that are provided for attachment to a spreader bar fitted with conventional eye hooks (Appendix I). Three recessed, precast inserts in the lid are provided for attachment of quick-disconnect lift fittings. Figure 6 illustrates lifting equipment features.

Primary sealant is placed on the horizontal lid step circumscribing the inside top of the container before loading. A tapered loading ring, positioned over the top edge and lid step, serves to protect the lid sealant and epoxy coatings inside the container from damage by guiding the EPICOR-II liner into position. The EPICOR-II liner is positioned above the container, aligned with respect to the container (Figure 3), and then lowered into the container, eventually coming to rest upon a polyethylene base plate filled with amphoteric material. The liner then is released from the hoist. The loading ring is lifted off and set aside, and the lid lifted and placed in the primary sealant. The lid is fitted with self-centering features, which ensure a 1-inch annular groove between the lid and container body (Figure 4).

A pourable and/or pumpable epoxy grout is placed remotely in the annular groove between the lid and container body. That epoxy grout prevents migration of corrosive materials along the boundary between the lid and concrete body. The recesses of the three lift inserts of the lid also are filled with the same pourable epoxy grout (see Figure 5). The grout is allowed to set (4-10 hours) before the container is moved. Next, the spreader bar is attached to the container eyes and the container is moved to an interim storage location for 48 hours, the time necessary for complete curing of the grouted joint.

2.3.2 Container Disposal

When the grout materials have cured, the HIC containing an EPICOR-II liner is ready for disposal. The loaded HIC is transferred to a Type-B shipping cask; the closed cask is placed on the transport trailer; and the

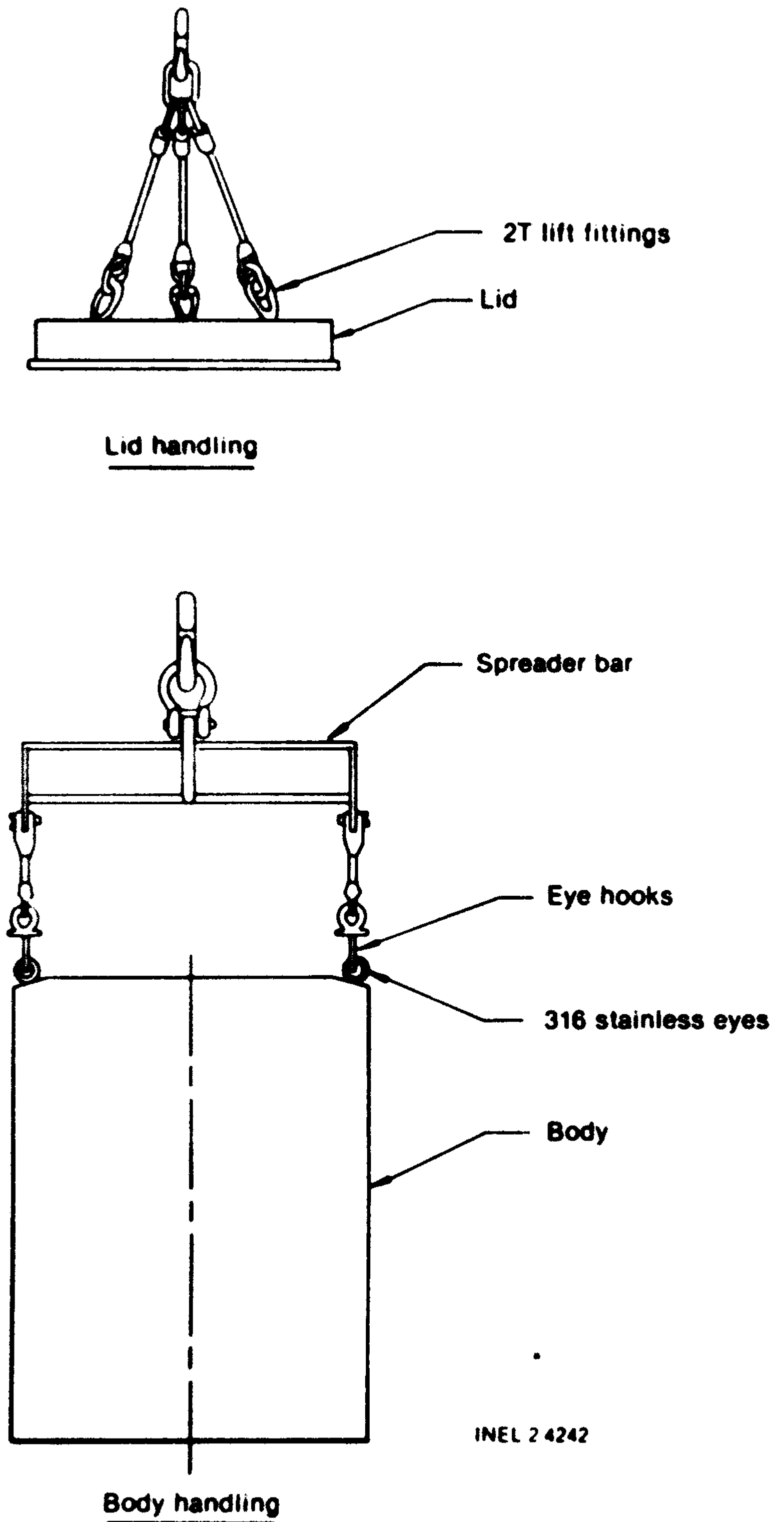


Figure 6. Rigging equipment of the HIC.

whole system is sent to a commercial disposal site. At the disposal site, the lid of the shipping cask is removed and the HIC is hoisted from the cask and transferred to the bottom of the disposal pit.

2.4 Prototype Fabrication

Two prototype HICs (designated S/N001 and S/N002) were built as a part of EG&G Subcontract K-9063. Those prototypes, both pictured in Figure 7, were fabricated for testing to verify that designs satisfy requirements. One was used to develop and demonstrate techniques for disposal of the EPICOR-II liner. The other was used as the test vessel in independent review/evaluation of container design. Both prototypes are identical to the container recommended for use in disposal of the EPICOR-II liners, except in the following respects:

1. S/N001 was fitted with an auxiliary test port to allow verification of sealing effectiveness (Appendix A). The coating on the exterior was omitted to permit visual inspection of cracks following each qualification drop test. Nuclear Packaging, Inc., performed the drop tests as a part of vendor evaluation tests (see Appendix E).

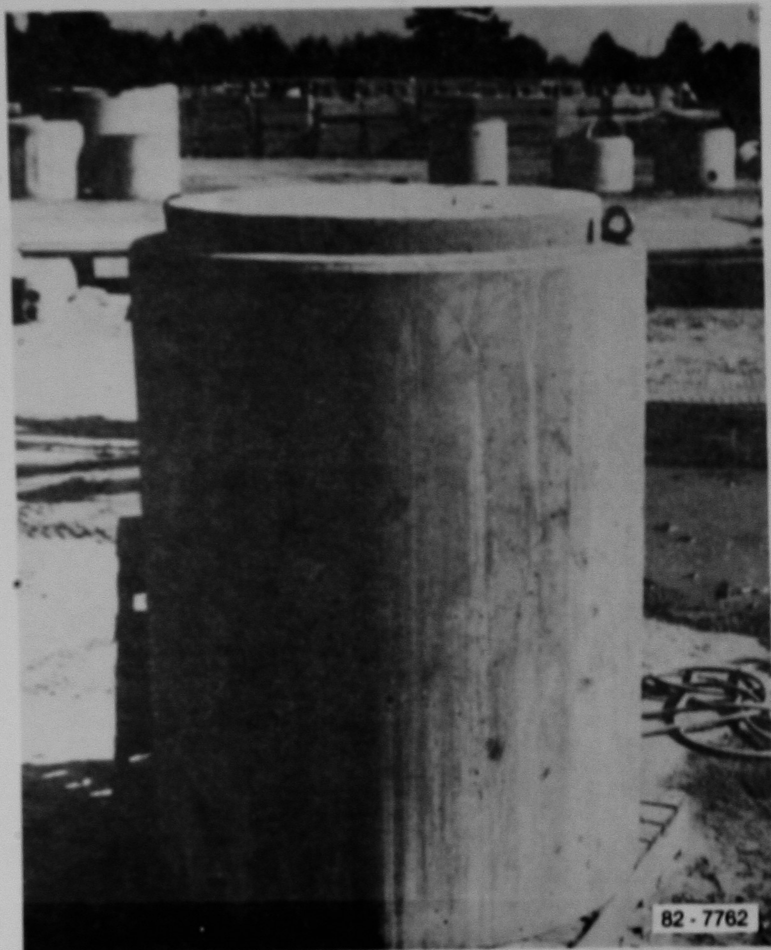
2. S/N002 was fitted with two auxiliary test ports for EG&G Idaho testing of seal and vent operations.

Fabrication work was divided among three crafts:

1. Steel fabrication shop--for the HIC steel liner and auxiliary equipment (loading ring and lift fixtures)

2. Machine shop--for the vent assembly

3. Concrete precast yard--for the container body and lid assembly.



(A) S/N001, uncoated, ready for drop-testing.

(B) S/N002, coated, ready for delivery to INEL.

Figure 7. Prototype High-Integrity Containers.

2.4.1 Fabrication of the Steel Liner

The steel liner consisted of a right circular cylinder with a flat plate bottom and a rolled-angle top flange, as pictured in Figure 8. Reinforcing studs were attached to the liner with an automatic stud gun. The fabrication was simple and straightforward, except for the following:

1. The tightest attainable tolerances for the top-welded flange, which eventually mates with a precision concrete, lip-casting form, were maintained using thin-gauge weldments; then the fabrication was "sprung" to shape following completion of all welding.

2. The primer (Phenoline 300 Orange) for the corrosion-resistant coating was a mica-filled epoxy, mixed and applied with precise process control using equipment (nozzles), flow rates, line sizes, and so forth, specified by the coating manufacturer.

Nondestructive examinations were performed to verify that the coatings were applied correctly. To ensure adequate film thickness and coating adhesion, the coating was applied by brush to tight areas, welds, and corners on the concrete anchor studs.

The following coating inspections were performed:

1. Verification that the coating manufacturer had provided the appropriate documentation required by ANSI N101.4 ("Quality Assurance for Protective Coatings Applied to Nuclear Facilities").

2. Verification that the coating applicator had written procedures conforming to the requirements of ANSI N101.4 and that the written procedures had been followed.

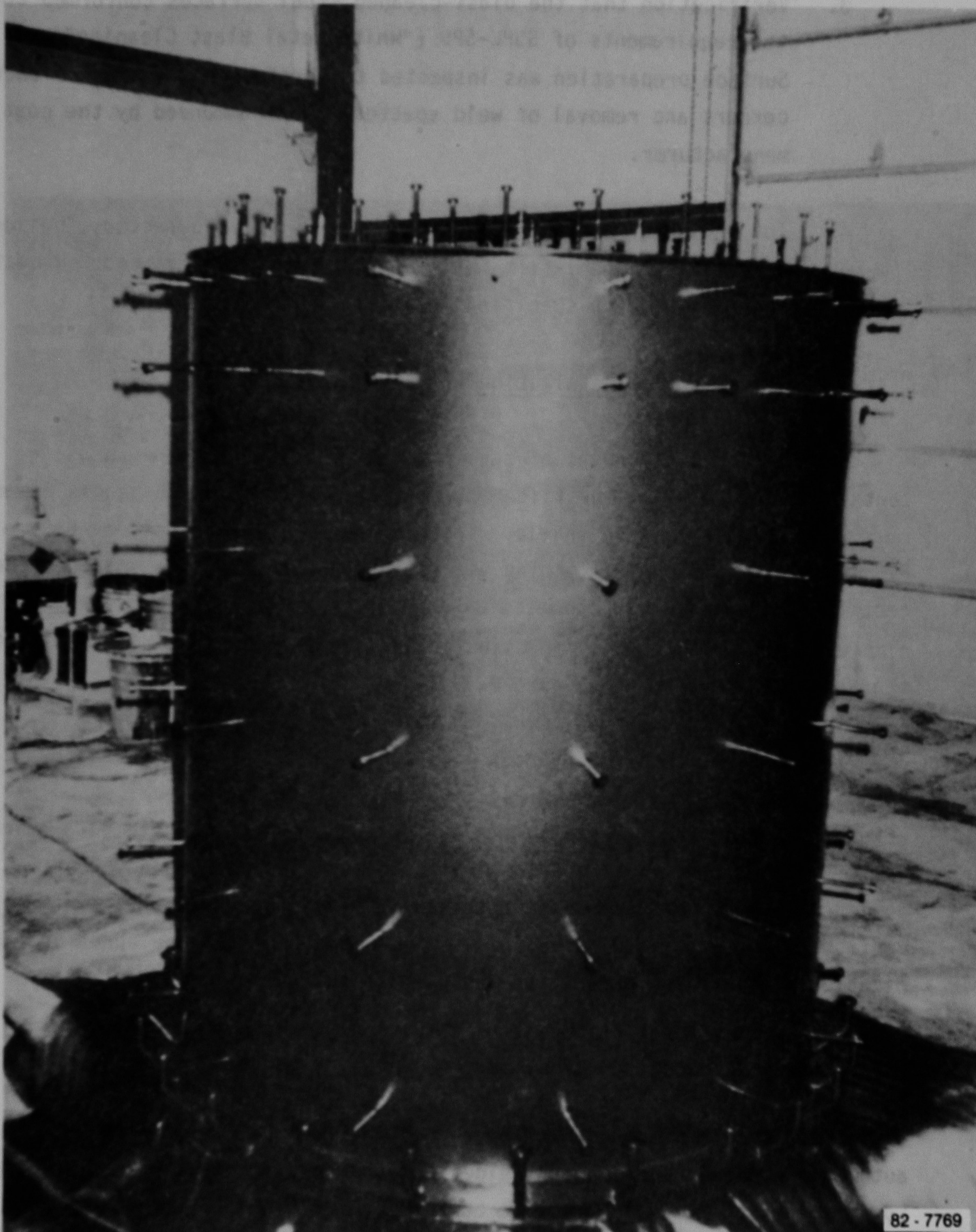


Figure 8. Steel liner with reinforcing studs of the High-Integrity Container after being coated with epoxies.

3. Verification that the blast-cleaned steel surfaces conformed to the requirements of SSPC-SP5 ("White Metal Blast Cleaning"). Surface preparation was inspected to verify the rounding of sharp corners and removal of weld spatter, as recommended by the coating manufacturer.

4. Inspection of the applied coating with pinhole detectors, holiday detectors, and dry-film-thickness gauges to verify that the coating conformed to specified requirements.

2.4.2 Fabrication and Installation of the Vent Assembly

The principal component of the vent assembly is a machined housing containing the polyethylene filter stack (Dwg. EP-20-06D of Appendix A) and surrounded by a cast-lead shield. The housing is connected at one end to a PVC water trap and outlet fitting via stainless steel tubing. At the other end, the filter assembly connects to a 5-micron stainless steel filter nipple attached to the lid corrosion barrier. The installed components of the assembly are shown in Figure 9.

To achieve acceptable hydrostatic head retention, a trial-and-error, assembly-and-test sequence was used. Units that performed unacceptably were disassembled and rebuilt, with the polyethylene filter elements being replaced each time. That approach was necessary because there were significant variations in flow characteristics of filter elements. That variation seemed to be caused by differing amounts of release agent in fabrication of sintered, porous, polyethylene filters.

2.4.3 Fabrication of the Rebar Cage

Spiral, circumferential reinforcing bars (rebars) were wound by an automatic wrapping machine and welded to straight, longitudinal spacer bars. Longitudinal structural bars were bent to proper U-shape (see Figure 10). The steel liner was inverted and supported on a circular steel form, which shaped the lid step and sloped the top surface.

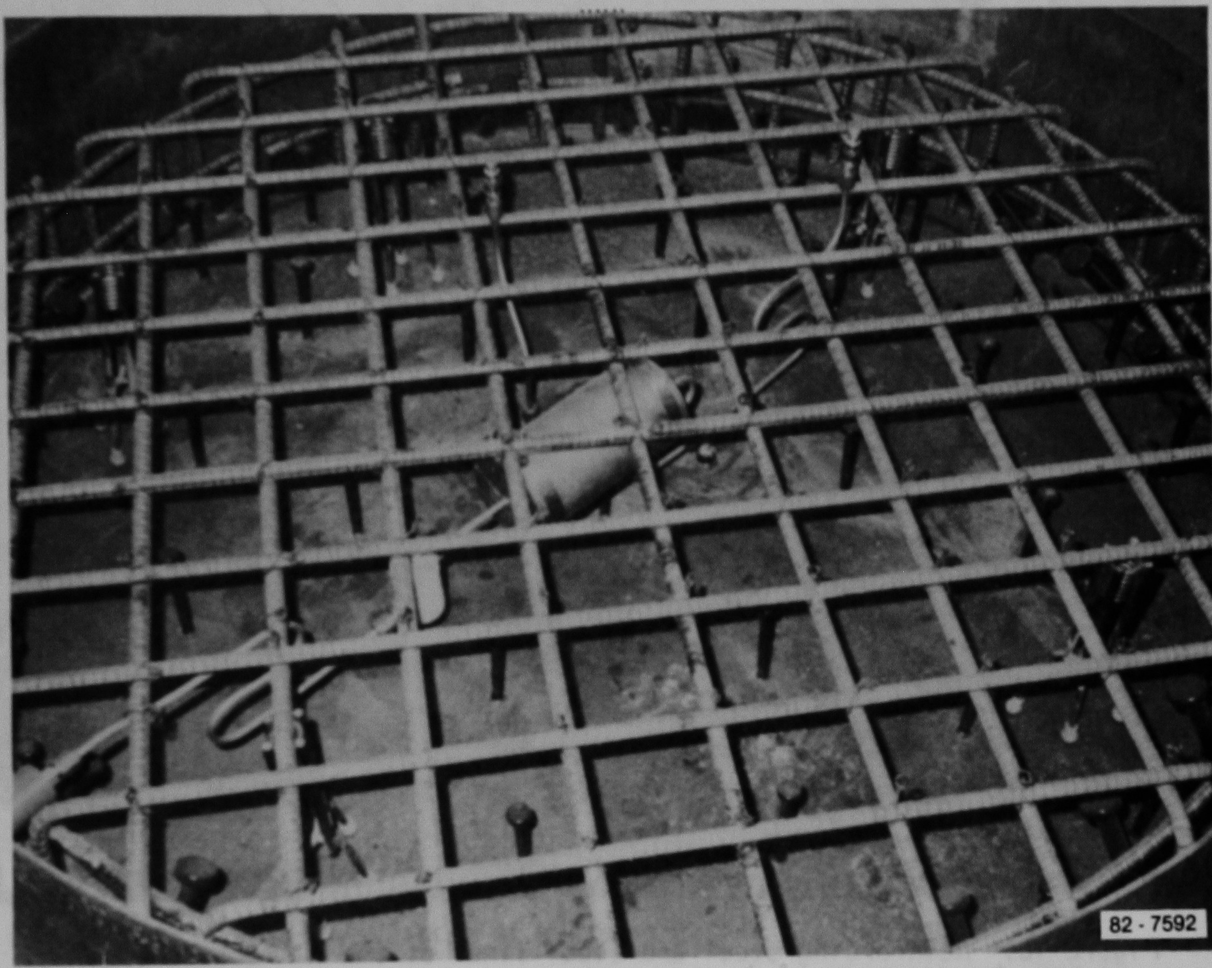


Figure 9. Vent system in the lid of the prototype High-Integrity Container (S/N002).

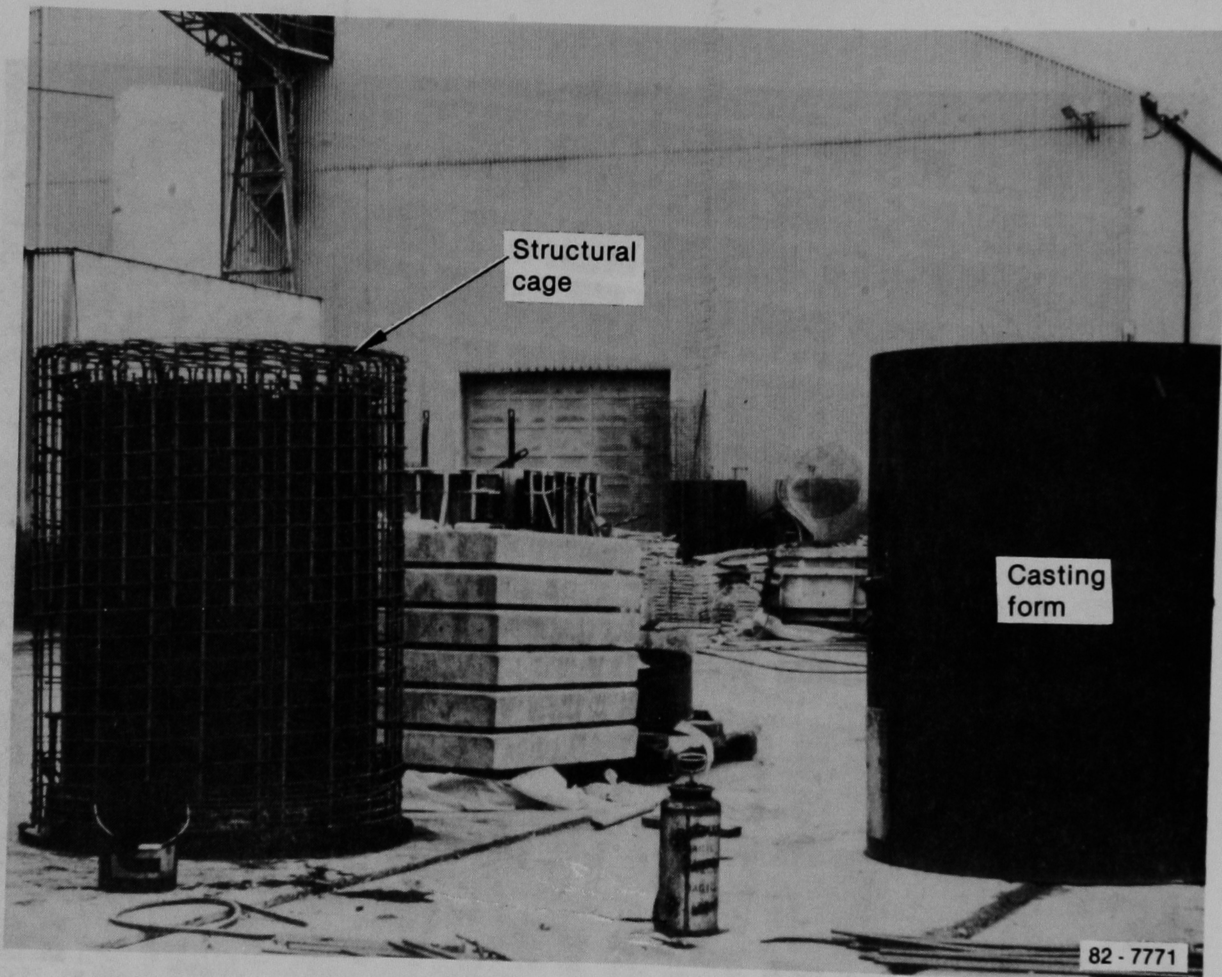


Figure 10. Reinforcing steel and steel liner of the HIC before casting.

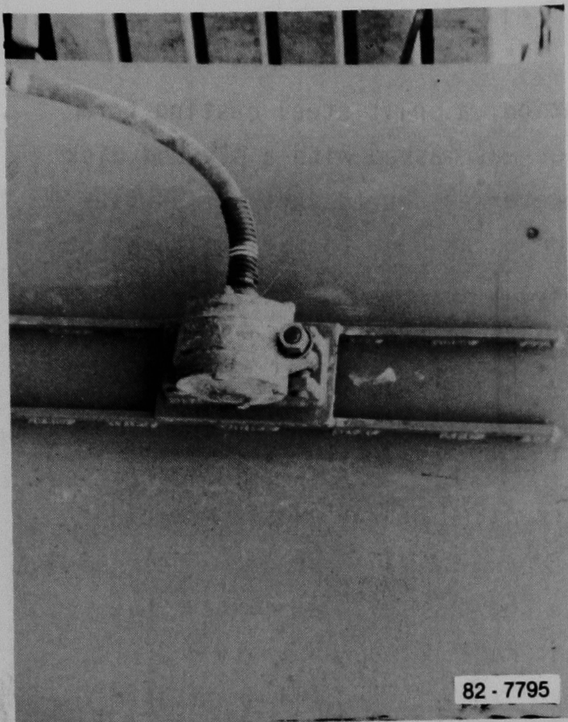
2.4.4 Concrete Casting

Following completion of rebar fabrication, a split steel casting form was placed around the rebar cage. The liner was masked with a plywood disk equal in diameter to the rebar cage. Concrete was poured into the annular space between the steel casting form and the rebar cage to prevent abrasion of the outer coating of the steel liner. Voids in the concrete were eliminated during casting by using pneumatic-form vibrators like the one pictured in Figure 11. Photographs in Figure 12 show the appearance and surface characteristics of the body casting immediately after removal of the forms.

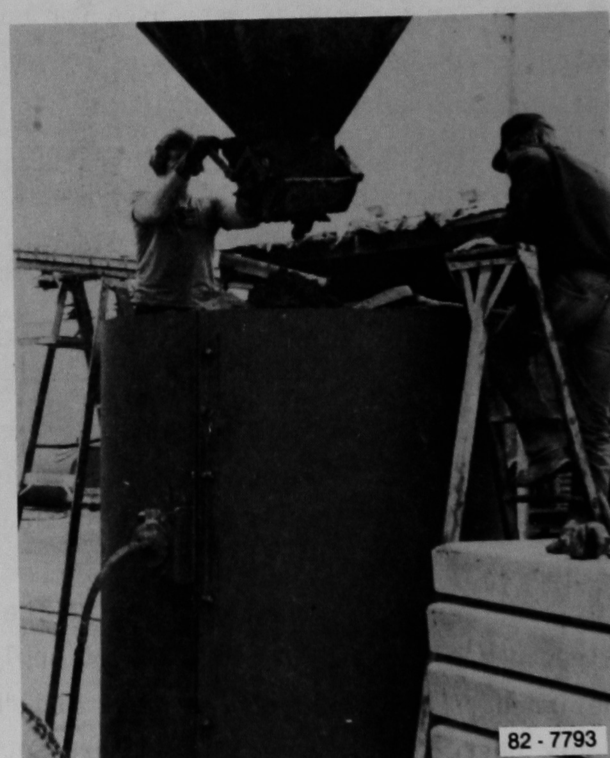
Similar techniques were used for construction of the lid (Figure 13), except voids were prevented by using small, hand-held vibrators. Recessed lifting lugs were positioned in the lid via the three-legged fixture pictured in Figure 13(A). The low water/cement ratio of approximately 0.32 produced concrete with minimum permeability. The concrete mix contained air-entraining agents and super-plasticizers to improve workability.

Upon completion of the castings, stainless steel body lift lugs were threaded into inserts located at the base of "blocked-out" pockets (see Figure 12). The pockets subsequently were filled with a radiation-resistant epoxy mortar. Following the 28-day curing period, all lift inserts were tested to 150% of individual working loads.

The surface coat was applied to the outside concrete surface in two steps. The first step consisted of applying a thin film of Carboline 195 designed to fill all surface voids and "bug holes." A squeegee was used to "work out" all entrapped air and prevent formation of pinhole defects; thinner was added to improve workability of the film material. In the second step, additional Carboline 195 surface material was applied to build coating thickness to the specified value. The exterior coat, Carboline 191HB, was applied by spraying.



(A)



(B)

Figure 11. Installation of a form vibrator (A); placement of concrete (B).

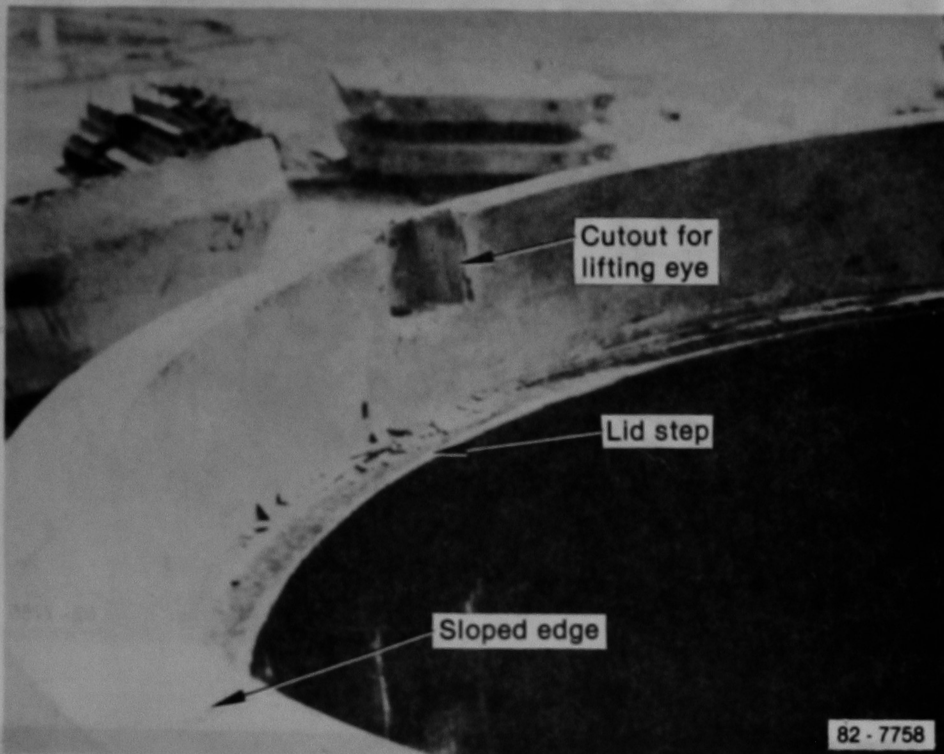
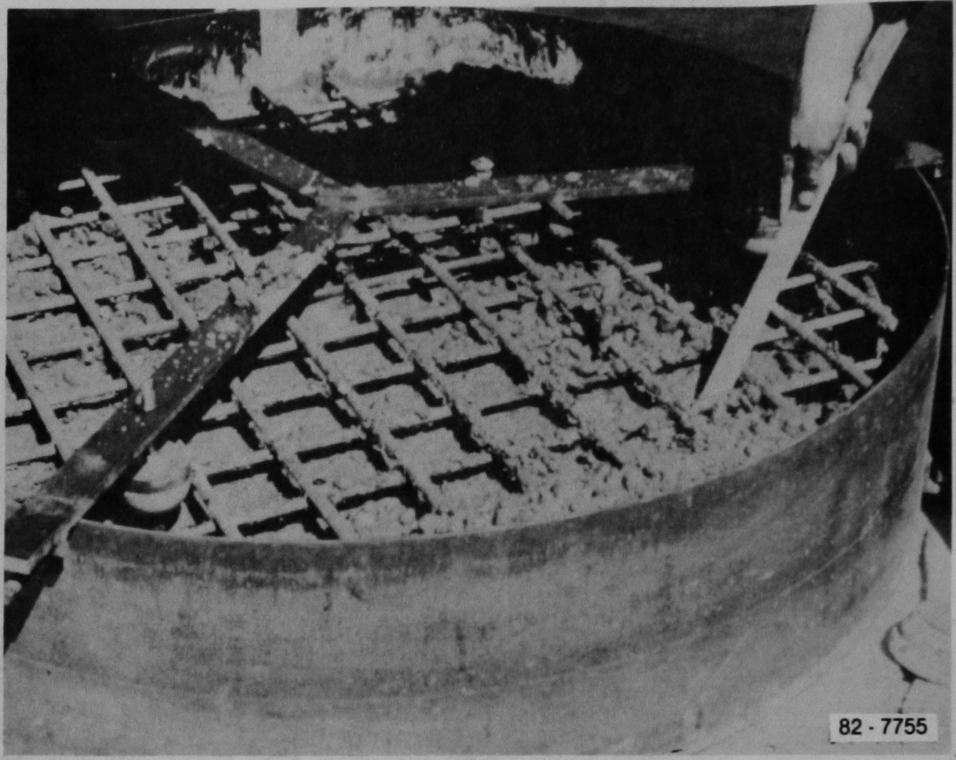


Figure 12. Top-edge detail before and after installation of lift eyes.



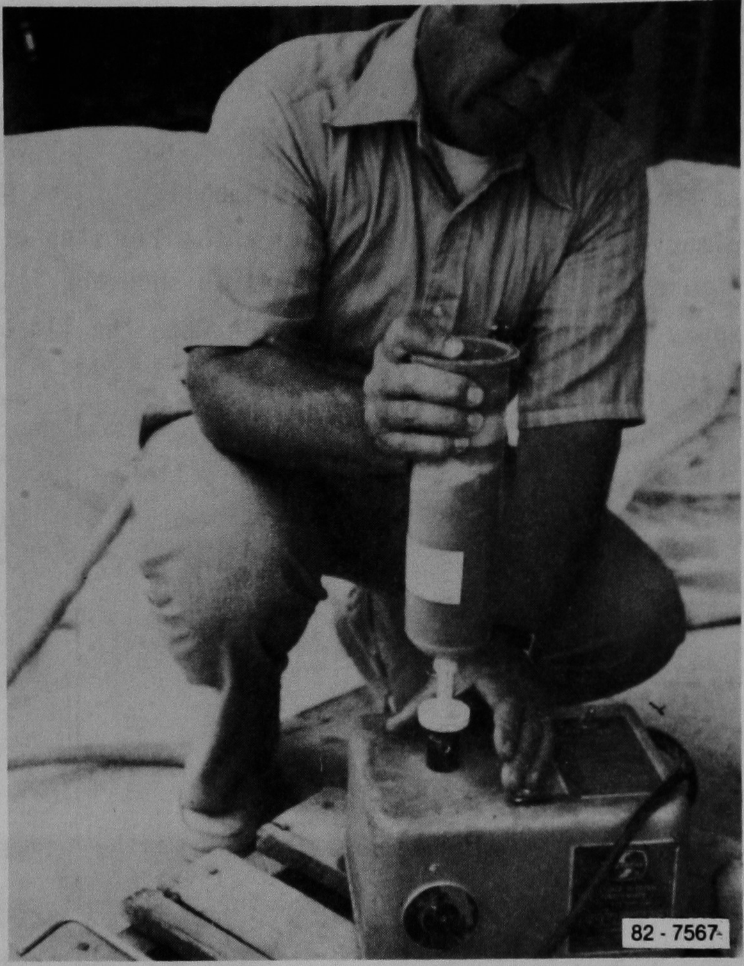
(A)

(B)

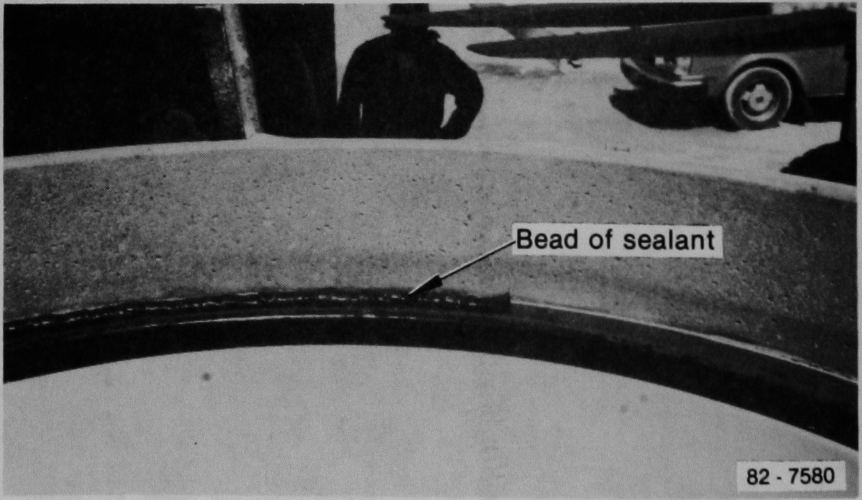
Figure 13. Lid fabrication with use of a submerged vibrator (A); the finished casting (B).

2.4.5 Lid Installation

The lid of S/N001 was affixed to the container body with the primary and secondary seal materials to demonstrate suitability of the design. Mixing of the primary epoxy and its placement on the lid step of the body is pictured in Figure 14. Photographs of Figure 15 show the lid in place on the primary epoxy seal, and the annular gap between the lid and container body filled with secondary epoxy.

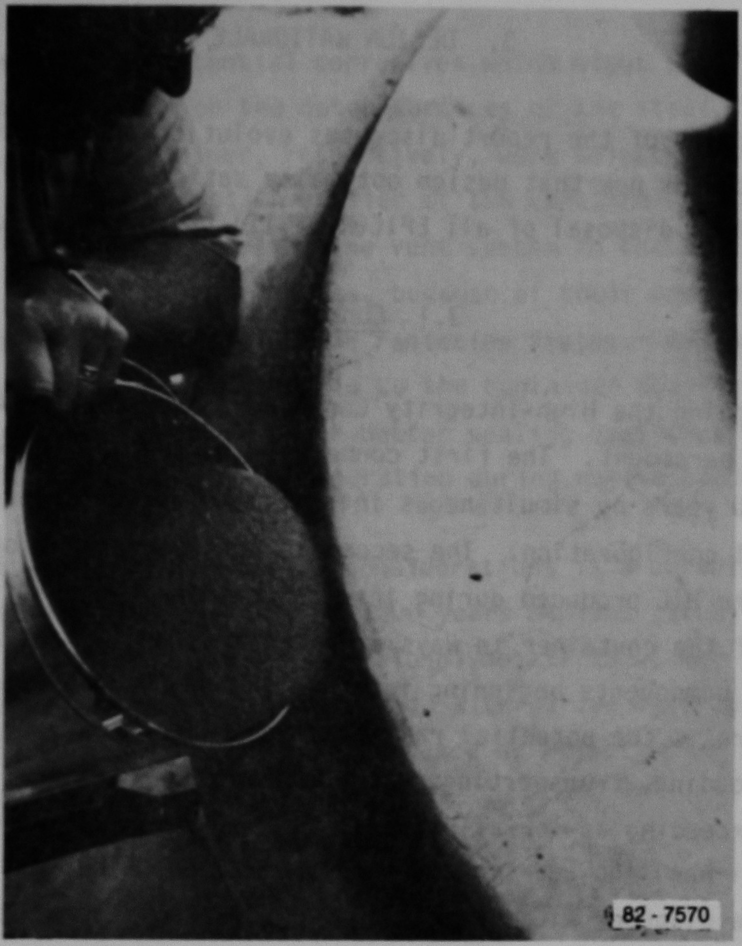


(A)

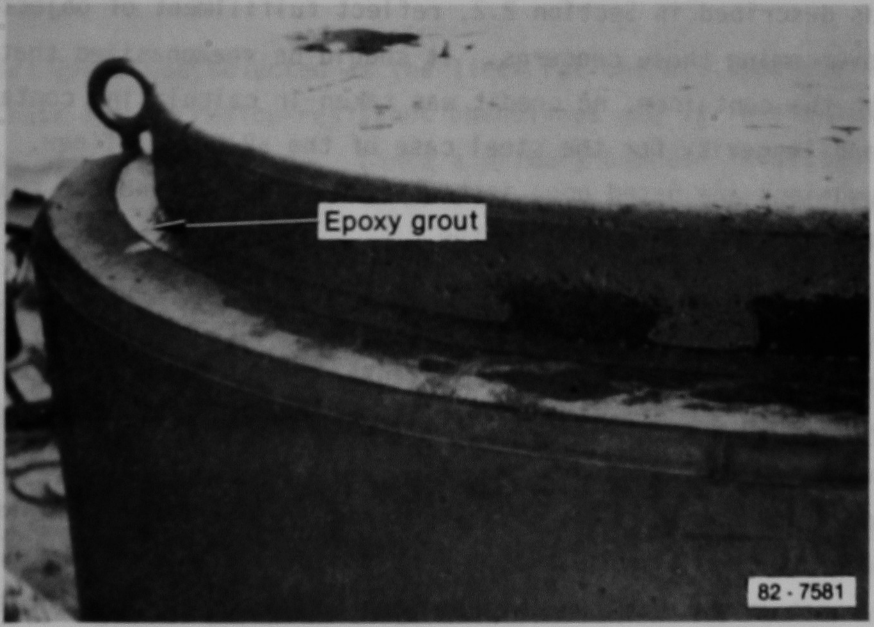


(B)

Figure 14. Mixing of the primary sealant (A); a bead of primary sealant on the lid step (B).



(A)



(B)

Figure 15. Final installation of the lid on the body of the HIC (A); secondary epoxy filling annulus between the lid and the body (B).

3. DESIGN RATIONALE

This section of the report discusses evolution of the design of the HIC, and discusses how that design optimally satisfies design requirements that will affect disposal of all EPICOR-II liners in storage at INEL.

3.1 Concerns

In designing the High-Integrity Container, overcoming some fundametal concerns are paramount. The first concern is failure of the container in less than 300 years by simultaneous internal and external corrosion while in a disposal configuration. The second is passive exhaustion of potential gases from the HIC produced during internal chemical activity. The third is failure of the container in ways other than by methodical and sequential breaching of components beginning internad and proceeding externad. The fourth concern is the potential radiation hazard to both operators and public during loading, transporting, and disposing the container. The fifth concern is exceeding as-low-as-reasonably-achievable (ALARA) goals, which influence all handling and transporting operations. The last concern is burdening the disposer with unnecessary costs associated with fabricating, loading, transporting, and disposing of containers. Thus, design selections, as described in Section 2.2, reflect fulfillment of objectives leading to overcoming those concerns. It should be reemphasized that, in designing the container, no credit was taken in calculating container durability and longevity for the steel case of the EPICOR-II liner. Instead, all assumptions are based upon instantaneous disappearance of that case once the EPICOR-II liner is sealed in the HIC.

In selecting materials and/or mechanical parts for components of the container, those materials or parts eventually chosen better fulfilled specific needs than comparable materials or components. For example, the phenolic-coated, steel liner, as part of the internal corrosion barrier, was selected after comparing its advantages and disadvantages with liners constructed of various stainless steels or polyethylene. An amphoteric material, as another part of the internal corrosion barrier, was chosen for placement in the bottom of the interface between the EPICOR-II liner and container to neutralize potential corrosives which might seep into that space. Coatings of epoxy on the outer surfaces of the steel liner and concrete portion of the container, respectively, were selected in the constructing the external corrosion barrier of the container system. The special water traps and filters of the vent system in the container lid were selected in favor of other parts, because of their mechanical simplicity and prolonged operability in high radiation fields. Redundant epoxy seals were chosen for binding the lid to the container body in lieu of mechanical devices, because of their better sealing qualities in a high radiation field and their ease of operation during remote handling.

The resultant product from all considerations is a durable container with a calculated life expectancy of 1200 years minimum (study Appendix B). The following subsections provide additional detail about why specific features, materials, and parts were selected, alternative materials and parts considered, and verbiage regarding acceptance or rejection of candidate material and/or parts.

3.2 Internal Corrosion Barrier

3.2.1 Steel Liner

A steel liner was selected as the liner for the HIC, because it is a good substrate for corrosion-resistant phenolines and is less expensive than other types of metal (Table 4). Since a primary concern in design of the HIC was reducing corrosion (both internal and external) while maximizing longevity of the container at the lowest possible cost, the use of multiple corrosion- and radiation-resistant materials in two complementary corrosion barriers precluded the desirability of using one expensive material highly resistant to corrosion. Therefore, stainless steel appeared less attractive and more susceptible to failure over the design lifetime of the container, unless it too were protected with some material(s). The concept of a steel liner armed with multiple layers of phenoline became the design choice.

TABLE 4. COST DATA FOR ALTERNATIVE METAL LINERS

Material	Corrosion Behavior	Relative Cost Multipliers[a]		Dollars/Pound	
		Fabrication	Raw Material	Fabrication	Raw Material
Titanium	Satisfactory, except for resistance to sulfate ions	9.6	8.0	21.68[b]	2.24
Monel	Not resistant to sulfuric and sulfurous acids	6.6	7.5	14.90[b]	2.10
304 CRES	Not as resistant as 316	1.9	4.5	4.25[b]	1.25[c]
316 CRES	Satisfactory, except for pitting from chlorides	3.4	7.2	7.59[b]	2.02[c]
20-Cb-3	Better than 316 CRES	7.2	22.5	16.26[b]	6.29[c]
A-36	Baseline comparison	1.0	1.0	2.25[d]	0.28

a. Relative to carbon steel (A-36).

b. Based on quotations from four fabricators (April 1981).

c. Based on quotation from material supplier (ESCO, December 1981).

d. Assumes $1.55 for fabrication + 45% markup (overhead, profit).

It is interesting, however, that the conceptual version of the HIC developed by NuPac included an internal liner/corrosion barrier of uncoated Carpenter 20-Cb-3 stainless steel. In that initial design, Carpenter 20 was chosen over less expensive types of stainless steel (e.g., 316) because it has the greatest resistance to corrosion by chlorides, as revealed in Table 5.

TABLE 5. RESISTANCE OF CANDIDATE STAINLESS STEEL LINER MATERIALS TO CORROSION

Corrodant	Stainless Steel Corrosion Resistance[a]		
	304	316	20-Cb-3
Sulfur dioxide (SO_2)	X	●	○
Ferric nitrate	○	○	●
Ferric sulfate	●	●	●
Ferrous sulfate	○	○	○
Ferrous chloride	X	X	□
Sulfuric acid	X	X	●
Sulfurous acid	○	○	○
Nitrous acid	X	--	--
Carbonic acid	X	○	●
Hydrochloric acid (air-free)	X	X	X
Aluminum sulfate (with amphoteric material)	●	●	●
Aluminum chloride (with amphoteric material)	X	□	●

a. From Reference 5; at <125°F and <10% concentration.

Key: Per National Association of Corrosion Engineers:

Symbols	Per Year (in.)	300 Years (in.)
●	<0.002	<0.60
○	<0.02	<6.0
□	0.02 to 0.05	6 to 15
X	>0.05	>15

Two other types of HIC liners also were considerd, viz., a roto-molded, polyethylene liner and a reinforced-epoxy coating applied over concrete.

Each type was augmented by an amphoteric neutralizing agent. Characteristics of the two alternatives are compared with a phenolic-coated steel liner in Table 6. The concept of a coated-steel liner is superior to the other two candidates.

3.2.2 Steel Liner Coatings

The primary corrosion barrier selected is a series of phenolic coatings, which singularly and collectively resists reacting with neutralized products from resin decomposition. The coatings are each applied to the steel liner under strict quality control conditions. Data sheets and test results for Phenoline 300 Orange primer and Phenoline 302 finish (included in Appendix J) verify the suitability of those phenoline coatings for this application.

3.2.3 Amphoteric Material

As insurance against possible internal corrosion of the HIC after disposal, an amphoteric material was incorporated into the internal corrosion barrier. By definition, an amphoteric material is capable of reacting chemically either as an acid or as a base. Thus, use of an amphoteric material (i.e., aluminum hydroxide) in the HIC will narrow the internal pH range from a possible 2 to 11 to the design value of 6 to 10.[a]

Aluminum hydroxide neutralizes via reactions similar to those shown below for sulfuric acid and sodium hydroxide, respectively:

---

a. EG&G firmly believes in the adequacy of the HIC design and its fulfillment of all requirements, including established pH specifications. However, pH conditions in EPICOR-II liners apparently are less aggressive than originally surmised, based upon pH analyses of two liners (i.e., PF-3, -16) by BCL.[6,7] Data recently collected by EG&G in its liner integrity study involving those liners confirm the 5.3 pH values measured by BCL. EG&G is continuing confirmation that low pH values (<4.0) are not anticipated in liquids of EPICOR-II liners.

TABLE 6. DECISION MATRIX--EVALUATION OF CANDIDATE LINERS FOR THE HIC

Option	Advantage	Disadvantage
Polyethylene roto-molded liner	Low production cost	Long leadtime tooling
	Easy to inspect	Degrading (cracking) in ultraviolet light
	Excellent corrosion resistance	Permeable to cesium
	Abrasion protection a possible integral feature	Questionable gamma resistance
		Large quantities of H_2 produced under gamma radiation
		Uncertain creep behavior
		Large coefficient of thermal expansion, 10 times greater than steel/concrete
		Condensate can form on unprotected walls of the container
Reinforced epoxy coating	Coating system basically qualified	Capabilities of bridging cracks with chopped glass are not proven
	Low material cost	Extensive manual labor required for preparation of surfaces to be coated
		Potentially large amount of inspection and repair work
		Rub strips required for abrasion protection
Coated steel liner cast in place as casting inner form of HIC	Liner serves as form for vessel	Moderate manual labor and Q.A. required
	Liner acts as an excellent crack-free substrate for coating	Steel has a potential for brittle fracture failure

TABLE 6. (continued)

Option	Advantage	Disadvantage
	Low production cost	Rub strips required for abrasion protection
	Coating system fully qualified--no testing required	
	Thermally compatible with concrete vessel	
	No condensate on vessel wall	

$$2\ Al(OH)_3 + 3\ H_2SO_4 \rightarrow Al_2(SO_4)_3 + 6\ H_2O) \quad . \tag{3-1}$$

$$Al(OH)_3 + NaOH \rightarrow Na(AlO_2) + 2\ H_2O \quad . \tag{3-2}$$

The quantity of aluminum hydroxide needed in the HIC is calculated for the following worst-case conditions:

1. All water content in the container reacts with degraded resin products to form an acid 10 times more concentrated than that found in degraded cation resin products analyzed by McFarland.[8]

2. All acid produced leaves the EPICOR-II liner without chemically reacting and is available to react with the aluminum hydroxide.

Consistent with calculations presented in Appendix C, the amount of resin mixture is assumed at 8.82×10^2 kg, of which 47% by weight is water. Therefore, 4.14×10^2 kg of water are assumed in an EPICOR-II liner. McFarland (Reference 6) determined the most acidic liquids from degradation of irradiated resin would have a pH of 2.5, which corresponds to 0.0035 N acid.

The 4.14×10^2 kg of water per EPICOR-II liner translates to 414 liters of solution, which will yield 1.45 equivalents of acid (414 liters x 0.0035 equivalents/liter). Applying the worst-case assumption, a solution 10 times more concentrated yields 14.5 equivalents of acid to be neutralized by aluminum hydroxide. The weight of aluminum hydroxide required to neutralize that amount of acid is calculated as follows:

$$14.5 \text{ equivalents} \times [(27 + 51)/3] \text{ g/equivalent} = 377 \text{ g, or } 0.83 \text{ lb.} \tag{3-3}$$

It is appropriate to use more amphoteric material in the HIC than the calculated minimum to ensure neutralization of any quantity of fluid that might leak from the EPICOR-II liner. Therefore, the design includes 20 pounds aluminum hydroxide mixed with an equal weight of water to form a paste.

It is important that the amphoteric material continue to function throughout the 300-year service life of the container. Although the aluminum hydroxide does undergo chemical change with time, temperatures remain sufficiently low to preclude formation of insoluble or ineffective chemical forms. Details of those changes are outlined in the following paragraph.

Amorphous aluminum hydroxide dissociates, depending on pH of the solute, according to the following:

$$Al(OH)_3 \rightarrow Al^{+++} + 3\ OH^- \tag{3-4}$$

$$Al(OH)_3 \rightarrow AlO_2^- + H^+ + H_2O\ . \tag{3-5}$$

At low pH, the Al^{+++} ion will predominate and at high pH the AlO_2^- ion will predominate. $Al(OH)_3$, the most soluble amphoteric material, is amorphous and is the form projected for use in the HIC (see Figure 16). Corundum (Al_2O_3) is the only stoichiometric pure oxide of aluminum, the formation of which depends on the conditions of preparation. Hydrated oxides can be converted to the pure oxide by heating to above 200°C.[9] The temperature that the amphoteric material will experience in the HIC (75°C) is not sufficient to convert hydrated forms to a pure oxide. The aluminum hydroxide, $Al(OH_3)$, is not stable; it tends to crystallize forming the monohydrate bohmite (λ-$Al_2O_3.H_2O$). Eventually bohmite changes to the trihydrate bayerite ($Al_2O_3.3\ H_2O$), and finally to the trihydrate hydrargillite. Each successive hydrated form has increased stability and reduced solubility in water, acids, and bases; but all are amphoteric and act to drive the pH toward neutral (pH =7).

3.3 External Corrosion Barrier

3.3.1 Reinforced-concrete Container Body

In designing the HIC, attention was focused on preventing deterioration of the reinforced-concrete body, and corrosion of the rebar cage. Concrete

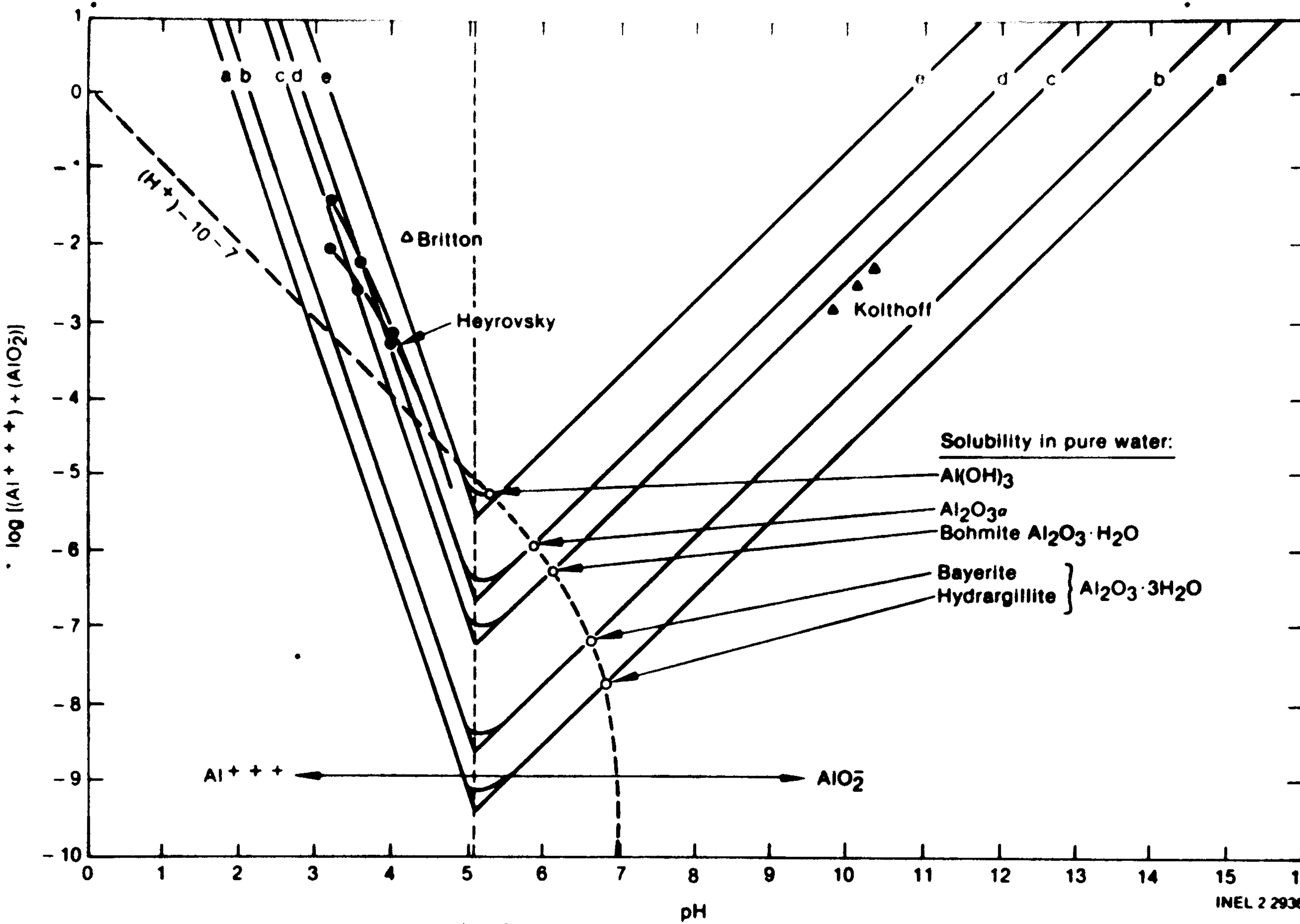


Figure 16. Graphic representation of amphoteric characteristics of various oxides of aluminum.

normally protects embedded steel from corrosion by being alkaline and forming a gamma, iron oxide, passivating film over its reinforcing steel. However, chloride ions in concentrations greater than 330 ppm tend to destroy the protective film, and initiate corrosion of rebar.[10,11]

Three precautions taken in designing the HIC protect against potential deteriorations of the concrete and corrosion of the rebar. The precautions permit use of the HIC in soils of disposal sites both in the western and eastern United States. Soils of western disposal sites are generally free of water and chlorides, and high in oxygen, whereas those of eastern sites are just the opposite (i.e., high in water and chlorides and low in oxygen).[12] In order for corrosion to occur, water, chlorides, and oxygen must be present. The three precautions are as follows:

1. Reinforcing cover of 1-1/2 inches or greater to ensure minimum permeability to rebar location, as shown in Figure 17 and Reference 13.

2. Exterior of the container coated with sealant to further slow the permeation of corrosion prerequisites (oxygen, chloride, water, etc.). Pinhole defects and chips in the concrete coating have little impact upon the coating effectiveness as a barrier to corrodant permeation. That is, the aggregate quantity of corrosive substances at the rebar determine corrosive potential, not the existence of a localized concentration of corrosive substances at the external concrete surface.

3. Water-to-cement ratio below 0.4 to minimize permeability, the effect of which is shown in Figure 18 and Reference 11.

3.3.2 External Coating

A heavy coating of epoxy applied to the ouside of the concrete container will minimize permeation of groundwater into the concrete. Carboline 195 Surfacer and Carboline 191 HB are used because they are nuclear

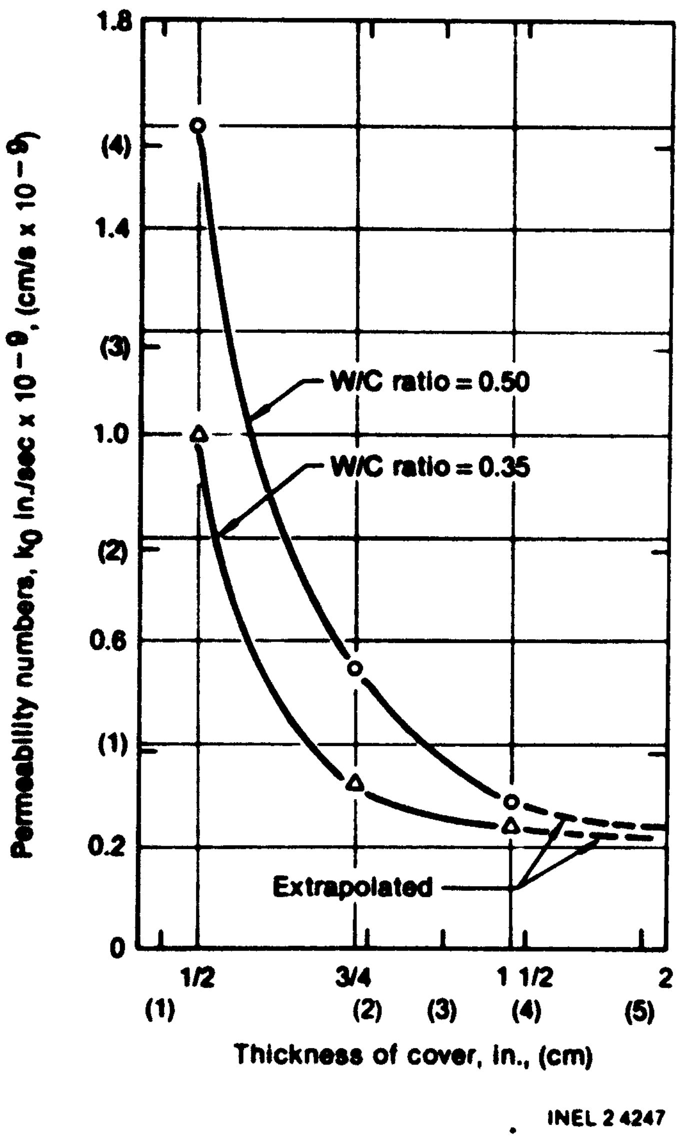


Figure 17. Effect of concrete cover over rebar on concrete permeability.

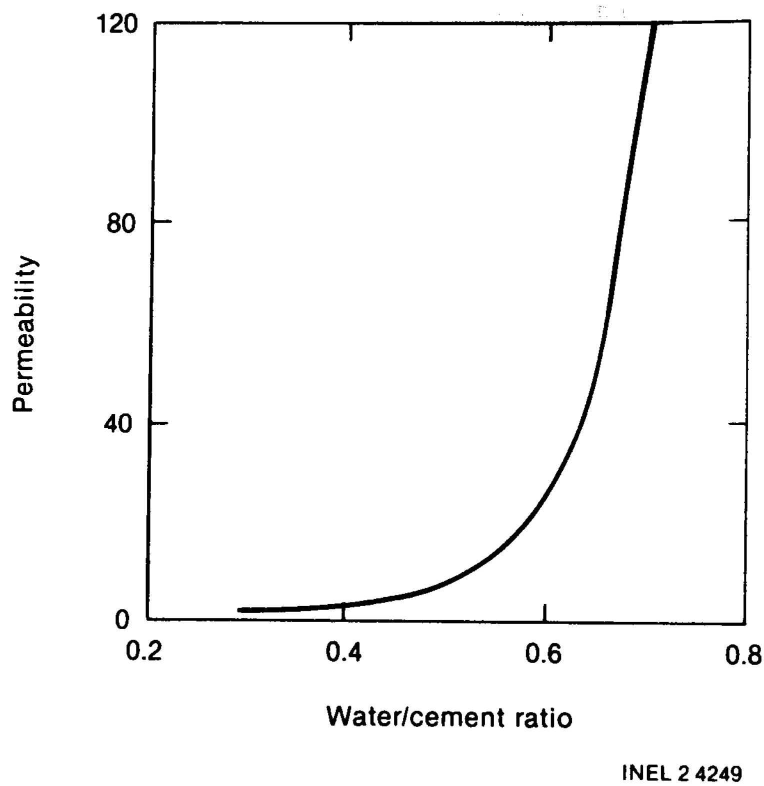


Figure 18. Effect of water content on concrete permeability.

qualified, have excellent resistance to the specified soil environments, are durable, and bond well to concrete. Data sheets for the carboline coating system are included in Appendix J.

3.4 Selection of Vent System

Two basic approaches were considered to satisfy the vent system requirements. The first approach employed active components such as check valves. The second approach used passive components only.

The initial version of the HIC had an active vent system consisting of:

1. Polyethylene check valves

2. A water trap

3. A top vent orifice and a nonmetallic particulate filter.

The design approach subsequently was changed in favor of a passive vent system, primarily because of concern over the ability of the check valves to provide a 300-year functional life. An evaluation of operational requirements for the check valve showed that the last vent cycle could occur as late as year 256 after being put into operation. That meant the valve would have to retain sealing and operational capabilities for 256 years. In a radiation field, it was considered unlikely that a check valve would remain functionally adequate for such a long time.

The final version of the HIC employs a passive vent system consisting of:

1. A porous polyethylene filter with a pore size of 1 micron

2. A water trap

3. A metallic filter nipple

4. A Porex pneumatic silencer, which serves as a mud filter.

While a passive vent system is free of mechanical difficulties, concerns over functional life in unfavorable environments must still be addressed.

3.4.1 Porous Metal Fiters

Porous metal filters were considered for use in the vent system because they lack the moving parts of check valves, and they passively permit removal of gases from the HIC. Filters get their liquid retention capabilities from the surface tension properties of liquids. The amount of pressure at which hydrophilic filters can retain liquids is given by:[14]

$$p = \frac{4\lambda}{d} \qquad (3\text{-}6)$$

where

p = pressure head of retained liquid

d = pore diameter

λ = surface tension coefficient.

The surface tension coefficient is 12.8 for water at 68°F and 72.15 for 4.2% HNO_3 at 68°F. Water retention capability as a function of pore size is shown in Figure 19 for pressures up to 40 psig. Apparently, filters with a 1-micron or smaller pore size can retain water from a 40-psi hydrostatic head.

Unfortunately, porous metal filters are hydrophilic, which means that water tends to be attracted to the walls, forming a miniscus as shown in Figure 20. Liquids tend to wick through the pores of hydrophilic materials,

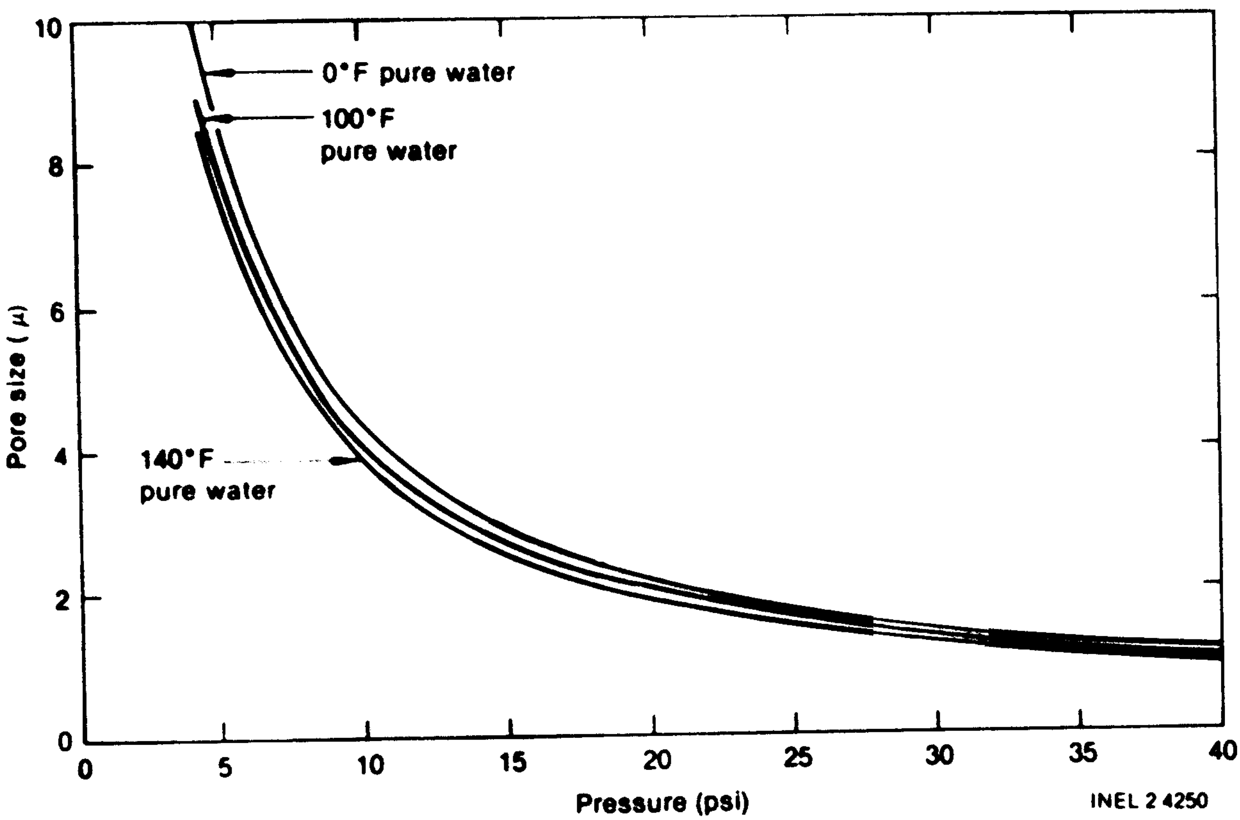


Figure 19. Ability of hydrophilic filters to retain water against a pressure head.

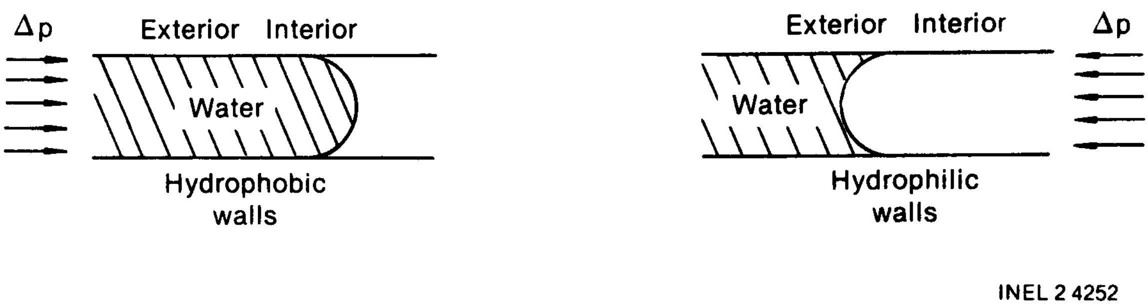


Figure 20. Comparison of fluid wetting action in hydrophobic and hydrophilic materials.

which become saturated. In order for the system to pass gas, the liquid must be purged from the filter. The surface tension, then, works to retain the gas. Once wetted, the hydrophilic filter will retain gas at the same pressure as it retains liquid. For this reason, porous metal filters were not selected for use in the vent mechanism.

3.4.2 Porous Nometallic Filters

Some available nonmetallic, hydrophobic filter materials satisfy the requirements to hold water at 40 psig and pass gas at very low pressures. They also survive a mildly corrosive atmosphere in a moderate radiation field. Candidate materials are polyethylene, polypropylene, polycarbonate, polyvinylidenedifluoride, and polytetrafluoroethylene. Radiation damage threshold values, based upon 80% retention of strength, are as follows:[15]

Material	Dose (rads)
Polyethylene	10^9
Polypropylene	10^8
Polyvinylidenedifluoride	10^7 [a]
Polycarbonate	10^7 [a]
Polytetraflouroethylene	10^5 to 10^6

All materials listed above possess adequate chemical stability to function in the mildy corrosive environment of the vent. Some products made from those materials are structurally fragile and do not qualify for use in the HIC vent system. Porous polyethylene and polypropylene material for industrial applications are available, with pore sizes ranging from 10 to 25 microns. Die cut/cast filter elements are available in a minimum pore size of 0.5 micron. Pore sizes as low as 0.1 micron are obtainable from polycarbonate. Gas flow rates are given below:

$$q = 2.28 \times 10^{-4} P^{0.83} D^{2.29} t^{-1.16} \tag{3-7}$$

a. Engineering estimate without supporting data.

where

q = flow rate, cfm/ft^2

P = pressure head, inches H_2O

D = pore size, microns

t = thickness, inches.

A hydrophobic material supports a hydrostatic head differential of

$$p = \frac{42.235}{d} \tag{3-8}$$

where

p = pressure head (psi)

d = pore diameter (μm).

Pressure reversal, or even removal of pressure head differential, permits surface tension forces to purge water from the hydrophobic filter material. In exactly the same fashion, surface tension forces purge gases from the hydrophilic filter material upon removal of the gas head differential. In other words, in the absence of head differential, a hydrophobic filter "dries," whereas a hydrophilic filter remains "wet." Consequently, only hydrophobic filters are suitable for the HIC vent system.

The HIC filter design also incorporates features that

1. Maintain the radiation dose below about 1/10 of the damage threshold to polyethylene

2. Provide the filter elements with adequate mechanical support, thereby avoiding long-term creep.

Since the design requirements of the HIC were established, it has become evident that the EPICOR-II prefilter liners from TMI will be disposed in the western part of the United States. Disposal sites in the West do not have a significant amount of moisture at required disposal depths (viz., 30 to 90 ft below the surface). If final disposition is in an arid site, the requirement for a liquid-penetration barrier in the vent system could be deleted.

3.4.3 Membranes

No membrane offers much reliable or practical alternative to porous, nonmetallic filters. The membranes evaluated for use are as follows:

1. Metallic membranes

2. Nonmetallic sheets

3. Hollow silicon-fiber elements.

The bulk of generated gas is hydrogen, which readily migrates across material boundaries. Silver-palladium membranes are known to pass hydrogen via chemical transformation processes involving formation of hydrides within the membrane. The silver-palladium membrane concept is not suitable for HIC application because of the following reasons:

1. Only H_2 is "passed"; other gases are not. Gases other than hydrogen also are generated in the HIC

2. Uncertainty in H_2 flow rates requires conservative sizing of the membrane (2-6-inch dia.)

3. High unit cost.

Nonmetallic membranes of polyethylene, polypropylene, and silicon rubber have predictable permeation characteristics for the gas composition given in Appendix C (H_2, CO, CO_2, etc.). For example, a 1-mil-thick polyethylene sheet with 1-ft^2 area will pass approximately 0.01 mole/day ("best estimate" peak flow-rate). To pass the design flow rate of 0.1 mole per day would require 10 ft^2 of membrane. Packaging and mechanical support of such a membrane is impractical.

3.5 Epoxy Seals

Two redundant epoxy seals were selected to attach the lid to the HIC body. Chemical bonding of the lid to the body provides adequate joint strength and also functions as a leakproof seal. As demonstrated in the data sheets included in Appendix K, the epoxy materials are resistant to acids and alkalies. Therefore, they act as effective corrosion barriers, as well as serve to structurally attach the lid and seal the container.

The maximum integrated dose to the epoxy seals is estimated at 175 Mrads. Test data on chemically similar compounds have shown only a 2.2% decrease in flexural strength and a shrinkage of less than 0.3% after a radiation dose of 350 Mrads (see Adhesive Engineering Technical Bulletin No. AE-455 included in Appendix K). Therefore, the sealing compounds have adequate radiation resistance for use in the HIC.

In selecting a method of attaching the lid to the container body, the following factors were considered:

1. Radiation exposure to personnel involved in installing the lid

2. Worst-case applied mechanical loads that must be borne by the attachment system

3. Procurement and operating costs

4. Ease of operation.

Two basic approaches were considered: (a) a gasket bolted lid, and (b) a chemically sealed and bonded installation. The first approach was discarded because of problems associated with bolting down the lid in a radiation field. The strength of the radiation field around the HIC is too high to permit hands-on operation. Therefore, remote operations would be required for bolting the lid in place. Remotely threading nuts on bolts is a difficult and time-consuming operation.

The other approach, chemically sealing and bonding the lid in place, is more reasonable, because installation of the epoxy sealant can be accomplished by using hands-on operation before the EPICOR-II liner is placed in the HIC. That operation is made possible by the 4-hour pot life of the epoxy. After the epoxy seal bead is placed on the lid step of the container body, there is time to remotely put the EPICOR-II liner in the container and set the lid in place. Since it is relatively simple to pour remotely an epoxy grout into the annular gap between the lid and the container body, and because the grout is self-leveling, the epoxy bonding and sealing approach was adopted. The epoxy provides ease of installation and meets strength requirements. [The grout material is at least 50% stronger than the concrete used in the HIC.]

Alternatives to epoxy seals were an inorganic concrete grout or a Portland cement/concrete mix. Those alternatives were rejected on the advice of structural and chemical consultants, because they do not form structural bonds with other concretes or make tighter seals than the epoxies.

Additional considerations relating to the suitability of epoxy material are as follows:

1. In less than three days, the seal grout will reach a strength comparable with concrete. At that time, the internal pressure of the container (as calculated in the design basis case) will be 0.02 psig, which is much less than the pressure required to overcome the weight of the lid (1.15 psig). Thus, there is little possibility that pressure buildup during the grout-curing period would compromise the seal.

2. Calculations in Appendix H demonstrate that the mechanism of container failure due to overpressurization will be related to things other than failure of epoxy seals.

3.6 Selection of Structural Features, Including Lifting Attachments

The geometry of the EPICOR-II liner (48-inch OD x 60.63 inches H), plus the requirement for stackability, lead to selection of a right circular cylinder configuration for the container. For a cylindrical container, the external-pressure requirement of 150 psi established the container dimensions. For the cylindrical sidewalls, buckling considerations determined thickness. For the flat circular ends, bending stress considerations dictated thickness. Table 7 illustrates how those requirements translated directly to the selection of principal dimensions of the container. Minimum section thicknesses were determined by cover requirements over rebar. Concrete was selected as the best material for container structural requirements.

During detail design, the simple right circular geometry was altered slightly at the top to provide an approximately 4-inch-deep step around the top edge. The step was achieved by cutting some 4 inches off the container body below the top of the lid surface. The step functions as

1. A protected recess for the vent outlet, by not trapping water

2. A pocket to allow use of fixed, vertical body-lifting lugs without compromising container stackability.

Considerations leading to selection of lift attachments included the following four items. Least-cost solutions were selected given equivalent performances. The four considerations were as follows:

1. Health and safety considerations mandate quick-disconnect or remote-handling features

2. Stacking requirements dictate that fittings be located below the top of the lid surface or be removable by remote means

TABLE 7. COMPARATIVE PERFORMANCES OF CANDIDATE MATERIALS FOR THE HIC

Parameter	Polyethylene (F_{cr} = 750 psi)[a]	Concrete (f_c' = 6,000 psi)	Steel (F_y = 30,000 psi)[b]
Properties			
F (psi)	750	($0.6f_c'$) 3,600	20,000
E (psi)	1×10^5	4.4×10^6	29×10^6
μ	0.45	0.2	0.3
Cylindrical Wall Thickness (in.)			
Hoop compression			
$t = \frac{PR^c}{F}$	4.90	1.02	0.18
Buckling (in.)			
$t = R \left(\frac{6.67P\,(1-m^2)}{E}\right)^{1/3}$	4.89	1.47	0.77
Flat-End Head Thickness (in.)			
Bending			
$t = R \left(\frac{6.67P\,(1-m^2)}{E}\right)^{1/3}$	4.89	1.47	0.77

TABLE 7. (continued)

Parameter	Polyethylene (F_{cr} = 750 psi)[a]	Concrete (f_c' = 6,000 psi)	Steel (F_y = 30,000 psi)[b]
Shear (Concrete only)			
$t = R \frac{RP}{7 f_c'}$	--	6.78	--
Minimum Section Thickness (in.)	0.25	6.0	0.10
Selected Outer Dimensions[d] (in.)	59 OD x 89 H	61.5 OD x 84 H	51 OD x 68 H
Approximate Cost Factors			
Unit material cost	\$2.00/lb	\$300/yd^3	\$3.00/lb
Unit weight (lb/ft^3)	60	145	490
Container Volume	72.06 ft^3	2.80 yd^3	11.64 ft^3
Container Height (lb)	4,324	10,9070	5,703
Container Structure Cost	\$8,647.00	\$841.00	\$17,108.00

a. Long-term stress from creep rupture governs (500-1000 psi).

b. Stainless assumed for corrosion protection.

c. P = 150 psi; R = 24.5 inches.

d. Assumed internal cavity dimensions: 49 in. ID x 63 in.

3. Corrosion-prevention principles dictate that all penetrations of the outer container surface either be sealed or be made of corrosion-resistant material not oxidized by groundwater

4. The structure, geometry, and orientation of fittings must minimize the stresses imposed in the outer surface of the container, thus minimizing surface cracking.

Lid fittings could be recessed, or radial stainless steel grapple pins could be located within the top 4 inches around the periphery of the lid. Conventional recessed precast steel anchors were selected because they satisfy all requirements at lower cost. The anchor recesses must be grouted after installation of the lid in order to prevent water from collecting there. Circumferential stainless steel grapple pins were not used because of high prying stresses induced in the lid, and the high cost of custom design and fabrication.

"Swift Lift" precast steel anchors initially were contemplated for the body, but they were discarded because of difficulty of remotely sealing the recesses. Simple stainless steel cable loops also were removed from further consideration due to localized prying stresses in the concrete surface. Stainless steel eyes, with essentially the same embedment geometry as recessed anchors, were chosen for the body. The 316 stainless steel eyes are not subject to oxidation in groundwater, and they cannot initiate the kinds of concrete-splitting failures typical of unprotected steel embedments.

4. RECOMMENDED DESIGN CHANGES

Some cost savings in the manufacture of HICs may be realized by making minor changes to the design. The changes recommended here will simplify container fabrication. They are as follows:

1. Shorten shear studs on the steel liner from 4 inches to 3.5 inches (Item 4, Dwg. EP-20-04D of Appendix A). This change will eliminate interference with the rebar cage and simplify the fitting of the cage around the steel liner.

2. Reduce the width of the annular grout joint between the lid and body from 1 inch to 1/2 inch (Item 5 of Dwg. EP-20-101D of Appendix A). The 1-inch clearance is not needed, since precision steel casting forms are used for both the body and lid.

3. Delete the polyethylene filter elements and filter shielding assembly of the vent system (Item 6 of Dwg. EP-20-06D and Item 4 of Dwg. EP-20-102D of Appendix A). The function of those filter elements is to prevent intrusion of water into the container while allowing the venting of gases generated in the container. If the containers are disposed of at the commercial disposal facility near Hanford Washington, the need for this assembly is eliminated. Other filter elements in the system will retain particulate matter. The shield is no longer necessary, since the inorganic components are not susceptible to radiation damage.

4. Increase the height of the container cavity by 0.5 inch (Item 1 of Dwg. EP-20-101D of Appendix A). The fit-check with a dummy EPICOR-II liner demonstrated that EPICOR-II liners are out of tolerance and that clearance with the HIC lid is too small. Such inconsistencies make placement of the lid on the container difficult.

5. REFERENCES

1. R. Chapman, Specification: High-Integrity Waste Disposal Overpack Container, ES-50652B, April 14, 1981, EG&G Idaho, Inc.

2. J. D. Yesso, V. Pasupathi, L. Lowry, Characterization of EPICOR II Prefilter Liner 16, GEND-015, Battelle Memorial Institute Columbus Laboratories, August 1982.

3. TRW--Nelson, Embedment Properties of Headed Studs, Design Data Bulletin 10.

4. AISC, Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings, 7th Edition, Chicago: AISC.

5. National Association of Corrosion Engineers (NACE), Corrosion Data Survey, 1967 Edition.

6. J. D. Yesso, V. Pasupathi, L. Lowry, Characterization of EPICORE-II Prefilter Liner 16, GEND-015, August 1982.

7. N. L. Wynhoff and V. Pasupathi, Characterization of EPICOR-II Prefilter Liner 3, GEND-027, April 1983.

8. R. C. McFarland, Analysis of Irradiated Ion Exchange Materials, Georgia Institute of Technology, Final Research Report, Project A60-611, Contract No. 526325-5, May 1981.

9. A. Cotton and G. Wilkinson, Advanced Organic Chemistry, 2nd Edition, New York: Interscience Publishers Division of Wiley, 1966, p. 439.

10. D. A. Lewis, "Some Aspects of the Corrosion of Steel in Concrete," Proceedings of the First International Congress on Metallic Corrosion, 1962, pp. 547-555.

11. G. J. Verbeck, Mechanisms of Corrosion of Steel in Concrete, ACI Publication SP-49-3, 1975.

12. M. Romanoff, Underground Corrosion, NBS Circular 579, April 1957.

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14. R. L. Daugherty and J. B. Franzini, Fluid Mechanics with Engineering Applications, 7th Edition, New York: McGraw-Hill Book Co., pp. 16-17.

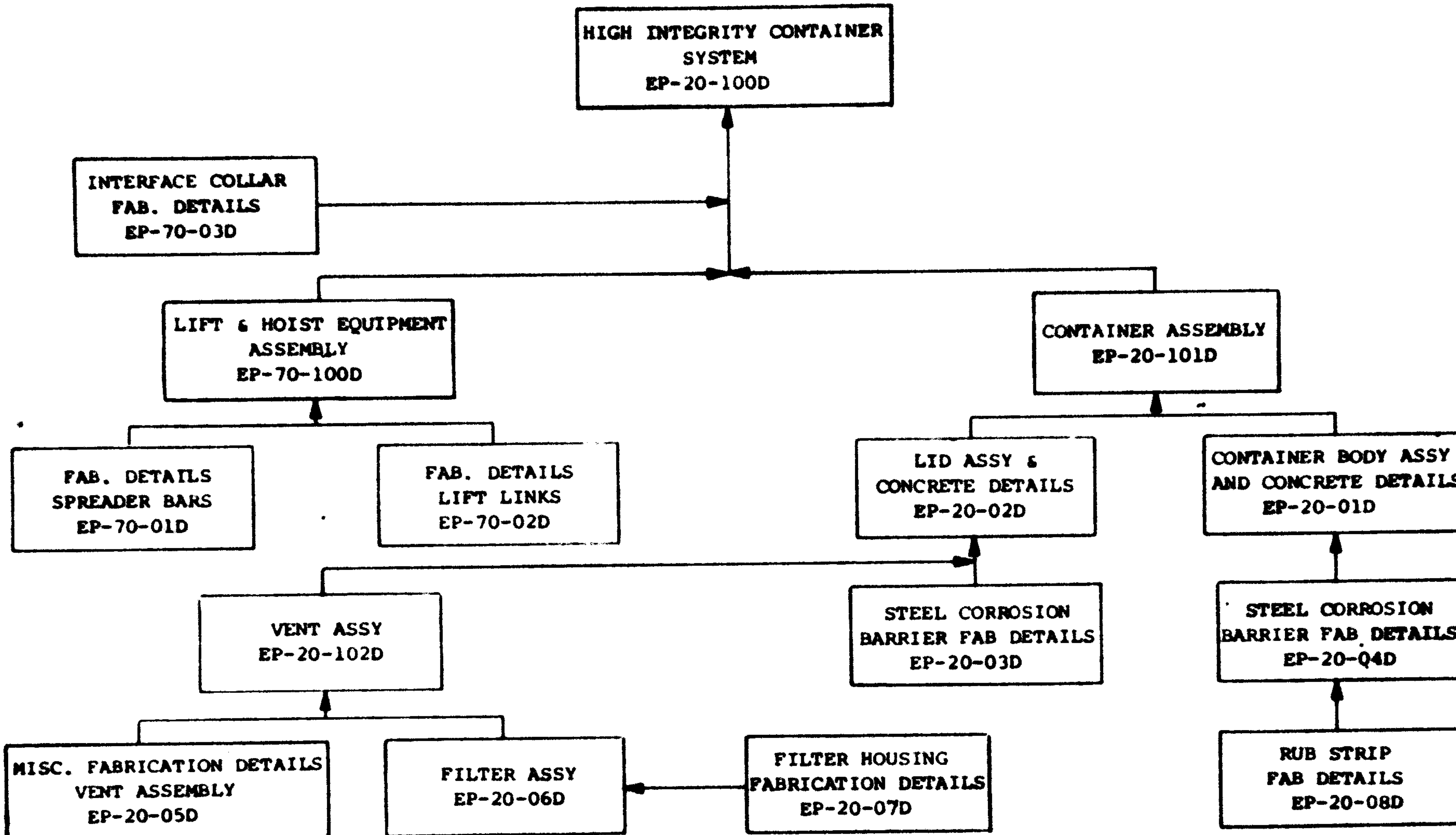
15. Faeger, Engineering Compendium on Radiation Shielding, Springer-Verlag, 1975.

APPENDIX A

HIGH-INTEGRITY CONTAINER DESIGN

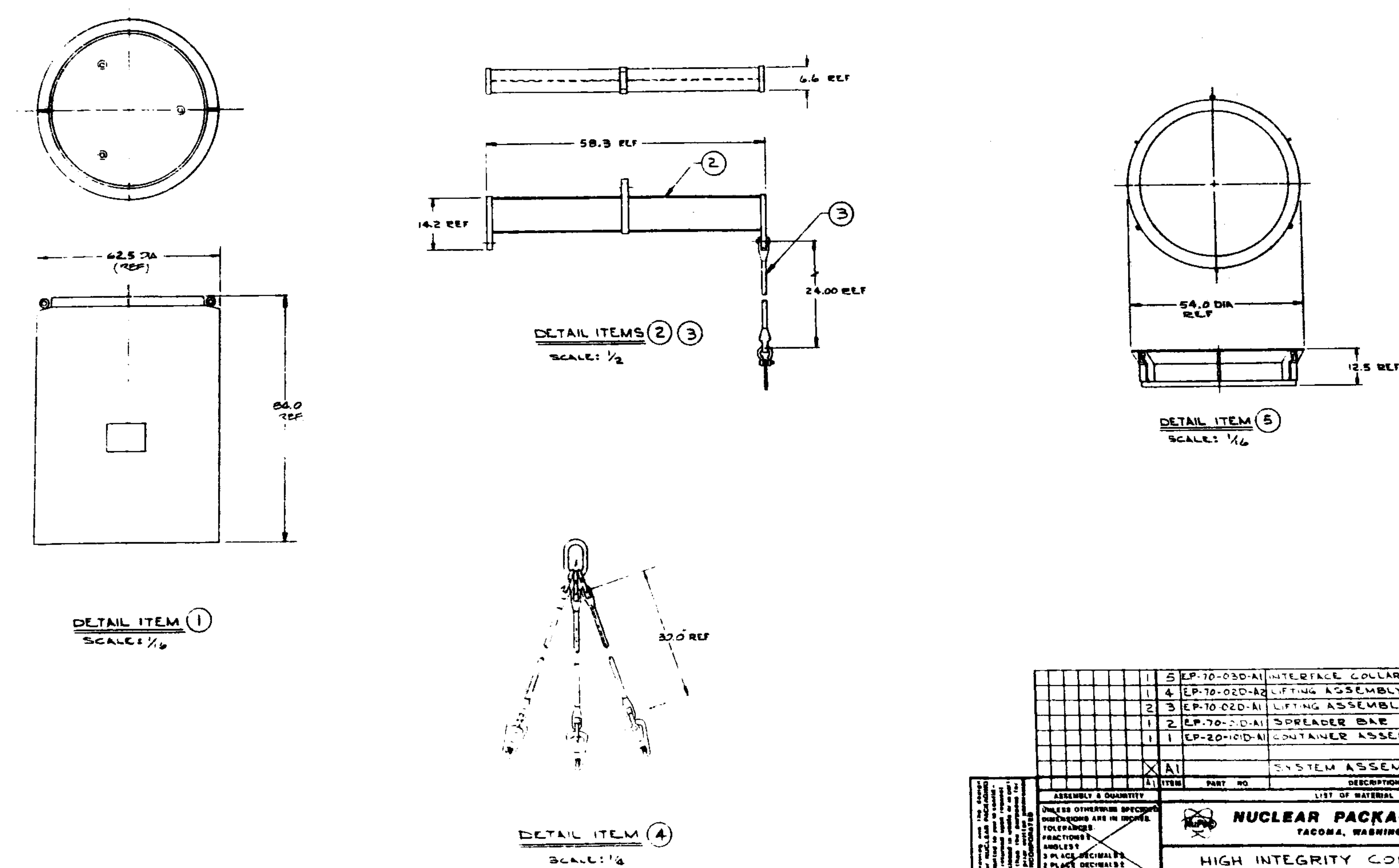
DRAWING TREE

HIGH INTEGRITY WASTE DISPOSAL CONTAINER



REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED
C-5 D7 C-2	A	1. REVISE DIMENSIONS PER DIAMETER CHANGE CUSTOMER (EG&G) CHANGE #1, DDR NO. CMB-010 2 REVISE ITEM 5 PER REDESIGN FOR ROTATED LEFT EYE.	[illegible]	[illegible]



	ITEM	PART NO.	DESCRIPTION
1	5	EP-70-030-A1	INTERFACE COLLAR
1	4	EP-70-020-A2	LIFTING ASSEMBLY
2	3	EP-70-020-A1	LIFTING ASSEMBLY
1	2	EP-70-010-A1	SPREADER BAR
1	1	EP-20-101D-A1	CONTAINER ASSEMBLY
X	A1		SYSTEM ASSEMBLY

ASSEMBLY & QUANTITY — LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES: FRACTIONS ± ANGLES ± 3 PLACE DECIMALS ± 2 PLACE DECIMALS ± 1 PLACE DECIMALS ±

DO NOT SCALE THIS DRAWING

NEXT ASSY | USED ON — APPLICATION

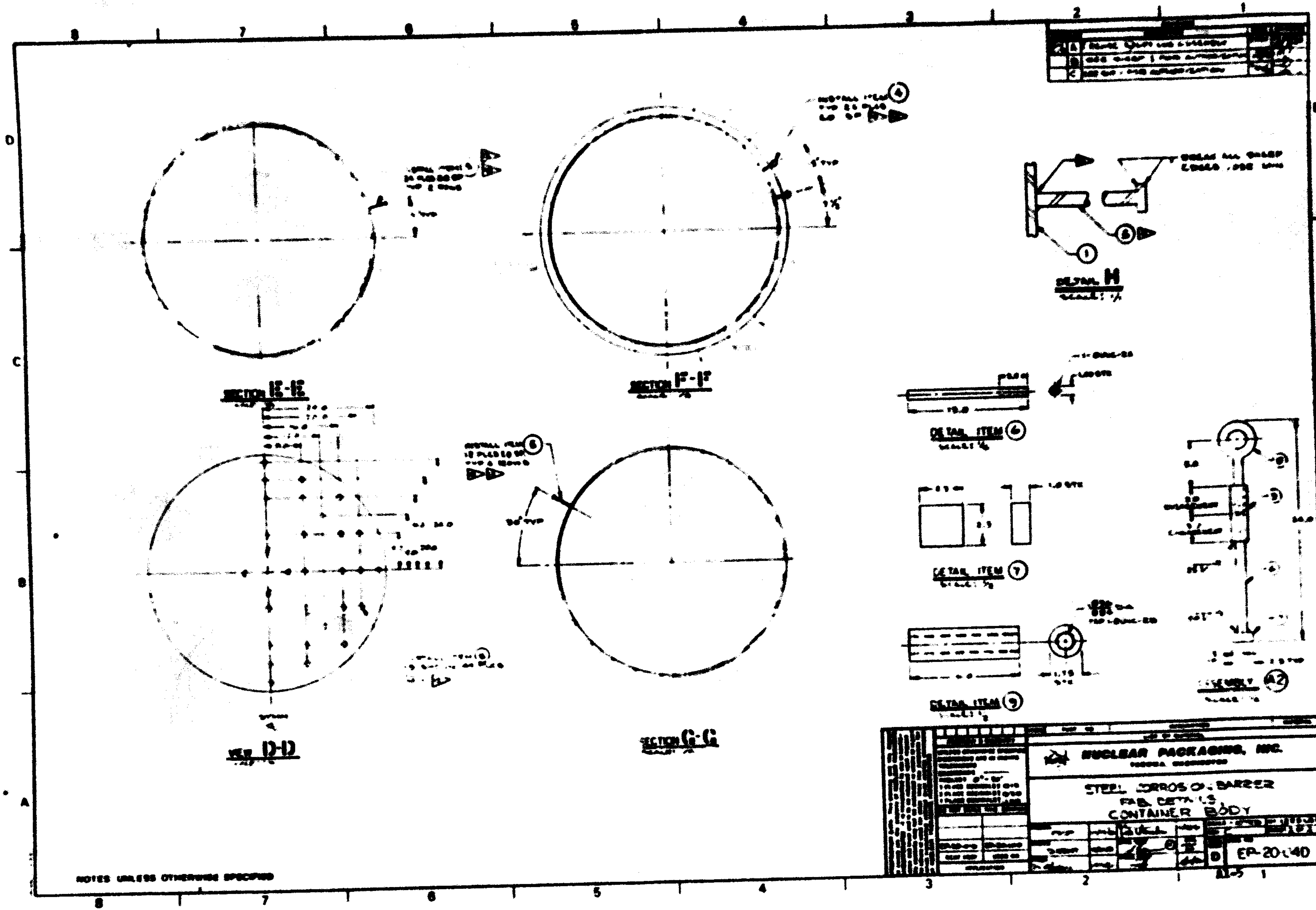
NUCLEAR PACKAGING, INC.
TACOMA, WASHINGTON

HIGH INTEGRITY CONTAINER SYSTEM

DRAWN WALKER/CULTUM 2-3-81 — SIZE D — DWG NO. EP-20-100

NOTES: UNLESS OTHERWISE SPECIFIED

A1-1



SECTION G-G
VIEW D-D
DETAIL H
DETAIL ITEM 6
DETAIL ITEM 7
DETAIL ITEM 9
NUCLEAR PACKAGING, INC.
STEEL CORROSION BARRIER
FAB. DETAILS,
CONTAINER BODY
EP-20-040
NOTES UNLESS OTHERWISE SPECIFIED

ZONE	LTR	DESCRIPTION	DATE	APPROVED
2B7	C	INCORPORATED SDR 2615-EP-122	7/20/8?	

ZONE	LTR	DESCRIPTION	DATE	APPROVED
A-6, C-8, D-2, B-2	A	1. REVISE DIMENSIONS PER DIAMETER CHANGE, CUSTOMER (EG&G) CHANGE #1, DCR NO. CMB-00 2. ADD 3RD COATING, INTERIOR SURFACE 3. REVISE ITEMS 6-9 PER ALTERED LUG SIZE		
	B	INCORPORATED DCN EP-04		

16. EQUIVALENT SOURCES OF SUPPLY AND/OR COMPONENTS MAY BE SUBSTITUTED UPON APPROVAL OF ENGINEERING.

15▷ SOURCE OF SUPPLY: NORTHWEST WIRE ROPE
2301 LINCOLN AVENUE
TACOMA, WA 98421
OR CAMPBELL CHAIN DIVISION
3990 EAST MARKET STREET
YORK, PENNSYLVANIA 17402

14. ALL SURFACES OF PART NO. EP-20-04D-A1 (INTERIOR AND EXTERIOR) SHALL BE FINISHED WITH A PHENOLIC COATING SYSTEM IN STRICT ACCORD WITH NUPAC SPECIFICATION PP-02 AND MANUFACTURERS RECOMMENDATIONS. APPROVED MATERIALS FOR THIS NUCLEAR SERVICE ARE:

A. PRIMER: PHENOLINE 300 ORANGE, MINIMUM DRY FILM THICKNESS 8 MILS.

B. SECOND COAT: PHENOLINE 302 (BLACK), MINIMUM DRY FILM THICKNESS 8 MILS.

C. THIRD COAT (INTERIOR ONLY): PHENOLINE 302 (GREEN), MINIMUM DRY FILM THICKNESS 8 MILS.

SOURCE OF SUPPLY: CARBOLINE
350 HANLEY INDUSTRIAL COURT
ST. LOUIS, MO 63144

13▷ ATTACH TAG WITH EP-20-04D-A1 AND APPLICABLE REV. NO. IN .25 INCH CHARACTERS STAMPED ON SURFACE.

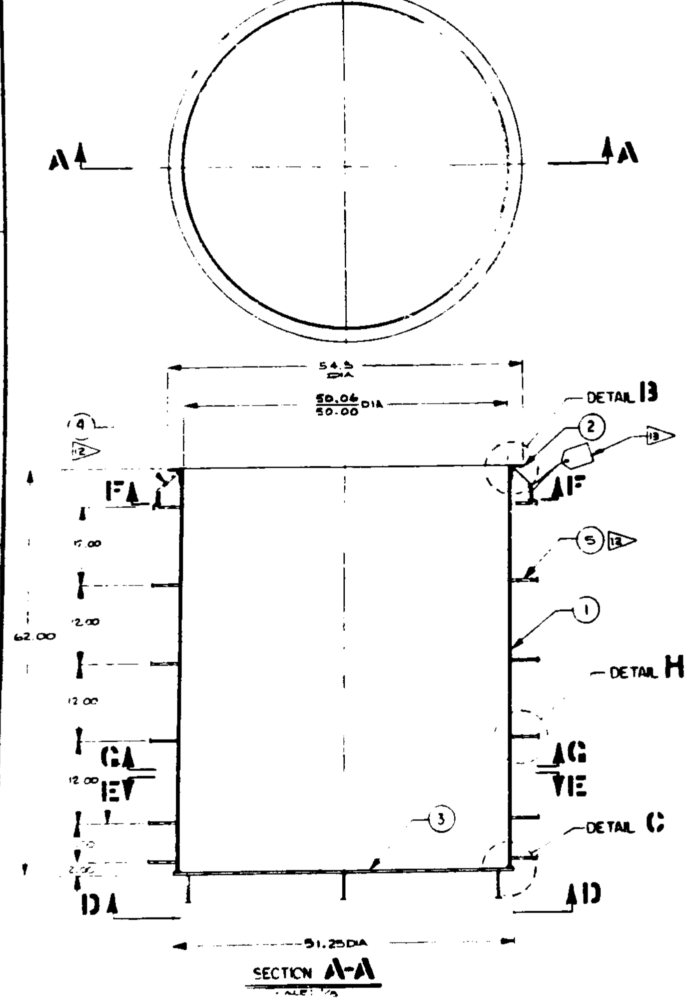
12▷ SOURCE OF SUPPLY: T.R.W. NELSON DIVISION
TOLEDO AVE & EAST 28TH ST.
LORAIN, OHIO 44055
(216) 245-6931

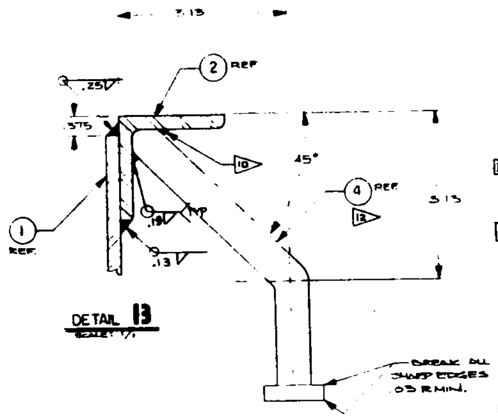
NELSON FLUXED HEADED ANCHOR STUDS (OR APPROVED EQUAL) MAY BE USED AS CONCRETE ANCHORS. STUDS SHALL BE AUTOMATICALLY END WELDED IN THE SHOP OR FIELD. STUDS ARE TO BE WELDED ON CENTERS AS SHOWN ON THE DRAWINGS. ALL WELDS SHALL BE MADE IN ACCORDANCE WITH RECOMMENDATIONS OF THE NELSON STUD WELDING COMPANY.

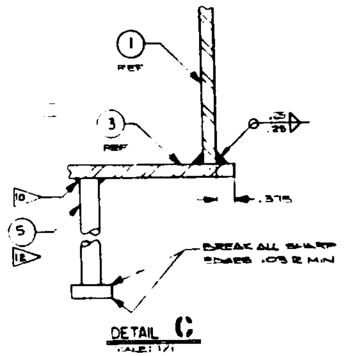
11. SURFACE PREPARATION, FINISH AND INSPECTION OF ALL EXPOSED SURFACES SHALL BE IN ACCORDANCE WITH NUPAC SPECIFICATION PP-02.

10▷ AT EACH ITEM (4) AND (5) ATTACHMENT POINT, COAT ALL WELD SURFACES AND ADJACENT SURFACES (WITHIN .50 INCH PROXIMITY) WITH A PHENOLIC PRIMER. CARBOLINE PHENOLINE 300 ORANGE IS APPROVED FOR THIS NUCLEAR SERVICE. THIS COATING SHALL BE APPLIED BEFORE APPLICATION OF COATING SYSTEM, PER NUPAC SPECIFICATION PP-02.

9. LIFTING, HANDLING, STORAGE AND SHIPPING OF SUB-ASSEMBLIES AND ASSEMBLIES SHALL BE IN STRICT ACCORDANCE WITH NUPAC SPECIFICATION H-11.







		ITEM	PART NO	DESCRIPTION	MATERIAL
2		9	EP-20-04D-9	RD. BAR, 1.75 O.D. x 6.1 LG.	ASTM-A36
2		8	EP-20-04D-8	EYE BOLT FORGING, PATTERN M28-ST, STOCK NO. 690-S115 (15▷)	316 CRES
2		7	EP-20-04D-7	PLT., 1.00 THK. x 2.3 x 2.3	ASTM-A36
2		6	EP-20-04D-6	RD. BAR, 1.00 O.D. x 11.0 LG	ASTM-A36
	241	5	EP-20-04D-5	HEADED STUDS .38 DIA x 4.0 LG.	12▷
	24	4	EP-20-04D-4	HEADED STUDS .63 DIA x 6.4 LG.	12▷
	1	3	EP-20-04D-3	PLT., .25 THK. x 51.3 x 51.3	ASTM-A36
	1	2	EP-20-04D-2	ANGLE, .25 x 2.0 x 2.0	ASTM-A36
	1	1	EP-20-04D-1	PLT., .25 THK. x 61.4 x 157.9	ASTM-A36
X		A2	EP-20-04D-A2	LIFTING EYE	
	X	A1	EP-20-04D-A1	STEEL CORROSION BARRIER WELDMENT	
A2	A1			LIST OF MATERIAL	

ASSEMBLY & QUANTITY

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES.
TOLERANCES
ANGLES ± 0°-30'
3 PLACE DECIMALS ± .010
2 PLACE DECIMALS ± .03
1 PLACE DECIMALS ± .1
DO NOT SCALE THIS DRAWING

EP-20-04D	EP-20-010
NEXT ASSY	USED ON
APPLICATION	

NUCLEAR PACKAGING, INC.
TACOMA, WASHINGTON

STEEL CORROSION BARRIER
FAB DETAILS
CONTAINER BODY

DRAWN REP · CHECK D. KENT · SCALE NOTED · REV C · SHEET 1 OF 2 · SIZE D · DWG NO. EF-20-04D

8. ALL CONTINUOUS WELDS SHALL BE LIQUID PENETRANT INSPECTED ON FINAL PASS IN ACCORDANCE WITH ASME CODE SECTION III, DIVISION 1, SUBSECTION NB, ARTICLE NB-5000 AND SECTION V, ARTICLE 6.

7. ALL WELDING, PROCEDURES AND PERSONNEL SHALL BE QUALIFIED IN ACCORDANCE WITH AWS D1.1 OR ASME CODE, SECTION IX. WELD PROCEDURES SHALL BE AVAILABLE FOR AUDIT OR REVIEW.

6. MATERIAL SIZES LISTED IN THE DESCRIPTION COLUMN ARE FOR REFERENCE ONLY. MANUFACTURER SHALL CONFIRM ACTUAL REQUIREMENTS PRIOR TO FABRICATION.

5. MARK ALL COMPONENTS AND SUBASSEMBLIES DURING FABRICATION PER RDT F7-31-1369 USING FELT TIP MARKING PEN WITH PART NO. -(APPLICABLE DASH NUMBER) AND REVISION NUMBER.

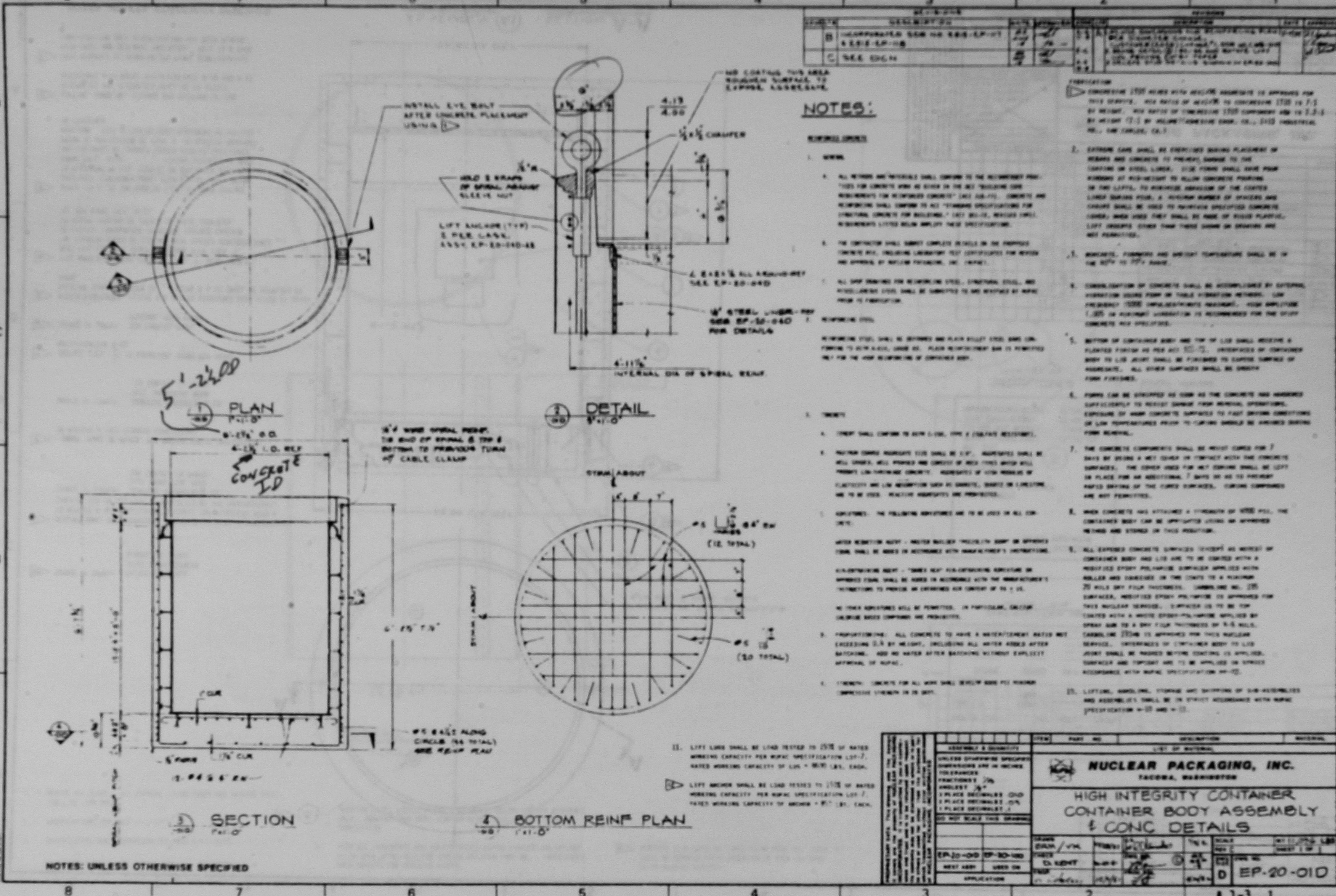
4. REMOVE ALL BURRS. ALL CORNERS, SHARP EDGES AND MACHINE RADII SHALL BE .03R MIN.

3. WELD SYMBOLS PER AWS A2.4-79.

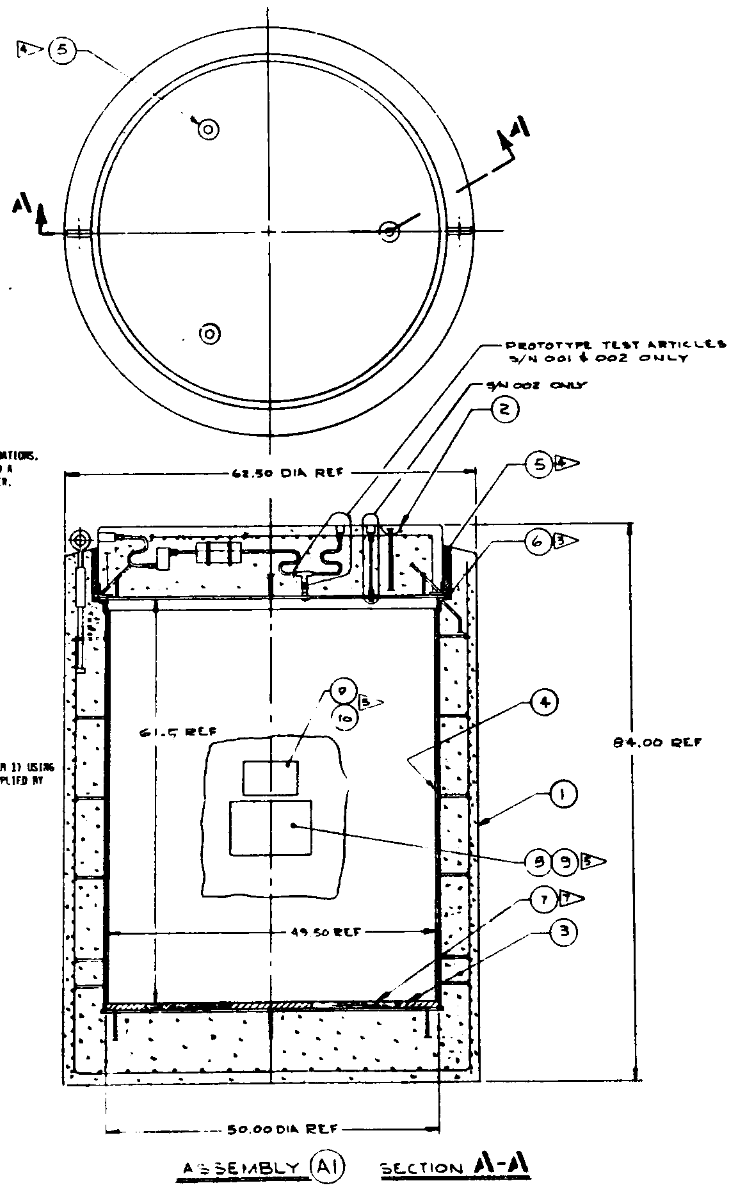
2. ABBREVIATIONS PER ANSI Y1.1-1972.

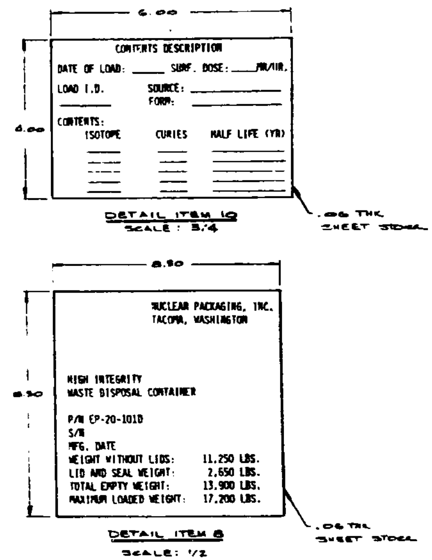
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5-1973.

NOTES: UNLESS OTHERWISE SPECIFIED.


NOTES:
PLAN
DETAIL
SECTION
BOTTOM REINF PLAN
INSTALL EYE BOLT AFTER CONCRETE PLACEMENT USING
LIFT ANCHOR (TYP) 3 PER CASK
INTERNAL DIA OF SPIRAL REINF.
CONCRETE I.D.
5'-2¼ OD
(12 TOTAL)
(20 TOTAL)
NUCLEAR PACKAGING, INC.
TACOMA, WASHINGTON
HIGH INTEGRITY CONTAINER
CONTAINER BODY ASSEMBLY
& CONC DETAILS
DO NOT SCALE THIS DRAWING
NEXT ASSY
USED ON
APPLICATION
EP-20-010
NOTES: UNLESS OTHERWISE SPECIFIED

ZONE	LTR	REVISIONS DESCRIPTION	DATE	APPROVED
A-5 D-8	A	1. REVISE DIMENSIONS PER DIAMETER CHANGE, CUSTOMER (EG&G) CHANGE #1, DDE NO. CMB-010.		
	B	INCORPORATED DCN, EP-06 & EP 07		
	C	SEE DCN		





10. SOURCE OF SUPPLY: KAISER CHEMICALS
38505 CHERRY STREET
NEWARK, CA 94560

9. SEALANT SHALL BE COMPOUNDED, PER MANUFACTURERS RECOMMENDATIONS, TO ACHIEVE A GEL CONSISTENCY SUITABLE FOR PLACEMENT WITH A CAULKING GUN OR GEL PUMP AS SPECIFIED BY THE MANUFACTURER.
SOURCE OF SUPPLY: ADHESIVE ENGINEERING CO.
1411 INDUSTRIAL ROAD
SAN CARLOS, CA 94070

8. GROUT SHALL BE MIXED, PER MANUFACTURERS INSTRUCTIONS, TO ACHIEVE A FREE FLOWING CONSISTENCY.
SOURCE OF SUPPLY: ADHESIVE ENGINEERING CO.
1411 INDUSTRIAL ROAD
SAN CARLOS, CA 94070

7. INSTALL ITEM 7 IN LOCATIONS SHOWN PER NUPAC SPECIFICATION N-12

6. SOURCE OF SUPPLY: DOW CORNING CORP.
MIDLAND, MICH 48640

5. ATTACH NAMEPLATES, (ITEMS 8 & 10) TO CONTAINER BODY, (ITEM 1) USING SILICONE SEALANT, (ITEM 9). - ITEMS 8 & 10 SHALL BE SUPPLIED BY NUPAC.

4. FILL ANNULUS BETWEEN ITEMS 1 AND 2 WITH ITEM 5. ALSO FILL LID LIFT INSERT RECESSES WITH ITEM 5. THE ADJACENT EDGES OF LID AND BODY COATED SURFACES SHALL BE LIGHTLY SANDBLASTED TO REMOVE SURFACE LATENCE TO ASSURE BONDING OF ITEM 5 TO THESE SURFACES. ALL PER NUPAC SPEC. N-12.

3. APPLY .50 X .25 THK BEAD OF ITEM 6 OVER SURFACE INDICATED (CONTAINER BODY, ITEM 1, LID STEP) PRIOR TO PLACEMENT OF LID, ITEM 2, IN CONTAINER BODY PER NUPAC SPEC. N-12. FAYING SURFACES OF BODY AND LID SHALL BE LIGHTLY SANDED WITH 40 GRIT PAPER PRIOR TO APPLICATION OF ITEM 6 TO ACHIEVE MAXIMUM ADHESION. THIS ACTION PRECEDES PLACEMENT OF PAYLOAD IN CONTAINER.

2. LIFTING, HANDLING, STORAGE AND SHIPPING OF SUB-ASSEMBLIES AND ASSEMBLIES SHALL BE IN STRICT ACCORDANCE WITH NUPAC SPECIFICATIONS N-10 AND N-11.

1. THIS ASSEMBLY IS SHOWN IN ITS FINAL CONFIGURATION WITH GROUT AND SEALANTS INSTALLED. THIS IS A TRUE CONFIGURATION ONLY AFTER PAYLOAD HAS BEEN PLACED.

NOTES: UNLESS OTHERWISE SPECIFIED

LIST OF MATERIAL

A1 (QTY)	ITEM	PART NO	DESCRIPTION	MATERIAL
1	10		.06 THK SHT X 4.00 X 6.00	300 SST
1/8	9		SILICONE RUBBER SEALANT-BLACK	6
1	8		.06 THK SHT X 8.50 X 8.50	304 SST
[illegible]	7		HYDRATED ALUMINUM OXIDE	7 10
[illegible]	6		ADHESIVE GEL, RADIATION RESISTANT CONCRESIVE AEX-1512	9
[illegible]	5		FLOWABLE GROUT, RADIATION RESISTANT CONCRESIVE AEX-1512	8
1	4	EP-20-08-1	RUB STRIP - WALL	
1	3	EP-20-08-2	RUB STRIP - BASE	
1	2	EP-20-020-A1	LID ASSY AND CONCRETE DETAILS	
1	1	EP-20-010-A1	CONTAINER BODY ASSY AND CONCRETE DETAILS	
X	A1		ASSEMBLY	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
FRACTIONS ±
ANGLES ±
3 PLACE DECIMALS ±
2 PLACE DECIMALS ±
1 PLACE DECIMALS ±
DO NOT SCALE THIS DRAWING

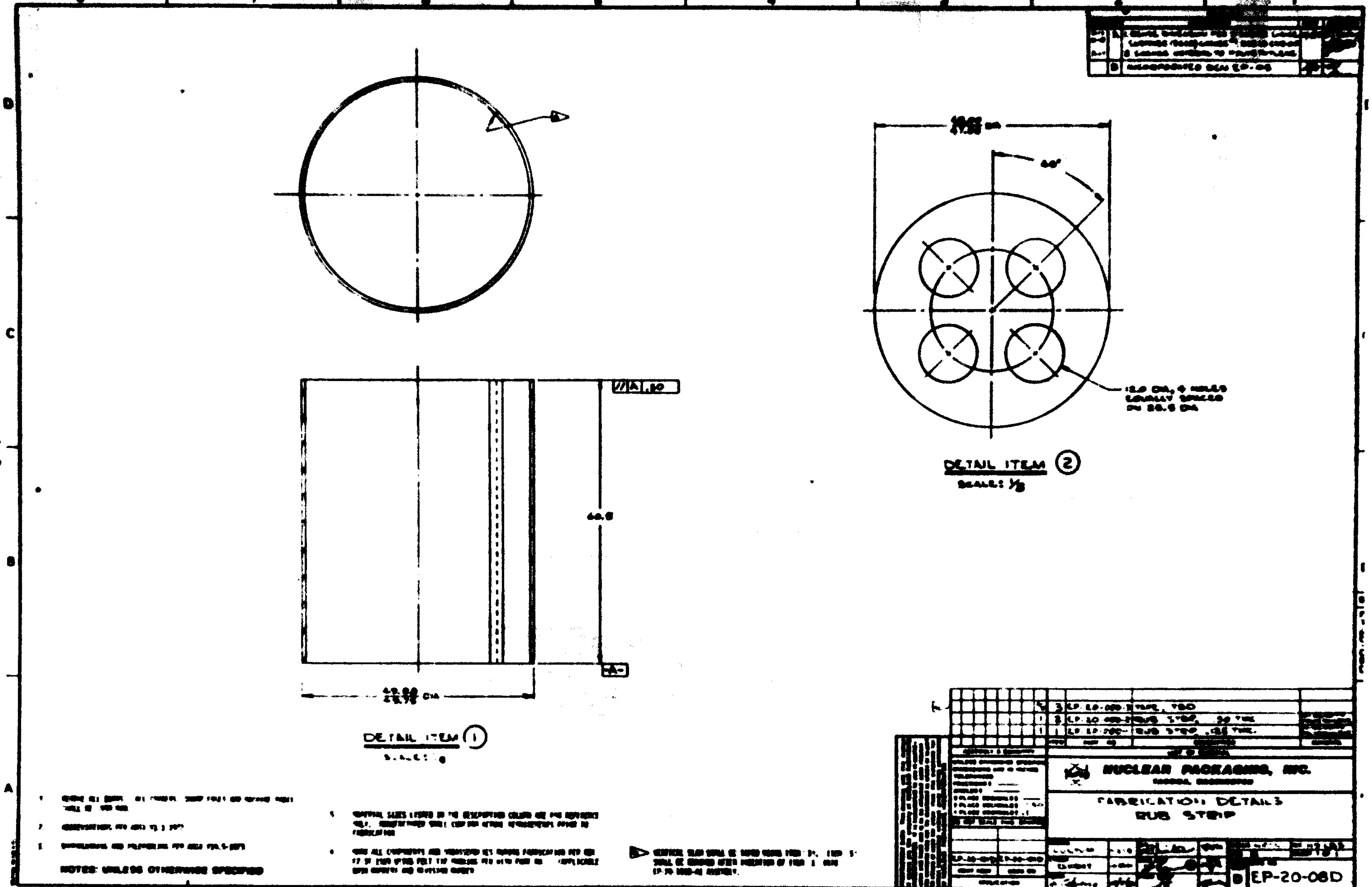
NEXT ASSY: EP-20-100 D | USED ON: EP-20-100D
APPLICATION

NUCLEAR PACKAGING, INC.
TACOMA, WASHINGTON

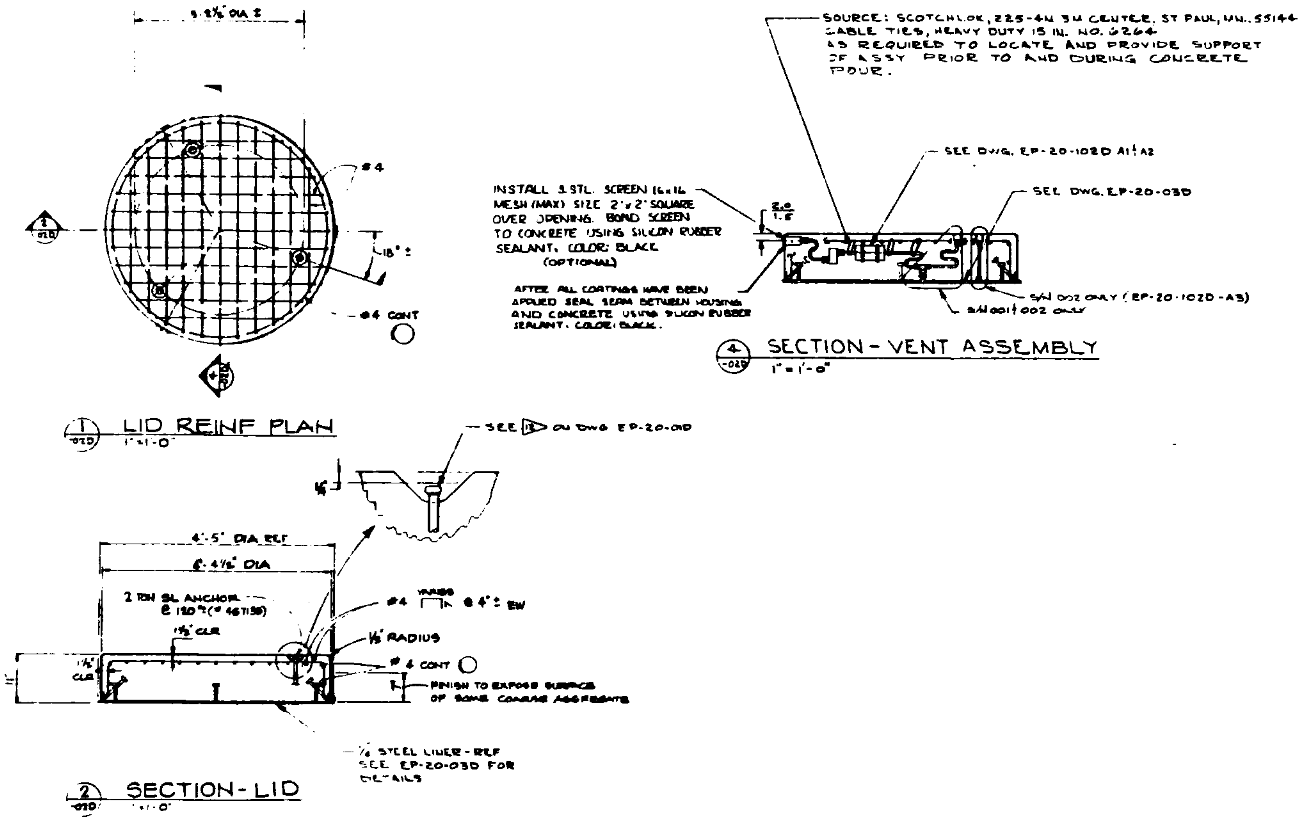
CONTAINER ASSEMBLY

DRAWN: CULTUM 10-20-81
CHECK: D KENT
SIZE: D DWG NO: EP-20-101D
SCALE: 1/8 WT 13,876 LB
REV C SHEET 1 OF 1

A 1-2


DETAIL ITEM 1
DETAIL ITEM 2
SCALE: 1/8
NUCLEAR PACKAGING, INC.
FABRICATION DETAILS
RUB STRIP
NOTES: UNLESS OTHERWISE SPECIFIED
EP-20-08D

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
6-A 8-D 6-A 8-B 6-C	A	1. REVISE DIMENSIONS AND REINFORCING PLAN PER DIAMETER CHANGE, CUSTOMER (EG&G) CHANGE #1, DDR NO. CMB-010 2 DELETE STUD DETAIL SHOWN ON EP-20-04D 3. ADD LOAD TEST NOTE.	4/7/83	
D-3 D-4	B	INCORPORATED DCN # EP-06		
	C	SEE DCN	7/15/83	



A-10

FOR GENERAL NOTES SEE EP-20-01D

ITEM	PART NO.	DESCRIPTION	MATERIAL
LIST OF MATERIAL			

ASSEMBLY & QUANTITY

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
FRACTIONS ± 1/8
ANGLES ± ½°
3 PLACE DECIMALS ± .010
2 PLACE DECIMALS ± .030
1 PLACE DECIMALS ± .100
DO NOT SCALE THIS DRAWING

EP-20-01D	EP-20-100D
NEXT ASSY	USED ON
APPLICATION	

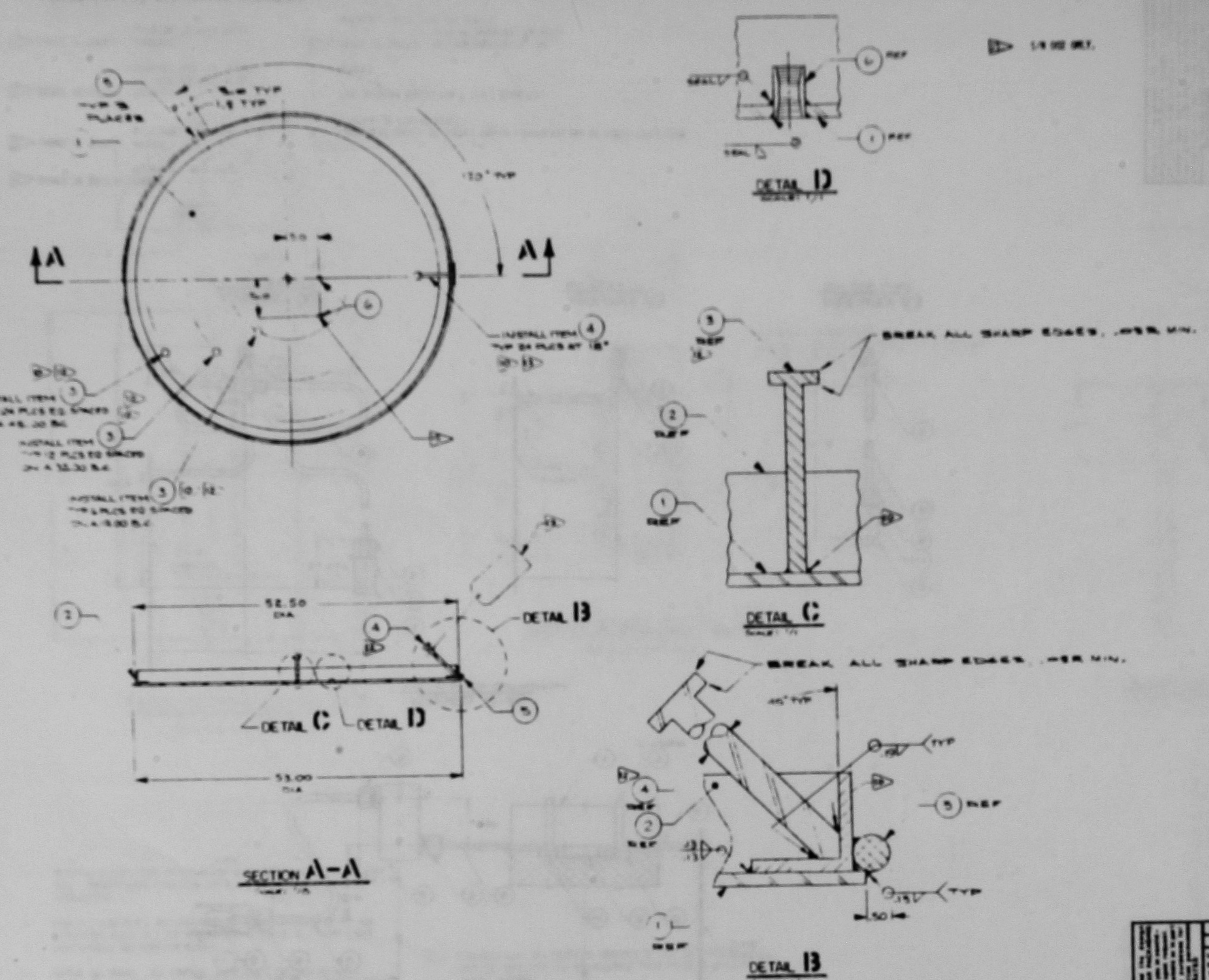
NUCLEAR PACKAGING, INC.
TACOMA, WASHINGTON

HIGH INTEGRITY CONTAINER
LID ASSEMBLY &
CONCRETE DETAILS

DRAWN BRM/VK
CHECK D KENT 10-19-81
SCALE: 1" = 1'-0"
WT 2,531 LBS
REV C
SHEET 1 OF 1
DWG SIZE D
DWG NO EP-20-02D

NOTES: UNLESS OTHERWISE SPECIFIED

A 1-7 1



10. ALL SURFACES OF PART NO. EP-20-030-A1 (INTERIOR AND EXTERIOR) SHALL BE FINISHED WITH A PHENOLIC COATING SYSTEM IN STRICT ACCORD WITH NUPAC SPECIFICATION PP-02 AND MANUFACTURERS RECOMMENDATIONS. APPROVED MATERIALS FOR THIS NUCLEAR SERVICE ARE:

A. PRIMER: PHENOLINE 310 ORANGE, MINIMUM DRY FILM THICKNESS 4 MILS.

B. SECOND COAT: PHENOLINE 302 (BLACK), MINIMUM DRY FILM THICKNESS 4 MILS.

C. THIRD COAT (INTERIOR ONLY): PHENOLINE 302 (GREEN), MINIMUM FILM THICKNESS 4 MILS.

SOURCE OF SUPPLY: CARBOLINE
350 HANLEY INDUSTRIAL COURT
ST. LOUIS, MO. 63144

ATTACH WIRE TAG IN APPROXIMATE LOCATION SHOWN. IMPRINT ON TAG IN .25 INCH HIGH CHARACTERS: "EP-20-030-A1" ALONG WITH APPLICABLE REVISION NUMBER.

NELSON FLUXED HEADED ANCHOR STUDS (OR APPROVED EQUAL) MAY BE USED AS CONCRETE ANCHORS. STUDS SHALL BE AUTOMATICALLY END WELDED IN THE SHOP OR FIELD. STUDS ARE TO BE WELDED ON CENTERS AS SHOWN ON THE DRAWINGS. ALL WELDS SHALL BE MADE IN ACCORDANCE WITH RECOMMENDATIONS OF THE NELSON STUD WELDING COMPANY.

SOURCE OF SUPPLY: T. R. W. NELSON DIVISION
TOLEDO AVENUE & EAST 28TH ST.
LORAIN OHIO 44055
(216)245-6951

11. SURFACE PREPARATION, FINISH AND INSPECTION OF ALL EXPOSED SURFACES SHALL BE IN ACCORDANCE WITH NUPAC SPECIFICATION PP-12

AT EACH ITEM (3) AND (4) ATTACHMENT POINT, COAT ALL WELD SURFACES AND ADJACENT SURFACES (WITHIN .50 INCH PROXIMITY) WITH A PHENOLIC PRIMER. CARBOLINE PHENOLINE 310 ORANGE IS APPROVED FOR THIS NUCLEAR SERVICE. THIS COATING SHALL BE APPLIED BEFORE APPLICATION OF COATING SYSTEM, PER NUPAC SPECIFICATION PP-02

9. LIFTING, HANDLING, STORAGE AND SHIPPING OF SUB-ASSEMBLIES AND ASSEMBLIES SHALL BE IN STRICT ACCORDANCE WITH NUPAC SPECIFICATION H-11.

QTY	ITEM	PART NO.	DESCRIPTION	MATERIAL
1	6	EP-20-030-6	COUPLING, 1/2 NPT	304 S. STL.
3	5	EP-20-030-5	RD. BAR, .75 DIA × 3.0	ASTM A36
24	4	EP-20-030-4	HEADED STUD .63 DIA × 6.38 LG	
41	3	EP-20-030-3	HEADED STUD .38 DIA × 4.0 LG	
1	2	EP-20-030-2	ANGLE .25 × 2.00 × 2.00	ASTM A36
1	1	EP-20-030-1	PLT. .25 THK. × 53.1 × 53.1	ASTM A36
	A1	EP-20-030-A1	STEEL CORROSION BARRIER WELDMENT	

LIST OF MATERIAL

NUCLEAR PACKAGING, INC.
TACOMA, WASHINGTON

STEEL CORROSION BARRIER
FAB DETAILS
LID ASSEMBLY

D EP-20-030

A 1-8

8. ALL CONTINUOUS WELDS SHALL BE LIQUID PENETRANT INSPECTED ON FINAL PASS IN ACCORDANCE WITH ASME CODE SECTION III, DIVISION 1, SUBSECTION NB, ARTICLE NB-5000 AND SECTION V, ARTICLE 6.

7. ALL WELDING, PROCEDURES AND PERSONNEL SHALL BE QUALIFIED IN ACCORDANCE WITH AWS D1.1 OR ASME CODE, SECTION IX. WELD PROCEDURES SHALL BE AVAILABLE FOR AUDIT OR REVIEW.

6. MATERIAL SIZES LISTED IN THE DESCRIPTION COLUMN ARE FOR REFERENCE ONLY. MANUFACTURER SHALL CONFIRM ACTUAL REQUIREMENTS PRIOR TO FABRICATION.

5. MARK ALL COMPONENTS AND SUBASSEMBLIES DURING FABRICATION PER NOT F7-37-1969 USING FELT TIP MARKING PEN WITH PART NO. -(APPLICABLE DASH NUMBER) AND REVISION NUMBER.

4. REMOVE ALL BURRS. ALL CORNERS, SHARP EDGES AND MACHINE RADII SHALL BE .030 MIN.

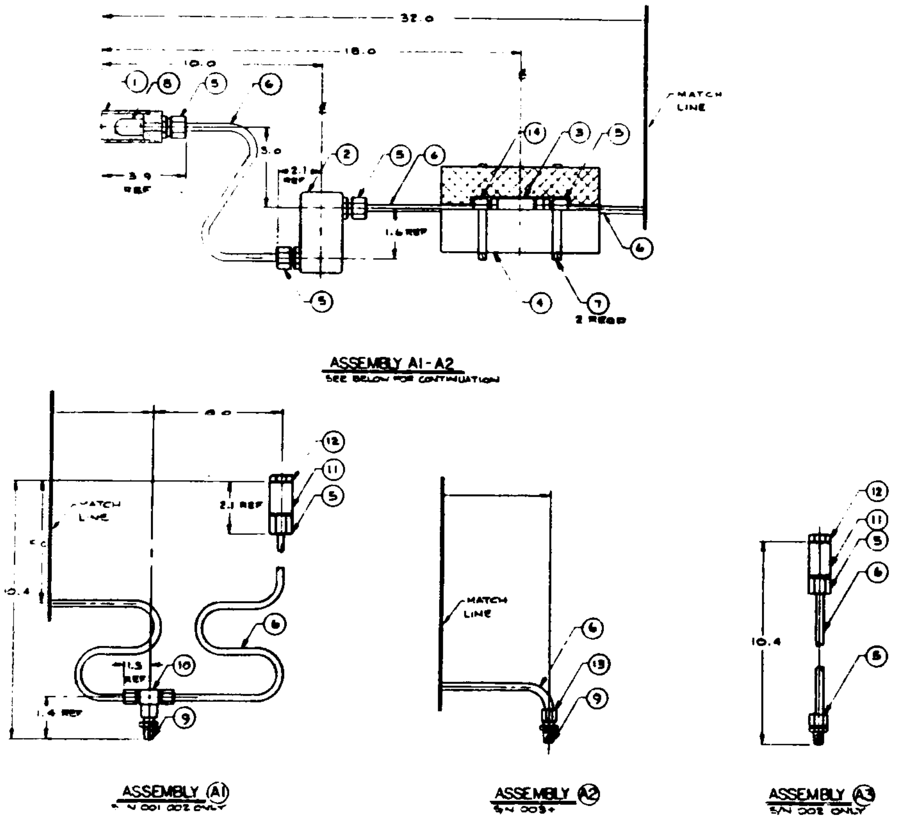
3. WELD SYMBOLS PER AWS A2.4-79.

2. ABBREVIATIONS PER ANSI Y1.1-1972.

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5-1973.

NOTES: UNLESS OTHERWISE SPECIFIED

ZONE	LTR	REVISIONS DESCRIPTION	DATE	APPROVED
	C	REDRAWN, INCORPORATED DCN EP-06 / SDR NO. 2522-EP-115		



A3	A2	A1	ITEM	PART NO	DESCRIPTION	MATERIAL	
	1	1	14	4-6-FBU-SS	MALE CONNECTOR		4
	1		13	4GBU-SS	FEMALE CONNECTOR		4
1		1	12	1/8-HP-SS	HEX HEAD PLUG		4
1		1	11	1/8-GG-SS	PIPE CONNECTOR		4
		1	10	4-OBU-SS	FEMALE BRANCH TEE		4
	1	1	9	20065-1-5	FILTER, NIPPLE (TRI-DOT) 1/8 NPT		5
	1	1	8		POREX PNEUMATIC SILENCER 1/8 NPT		1
	2	2	7	NO. 4	CLAMP	SST	2
A/R	A/R	A/R	6		TUBING, 1/4 O.D. HEAVY WALL	SST	3
2	4	5	5	4-FBU-SS	MALE CONNECTOR		4
	1	1	4	EP-20-050 A3	FILTER SHIELDING ASSEMBLY		
	1	1	3	EP-20-060-A1	FILTER MEMBRANE ASSEMBLY		
	1	1	2	EP-20-050-A1	FLUID TRAP ASSEMBLY		
	1	1	1	EP-20-060-A2	PRE FILTER HOUSING ASSEMBLY		
•			A3		SECONDARY VENT ASSY, S/N 002		
	•		A2		VENT ASSEMBLY, S/N 003 +		
		•	A1		VENT ASSEMBLY, S/N 001, 002		

ASSEMBLY & QUANTITY — LIST OF MATERIAL

4. SOURCE OF SUPPLY: PARKER
CLEVELAND, OHIO 44112

3. SOURCE OF SUPPLY: PARKER
WICKLIFFE, OHIO 44092

2. SOURCE OF SUPPLY: FLEXAUST
199 THOUSAND OAKS BLVD.
THOUSAND OAKS, CA 91360

1. SOURCE OF SUPPLY: GLASROCK
FAIRBURN, GEORGIA 30213

8. EQUIVALENT SOURCE OF SUPPLY AND/OR COMPONENTS MAY BE SUBSTITUTED UPON APPROVAL OF ENGINEERING.

7. TUBE BENDING RADIUS MIN 3 TIMES DIAMETER.

6. REMOVED

5. SOURCE OF SUPPLY: MECIPON INDUSTRIES, INC
CITY OF INDUSTRY, CA 91745
MATERIAL: AISI TYPE 300 SERIES

NOTES: UNLESS OTHERWISE SPECIFIED

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONS ± —
ANGLES ± —
3 PLACE DECIMALS ± —
2 PLACE DECIMALS ± —
1 PLACE DECIMALS ± .5
DO NOT SCALE THIS DRAWING

NEXT ASSY	USED ON
EP-20-050	EP-20-100

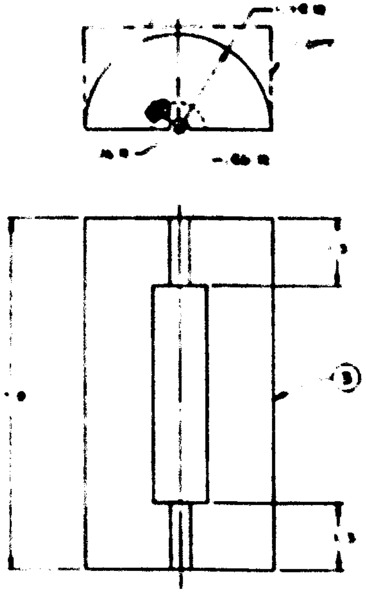
APPLICATION

NUCLEAR PACKAGING, INC.
TACOMA, WASHINGTON

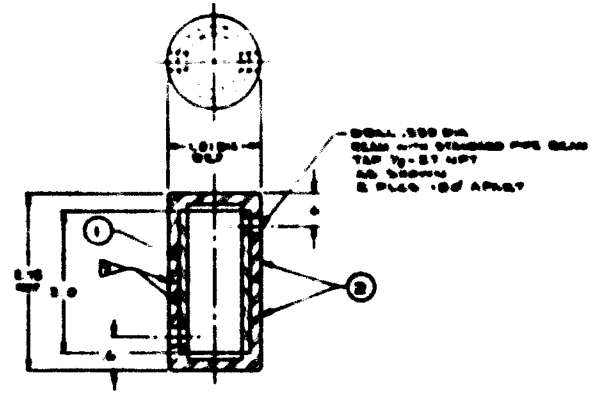
SYSTEM VENT ASSEMBLY

DRAWN C.P. 7/21/82 — SCALE NONE — REV C — SHEET 1 OF 1

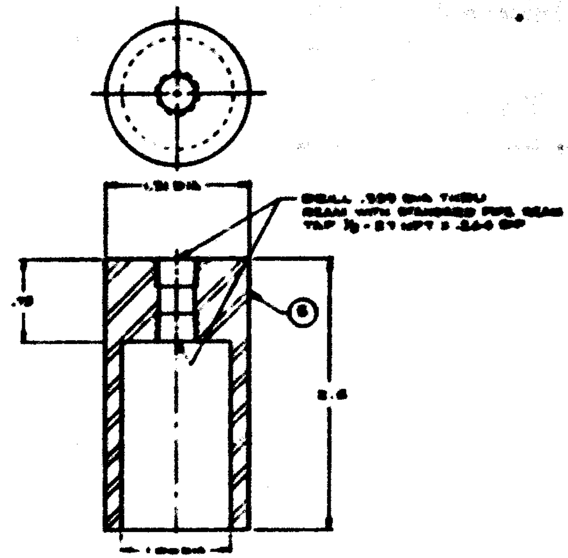
SIZE D — DWG NO EP-20-102D



FABRICATION DETAIL (A3)
SCALE: FULL



FABRICATION DETAIL (A1)
SCALE: FULL



FABRICATION DETAIL (A2)
SCALE: 2/1

NOTES UNLESS OTHERWISE SPECIFIED

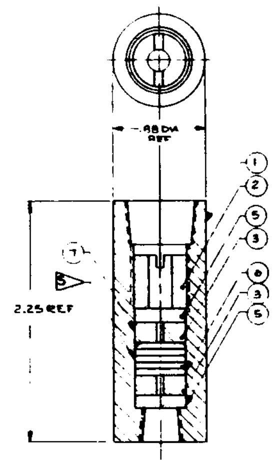
Item	Description
6	PVC COUPLING
5	PVC BAR
4	REMOVED
3	LEAD
2	PVC CAP
1	PVC PIPE
A3	FILTER SHIELDING ASSY
A2	PVC FILTER HOUSING ASSY
A1	FLUID TRAP ASSY

NUCLEAR PACKAGING, INC.
TACOMA, WASHINGTON

MISCELLANEOUS
FAB DETAILS
VENT ASSEMBLY

D EP-20-050

ZONE	LTR	REVISIONS DESCRIPTION	DATE	APPROVED
	A	REVISED AND REDRAWN - ALTERED NOTE STACK AND END PLUGS		
	B	INCORPORATED SDR NO. 2522-EP-115		



5. DIE STAMP WITH LOW STRESS IMPRESSION STAMP USING .25 IN. HIGH CHARACTERS WITH EP-20 06D-A1 AND APPLICABLE REV. NO.

5 IMMEDIATELY PRIOR TO INSERTION INTO BORE OF ITEM (1) STACK ALL ITEMS (3), (5), (6) (IN ORDER OF INSTALLATION) ALIGN ALL ITEMS AND COAT ALL EXPOSED EDGES WITH A COAT OF ITEM (7) MIN. .010 THICK. INSTALL THIS COATED STACK INTO ITEM (1) BORE. INSTALL AND TIGHTEN ITEM (2) TO HAND TIGHT PLUS 1/2 TURN, REMOVE ANY EXCESS OF ITEM (7) THAT EXTRUDES INTO EITHER END OF ITEM (1) BORE, TAKING EXTREME CARE THAT ALL DISLODGED PIECES ARE REMOVED FROM BORE AND ITEM (5) SURFACES.

4 SOURCE OF SUPPLY: (POROUS HI-DENSITY POLYETHYLENE DISC) GENERAL POLYMERIC, 621 FRANKLIN STREET, WEST READING, PA 19611

3 SOURCE OF SUPPLY: DOW CORNING CORPORATION, MIDLAND, MICH., USA 48640

2 SOURCE OF SUPPLY: MOTT METALLURGICAL CORP., FARMINGTON INDUSTRIAL PARK, FARMINGTON, CONN. 06032

1 DELETED, REV. B

NOTES: UNLESS OTHERWISE SPECIFIED

QTY	ITEM	PART NO	DESCRIPTION	MATERIAL
AR	7		SILICON RUBBER SEALANT CLEAR	3
5	6		FILTER DISK, 1μ .062THK	4
2	5		FILTER DISK, 40μ .125THK SST	2
	4		DELETED, REV B	
2	3	EP 20-07D-3	SPACER	
1	2	EP-20-07D-2	INSERT	
1	1	EP-20-07D-1	BODY	
1	A1		FILTER ASSEMBLY	

LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
FRACTIONS ±
ANGLES ±
3 PLACE DECIMALS ±
2 PLACE DECIMALS ±
1 PLACE DECIMALS ±
DO NOT SCALE THIS DRAWING

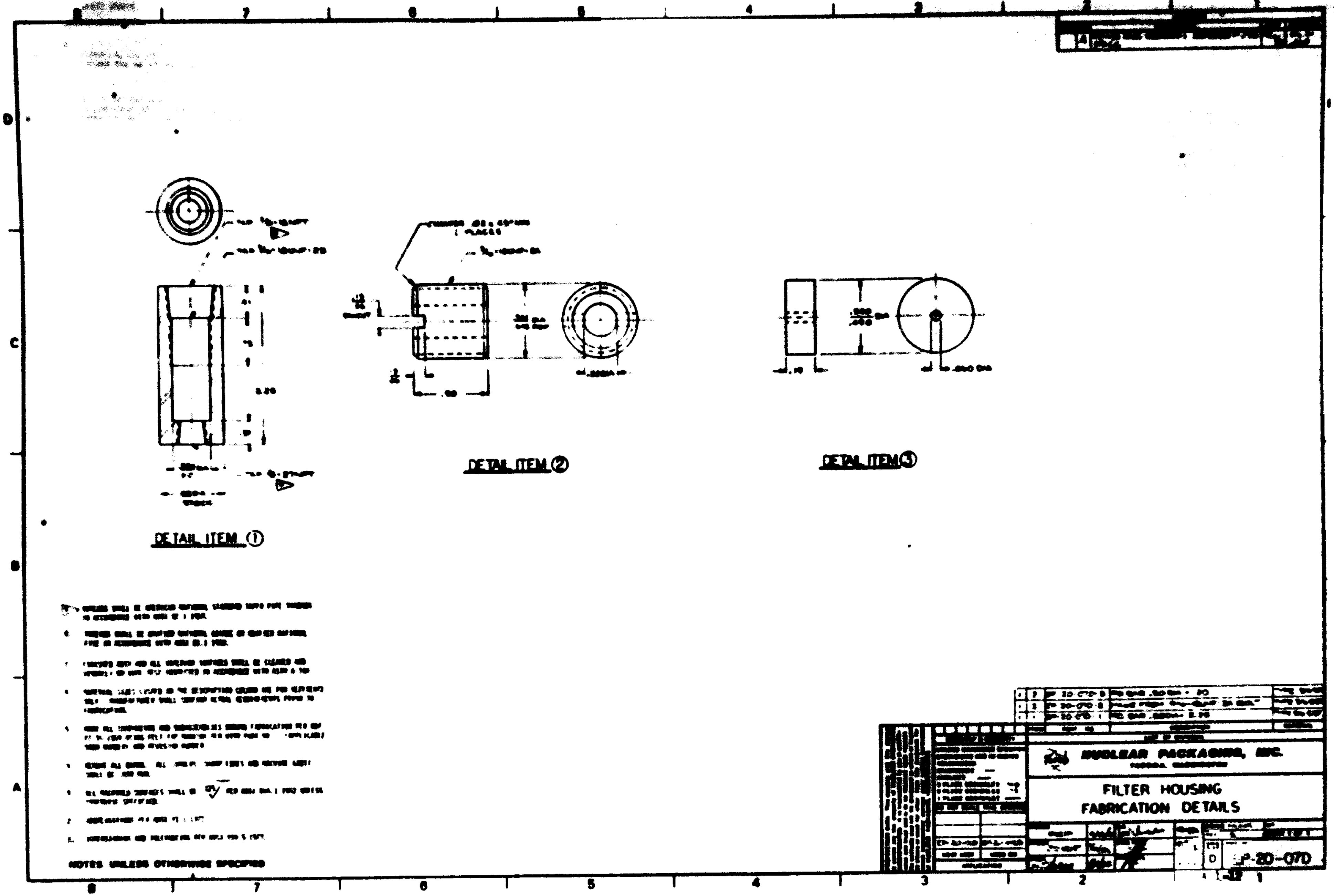
NEXT ASSY | USED ON
APPLICATION

NUCLEAR PACKAGING, INC.
TACOMA, WASHINGTON

FILTER ASSEMBLY

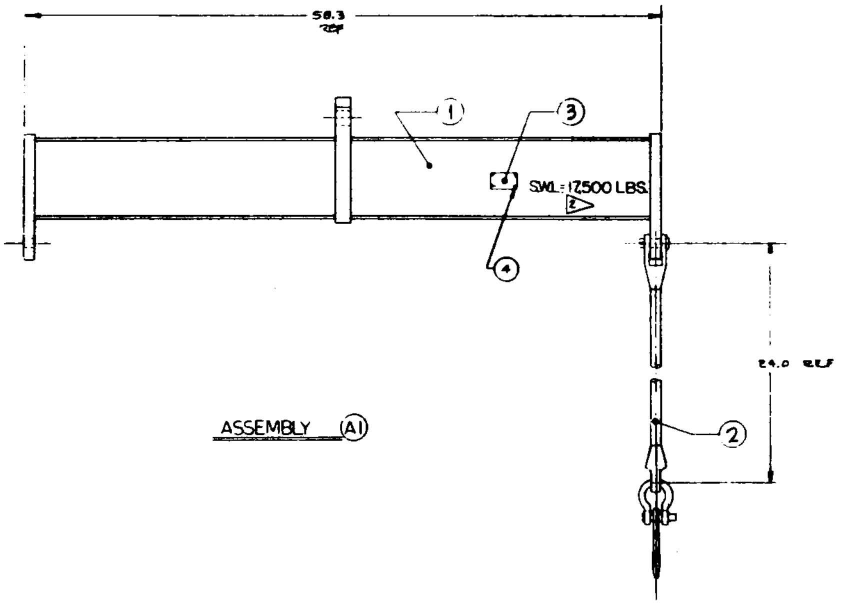
SCALE NONE | REV B | SHEET 1 OF 1 | SIZE D | DWG NO EP-20-06D

A 1-11



DETAIL ITEM ①
DETAIL ITEM ②
DETAIL ITEM ③
NOTES UNLESS OTHERWISE SPECIFIED
NUCLEAR PACKAGING, INC.
FILTER HOUSING
FABRICATION DETAILS
D
P-20-07D

ZONE	LTR	DESCRIPTION	DATE	APPROVED
C-6 / A-5	A	1. REVISE DIMENSIONS PER DIAMETER CHANGE, CUSTOMER (EG&G) CHANGE #1, DDR NO. CMB-010 2. ROTATE BOOK 90°		
	B	INCORPORATED DCN		
	C	SEE DCN	9-82	



ASSEMBLY (A1)

A1	ITEM	PART NO.	DESCRIPTION	MATERIAL
4	4		DRIVE SCREW, 1/8 DIA × .38 LG	
1	3		I.D. PLATE	
2	2	EP-10-020-A1	LIFTING ASSEMBLY	
1	1	EP-10-010-A1	SPREADER BAR ASSEMBLY	
X	A1	EP-10-100D-A1	LIFT & HOIST EQUIPMENT ASSEMBLY	

LIST OF MATERIAL

2 STENCIL SAFE WORKING LOAD CAPACITY ON COMPONENT IN APPROXIMATE LOCATION SHOWN. CHARACTERS SHALL BE 2.00 INCH MIN. IN HEIGHT AND SHALL BE BLACK.

1 FINISHED ASSY AND ALL INTERIOR SURFACES SHALL BE CLEANED AND VISUALLY OR WIPE-TEST INSPECTED IN ACCORDANCE WITH ASTM A-380.

NOTES: UNLESS OTHERWISE SPECIFIED

ASSEMBLY & QUANTITY

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES: FRACTIONS ± ANGLES ± 1 PLACE DECIMALS ± 2 PLACE DECIMALS ± 3 PLACE DECIMALS ±

DO NOT SCALE THIS DRAWING

NEXT ASSY	USED ON
EP-20-100D	EP-30-100D

APPLICATION

NUCLEAR PACKAGING, INC.
TACOMA, WASHINGTON

LIFT & HOIST EQUIPMENT ASSEMBLY

DRAWN R.W. 12-4-81 | CHECK | ENGR | QA | DWG APPR | PROD

SCALE: 1/16 | WT | REV C | SHEET 1 OF 1

SIZE D | DWG NO EP-10-100D

A-17

12. PAINT ALL EXPOSED CARBON STEEL SURFACES FOLLOWING LOAD TEST AND NDT, AS FOLLOWS:

PRIMER

A. RUST-OLEUM #769, IF SURFACE VERY RUSTY, 1-2 MILS DRY
#7773, IF SURFACE CLEAN, DEGREASED OR SANDBLASTED, 1-2 MILS DRY

B. FARWEST PAINT CO. #3052, ANY SURFACE, 1-2 MILS DRY

TOP COAT

A. RUST-OLEUM #7792 INDUSTRIAL ENAMEL, GLOSS WHITE, 1-2 MILS DRY

B. FARWEST PAINT CO. #3000 MARINE ENAMEL, GLOSS WHITE, 1-2 MILS DRY
#2500 EQUIPMENT ENAMEL, GLOSS WHITE, 1-2 MILS DRY

11. ASSEMBLY SUPPLIER SHALL TEST AND CERTIFY EACH ASSY TO 150% OF RATED WORKING LOAD. RATED LOAD = 17,500 LBS.

10. DIE STAMP WITH LOW STRESS IMPRESSION STAMP USING .25 IN. HIGH CHARACTERS WITH EP-70-010 AND APPLICABLE REV. NO. IN APPROXIMATE LOCATION SHOWN.

9. REMOVED

8. FOLLOWING LOAD TEST ALL WELDS SHALL BE LIQUID PENETRANT INSPECTED ON FINAL PASS IN ACCORDANCE WITH ASME CODE SECTION III, DIVISION 1, SUBSECTION NB, ARTICLE NB-5000 AND SECTION V, ARTICLE 6.

7. ALL WELDING, PROCEDURES AND PERSONNEL SHALL BE QUALIFIED IN ACCORDANCE WITH AWS D1.1 OR ASME CODE, SECTION IX. WELD PROCEDURES SHALL BE AVAILABLE FOR AUDIT OR REVIEW.

6. MATERIAL SIZES LISTED IN THE DESCRIPTION COLUMN ARE FOR REFERENCE ONLY. MANUFACTURER SHALL CONFIRM ACTUAL REQUIREMENTS PRIOR TO FABRICATION.

5. MARK ALL COMPONENTS AND SUBASSEMBLIES DURING FABRICATION PER NOT EP-57-1369 USING FELT TIP MARKING PEN WITH PART NO. (APPLICABLE DASH NUMBER) AND REVISION NUMBER.

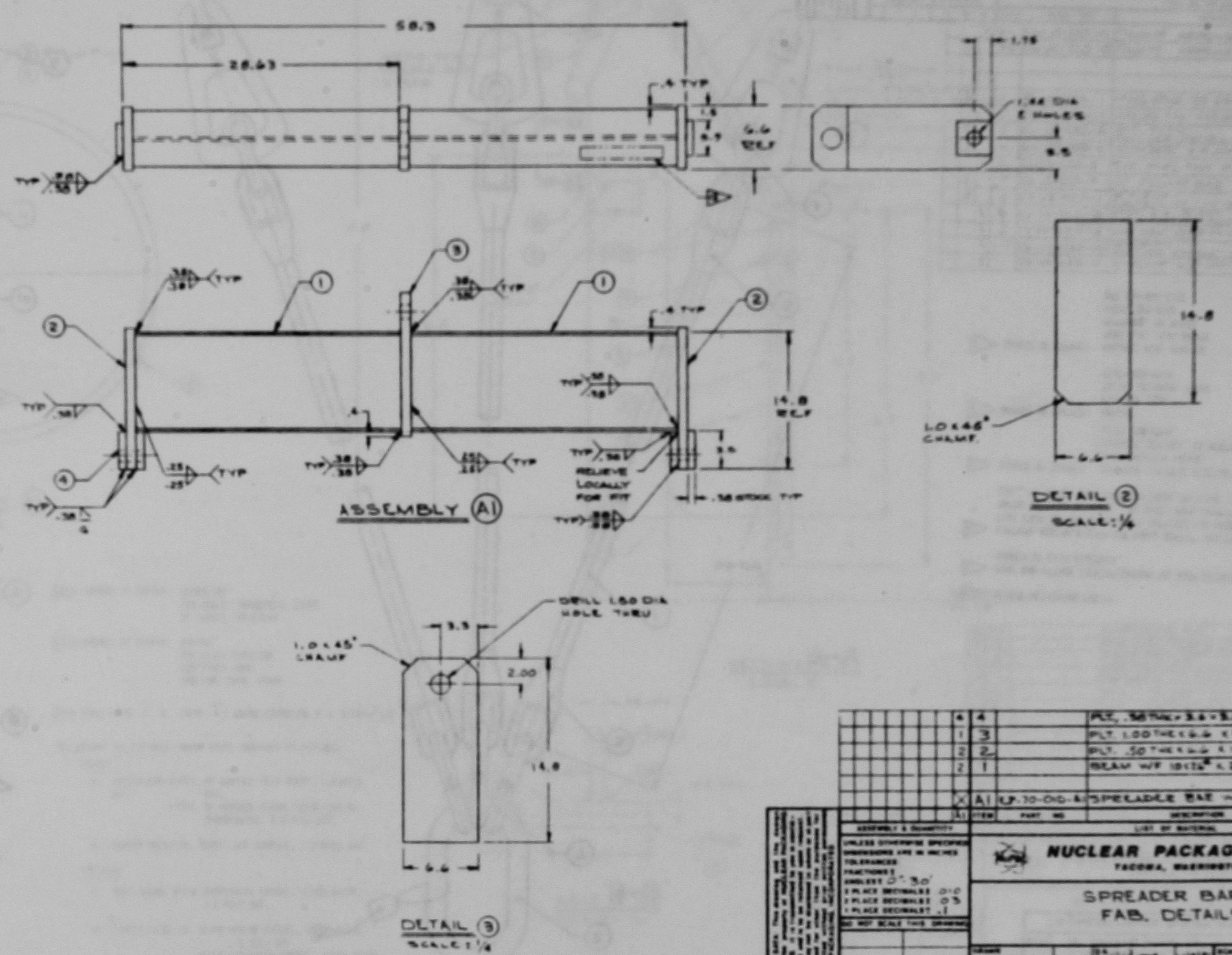
4. REMOVE ALL BURRS. ALL CORNERS, SHARP EDGES AND MACHINE RADII SHALL BE .03R MINIMUM.

3. WELD SYMBOLS PER AWS A2.4-79.

2. ABBREVIATIONS PER ANSI Y1.1-1972.

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5-1973.

NOTES: UNLESS OTHERWISE SPECIFIED



REVISIONS

ZONE	LTR	DESCRIPTION
	A	1. REVISE DRAWING PER CUSTOMER (EG&G) CHANGE; 2. CHANGE WELD DETAIL AND LUG PLATES FOR FABRICATION; 3. CHANGE PAINTING
	B	INCORPORATED DCN EP-03
	C	SEE DCN

QTY	ITEM	PART NO.	DESCRIPTION	MATERIAL
4	4		PLT. .38 THK × 3.4 × 3.4	ASTM-A36
1	3		PLT. 1.00 THK × 6.6 × 14.8	ASTM-A36
2	2		PLT. .50 THK × 6.6 × 14.8	ASTM-A36
2	1		BEAM W/F 10 × 12 × 28.2	ASTM-A36
X	A1	EP-70-010-A1	SPREADER BAR WELDMENT	

LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
FRACTIONS ±
ANGLES ± 0°-30'
3 PLACE DECIMALS ± .010
2 PLACE DECIMALS ± .03
1 PLACE DECIMALS ± .1
DO NOT SCALE THIS DRAWING

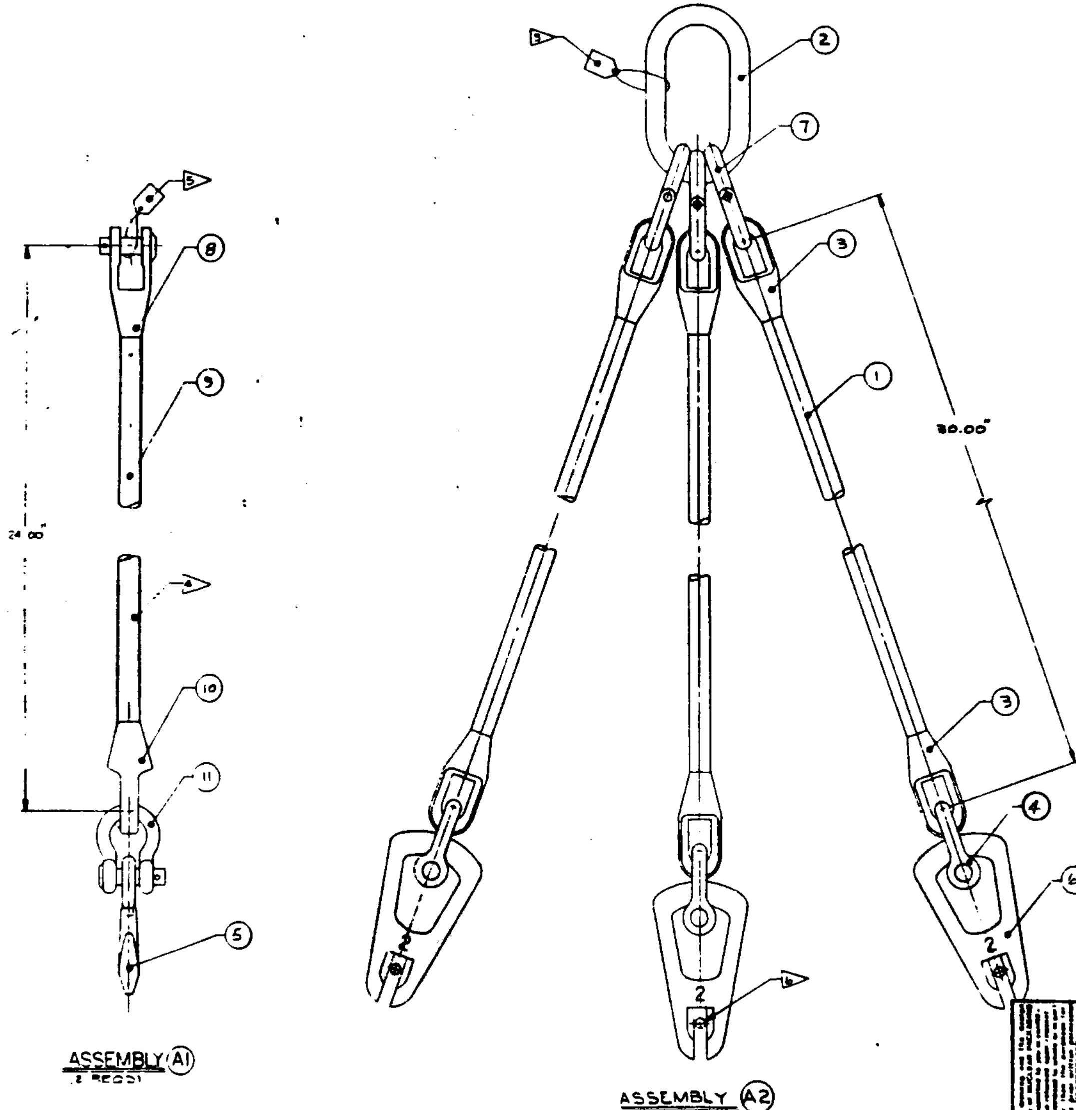
NEXT ASSY: EP-70-000 | USED ON: EP-70-000
APPLICATION

NUCLEAR PACKAGING, INC.
TACOMA, WASHINGTON

SPREADER BAR
FAB. DETAILS

DRAWN: CULTUM
SIZE: D
DWG NO.: EP-70-010
REV: C

A-1-14



ASSEMBLY (A1)
(2 REQ'D)

ASSEMBLY (A2)

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
B-1 A-7	A	1. REVISE SIZES FOR INCREASED WEIGHT AND PER DIAMETER CHANGE, CUSTOMER (EG&G) CHANGE #1, DOR NO. CMB-201 2 ROTATE HOOK 90°		
	B	INCORPORATED DCN EP-08		

6 REMOVE RETAINING PIN.

5 MARK AND ATTACH IDENTIFICATION TAG WITH APPROPRIATE PART NUMBER OF EACH ASSEMBLY.

4 LIFTING ASSEMBLY SUPPLIER SHALL CERTIFY AND PROVIDE TEST REPORT THAT EACH A1 AND A2 ASSEMBLY SUPPLIED HAS BEEN TESTED TO 150% OF RATED WORKING CAPACITY. A1 RATED WORK CAPACITY EQUAL TO 1,750 LBS., A2 RATED WORK CAPACITY EQUAL TO 2,600 LBS. (TOTAL).

3 SOURCE OF SUPPLY: SUPERIOR CONCRETE ACCESSORIES, INC.
9415 SORENSEN AVENUE
SANTA FE SPRINGS, CA 90670
(213) 698-7954

2 SOURCE OF SUPPLY: CROSBY
P.O. BOX 3128
TULSA, OKLAHOMA 74101
(918) 834-4611

1 SOURCE OF SUPPLY: PACIFIC WIRE ROPE CO.
3255 N.W. YEON AVENUE
PORTLAND, OR 97210
(503) 223-5100
TWX 910-646-1556

A2	A1	ITEM	PART NO	DESCRIPTION	MATERIAL
	2	11	EP-70-02D-11	SHACKLE, 4 1/2 TON, G213	2
	2	10	EP-70-02D-10	SPELTER SOCKET, .75 ROPE DIA G-417	2
	2	9	EP-70-02D-9	WIRE ROPE .75 DIA 6x19 IWRC [illegible]	1
	2	8	EP-70-02D-8	OPEN SPELTER SOCKET, .75 ROPE DIA G-416	2
3		7	EP-70-02D-7	CONNECTING LINK, 50 CHAIN SIZE # A-336	2
3		6	EP-70-02D-6	SL LIFTING EYE, 2 TON, 467325	3
	2	5	EP-70-02D-5	EYE HOIST HOOK, 4 1/2 TON # 322A	2
3		4	EP-70-02D-4	SHACKLE, 3 1/4 TON, G213	2
6		3	EP-70-02D-3	SPELTER SOCKET .50 ROPE DIA G-417	2
1		2	EP-70-02D-2	MASTER LINK, 1.00 DIA # A-342	2
3		1	EP-70-02D-1	WIRE ROPE .50 DIA 6x19 IWRC [illegible]	1
X		A2	EP-70-02D-A2	LIFTING ASSEMBLY	4
	X	A1	EP-70-02D-A1	LIFTING ASSEMBLY	4

ASSEMBLY & QUANTITY — LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
FRACTIONS ± 1/8
ANGLES ± —
2 PLACE DECIMALS ± —
2 PLACE DECIMALS ± .25
1 PLACE DECIMALS ± —
DO NOT SCALE THIS DRAWING

EP-70-02C	EP-70-102C
NEXT ASSY	USED ON
APPLICATION	

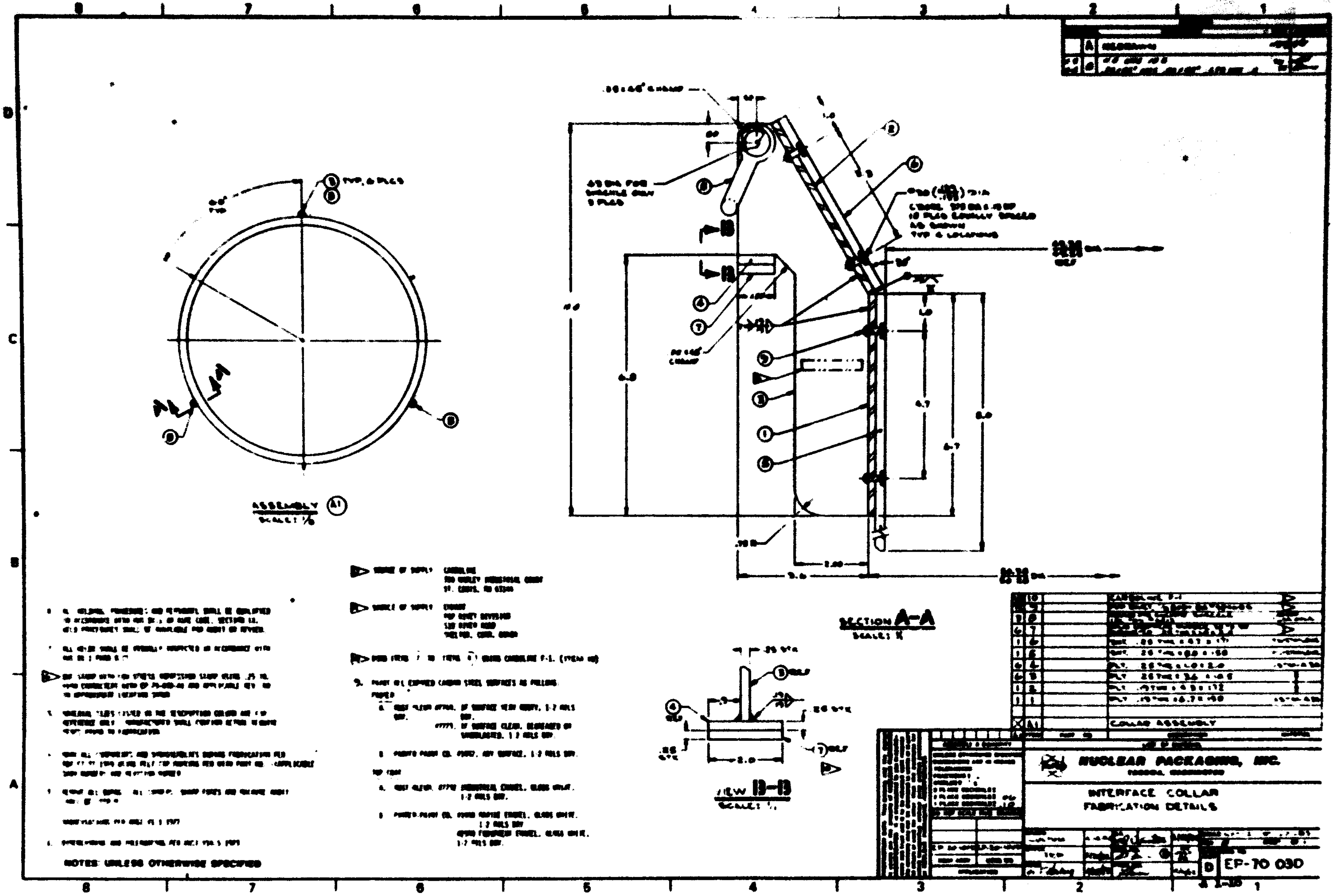
NUCLEAR PACKAGING, INC.
TACOMA, WASHINGTON

LIFT LINKS
FAB. DETAILS

DRAWN PCP — CHECKED — SCALE — SHEET 1 OF 1 — SIZE D — DWG NO. EP-70-02D

NOTES: UNLESS OTHERWISE SPECIFIED

A-18



ASSEMBLY
SECTION A-A
VIEW B-B
NOTES: UNLESS OTHERWISE SPECIFIED
COLLAR ASSEMBLY
NUCLEAR PACKAGING, INC.
INTERFACE COLLAR
FABRICATION DETAILS
EP-70 030

APPENDIX B

SINGLE-FAILURE AND RELIABILITY ANALYSES OF HIGH-INTEGRITY CONTAINER

Holloran & Associates

APPENDIX B
SINGLE-FAILURE AND RELIABILITY ANALYSES OF HIGH-INTEGRITY CONTAINER

B.1 Introduction

The High-Integrity Container (HIC) must provide safe, reliable, below-ground disposal of radioactive TMI-2 wastes for 300 years. The purpose of this appendix is to provide single-failure analyses for the HIC design, as shown in Figures B-1 and B-2. Those failure analyses have been combined because of their close interrelationship. A formal fault tree analysis is not required specifically by the specification. However, a fault tree methodology is used as a design tool to aid in identifying the single failures that could lead to any loss of container integrity. Fault trees also are used in developing the quantitative reliability estimate. This appendix is divided into two sections that describe the updated fault trees and how they are used to provide the required single-failure and reliability analyses.

The set of fault trees prepared for use in the single-failure and reliability analyses reflect the revisions in the design and are included as Figures B-3 through B-7. The various container systems identified on the fault trees and referred to in the text of this appendix are described in detail in the body of the report. The primary failure events and a brief discussion of each is provided in Table B-1.

B.2 Single-Failure Analysis

As the top fault tree event (Figure B-3) illustrates, four basic failure modes can result in a loss of container integrity; namely, (a) barrier penetration, (b) penetration of the seals, (c) an open failure of the vent, and (d) overpressurization following a plugging of the vent.

B.2.1 Barrier Penetration

Figure B-4 reveals that at least three corrosion-barrier failures must occur to cause loss of container integrity. Those failures are described in Table B-1, event numbers 1.1.1 to 1.3.3.

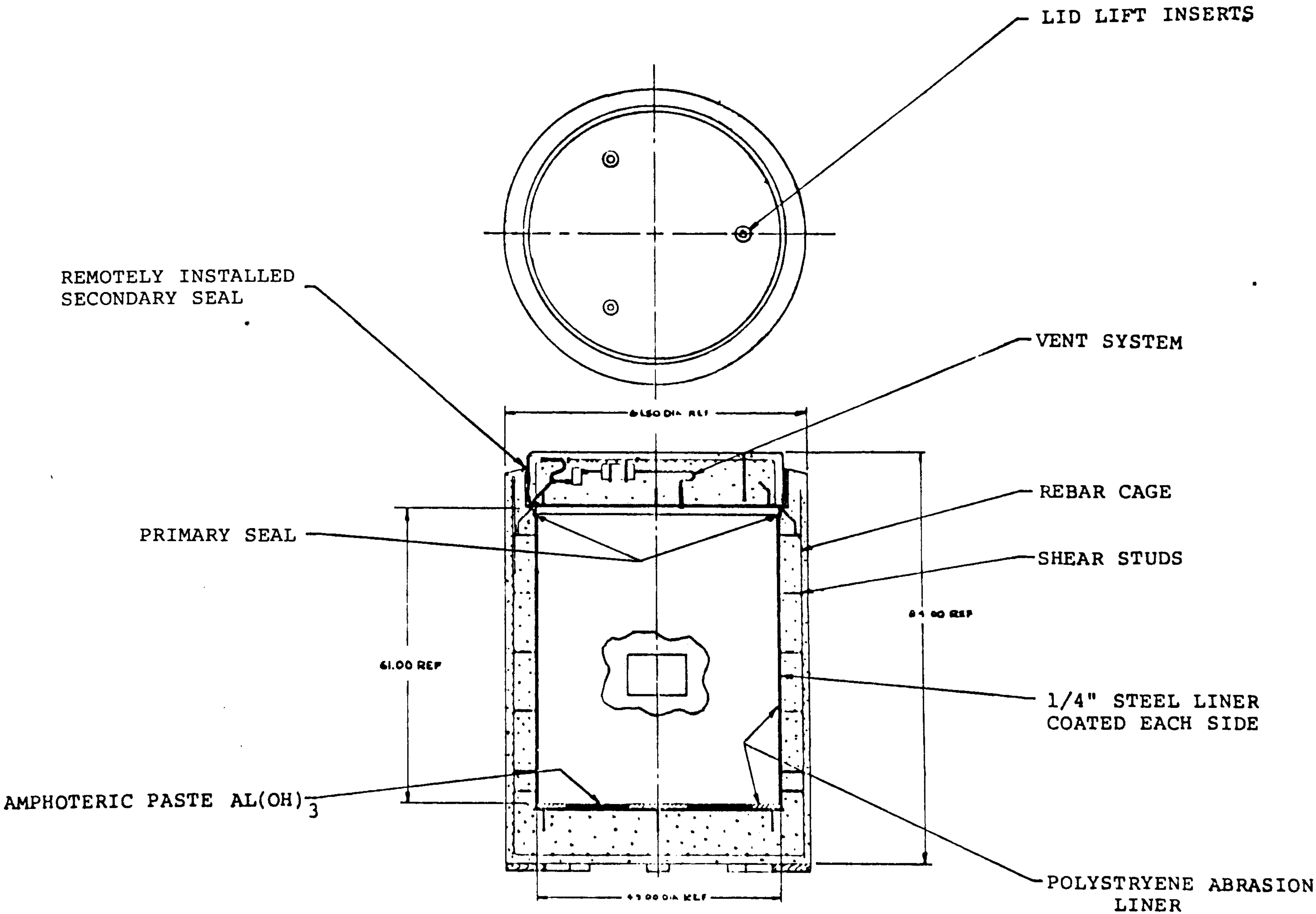


Figure B-1. HIC configuration.

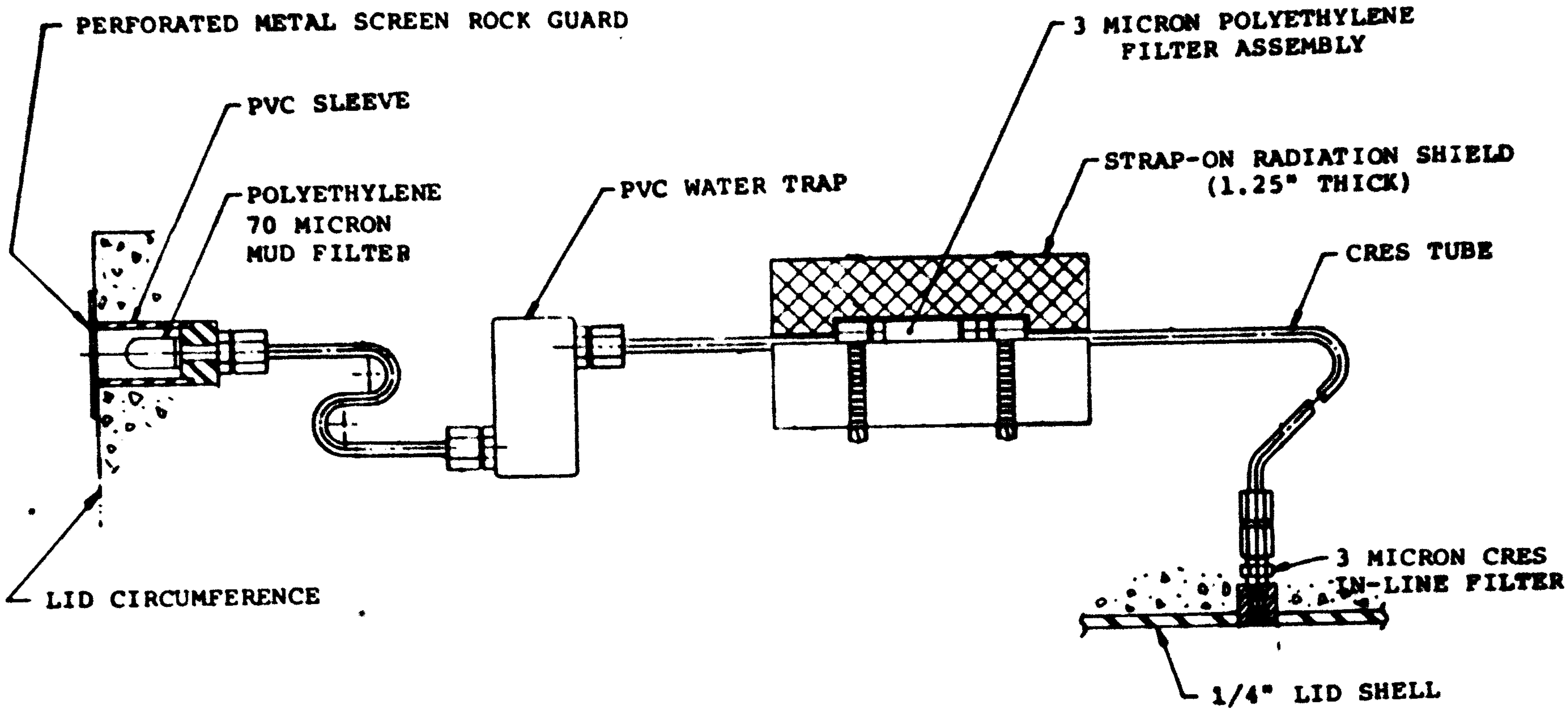


Figure B-2. HIC vent assembly (lid mounted).

$$MTTF = \frac{300 \text{ YEARS}}{.249} = 1204 \text{ YEARS}$$

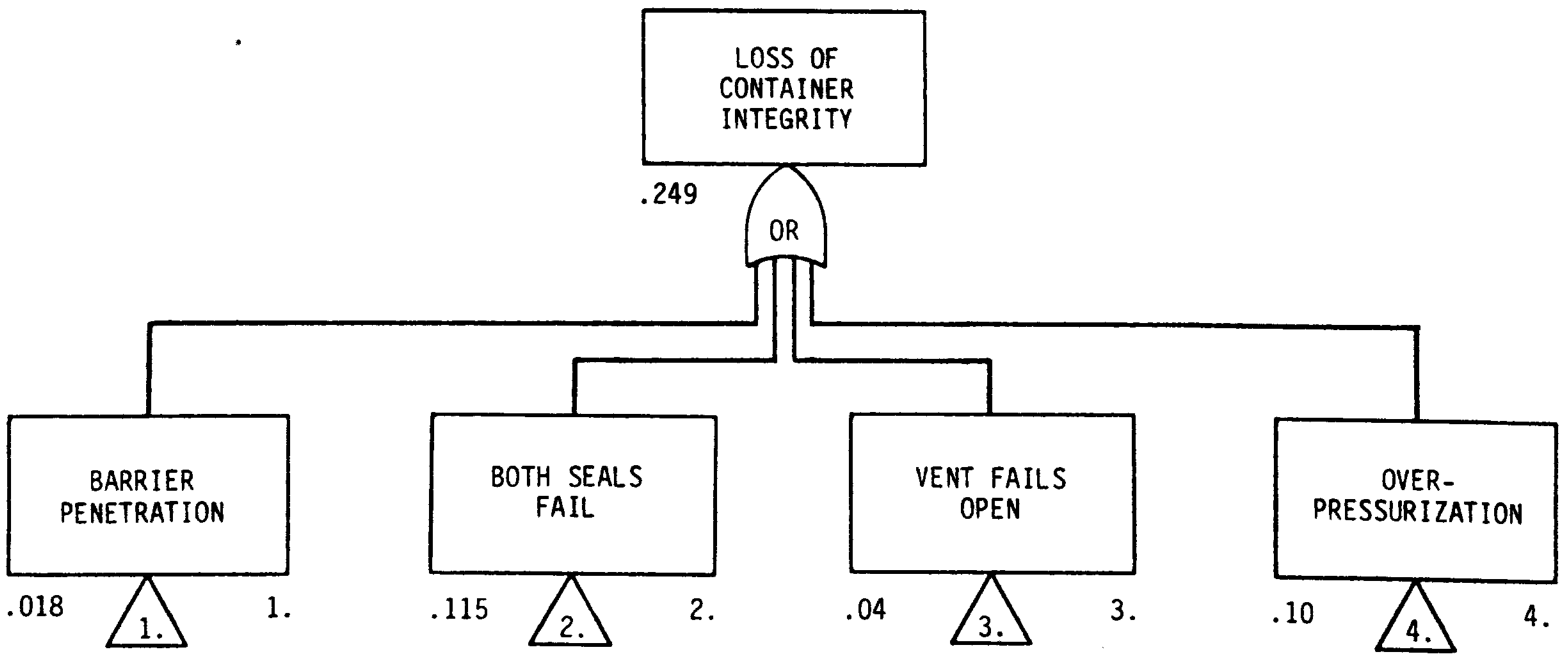


Figure B-3.

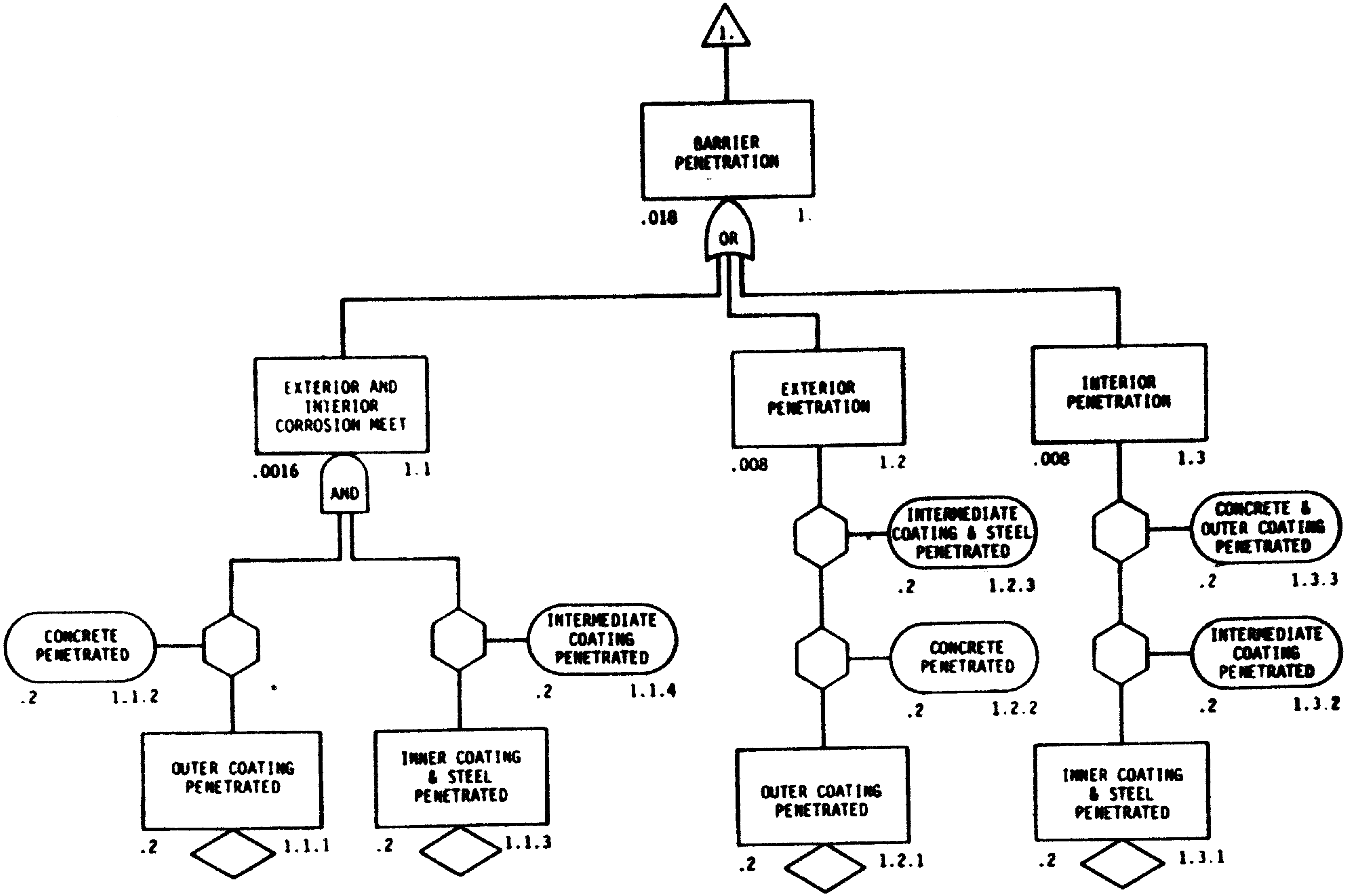

1.
BARRIER PENETRATION
.018
1.
OR
EXTERIOR AND INTERIOR CORROSION MEET
.0016
1.1
AND
EXTERIOR PENETRATION
.008
1.2
INTERIOR PENETRATION
.008
1.3
CONCRETE PENETRATED
.2
1.1.2
INTERMEDIATE COATING PENETRATED
.2
1.1.4
OUTER COATING PENETRATED
.2
1.1.1
INNER COATING & STEEL PENETRATED
.2
1.1.3
INTERMEDIATE COATING & STEEL PENETRATED
.2
1.2.3
CONCRETE PENETRATED
.2
1.2.2
OUTER COATING PENETRATED
.2
1.2.1
CONCRETE & OUTER COATING PENETRATED
.2
1.3.3
INTERMEDIATE COATING PENETRATED
.2
1.3.2
INNER COATING & STEEL PENETRATED
.2
1.3.1

Figure B-4.

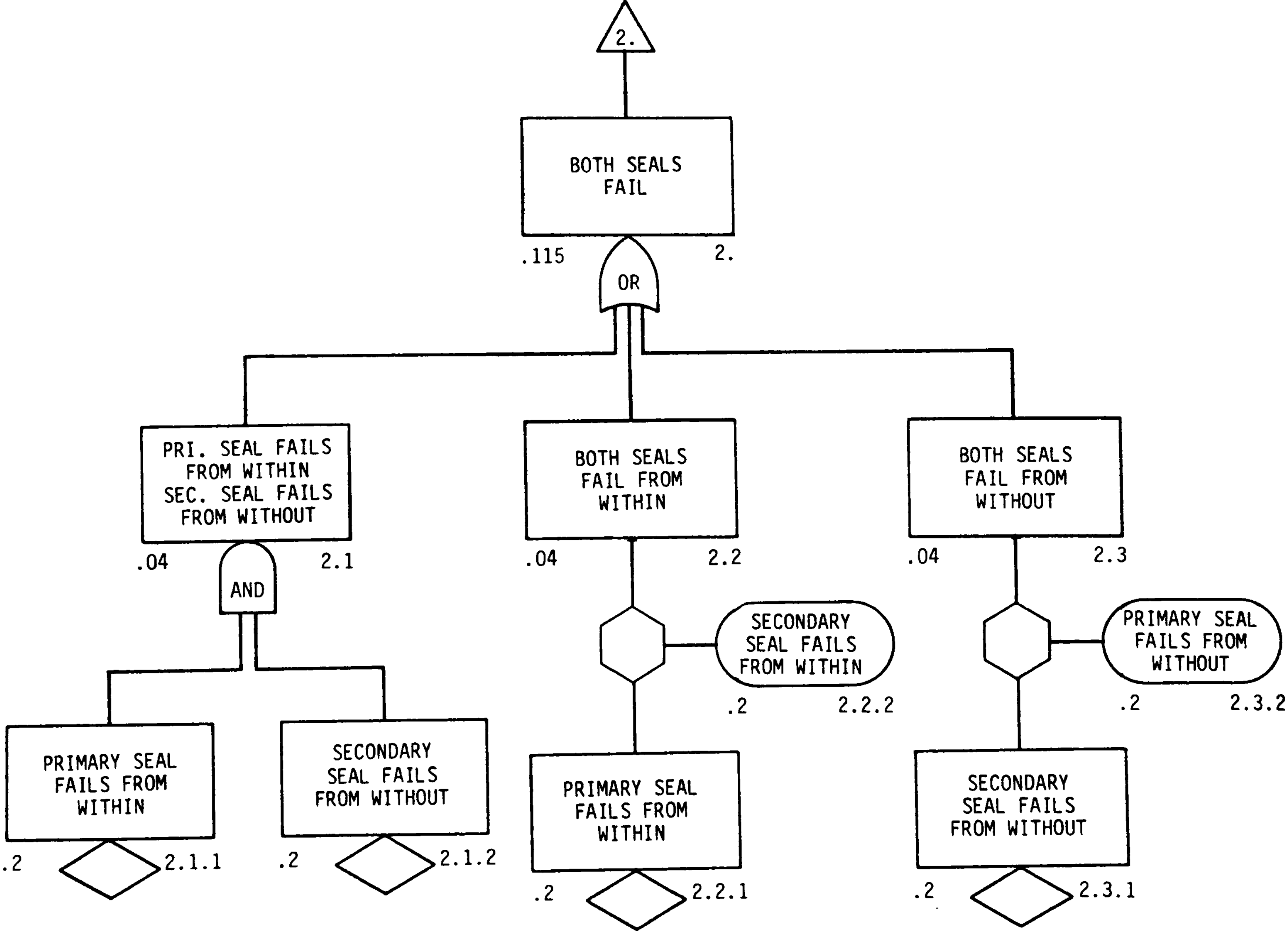

2.
BOTH SEALS FAIL
.115
2.
OR
PRI. SEAL FAILS FROM WITHIN SEC. SEAL FAILS FROM WITHOUT
.04
2.1
AND
BOTH SEALS FAIL FROM WITHIN
.04
2.2
BOTH SEALS FAIL FROM WITHOUT
.04
2.3
SECONDARY SEAL FAILS FROM WITHIN
.2
2.2.2
PRIMARY SEAL FAILS FROM WITHOUT
.2
2.3.2
PRIMARY SEAL FAILS FROM WITHIN
.2
2.1.1
SECONDARY SEAL FAILS FROM WITHOUT
.2
2.1.2
PRIMARY SEAL FAILS FROM WITHIN
.2
2.2.1
SECONDARY SEAL FAILS FROM WITHOUT
.2
2.3.1

Figure B-5.

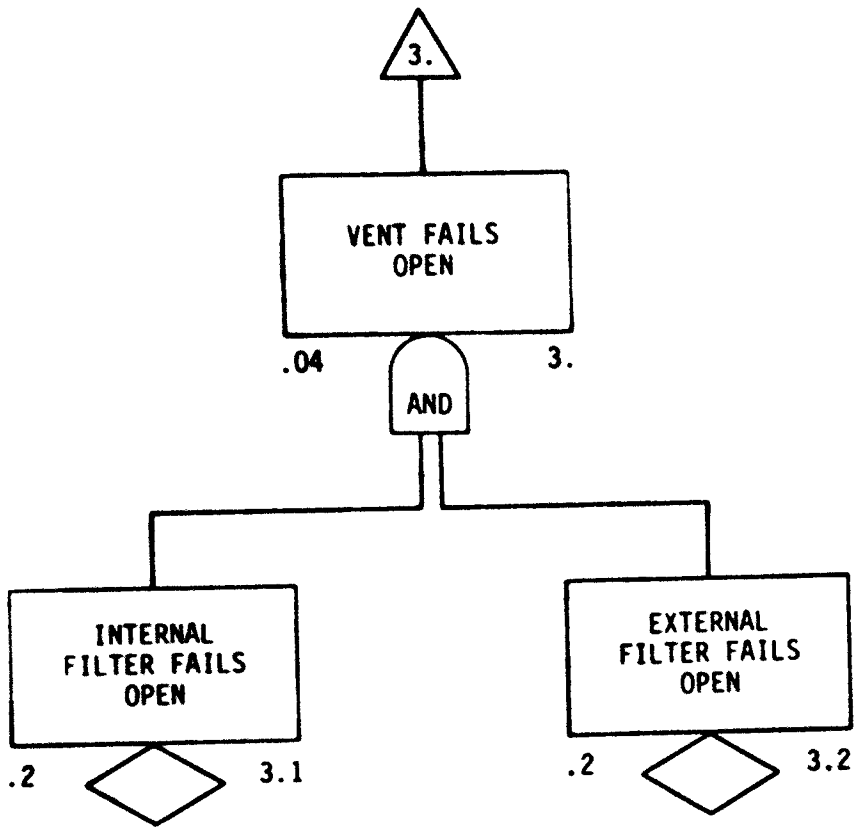

3.
VENT FAILS OPEN
.04
3.
AND
INTERNAL FILTER FAILS OPEN
.2
3.1
EXTERNAL FILTER FAILS OPEN
.2
3.2

Figure B-6.

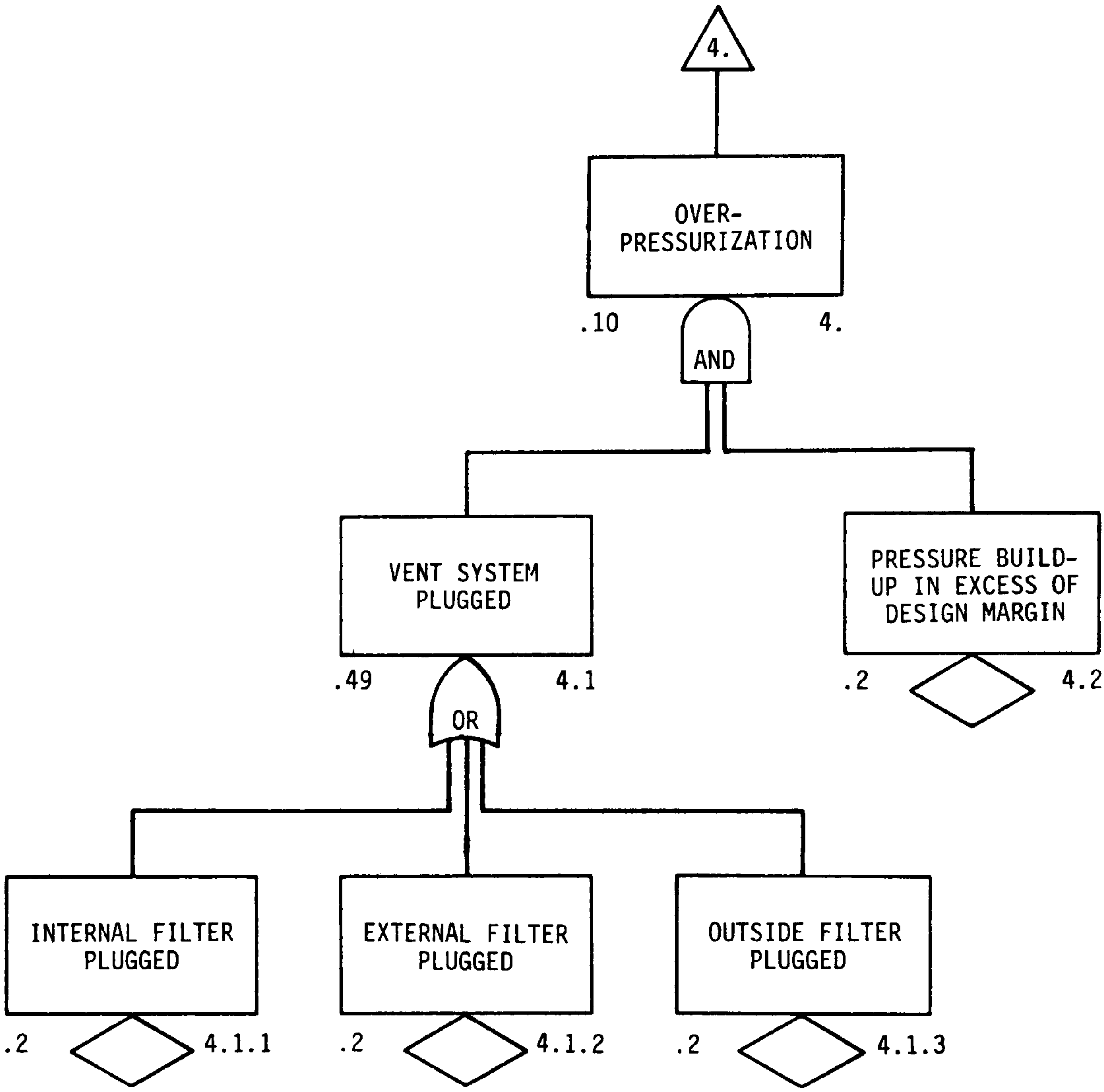

4.
OVER-
PRESSURIZATION
.10
4.
AND
VENT SYSTEM
PLUGGED
.49
4.1
OR
PRESSURE BUILD-
UP IN EXCESS OF
DESIGN MARGIN
.2
4.2
INTERNAL FILTER
PLUGGED
.2
4.1.1
EXTERNAL FILTER
PLUGGED
.2
4.1.2
OUTSIDE FILTER
PLUGGED
.2
4.1.3

Figure B-7.

TABLE B-1. FAILURE RATE PROBABILITY

Primary Event Number	Event	Assumed Failure Probability in 300-year Life	Features Designed to Prevent or Mitigate Primary Failure
1.1.1	Outer coating penetrated from outside	0.2	A nuclear-qualified coating, applied in accordance with the manufacturer's recommendation, is visually inspected (see Section 2.2.2 of the main report). Due to the radiation exposure and length of the container lifetime, gas may develop in the concrete to cause a few localized pressure blisters in the external coating.
1.1.2	Concrete penetration from outside	0.2	Concrete used is resistant to attack by the worst-case disposal environment in case the outer coating fails (see Section 2.2.2 of the main report).
1.1.3	Inner coating and HIC steel liner penetrated from inside	0.2	A nuclear-qualified coating (phenoline) is applied in accordance with the manufacturer's recommendations and thoroughly inspected. A polystyrene abrasion liner and amphoteric material are used to protect the phenoline coating from abrasion during loading and to neutralize any acids or alkalies that corrode the EPICOR-II prefilter liner (see Section 2.2.2 of the main report).

TABLE B-1. (continued)

Primary Event Number	Event	Assumed Failure Probability in 300-year Life	Features Designed to Prevent or Mitigate Primary Failure
1.1.4	Intermediate coating penetrated from inside	0.2	Since the intermediate phenoline coating will be supported by the concrete even if the steel liner is penetrated, the phenoline coating is still an effective barrier. The same nuclear-qualified coating and application procedures used for the interior phenoline coating (Event 1.1.3) are used for the intermediate phenoline coating. If the phenoline coating somehow fails and the steel liner corrodes, enough time probably will have elapsed and enough additional neutralization of the mixture will have occurred in the corrosion of the steel that the intermediate phenoline coating will survive (see Section 2.2.2 of the main report).
1.2.1	Outer coating penetrated from outside	0.2	Same as Event 1.1.1.
1.2.2	Concrete penetrated from outside	0.2	Same as Event 1.1.2.

TABLE B-1. (continued)

Primary Event Number	Event	Assumed Failure Probability in 300-year Life	Features Designed to Prevent or Mitigate Primary Failure
1.2.3	Coated container liner penetrated from outside	0.2	The intermediate phenoline coating is designed to resist corrosive environments more severe than the most extreme soil environment specified. The concrete portion of the container will be poured in sections to reduce the possibility of damage to the intermediate phenoline coating (see Section 2.2.2 of the main report).
1.3.1	Inner coating and steel liner penetrated from inside	0.2	Same as Event 1.1.3.
1.3.2	Intermediate coating penetrated from inside	0.2	Same as Event 1.1.4.
1.3.3	Concrete and outer coating penetrated from inside	0.2	The concrete is resistant to corrosive soil environments, and its thickness requires considerable time to penetrate. Furthermore, the amphoteric material coupled with the neutralization from corrosion of the steel effectively will neutralize the mixture that could contact the concrete from inside. The concrete also has some amphoteric properties that tend to neutralize any acid or base that gets through the phenoline-coated steel liner.

TABLE B-1. (continued)

Primary Event Number	Event	Assumed Failure Probability in 300-year Life	Features Designed to Prevent or Mitigate Primary Failure
2.1.1	Primary seal fails from inside	0.2	The primary seal is a long-pot-life epoxy with excellent chemical-resistance properties. It should resist attack by materials from either inside or outside the container (see Section 2.2.1 of the main report).
2.1.2	Secondary seal fails from outside	0.2	The secondary seal is a rapid-curing epoxy that will bond to the concrete and provide an effective seal. It should resist chemically anything that attacks it from either the disposal environment or failure of the primary seal from inside (see Section 2.2.1 of the main report).
2.2.1	Primary seal fails from inside	0.2	Same as Event 2.1.1.
2.2.2	Secondary seal fails from inside	0.2	Same as Event 2.1.2.
2.3.1	Secondary seal fails from outside	0.2	Same as Event 2.1.2
2.3.2	Primary seal fails from outside	0.2	Same as Event 2.1.1.

TABLE B-1. (continued)

Primary Event Number	Event	Assumed Failure Probability in 300-year Life	Features Designed to Prevent or Mitigate Primary Failure
3.1	Internal filter fails open	0.2	The internal CRES in-line filter is a commercially manufactured, high-quality, passive element. It is not susceptible to radiation damage and has structural strength well beyond the burst pressure of the container (see Section 2.2.3 of the main report).
3.2	Main filter fails open	0.2	The polyethylene filter elements are shielded by both the concrete lid and the supplemental lead shielding. They are supported by sintered metal filters; the entire vent assembly is expected to withstand pressures exceeding the container design strength (see Section 2.2.3 of the main report).
4.1.1	Internal filter plugged	0.2	The internal CRES in-line filter is protected from external foreign material by the external polyethylene filter. Furthermore, the entire vent system is protected from foreign material by a 70-micron polyethylene bulb filter. The location of the vent system near the center of the lid will prevent the seal-pouring operation from plugging the vent (see Section 2.2.3 of the main report).

TABLE B-1. (continued)

Primary Event Number	Event	Assumed Failure Probability in 300-year Life	Features Designed to Prevent or Mitigate Primary Failure
4.1.2	Main filter plugged	0.2	The polyethylene filter is protected from plugging by the internal CRES in-line filter and the outside polyethylene bulb filter. Since the vent outlet is recessed behind a screen that is flush with the surface of the lid, the likelihood of the vent becoming plugged during seal-pouring operations is remote (see Section 2.2.3 of the main report).
4.1.3	Outside filter plugged	0.2	The outside polyethylene bulb filter is protected from the disposal environment by a metal grate over a recessed area where the filter is attached to the conduit. This polyethylene bulb filter has resistance to radiation exposure. Also, the filter is weaker than the container structure, seals, or remainder of the vent system. Thus, if the polyethylene bulb filter does become plugged, it will burst (see Section 2.2.3 of the main report).

TABLE B-1. (continued)

Primary Event Number	Event	Assumed Failure Probability in 300-year Life	Features Designed to Prevent or Mitigate Primary Failure
4.2	Pressure buildup in excess of design margin	0.2	If the venting system becomes plugged, the best-estimate gas-generation calculation shows that the expected burst pressure of the container will not be reached (see Section 2.2.3 of the main report).

B.2.2 Seal Penetration

Figure B-5 reveals that two separate seal failures are required to cause loss of container integrity. Those failures are described in Table B-1, event numbers 2.1.1 to 2.3.2.

B.2.3 Open Failure of the Vent

As shown in Figure B-2, the present design has two devices in series that prevent solids from entering or leaving the container. As shown in Figure B-6, two independent failures are required for a loss of HIC integrity through the vent path, not counting overpressurization. Those failures are described in Table B-1, event numbers 3.1 and 3.2.

B.2.4 Overpressurization

There is only a single vent path, as shown in Figure B-2. Therefore, only a single failure is required to plug the vent system. Theoretically, if the vent is totally plugged, failure of either the vent or the container structure could result. Such a failure is unlikely, however, because of the excess design capacity of the vent system and the container, as described in the following paragraphs and in Section 3.2 of the main report.

Figure B-7 identifies the various failure modes that can lead to an overpressurization and cause a loss of container integrity. Those failure modes are described in Table B-1, event numbers 4.1.1 and 4.2. As stated in Section 3.2 of the main report, each vent is expected to have a capacity 20 times greater than the design basis when 50% plugged. In other words, the venting system can relieve the design basis gas generation when it is 98% plugged. The vents are passive and provide continuous relief; thus, pressures sufficient to endanger the vent structures should not accumulate. It is unlikely that vents will plug sufficiently for the container pressure to rise above the specified level, considering the conservatism of their excess design capacity (see Appendix C), the decreasing rate of gas generation with time, and the protected location of the vent.

If, in spite of all these factors, the vent system plugs or never operates, the resulting maximum gas pressure in the HIC would be substantially less than the burst pressure of the container. Even with the design basis gas-generation rate, (five times the best-estimate generation rate,) the maximum pressure buildup would be less than the burst pressure of the container, supplemented by the lithostatic head (see Appendices E and H).

B.3 Reliability Analysis

The HIC would sustain a significant structural failure in order to allow either water to flow through the container or the degraded resin mixture to escape. As described in Section B.2, an overpressurization sufficient to cause a structural failure of the container is not likely to occur.

For radioactive material to escape following a vent system failure, the container must fill with water, then the radioactive material inside the HIC must diffuse out. However, the nature of the resin mixture removes ions from the water rather than allowing the contained radioactive ions to enter solution. Since diffusion is slow and the radioactive ions do not tend to leave the resin mixture, any release due to the vent system passing water is expected to be minor.

Unfortunately, little data are available for a valid quantitative prediction on the reliability of modern engineering materials over a period of 300 years. An arbitrarily assigned failure probability of 20% for each of the primary events listed in Table B-1 indicates the redundancy built into various aspects of the container.

The mean time to failure (MTTF) for the container, based on the arbitrarily assigned 20% failure probabilities, is 1,204 years (300-year lifetime multiplied by inverse of failure probability). The calculated probability numbers are given at the lower left-hand corner of each fault tree event.

If, in spite of all these factors, [illegible] plugs or never [illegible] ates, the result [illegible] pressure [illegible] substantially less than the burst pressure of the container [illegible] with the design gas generation [illegible] the pressure [illegible] maximum pressure [illegible] would be less than [illegible] of the container, supplemented [illegible] hydrostatic head [illegible]

[illegible] Analysis

[illegible] would [illegible] the gas [illegible] pressure [illegible] is not likely to occur.

[illegible]

APPENDIX C
ANALYSIS OF GAS EVOLUTION AND PRESSURES WITHIN THE HIC

Holloran & Associates

APPENDIX C
ANALYSIS OF GAS EVOLUTION AND PRESSURES WITHIN THE HIC

C.1 Introduction

The gas evolution and pressure buildup in the HIC was calculated to determine whether or not the container requires venting. If the HIC is to be vented, it is necessary to define the gas flow rate that the vent must pass to limit the pressure in the container. To evaluate the consequences of a vent path blockage, it is necessary to determine the maximum unvented container pressure. Two other parameters that must be calculated before the gas flow rate and unvented container pressure are (a) the bulk average radiation dose to the exchange media, and (b) the rate of gas evolution in the exchange media per unit radiation dose to the exchange media.

The equations presented for the various calculated parameters are straightforward. However, many variables are used in a few of the equations and there are many unit conversions. Therefore, the usual algebraic format for equations in technical reports is not used. Instead, variable names and conversion factor values are used, along with the associated units.

A computer program was developed to perform all the necessary calculations. Excerpts from the program output for the "best-estimate" case are included as tables in this appendix for the convenience of the reader. The complete output from the computer program for the "design basis" case is presented in an attachment to this appendix.

Table C-1 illustrates various mechanisms that can cause evolution of gases in the HIC. Radiolysis of the cation-exchange resin molecules and the bound water will be discussed first. Potential pressure-reduction mechanisms, (e.g., oxygen scavenging) are neglected in this analysis.

TABLE C-1. GAS-EVOLUTION MECHANISMS IN THE HIC

		N_2, O_2, H_2O	
Mechanism	Existing Atmosphere	Gas Generated	Gas Consumed
Gamma and beta radiation	Resin molecules (scission and decoupling)	SO_x NO_x CO_2 CO	O_2
	Bound water (dissociation)	H_2 O_2	
	Free water (dissociation)	H_2 O_2	
	EPICOR-II liner (scission and decoupling)	H_2 CO_2 CO	O_2
Corrosion	Acid generation in bound and free water		SO_x NO_x CO_2 CO
	Corrosion of iron by acid[a]	H_2	H_2O
	Corrosion of iron by water vapor	H_2	

a. Significant if only cation resin in EPICOR-II prefilter.

Other mechanisms involve gas evolution from polyethylene or polystyrene materials and corrosion of the carbon steel EPICOR-II prefilter structure. Those two mechanisms, described in Sections C.6 and C.7, do not make substantive contributions to total gas generation and can be neglected in design of the HIC.

C.2 Calculation of Integrated Doses

To determine the average integrated dose, it is necessary to establish an energy-deposition rate for each isotope. The isotopic distribution of the activity and the dose conversion applicable to the EPICOR-II prefilter also are required. Once those input parameters are determined, the integrated dose and dose rates to the exchange media can be calculated.

C.2.1 Energy Deposition

The absorbed energy in ergs/yr-Ci is obtained for each isotope via the equation:

Absorbed energy (ergs/yr-Ci) = absorbed disintegration energy (MeV/dis)

$$\times (1.602 \times 10^{6} \text{ ergs/MeV}) \times (3.7 \times 10^{10} \text{ dis/s-Ci})$$

$$\times (3600 \text{ s/h}) \times (24 \text{ h/day}) \times (365.25 \text{ days/yr}) \ . \qquad \text{(C-1)}$$

Multiplication of the maximum beta radiation energy for each source by a factor to account for the lost neutrino energy yields an average beta energy. The average beta energy is added to the gamma energy, and it is assumed that the total energy is absorbed in cation-exchange media. This formulation is conservative, since a small fraction of the beta energy and a significant fraction of the gamma energy will escape.

Energy deposition is calculated using an assumed average beta energy fraction of 0.39 for all decays, except the 2.27-MeV beta from ^{90}Sr where a measured value (0.41) is available. The assumed fraction is consistent with the upper-limit values determined by the method described in Reference 1. The MeV/disintegration values for each isotope are calculated from the following decay schemes:[2-4]

^{137}Cs Decay Scheme

1.173 MeV maximum beta energy (6%)
0.512 MeV maximum beta energy (94%)
0.662 MeV gamma (94%).

Absorbed disintegration energy = 0.837 MeV/disintegration.

^{90}Sr Decay Scheme

0.546 MeV maximum beta energy (100%)

2.27 MeV maximum beta energy with measured average energy of 0.93 MeV (99%)

0.52 MeV maximum beta energy (2%)

1.75 MeV gamma (0.02%)

Absorbed disintegration energy = 1.17 MeV/disintegration.

^{134}Cs Decay Scheme

0.662 MeV maximum beta energy (100%)

0.570 MeV gamma (23%)

0.605 MeV gamma (98%)

0.796 MeV gamma (99%)

1.038 MeV gamma (1%)

1.168 MeV gamma (2%)

1.365 MeV gamma (3.4%)

Absorbed disintegration energy = 1.85 MeV/disintegration.

Based on these decay schemes, the energy deposition for each isotope is calculated; results are given in Table C-2. After the energy deposition is calculated, a dose-conversion factor is calculated for determining the dose rate to the exchange media once the number of curies of each contained isotope is known.

C.2.2 Container Activity

To estimate the maximum number of curies present in an EPICOR-II prefilter, it is assumed that the 1300-Ci administrative limit on primary isotopes in a prefilter was applied only to isotopes with a half-life

TABLE C-2. SOURCE TERM DATA

BEST ESTIMATE	WITH 0 FT HEAD				
DATA	UNITS				
RESIN VOLUME	FEET^3 (TOTAL)	34	CATION RESIN FRACTION		.5
RESIN DENSITY	GRAMS/CC (WET)	.85INCLUDING VOIDS			TOTAL FOR
CATION RESIN MASS (GRAMS WET)		433296			ISOTOPES T 1/2
ISOTOPE	--	CS137	SR90	CS134	>5 YEAR
HALFLIFE	YEAR	30	28.2	2.05	NA
DECAY CONSTANT	YEAR-1	0.02	0.02	0.34	NA
ENERGY DEPOSIT	E12 ERG/YR•CI	1.57	2.19	3.46	NA
DOSE CONVERT	RAD/YR•CI	36118	50543	79853	NA
CI FRACTION	>5 YR T1/2	0.95	0.05		1.00
ACTIVITY	CI	1230	70	272	1300

greater than five years.[a] The only isotopes present of this nature are ^{137}Cs and ^{90}Sr. The ratio of ^{137}Cs to ^{90}Sr is obtained from the calculated curie deposition in PF-29 presented in Reference 5:

Activity (^{137}Cs)/[Activity (^{137}Cs) + Activity (^{90}Sr)] = 864/(864 + 48.8) Ci
Activity (^{90}Sr)/[Activity (^{137}Cs) + Activity (^{90}Sr)] = 48.8/(864 + 48.8) Ci.

The ^{134}Cs activity was obtained by taking the ratio of ^{134}Cs to ^{137}Cs in the calculated curie deposition for PF-29 and multiplying it by the total curies of ^{137}Cs. Table C-2 summarizes the results of the calculation along with the input data used and the energy deposition for each isotope.

C.2.3 Dose Conversion

Given the number of curies, the energy deposition per curie, and the mass into which the energy is deposited, it is straightforward to compute the dose conversion as shown below:

Dose conversion (rads/yr-Ci) = energy deposition (ergs/yr-Ci)

x 1 rad/(100 ergs/g)

x 1/resin mixture mass (g) (C-2)

where the resin mixture mass is given by the equation:

Resin mixture mass (g) = wet resin density (g/cm^3)

x resin volume (ft^3) x 28 320 cm^3/ft^3 (C-3)

where the total resin volume is 36 ft^3 (Reference 6), half of which is assumed to be cation resin.[7] The wet resin density with voids is 0.85 g/cm^3 (Reference 8). This density, slightly higher than that given

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a. This assumption is used to conservatively envelope the typical or representative values given in Table 1 of EG&G Specification ES-50652B for Liner PF-29.

in the specification,[7] is used for reasons of consistency since it is the appropriate value for the resin in which experiments on gas generation were performed.

C.2.4 Integrated Doses

The integral of the radioactive decay equation is used along with the initial activity to determine the bulk average integrated dose in the cation resin at the time of container loading. The equation used is:

Dose to HIC load (Mrads) = dose conversion (rads/yr-Ci)

$$\times (1\ \text{Mrad}/10^6\ \text{rads}) \times \text{activity (Ci)}$$

$$\times 1/Z(\text{yr}^{-1}) \times (1-e^{-Zt'}) \qquad \text{(C-4)}$$

where Z is the radioactive decay constant normally symbolized with a Greek Lambda (λ) and with units of yr^{-1}, and t' is the time to HIC loading in years--assumed to be two years. Table C-3 provides the results of the calculation of the total dose, for HIC loading two years after removal of the EPICOR-II prefilter from service. The table also identifies the contribution of each of the three isotopes.

The same basic equation is used to calculate the integrated dose to the exchange media following HIC loading, as follows:

Media dose since HIC load (Mrads) = dose conversion (rads/yr-Ci)

$$\times (1\ \text{Mrad}/10^6\ \text{rads}) \times \text{activity (Ci)}$$

$$\times 1/Z(\text{yr}^{-1}) \times [e^{-Zt'} - e^{-Z(t+t')}] \qquad \text{(C-5)}$$

where t is the time since HIC loading. Table C-3 also lists the integrated doses to the cation-exchange media at times throughout HIC life.

TABLE C-3. INDIVIDUAL ISOTOPE CONTRIBUTIONS

		CS137 DOSE MRADS	SR 90 DOSE MRADS	CS134 DOSE MRADS	TOTAL DOSE MRADS
YEARS TO CASK LOAD	2				
DOSE TO CASK LOAD		87	7	32	125

YEARS SINCE CASK LOAD		CS137 DOSE MRADS	SR 90 DOSE MRADS	CS134 DOSE MRADS	TOTAL DOSE MRADS
(1ST DAY)	0	0	0	0	0
1		42	3	9	55
2		83	7	16	106
4		162	13	24	199
8		310	24	30	365
16		568	44	33	644
32		960	74	33	1067
64		1418	108	33	1559
148		1777	133	33	1942
256		1832	136	33	2000
300		1835	136	33	2004

C.2.5 Dose Rate

An estimate of the average initial integrated dose in the HIC liner is provided by the maximum liner dose, shown for a uniform source distribution in Figure G-2 of Appendix G (717 rads/h initially; 210 Mrads integrated lifetime dose). That estimate of average dose is conservative, because much of the liner is not adjacent to the resin. Thus, it will be exposed to a lower dose.

C.2.6 Liner Dose since HIC Load

The dose rate following HIC load is calculated from the radioactive decay equation as follows:

$$\text{Dose rate (rads/day)} = \text{dose conversion (rads/yr-Ci)} \times \text{activity (Ci)} \times e^{-Z(t+t')} \times 1\ \text{yr}/365.25\ \text{days} \qquad \text{(C-6)}$$

where t is the time since HIC load, t' is the time to HIC load, and Z is the decay constant normally referred to with a λ. Table C-4 presents the total dose rate in the cation-exchange media (units of rads/day) at various intervals throughout HIC life. The table also presents the contribution of the three isotopes to the total dose rate.

C.3 Gas Generation in Exchange Media

In addition to the parameters calculated above, a value for the gas generation per absorbed dose in the cation-exchange media is needed to calculate the gas-generation rate. A "G" value for hydrogen of 0.1 molecule/100 eV is used for the best-estimate calculation; a value of 0.5 molecule/100 eV is used for the design basis calculation. It is assumed that 46.5% of the exchange-media mass is water, but that virtually all of the free water (<1% remaining) is removed. The value of 0.1 molecule/100 eV is consistent with data presented in References 5, 8, and 9. The value of 0.5 molecule/eV is chosen as the design basis gas-generation rate to allow an adequate margin for differences in the

TABLE C-4. DOSE RATES

YEARS SINCE CASK LOAD		CS137 DOSE RATE RADS/HOUR	SR90 DOSE RATE RADS/HOUR	CS134 DOSE RATE RADS/HOUR	TOTAL DOSE RATE RADS/HOUR
(1ST DAY)	0	4841	382	1259	6481
1		4730	373	899	6001
2		4622	363	641	5626
4		4414	346	326	5085
8		4024	314	84	4422
16		3345	258	6	3608
32		2311	174	0	2485
64		1103	79	0	1183
148		158	10	0	168
256		13	1	0	14
300		5	0	0	5

exchange-media type, composition, and moisture content. For example, calculations using the design basis gas-generation rate will be conservative even if:

1. Twice the allowable amount of free water is present in the pre-filter and is in the vicinity of the radioacitivy where hydrogen can evolve

2. Fifty percent of the radioactivity is distributed in the anion-exchange media, which has a substantially higher hydrogen-evolution rate than cation-exchange media.[7]

C.3.1 Gas-Generation Rate

The following equation is used:

$$\text{Gas-generation rate } (cm^3/g\text{-Grad}) = 1/H_2 \text{ fraction} \times G(H_2)(\text{molecules}/100\ eV)$$

$$\times\ 2.32 \times 10^{-8}\ (cm^3/g\text{-rad})/(\text{molecules}/100\ eV)$$

$$\times\ 10^9\ (\text{rads/Grad}) \qquad \text{(C-7)}$$

where it is conservatively assumed that hydrogen accounts for only two-thirds of the gas generation. Actually, review of References 5, and 10 through 12 indicates that the hydrogen generation will be closer to 75% of total gas generation.

C.3.2 Total Gas Generated

The following equation is used to determine the total gas generated in moles:

$$\text{Gas generated (moles)} = \text{dose (Mrads)} \times (1 \text{ Grad}/1000 \text{ Mrads})$$

$$\times \text{ resin density } (g/cm^3 \times \text{ resin volume } (ft^3)$$

$$\times \text{ gas-generation rate } (cm^3/\text{g-Grad})$$

$$\times 28{,}320\ (cm^3/ft^3) \times 1 \text{ mole}/22{,}400\ cm^3. \quad \text{(C-8)}$$

Table C-5 lists the calculated amount of gas, both hydrogen and nonhydrogen, produced throughout HIC life.

C.4 Gas Pressure in the HIC

Once the gas production has been calculated, pressure buildup in the container can be calculated using the following equations:

C.4.1 Unvented Gas Pressure

$$\text{Pressure (psia)} = \{1 + [\text{moles of gas} \times 22400\ cm^3/\text{mole} \times 1/\text{gas volume } (ft^3)$$

$$\times 1/28{,}320\ (cm^3/ft^3)]\} \times 14.7 \text{ psia}. \quad \text{(C-9)}$$

C.4.2 Gas Volume

$$\text{Gas volume } (cm^3) = [\text{total volume } (ft^3) - \text{resin volume } (ft^3) \times (1 - \text{resin void fraction})] \times 28{,}320\ (cm^3/ft^3) \quad \text{(C-10)}$$

where the total volume is based upon the external dimensions of the EPICOR-II prefilter and the tightest possible fit within a disposal container.

C.4.3 Resin Void Fraction

The resin void fraction given by the manufacturer is 40.1% (see Reference 11).

Volume in GPU
V of DOE SARS = 714 in 25.3 ft
x HIC Volume - E-II ...
60.49 - 51.5...
= 10.94
Total Volume ... HIC = 42.2

1125 LITERS

TABLE C-5. GAS QUANTITIES PRODUCED

DATA	UNITS				UNITS
GAS GEN RATE	CC/GRAMS*E9RAD	3.46	GAS VOLUME	39.74	CUBIC FT
RESIN VOLUME	FT^3 (CATION)	18.00	CATION RESIN	483296	GRAMS (WET)
RESIN DENSITY	GRAMS/CC	0.85	FRACTION OF		
RESIN VOID FRACTION		0.40	WATER IN RESIN	0.47	
TOTAL VOLUME	CUBIC FT	61.30	G-H2 RESIN	0.10	MOLECULES/100EV
H2 FRACTION		0.67	INITIAL GAS VOL	49.36	MOLES
YRS TO CASK LOAD	2				

YEARS SINCE CASK LOAD		NON-H2 MOLES	H2 MOLES	TOTAL GAS MOLES	UNVENTED GAS PRES PSIA
(1ST DAY)	0	0.00	0.01	.010427181184	14.70
1		1.21	2.45	3.66	15.77
2		2.33	4.74	7.07	16.77
4		4.40	8.94	13.34	18.60
8		8.06	16.37	24.43	21.85
16		14.24	28.92	43.16	27.33
32		23.58	47.87	71.44	35.60
64		34.45	69.94	104.40	45.25
148		42.92	87.14	130.06	52.76
256		44.21	89.76	133.98	53.90
300		44.29	89.91	134.20	53.97

C.4.4 Calculated Unvented Pressure

Table C-5 presents the calculated best estimate of the unvented pressure at various intervals during the HIC life. Figure C-1 presents a curve showing the unvented pressure after 300 years for various initial gas-generation rates.

C.5 Vent Operations

The operation of an assumed check valve-type venting system can be determined once the unvented gas pressure as a function of time has been calculated.

C.5.1 Differential Pressure

The unvented pressure inside the HIC, and the hydrostatic head determine the differential pressure:

Total differential gas pressure (psid) = unvented gas pressure (psia) - head pressure (psig) - 14.7 (psia) (C-11)

where the head pressure in psig is obtained from the equation:

Hydrostatic pressure (psig) = head height (ft) x 62.4 (lb/ft^3) x (1 ft^2/144 $in.^2$). (C-12)

Table C-6 provides the calculated unvented differential gas pressure in the container.

C.5.2 Vent Actuations

The number of times a mechanical check valve will actuate depends upon opening and closing pressure of the check valve. For purposes of

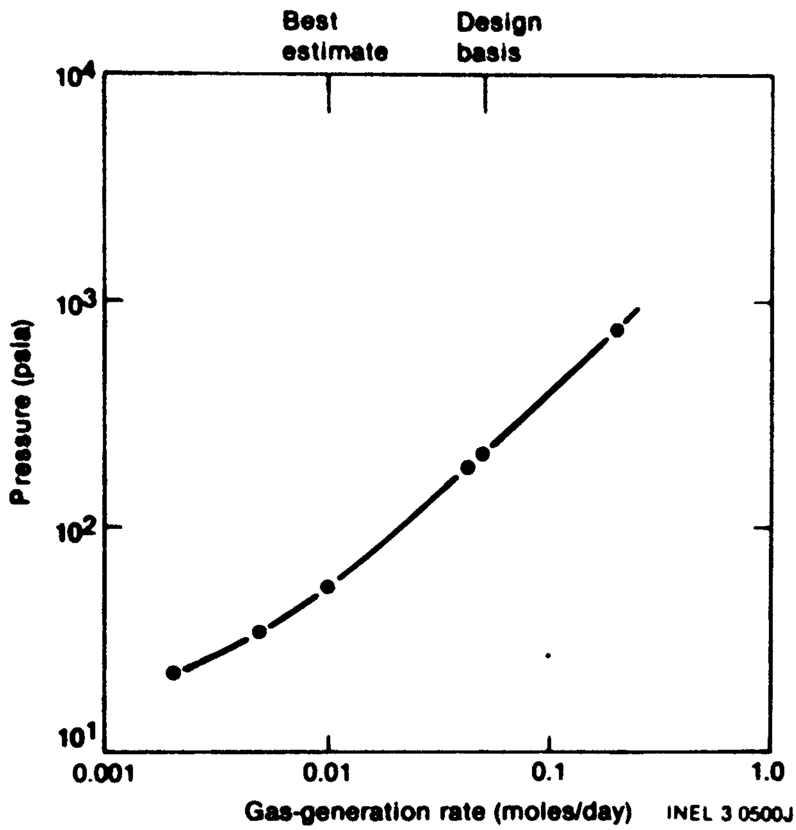

Figure C-1. Maximum unvented pressure (psia) vs gas-generation rate (moles/day).

TABLE C-6. RELIEF LIFTS

DATA	UNITS		CALCULATED VALUES	UNITS	
HYDROSTATIC HD	FT	0	HYDROSTATIC HD	0	PSID
RELIEF OPEN	PSID	10			
RELIEF SHUT	PSID	3			
YRS TO CASK LOAD		2			

YEARS SINCE CASK LOAD	DIFFERENTIAL TOTAL GAS PSID	* RELIEF LIFTS TO DATE	APPROXIMATE YEARS BETWEEN RELIEF LIFTS	MAXIMUM PSID IF RELIEF FAILS THIS YEAR
(1ST DAY) 0	0.00	0	9	39
1	1.07	0	10	38
2	2.07	0	10	37
4	3.90	0	11	35
8	7.15	0	13	32
16	12.63	1	11	27
32	20.90	2	16	18
64	30.55	3	34	9
148	38.06	5	242	1
256	39.20	5	2958	0
300	39.27	5	8203	0

illustration, an opening pressure of 10 psid and a closing pressure of 3 psid are used to estimate the number of times a mechanical relief check valve would lift for a given gas-generation history.

Lifts to date = (total unvented differential gas pressure (psid)
- relief open pressure (psid)/(relief open pressure
- relief close pressure)(psid). (C-13)

Table C-6 lists the number of relief lifts after HIC loading throughout HIC life.

C.5.3 Interval between Relief Lifts

This parameter is estimated by calculating how long it would take for the differential pressure to build up from the vent-closing pressure to the vent-opening pressure at the instantaneous gas-generation rate. The model creates an anomaly just before the first relief lift, as can be observed in Table C-6 where the years between lifts is 13 in the eighth year and 11 in the sixteenth year. That anomaly occurs because the first lift requires a larger pressure buildup than do subsequent lifts, and the first lift occurs between the eighth and sixteenth years.

Interval between relief lifts (years) = [(10^9 rads/Grad)/

dose rate (rads/day)] x [1/gas-generation rate (cm^3/g-Grad)]

x gas volume (ft^3) x 28,320 cm^3/ft^3

x [1/resin mixture mass (g)] x (1 year/365.25 days)

x (relief open pressure - relief close pressure)(psid)

x (1/14.7 psia). (C-14)

C.5.4 Maximum HIC Pressure if Vent Plugs in a Given Year

The likelihood of a vent failure increases with time. Therefore, it is necessary to determine the maximum pressure that can develop in the container if the vent plugs in a given year.

Maximum pressure if vent plugs in a given year (psia) =

unvented pressure at 300 years (psia)

- unvented pressure at time (psia). (C-15)

Table C-6 contains the results of this calculation for the best-estimate case. Figure C-2 is a graph of the unvented pressure versus time and the maximum pressure reached if a vent plugs in a given year.

C.6 Hydrogen Generation

Organic materials can deteriorate under intense radiation exposure. Hydrogen gas is often a product of that deterioration. If a polyethylene liner were used in the HIC, the relatively large gas-evolution rate from polyethylene would be considered. Table C-7 lists the calculated doses and gas-generation rates from a polyethylene liner at various times throughout HIC life. If a polystyrene liner were used, the gas-evolution rate (1.5 cm^3/g-Grad, according to Reference 13) would be inconsequential.

C.7 Gas Generation from EPICOR-II Prefilter Corrosion

Sufficient SO_2 is produced by radiolytic decomposition of cation resin to react with the entire prefilter structure if enough water is available to combine with the SO_2 to form sulfuric acid. However, experience with metals in corrosive environments indicates that the corrosion products in a relatively static environment soon become self-protecting (for example, iron anchors lost on the ocean bottom have been found largely intact after hundreds of years). Generally, unless there is some mechanism for continuously removing the corrosion products, the

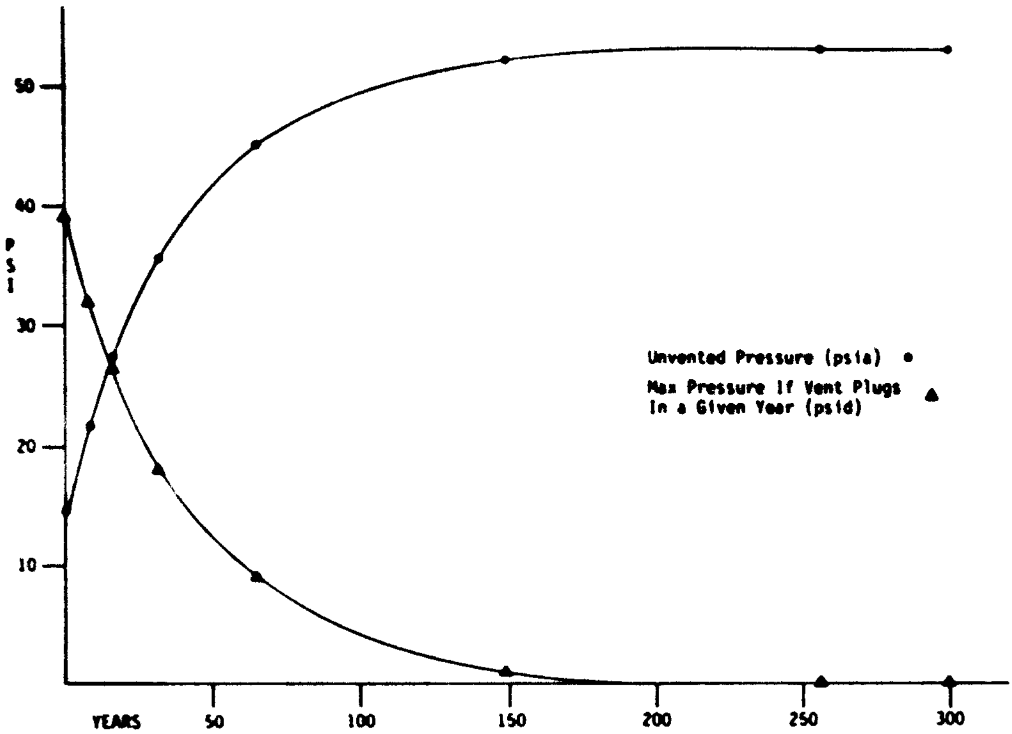

Figure C-2. Best estimate.

C-7. GAS GENERATION WITH A POLYETHYLENE LINER

LINER VOLUME 52511 CC

YEARS SINCE CASK LOAD	TOTAL LINER DOSE MRADS	LINER HYDROGEN GENERATION MOLES	MAXIMUM PRESSURE WITH LINER PSIA	LINER CAUSED PRESSURE INCREASE PSID
0	0	0.00	14.70	0.00
1	6	0.99	16.06	0.29
2	12	1.92	17.33	0.56
4	22	3.61	19.66	1.06
8	40	6.62	23.79	1.94
16	71	11.70	30.75	3.42
32	118	19.36	41.27	5.67
64	172	28.29	53.53	8.28
148	215	35.25	63.07	10.31
256	221	36.31	64.53	10.63
300	222	36.37	64.61	10.64

maximum weight loss is expected to be about 10% of the metal available for attack.[14] In the EPICOR-II prefilters, only that metal in contact with cation resin will be subject to attack, and then only after the internal coating has been penetrated.

Therefore, the maximum gas-generation rate from corrosion is obtained by assuming that 10% of the steel surface in contact with the resin mixture reacts with sulfuric acid produced from radiolytic decomposition of the cation resin to form hydrogen gas.

The total height of resin determines how much steel is available for corrosion. The total resin volume is 36 ft^3; the inside diameter of the cylinder is 47.5 in. Therefore, the height of the resin mixture is 35 inches. The iron surfaces that could react are the lower 35 inches of the 1/4-inch-thick cylinder walls, and the 0.63-inch-thick bottom of the cylinder. The volume multiplied by the density of iron (7.87 g/cm^3) gives the mass of iron that can be corroded. The value computed is:

$$\text{Mass of iron corroded (g)} = 0.10 \times [0.63 \text{ in.} \times 3.14 \times (48 \text{ in.})2/4$$

$$+ 0.25 \text{ in.} \times 3.14 \times 48 \text{ in.} \times 35 \text{ in.}] \times (2.54 \text{ cm/in.})^3$$

$$\times (7.87 \text{ g/cm}^3) = 3.17 \times 10^4 \text{g}. \quad \text{(C-16)}$$

The molar weight of iron is 55.8 g. One mole of hydrogen gas will be produced for each mole of iron consumed. Therefore,

$$\text{Hydrogen generation} = 3.17 \times 10^4 \text{g}/55.8\text{g/mole} = 568 \text{ moles}. \quad \text{(C-17)}$$

The SO_2 produced by radiolytic decomposition of cation resin will be produced at an exponentially decreasing rate with time. However, the coating must be corroded before the iron can be attacked, and the iron corrosion products soon provide protection to the iron. Attack at various locations in the container would occur at different times, which would not necessarily be closely coupled with the rate of production of SO_2. Therefore, a reasonable assumption is that the corrosion-related gas generation is approximately constant with time. Thus, the resulting maximum corrosion-related gas generation is 0.0052 mole per day.

The 0.0052-mole/day calculation assumes that only cation resin is present. It ignores the mitigating fact that the pH must be less than 4.0 for hydrogen generation to occur when iron is in contact with sulfuric acid.[15] Anion resin also is present in the EPICOR-II prefilters, and the alkaline decomposition products of the anion resin tend to neutralize the acidic decomposition products of the cation resin. Thus, the total amount of gas generated by corrosion of the prefilter structure is much less than that calculated.

C.8 Design Basis Gas Evolution and Pressures

The design basis calculation is identical to the best estimate, except that the gas generation is assumed to be a factor of five higher to account for uncertainties. The conservative gas-generation rate, radiation dose deposition, and neglected oxygen scavenging are sufficient to provide a conservative maximum estimate of the gas produced in the EPICOR-II prefilter.

Figure C-3 presents the results of the design basis gas-generation calculations. Computer output sheets are in Attachment 1.

The design basis gas-generation rate is 0.052 mole per day. The maximum differential pressure that would occur if the vent system plugged at HIC loading and never operated is 196 psid.

C.9 Findings

The primary result of this analysis is that a relatively low maximum pressure buildup occurs in the HIC even if it is not vented, viz., 39 psid. With a factor of 5 conservatism imposed on the gas-generation rate, the maximum pressure buildup is 196 psid. A check valve vent system that opened at 10 psid and closed at 3 psid would operate only 27 times

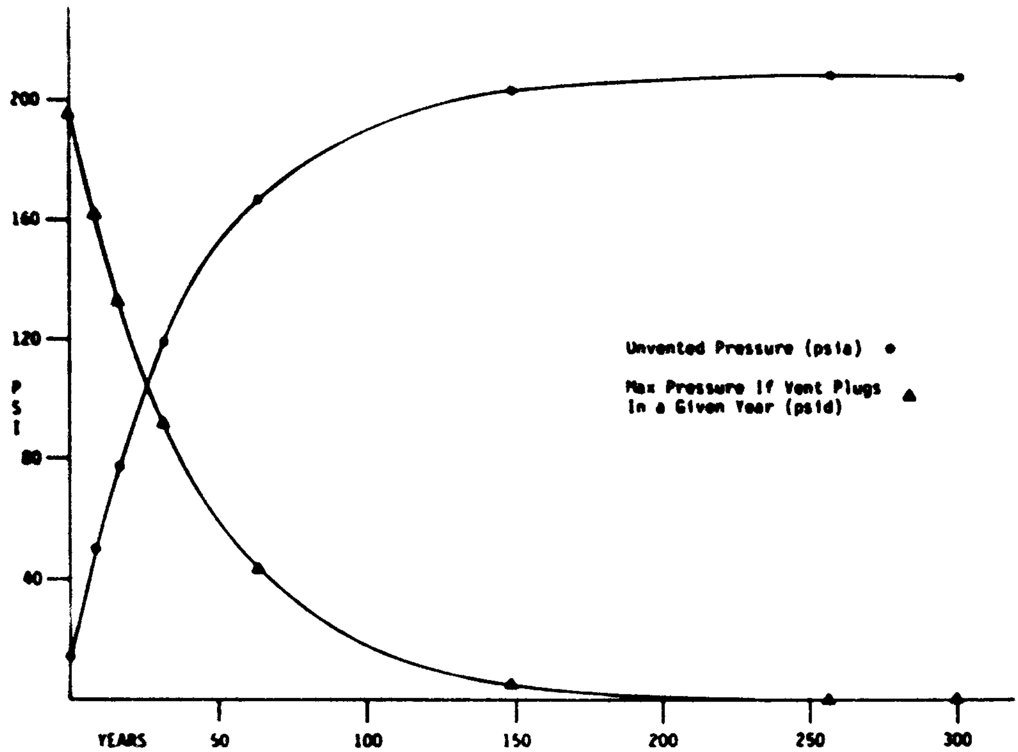

Figure C-3. Design basis.

during the 300-year HIC design life. Half of those operations would occur in the first 32 years. Finally, the gas generated by a polyethylene liner in the internal radiation field could increase the maximum differential pressure by 10.6 psid. Although this increase in not large, it is a factor to consider in choosing between polyethylene and other lining materials that have lower gas-generation rates, such as polystyrene.

C.10 References

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ATTACHMENT I

DESIGN BASIS ESTIMATE WITH 0 FT HEAD

DATA	UNITS					
RESIN VOLUME	FEET^3 (TOTAL)		36	CATION RESIN FRACTION		.5
RESIN DENSITY	GRAMS/CC (WET)		.85INCLUDING VOIDS			TOTAL FOR
CATION RESIN MASS (GRAMS WET)			433296			ISOTOPES T 1/2
ISOTOPE	--		CS137	SR90	CS134	)5 YEAR
HALFLIFE	YEAR		30	28.2	2.05	NA
DECAY CONSTANT	YEAR-1		0.02	0.02	0.34	NA
ENERGY DEPOSIT	E12 ERG/YR*CI		1.57	2.19	3.46	NA
DOSE CONVERT	RAD/YR*CI		36118	50543	79853	NA
CI FRACTION	)5 YR T1/2		0.95	0.05		1.00
ACTIVITY	CI		1230	70	272	1300
YEARS TO CASK LOAD		2				
			CS137 DOSE MRADS	SR 90 DOSE MRADS	CS134 DOSE MRADS	TOTAL DOSE MRADS
DOSE TO CASK LOAD			87	7	32	125

YEARS SINCE CASK LOAD	CS137 DOSE MRADS	SR 90 DOSE MRADS	CS134 DOSE MRADS	TOTAL DOSE MRADS
(1ST DAY) 0	0	0	0	0
1	42	3	9	55
2	83	7	16	106
4	162	13	24	199
8	310	24	30	365
16	568	44	33	644
32	960	74	33	1067
64	1418	108	33	1559
148	1777	133	33	1942
256	1832	136	33	2000
300	1835	136	33	2004

DATA	UNITS		CS137	SR90	CS134	TOTAL
HALFLIFE	YR		30	28.2	2.05	
DECAY CONSTANT	YR-1		0.02	0.02	0.34	
DOSE CONVERT	RAD/YR*CI		36118	50543	79853	
CI FRACTION	) 5 YR T1/2		0.95	0.05		1.00
ACTIVITY	CI		1230	70	272	1300
YRS TO CASK LOAD		2				

YEARS SINCE CASK LOAD	CS137 DOSE RATE RADS/HOUR	SR90 DOSE RATE RADS/HOUR	CS134 DOSE RATE RADS/HOUR	TOTAL DOSE RATE RADS/HOUR
(1ST DAY) 0	4841	382	1259	6481
1	4730	373	899	6001
2	4622	363	641	5626
4	4414	346	326	5085
8	4024	314	84	4422
16	3345	258	6	3608
32	2311	174	0	2485
64	1103	79	0	1183
148	158	10	0	168
256	13	1	0	14
300	5	0	0	5

DATA	UNITS				UNITS
GAS GEN RATE	CC/GRAMS*EVRAD	17.31	GAS VOLUME	39.74	CUBIC FT
RESIN VOLUME	FT^3 (CATION)	18.00	CATION RESIN	433296	GRAMS (WET)
RESIN DENSITY	GRAMS/CC	0.85	FRACTION OF		
RESIN VOID FRACTION		0.40	WATER IN RESIN	0.47	
TOTAL VOLUME	CUBIC FT	61.30	G-H2 RESIN	0.50	MOLECULES/100EV
H2 FRACTION		0.67	INITIAL GAS VOL	49.36	MOLES
YRS TO CASK LOAD	2				

YEARS SINCE	CASK LOAD	NON-H2 MOLES	H2 MOLES	TOTAL GAS MOLES	UNVENTED GAS PRES PSIA
(1ST DAY)	0	0.02	0.03	.052135905932	14.72
	1	6.04	12.26	18.29	20.05
	2	11.66	23.68	35.34	25.04
	4	22.00	44.68	66.68	34.21
	8	40.31	81.84	122.15	50.44
	16	71.22	144.59	215.81	77.85
	32	117.88	239.33	357.21	119.22
	64	172.2[illegible]	349.72	521.98	167.43
	148	214.60	435.70	650.30	204.98
	256	221.06	448.82	669.89	210.72
	300	221.43	449.57	671.00	211.04

DATA	UNITS		CALCULATED VALUES	UNITS	
HYDROSTATIC HD	FT	0	HYDROSTATIC HD	0	PSID
RELIEF OPEN	PSID	10			
RELIEF SHUT	PSID	3			
YRS TO CASK LOAD	2				

YEARS SINCE	CASK LOAD	DIFFERENTIAL = TOTAL GAS PSID	RELIEF LIFTS TO DATE	APPROXIMATE YEARS BETWEEN RELIEF LIFTS	MAXIMUM PSID IF RELIEF FAILS THIS YEAR
(1ST DAY)	0	0.02	0	2	196
	1	5.35	0	2	191
	2	10.34	1	1	186
	4	19.51	2	2	177
	8	35.74	4	2	161
	16	63.15	8	2	133
	32	104.52	14	3	92
	64	152.73	21	7	44
	148	190.28	26	48	6
	256	196.02	27	592	0
	300	196.34	27	1641	0

LINER VOLUME 52511 CC

YEARS SINCE	CASK LOAD	TOTAL LINER DOSE MRADS	LINER HYDROGEN GENERATION MOLES	MAXIMUM PRESSURE WITH LINER PSIA	LINER CAUSED PRESSURE INCREASE PSID
	0	0	0.00	14.72	0.00
	1	6	0.99	20.34	0.2[illegible]
	2	12	1.92	25.60	0.56
	4	22	3.61	35.27	1.06
	8	40	6.62	52.38	1.94
	16	71	11.70	81.27	3.42
	32	118	19.36	124.89	5.67
	64	172	28.29	175.71	8.28
	148	215	35.25	215.30	10.31
	256	221	36.31	221.34	10.63
	300	222	36.37	221.68	10.64

APPENDIX D

THERMAL ANALYSIS OF CONTAINER

R. T. Haelsig

Nuclear Packaging, Inc.

APPENDIX D

THERMAL ANALYSIS OF CONTAINER

D.1 Introduction

Thermal analyses of aboveground storage and belowground burial conditions have been conducted. The guiding assumptions of four bounding analyses are set forth below:

1. Case 1, Maximum Temperature Above Ground

   a. Decay heat
   b. Maximum ambient air temperature
   c. Maximum insolation

2. Case 2, Minimum Temperature Above Ground

   a. Decay heat
   b. Minimum ambient air temperature
   c. No insolation

3. Case 3, Maximum Burial Temperatures

   a. Decay heat
   b. Maximum ambient soil temperatures

4. Case 4, Minimum Burial Temperatures

   a. Decay heat
   b. Minimum ambient soil temperatures.

The results of these analyses provide the temperature estimates shown in Table D-1 for the HIC.

TABLE D-1. HIC TEMPERATURES

Case	Predicted Temperature (°F) Outer Surface	Inner Surface
1. Maximum, above ground	165.2	165.5
2. Minumum, above ground	-39.7	-39.4
3. Maximum, burial	93.0	93.2
4. Minimum, burial	57.0	57.2

D.2 Thermal Model Characteristics

The container is idealized as a simple, right circular cylinder of reinforced concrete, with cylindrical wall thickness of 6 inches and end thicknesses of 11 inches. It has an inner diameter and height of 49 and 62 inches, respectively, as depicted in Figure D-1.[a]

Specific physical property assumptions of the model are as follows:

1. The inner liner of carbon steel is assumed to possess a conductivity value of 26.5 Btu/hr-ft-°F (Reference 1)

2. The normal-density concrete is assumed to possess a density of 145 lb/ft^3 (Reference 3) and a conductivity of 0.7 Btu/hr-ft-°R (Reference 3)

3. The external-surface emissivity of the coated container is assumed to be 0.9-0.96 (Reference 3), corresponding to white (epoxy) paint.

a. The analysis was not repeated when the HIC outside diameter was increased to 62.5 inches since the larger diameter tends to reduce the heat flux. Thus, the existing analysis is more conservative than a new one would be.

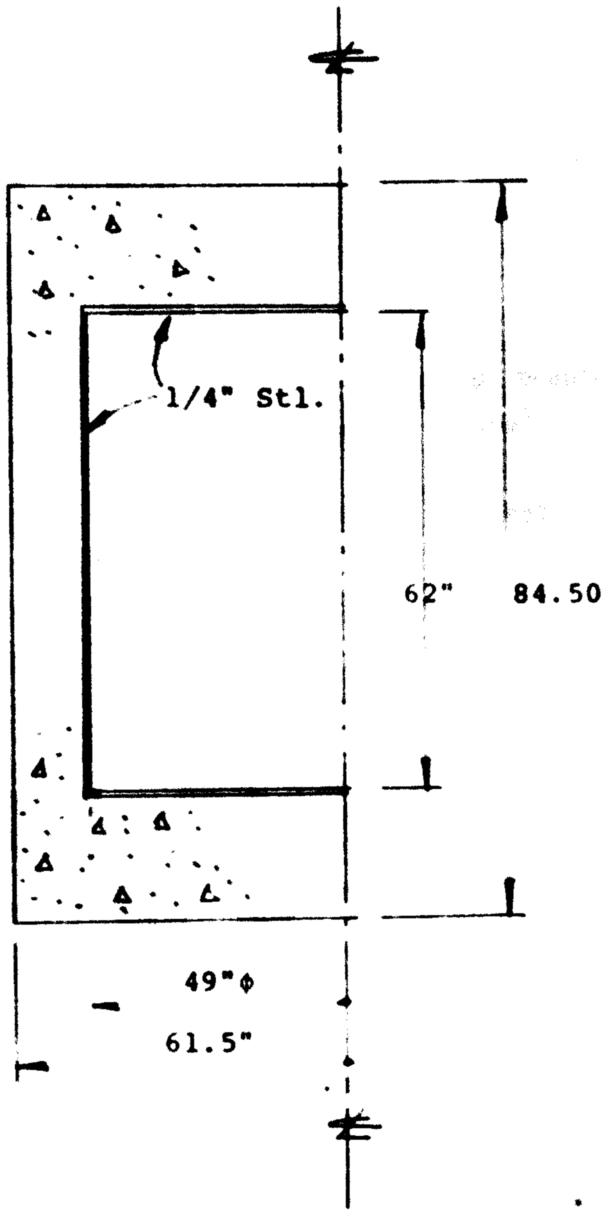

Figure D-1. Idealized thermal model.

4. For aboveground conditions (Cases 1 and 2), free convection to ambient air was assumed to obey the McAdam's film coefficient relations for laminar and turbulent flow, as follows:[4]

	Laminar ($Gr\ Pr < 10^9$)	Turbulent ($Gr\ Pr > 10^9$)
Sides	$h = 0.29 \left(\frac{\Delta T}{L}\right)^{1/4}$	$h = 0.19 (\Delta T)^{1/3}$
Top	$h = 0.27 \left(\frac{\Delta T}{L}\right)^{1/4}$	$h = 0.22 (\Delta T)^{1/3}$

5. For belowground conditions (Cases 3 and 4), soil properties defined in ES 50652B were utilized.

Results for all four cases were achieved using steady state analysis methods. The decay heat of (8W) (3.41) = 27.28 Btu/hr is assumed and applied to the steel liner. The conduction thermal resistance of sides and ends is found as follows:

Side Resistance

$$R_s = \frac{\ln(ro/ri)}{2\pi kL}$$

$$= \frac{\ln(30.75/24.75)}{2\pi\ (0.7)(62/12)} + \frac{\ln(24.75/24.5)}{2\pi\ (26.5)(62/12)}$$

(concrete) (steel)

$$= 9.5639 \times 10^{-3}\ °K\text{-hr/Btu} \quad . \qquad \text{(D-1)}$$

End Resistance

$$R_e = \frac{\Delta \ell}{kA};$$

$$A = \pi\ (49)^2/(4)(144) = 13.095\ ft^2$$

$$R_e = \frac{1}{13.095} \left(\frac{11/12}{0.7} + \frac{0.25/12}{26.5} \right) = 100.06 \times 10^{-3} \text{ °R-hr/Btu} \quad . \qquad \text{(D-2)}$$

D.3 Aboveground Analysis

In addition to a constant decay heat, q_d = 27.28 Btu/hr, insolation is applied to the cask surfaces in the Case 1, maximum temperature event, as follows:

$$q_s = \frac{(2950)}{12} \times \frac{\pi}{4} (61.5)^2/144 + \frac{(1475)}{12} \times \frac{(61.5)(84.5)}{144}$$

$$= 9507.17 \text{ Btu/hr} \quad . \qquad \text{(D-3)}$$

This insolation value is applied to the exterior of the cask. In concept, the thermal analysis model is as shown in Figure D-2.

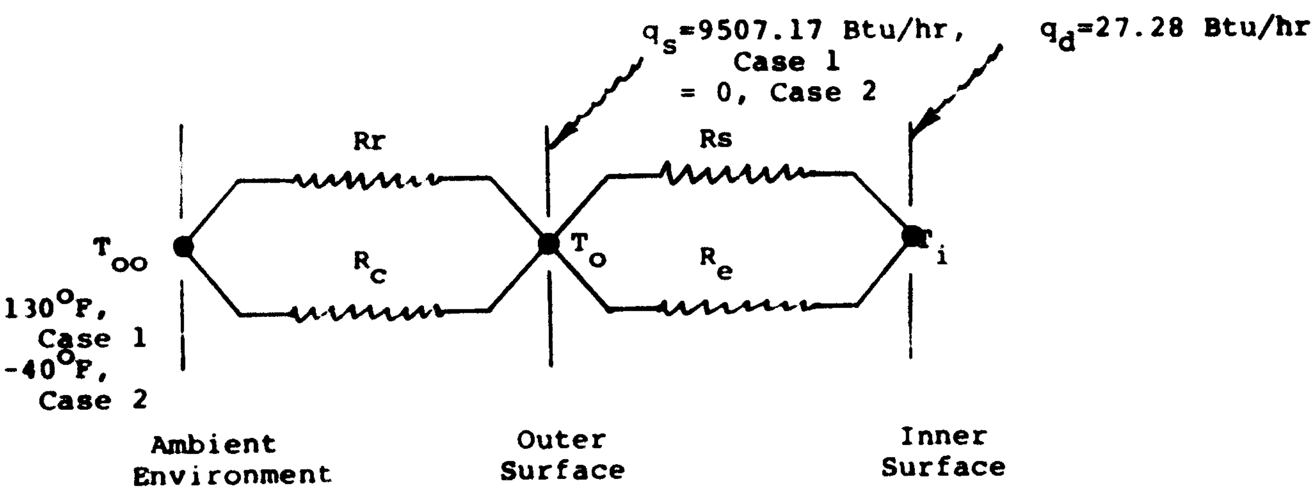

Figure D-2. Thermal analysis model.

The resistors, R_r and R_c, schematically represent nonlinear radiation and convection heat transfer modes, respectively. Representation is as follows:

Radiation

$q_r = K(To^4 - Too^4)$; $\sigma = 0.1714 \times 10^{-8}$ Btu/hr-ft^2-°R^4

$\epsilon = 0.9$(hot, Case 1) $= 0.96$(cold, Case 2)

$A_T = A_s + A_e = 134.00$ ft^2

$A_s = \pi\ (61.5)(84.5) = 16{,}326$ in.^{2} $= 133.37$ ft^2

$A_e = \frac{\pi}{4}(61.5)^2 = 2{,}971$ in.^{2} $= 20.63$ ft^2

$K = \sigma\epsilon A_T = 206.71 \times 10^{-9}$, Case 1

$K = \sigma\epsilon A_T = 220.49 \times 10^{-9}$, Case 2 . (D-4)

Convection

$q_c = hA(To - Too)$ (D-5)

where

h = film coefficient values defined in Section D.2.

Selection of appropriate values for laminar or turbulent flow depends upon the product (GrPr):

Pr = 0.72(100°F - 200°F, Air) (from Reference 3)

$$Gr = \frac{g\beta\rho^2}{\mu^2} (To - Too) L^3; \quad \frac{g\beta\rho^2}{\mu^2} = 1.76 \times 10^6 \text{ @ } 100°F$$
$$= 0.85 \times 10^6 \text{ @ } 200°F \qquad \text{(D-6)}$$

For sides: $L_s = \frac{84.5}{12} = 7.04$ ft .

For ends: $L_e = \frac{61.5}{12} = 5.13$ ft .

$(To - Too) = 30\text{-}50°F$.

Thus, the product (GrPr) can reasonably range from:

$(0.72)(30)(5.13)^3(0.85 \times 10^6) = 2.5 \times 10^9$ to

$(0.72)(50)(7.04)^3(1.76 \times 10^6) = 2.2 \times 10^{10}$.

The flow, therefore, is turbulent, and appropriate film coefficients are:

Sides $\quad h = 0.19(\Delta T)^{1/3}$

Ends $\quad h = 0.22(\Delta T)^{1/3}$.

The differing relations for side and ends sum as follows:

$$q_c = CA_T(To - Too)^{1+1/3}$$

$$C = \frac{(0.19\ A_s + 0.22\ A_c)}{A_T} = \frac{(0.19)(113.37) + (0.22)(20.63)}{134.00}$$

$$= 0.19462 \text{ Btu/hr-ft}^2\text{-°F} \qquad \text{(D-7)}$$

Thermal balance at the container exterior is achieved by iteration of the following expression:

$$f(To) = q_{in} - q_{out} = 0$$

$$q_{in} = q_d + q_s = 9534.45 \text{ Btu/hr, Case 1}$$

$$= 27.28 \text{ Btu/hr, Case 2}$$

$$q_{out} = q_r + q_c = K(To^4 - Too^4) + CA_T(To - Too) \qquad \textbf{(D-8)}$$

where

$K = 206.71 \times 10^{-9}$ Btu/hr-°R^4 (Case 1)

$K = 220.49 \times 10^{-9}$ Btu/hr-°R^4 (Case 2)

$C = 0.19462$ Btu/hr-ft^2-°F

$A_T = 134.0$ ft^2.

The results for aboveground cases 1 and 2 are shown in Table D-2. For both cases, the total thermal gradient from inside to outside is less than 0.24°F:

$$\Delta T = qR = (27.28) \times \frac{1}{\frac{1}{R_s} + \frac{1}{R_e}} = 0.238°F \quad . \qquad \textbf{(D-9)}$$

TABLE D-2. TEMPERATURE EXTREMES FOR ABOVEGROUND STORAGE

Case	Air Temperature (°F)	Heat (Btu/hr)	Temperatures (°F) Outer Surface	Inner[a] Surface
1. Maximum temperature	130	9534.45	165.21	165.45
2. Minimum temperature	-40	27.28	-39.67	-39.43

a. Based on parallel sum of side and end conduction resistors, R_s and R_e.

D.4 Belowground (Burial) Analyses

The analysis of a buried body generating internal heat is properly conducted using a periodic time domain solution with the body positioned at appropriate depth in a semiinfinite medium (soil). In this pure solution format, boundary conditions are applied at the soil surface in the form of periodically varying temperatures. The boundary temperatures would contain both annual and daily fluctuations.

Since the High-Integrity Container is buried at considerable depth, such rigor is not appropriate. A steady state solution has been applied assuming soil temperatures at a given distance from the container are constant. The container temperature is then found based upon the calculated soil temperature gradient and the assumed constant soil temperature at a given distance from the container.

Since the containers are assumed stacked, adiabatic conditions have been assumed at top and bottom of the container. Thus, the model reduces to a one-dimensional (radial) model of a cylindrical soil volume. The height of the soil cylinder is assumed equal to the container inner height (62 in. or 5.167 ft). The inner diameter of this soil cylinder is the container outer diameter (61.5 in. or 5.125 ft). The outer diameter, where soil temperatures are assumed constant, is determined from a calculated volume of soil. That volume of soil equals that required to store the total annual decay heat of the container with an average 2°F temperature rise.

The total annual decay heat is:

$$Q = (27.28 \text{ Btu/hr})(24)(365) = 238{,}973 \text{ Btu} \quad . \tag{D-10}$$

The volume of soil to store this heat with a 2°F average temperature rise is:

$$Q = C_p V \Delta T \rightarrow V = \frac{Q}{C_p \Delta T}$$

$$V = \frac{238973}{(0.2)(90)(2)} = 6{,}638 \text{ ft}^3 \quad . \tag{D-11}$$

But,

$$V = \frac{\pi}{4} (D_o^2 - D_i^2) L$$

$$D_o = (\frac{4V}{\pi L} + D_i^2)^{1/2}$$

$$= [\frac{(4)(6638)}{\pi(5.167)} + (5.125)^2]^{1/2} = 40.8 \text{ ft} \quad . \tag{D-12}$$

The temperature differential across the soil disk is:

$$\Delta T = qR = q \times \frac{\ln(D_o/D_i)}{2\pi k\ L} = 27.28 \frac{\ln(40.8/5.125)}{2\pi(0.25)(5.167)} = 6.97°\text{F} \quad . \tag{D-13}$$

The temperature differential across the container wall is:

$$\Delta T = qR_s = (27.28)(9.5639 \times 10^{-3}) = 0.26°F \quad . \qquad (D-14)$$

As a bounding check on the assumed soil disk diameter, consider conduction from this disk to the ground surface. The expression is:

$$q = kS\Delta T \rightarrow \Delta T = \frac{q}{kS} \qquad (D-15)$$

where

$k = 0.25$

$S = \dfrac{4.45\ D}{1 - \dfrac{D}{5.67Z}}$

$= 197.34$

$D = 40.8$ ft

$Z = 90$ ft (maximum burial depth).

The soil disk-to-ground surface differential is then found as:

$$\Delta T = \frac{27.28}{(0.25)(197.34)} = 0.55°F \quad . \qquad (D-16)$$

This small-magnitude temperature rise is "lost" in daily temperature variations and demonstrates adequate soil-to-surface heat transfer exists to support the assumptions of this analysis.

Results for belowground Cases 3 and 4 are shown in Table D-3.

TABLE D-3. HIC TEMPERATURE AFTER DISPOSAL

Case	Temperature (°F) Soil (Ts)	Outer Surface (To)	Inner Surface
3. Maximum temperature	86	93	93.2
4. Minimum temperature	50	57	57.2

D-5. References

1. L. B. Shappert, Cask Designers Guide, ORNL-NSIC-68, February 1970, p. 84.
2. R. C. Reese et al., ACI Code 318-63, paragraph 1102, 1963.
3. F. Kreith, Principles of Heat Transfer, 3rd Edition, Intext Educational Publishers, 1973.
4. J. P. Holman, Heat Transfer, New York: McGraw Hill Book Co., 1963, p. 168.

APPENDIX E

VENDOR EVALUATION TEST RESULTS

R. T. Haelsig

Nuclear Packaging, Inc.

APPENDIX E
VENDOR EVALUATION TEST RESULTS

E.1 Introduction

Detail test requirements and procedures are established in NuPac Procedure PT-04. All test results are summarized in NuPac Inspection Instruction and Report, EP-16, Revised August 20, 1982. This appendix briefly describes tests performed and summarizes significant findings. Findings are grouped into the following categories:

1. Vent function
2. Lifting and handling
3. Seal integrity
4. Handling accident events (drop and penetration).

E.2 Vent Functional Tests

Vent tests conducted using the setup shown in Figure E-1 were performed as follows:

1. Measurements of airflow rate under a 10-psig internal pressure differential.

   Air-flow remained constant over the four-hour measurement period:

   S/N001 0.469 to 0.476 cm^3/s
   S/N002 0.093 cm^3/s
   Acceptance criteria: >0.0135 cm^3/s.

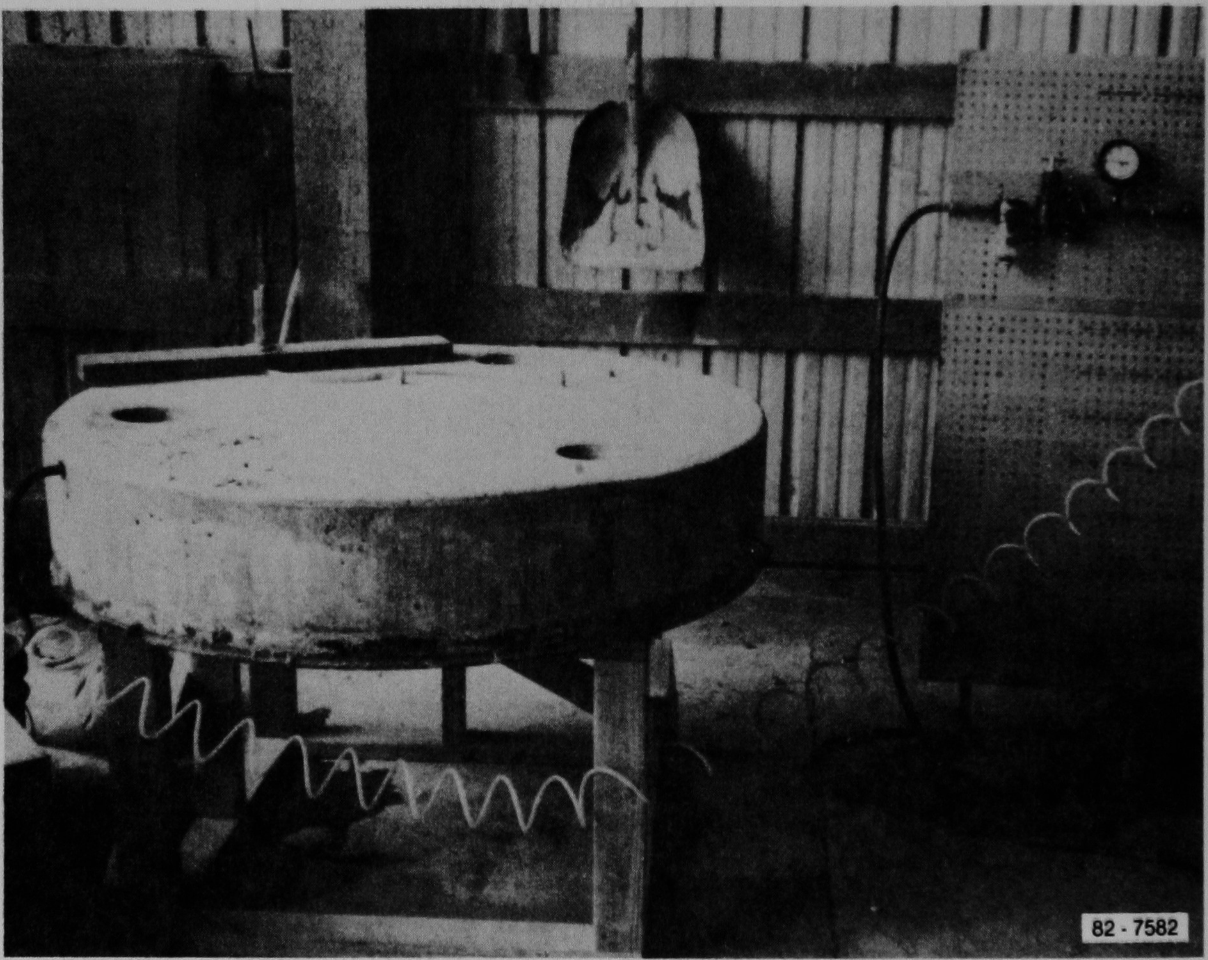

Figure E-1. Vent function test setup.

2. Proof test at 40 psig internal pressure for one hour. Flow rates were

S/N001	0.527 cm^3/s
S/N002	0.094 cm^3/s
Acceptable criteria:	No rupture.

3. Water flow at 10, 20, 30, and 40 psig external pressure differential. Those tests consisted of a "soak" time of two hours at pressure, excepting the first 10-psig application, which soaked 14 hours. Water flows were as follows:

Pressure (psig)	S/N001 (cm^3/h)	S/N002
10	None	None
20	0.042	None
30	1.75	None
40	5.25	None.

4. Final airflow measurements under a 10-psig internal pressure differential:

S/N001	0.449 to 0.477 cm^3/s
S/N002	0.038 to 0.091 cm^3/s[a]
Acceptable criteria:	>0.0135 cm^3/s.

Test results satisfy all applicable criteria and requirements. The variabilities of water-head retention and gas flow rates between S/N001 and S/N002 are pronounced but appear characteristic of the porous polyethylene

a. About two hours into the test, the filter clogged for a short period, then commenced to clear. It behaved as if a globule of water or other substance temporarily blocked the filter.

filter media. If large quantities of filters are built for this function, added process controls during fabrication are needed. For small-volume procurements, a trial-and-error selection process is more appropriate.

E.3 Lifting and Handling

Lift proof tests at 150% of working loads on all hardware were conducted in accordance with written load-test procedures. All tests of reusable hardware involved lifting known or measured loads. All tests of disposal hardware (container and lid) employed geometric setups that ensured the proper weight was applied to the loading device. Figure E-2 shows typical test arrangements. No distress or damage was observed in any of those tests; all hardware performed precisely as designed.

The compatibility of system components is shown in Figures E-3 through E-6.

Compatibility and function check measurements indicated the following:

1. Body to EPICOR-II liner

   a. Radial clearance: 7/16 to 1-11/16 inches

   b. Vertical clearance: 1/8 inches

2. Lid-to-body radial clearance: 3/4 to 1-3/4 inches

3. Plumb angle: 3/8 inches in 48 inches = 0.45 degrees.

E.4 Seal Integrity

Sealing was accomplished, and the container cavity was pressurized to 10 psig and held in excess of one hour with no pressure drop. All sealed surfaces and areas were soap bubble-checked per ANSI Standard N14.5; no

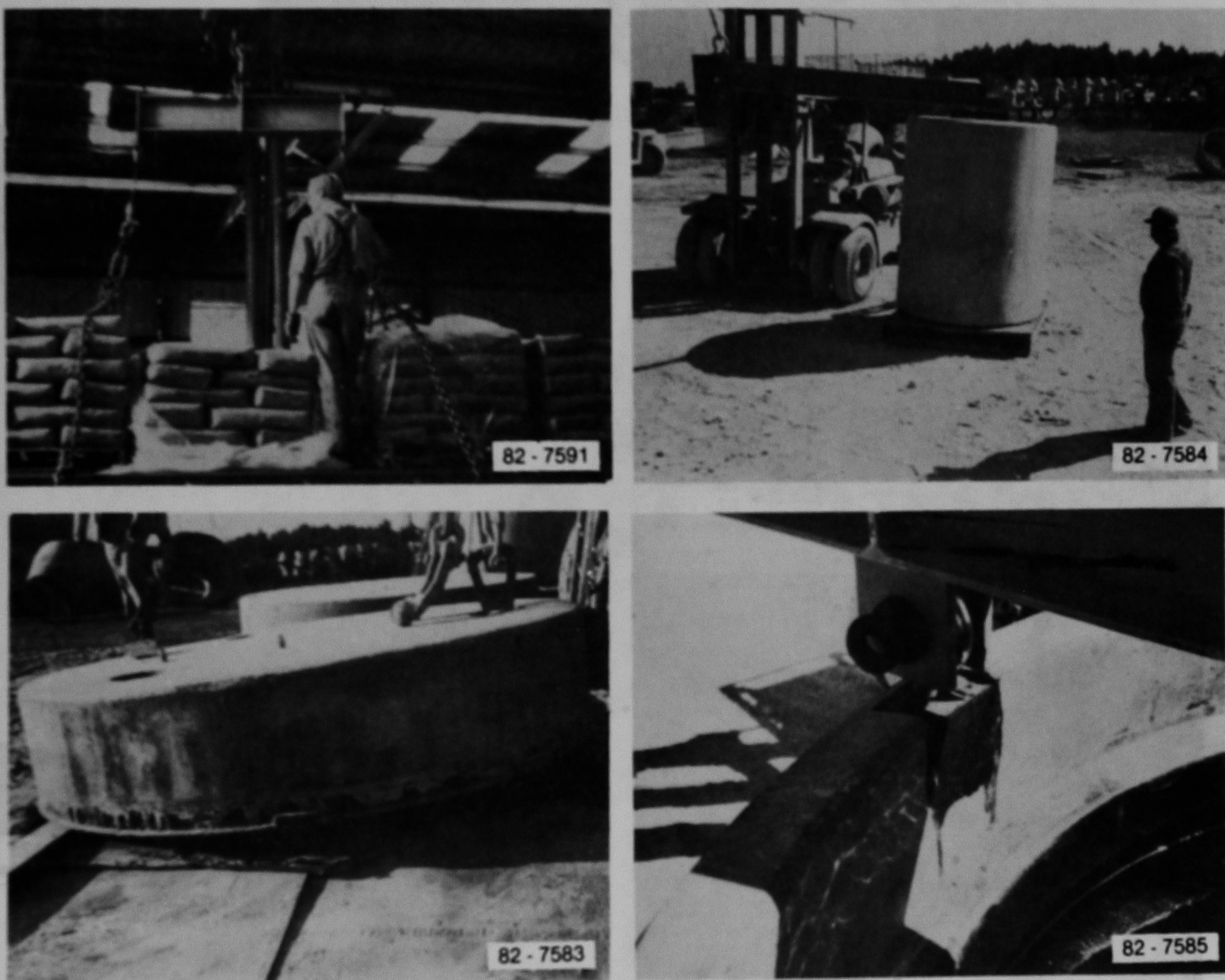

Figure E-2. Load testing.

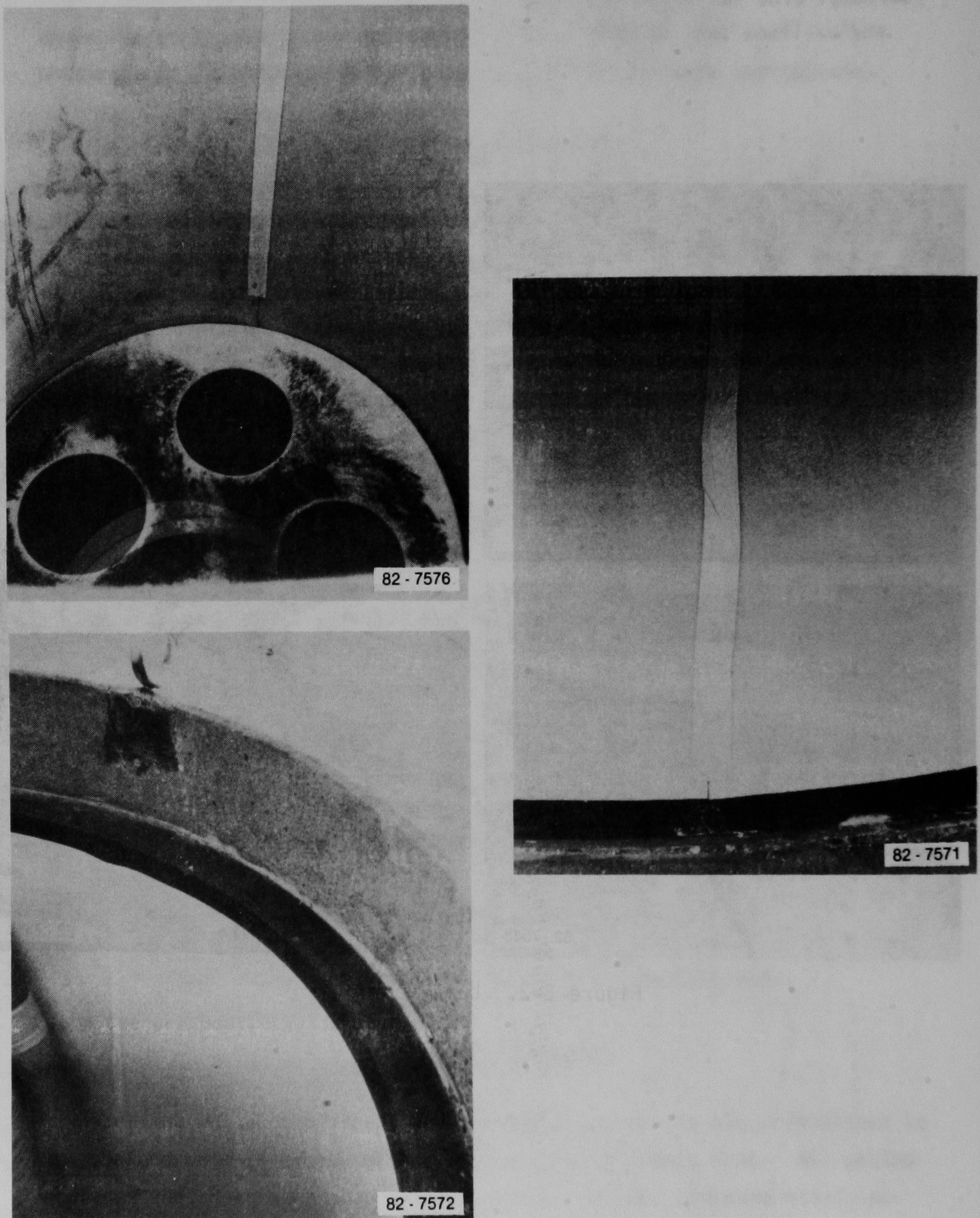

Figure E-3. Compatibility--body and abrasion liner.

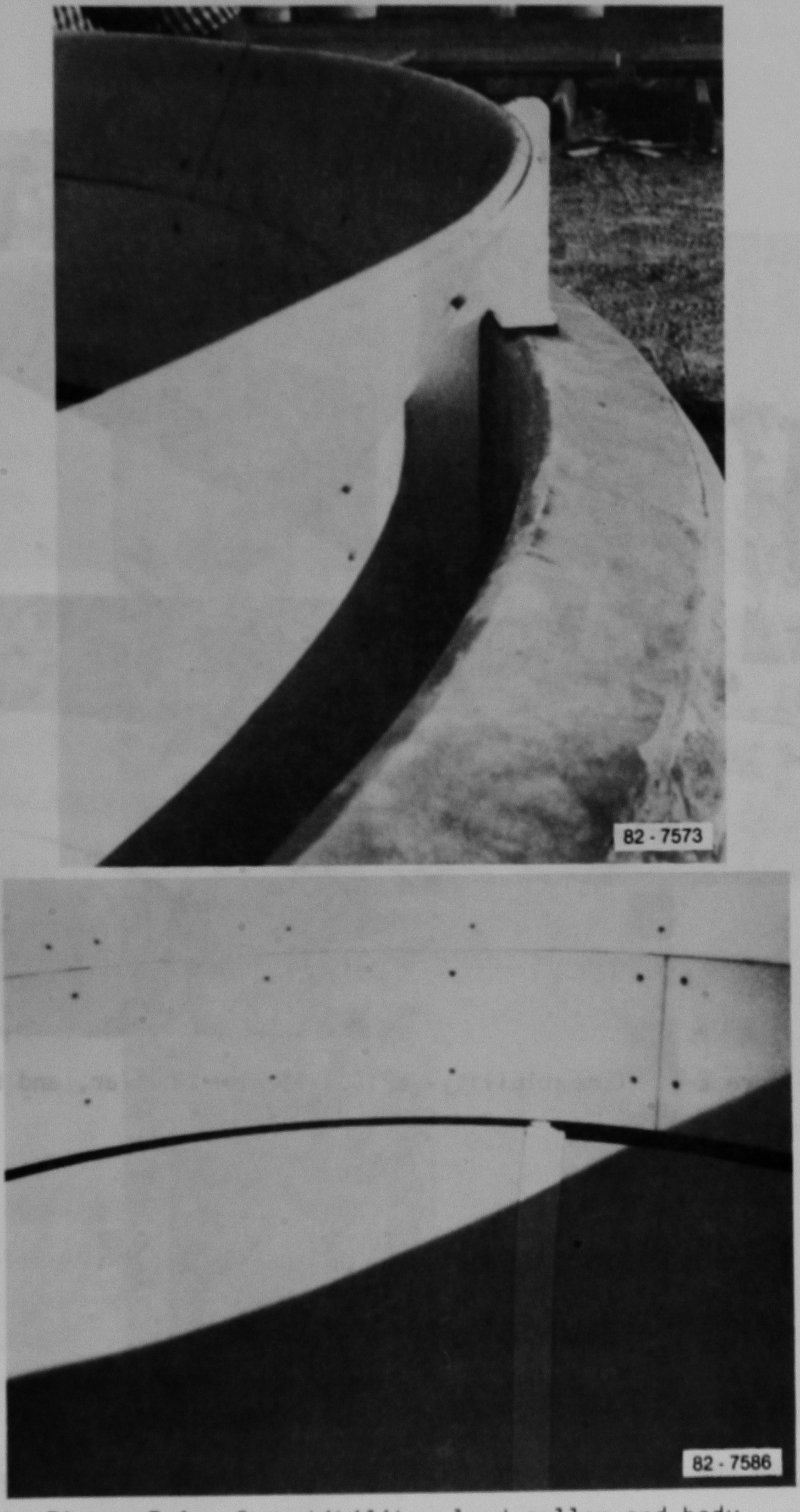

Figure E-4. Compatibility--load collar and body.

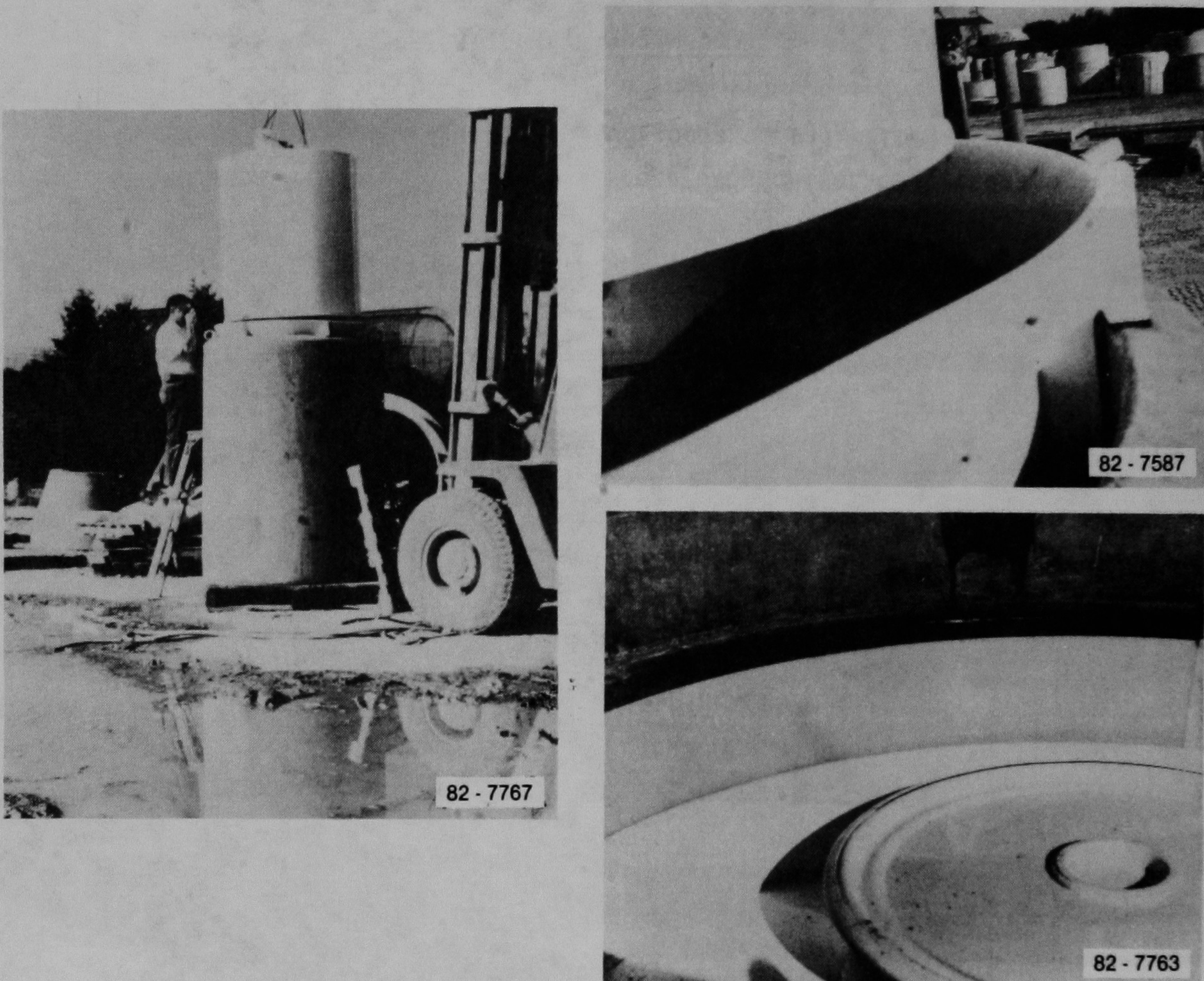

Figure E-5. Compatibility--EPICOR-II, load collar, and body.

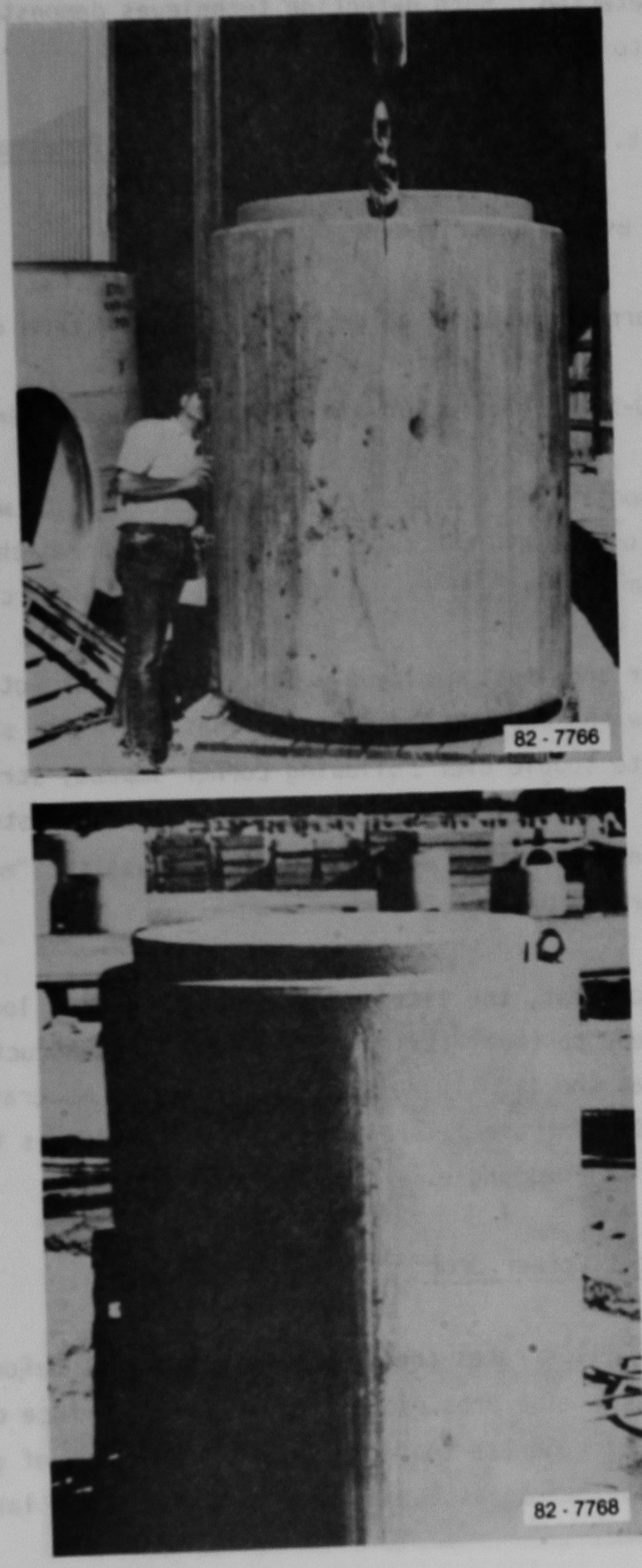

Figure E-6. Compatibility--lifting fixture, lid, and body.

leakage was detected. Both detection techniques demonstrated the container is leaktight to at least 10 psig.

E.5 Handling Accident Events (Drop Penetration)

The test events described herein consist of:

1. A corner impact on an unyielding surface from a 3-foot height

2. A 40-inch penetration pin drop on the container sidewall.

The events demonstrated the ability of the container to withstand Type-A normal conditions per 10 CFR 71. The package survived the Type-A tests with little damage and full retention of all functional capabilities.

The corner drop test employed a lifting bar that rotated the container to 42 degrees with respect to vertical. That angle was selected to cause the container to topple over following corner impact, striking the lid closure region in a "slap-down" impact. Analyses demonstrated that "slap-down" impact in conjunction with corner impact was the "most severe" orientation for the package.

In the drop test, the lifting bar produced modest local distress in the concrete adjacent to the lift lug eye due to the introduction of lateral prying forces at the lightly reinforced top edge. Moderate cracking developed as a result of those lateral forces just as soon as the container was hoisted at an inclined angle.

E.5.1 Three-Foot Corner Drop

Figure E-7 illustrates the drop test setup just before and at the instant of impact. The drop pad or "unyielding" surface consists of about 200,000 pounds of concrete topped with a 1-1/8 inches of grouted steel plate. The container is attached by a "quick release" latch and supported by a mobile crane.

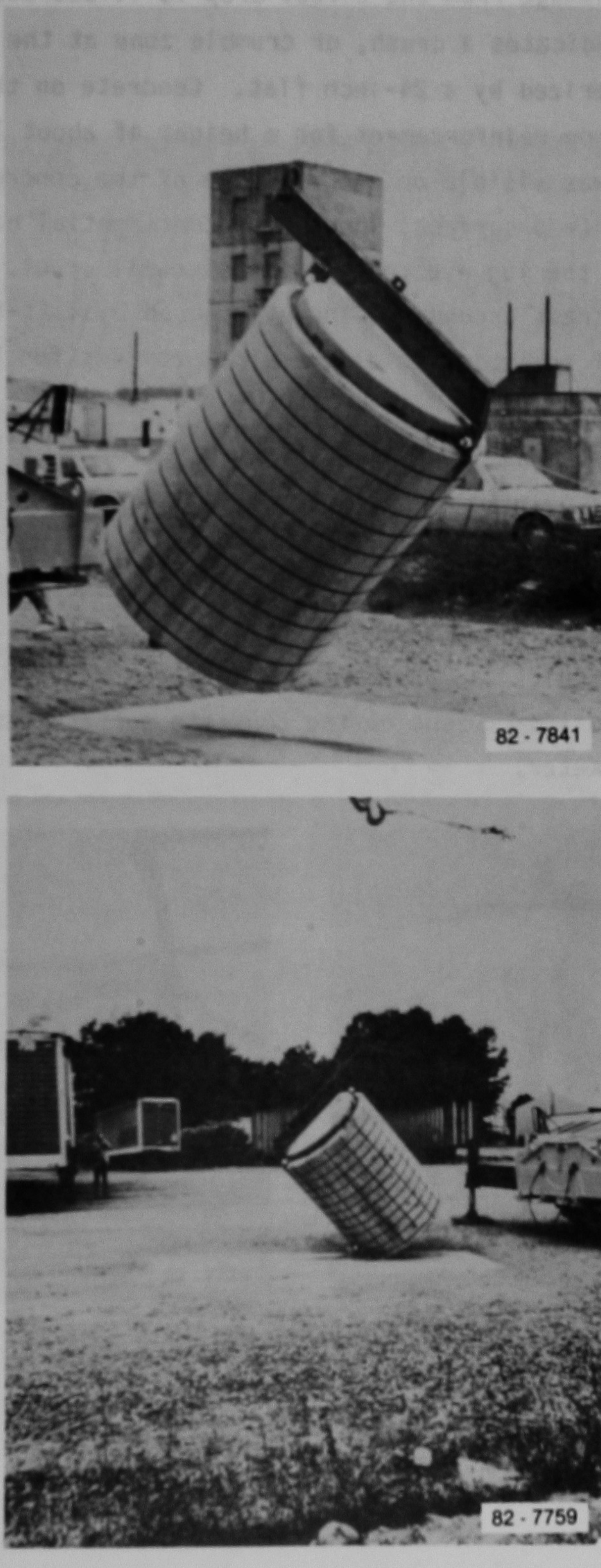

Figure E-7. Three-foot corner drop.

Resultant damage from the 3-foot drop is illustrated in Figure E-8. The top photo indicates a crush, or crumble zone at the point of initial impact, characterized by a 24-inch flat. Concrete on the sides spalled away from the hoop reinforcement for a height of about 12 inches. A small hairline crack was visible on the top edge of the concrete body sidewall. The epoxy grout (top surface) shows a circumferential hairline crack from the location of the lug eye to the body sidewall crack. The lower right photo shows distress around the lug eye caused by lift-fixture prying forces. None of the observed distress compromises functional performance of the container.

E.5.2 Penetration Test

The 40-inch-penetration pin drop test was conducted with a pin of proper size, shape, and weight, as defined in applicable regulations (see Figure E-9). Results showed no damage to the container. The impact produced a whitened impact zone on the concrete surface, which measured about 0.5 inch in diameter.

Figure E-8. Damage--3-foot drop test.

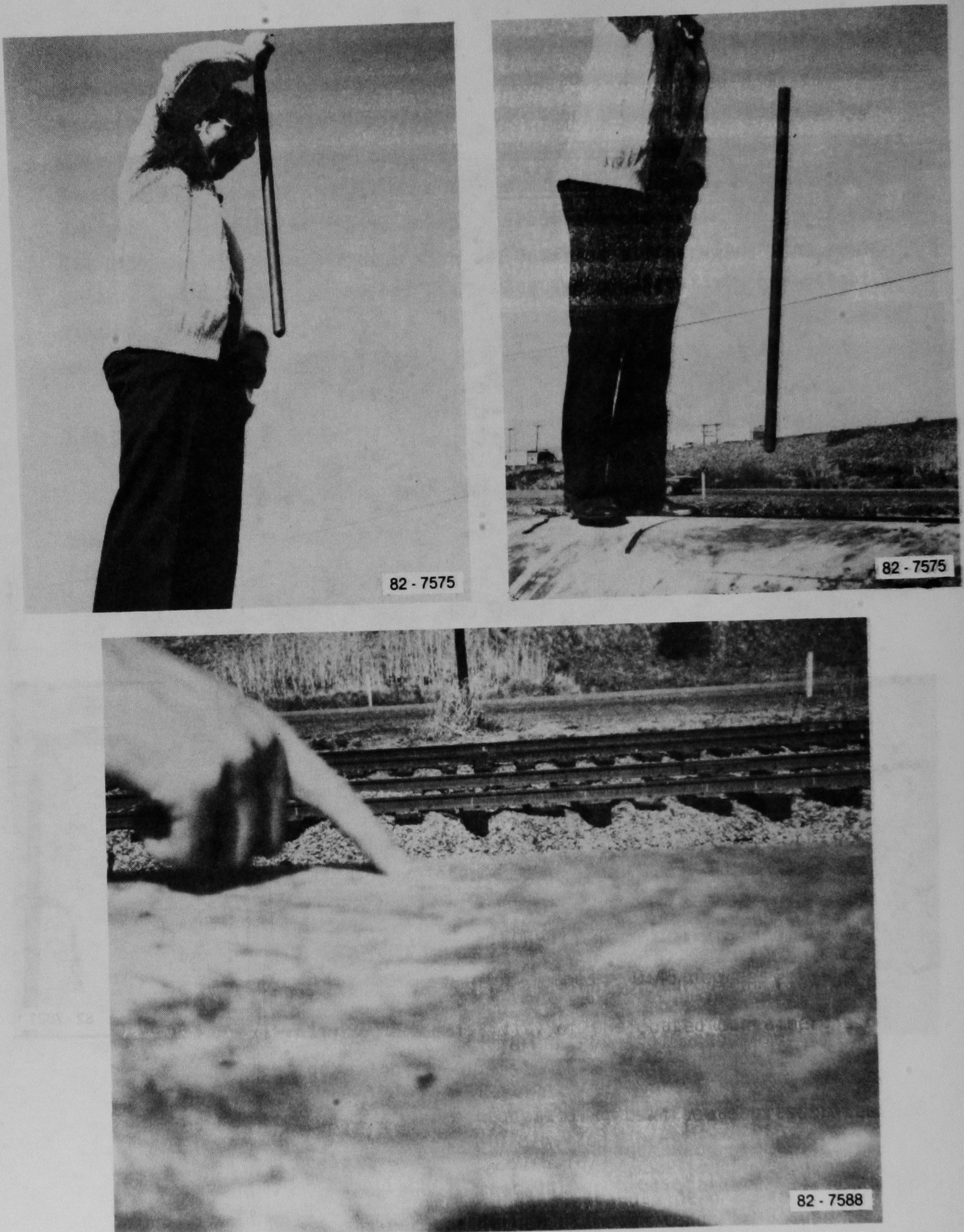

Figure E-9. Penetration drop test.

APPENDIX F

ANALYSIS OF CONTAINER VENTING

Steven R. Streutker

Nuclear Packaging, Inc.

APPENDIX F

ANALYSIS OF CONTAINER VENTING

Preliminary analysis of the container vent material indicated that gas flow rates greatly exceeding the needed 0.052 mole per day could be obtained with porous polyethylene disks of 5- to 10-micron pore size. The analysis was based on manufacturers' flow data. However, tests on the vent configurations using porous polyethylene showed that the filter disk could not stop water flow at pressures greater than 1 or 2 psi. Since that flow was not acceptable, further testing was conducted using filter material with a 1-micron pore size. No data are available from the manufacturer concerning airflow capabilities, so the final vent configuration was based entirely upon the test results obtained.

A fixture was constructed to allow testing of different filter materials and thicknesses. As shown in Figure F-1, the filter stack was placed between the two bolts, and the bolts were tightened slightly, putting a compressive load on the stack to ensure sealing at the top and bottom. Pressurized air or water was applied to the top surface of the stack through the passage drilled in the center of the bolt. Air or water that moved laterally through the filter material flowed to the annular space between the filter stack and chamber wall. This space was vented to the outside as shown, thus preventing any pressure buildup and subsequent leakage into the outlet passage, and ensuring passage of air or water entering the outlet through the full length of the filter stack.

Pressure applied to the upstream side of the filter stack by means of the apparatus shown in Figure F-2 is accurately controlled with the regulator and gauge in the line. In order to apply a hydrostatic load on the filter, the input line attached to the test fixture is disconnected at the elbow, partially filled with water, and then reattached. The line then is pressurized to the desired value, resulting in the desired hydrostatic pressure at the filter.

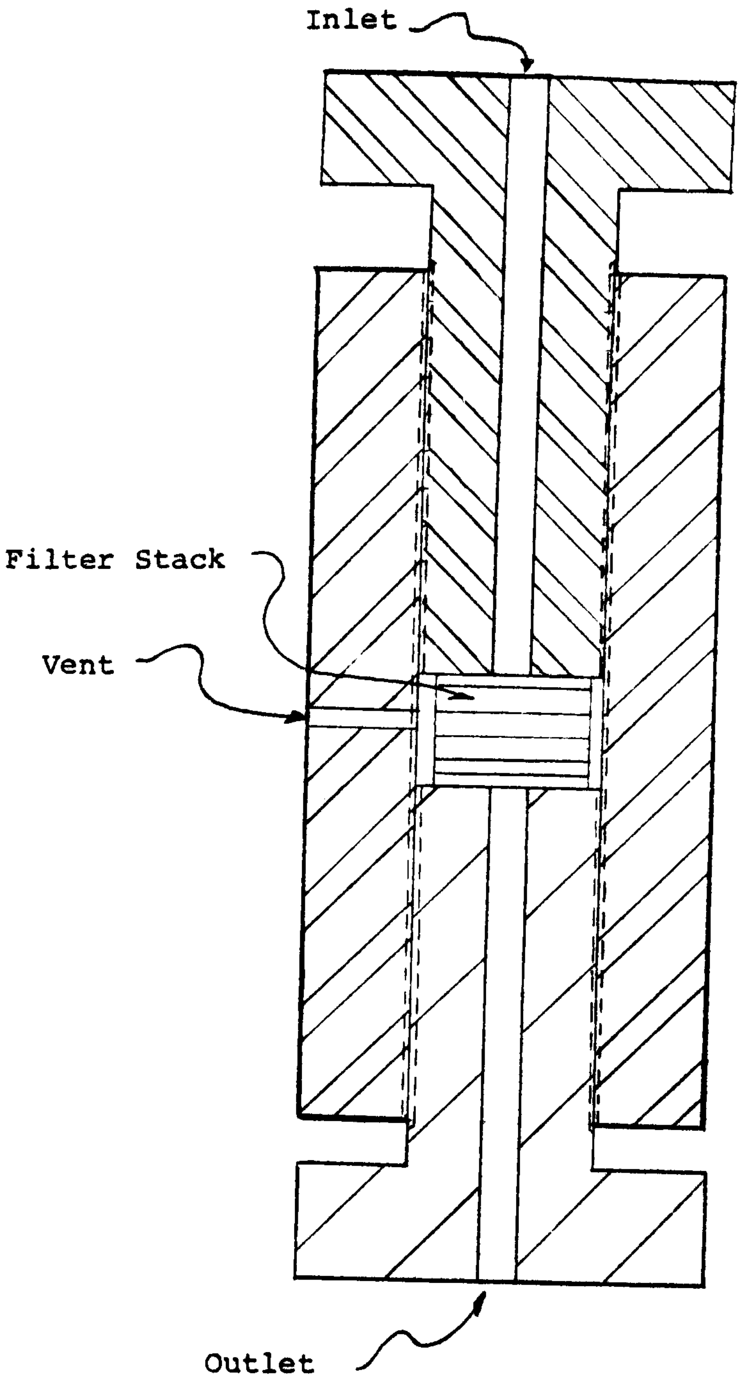

Figure F-1. Test fixture.

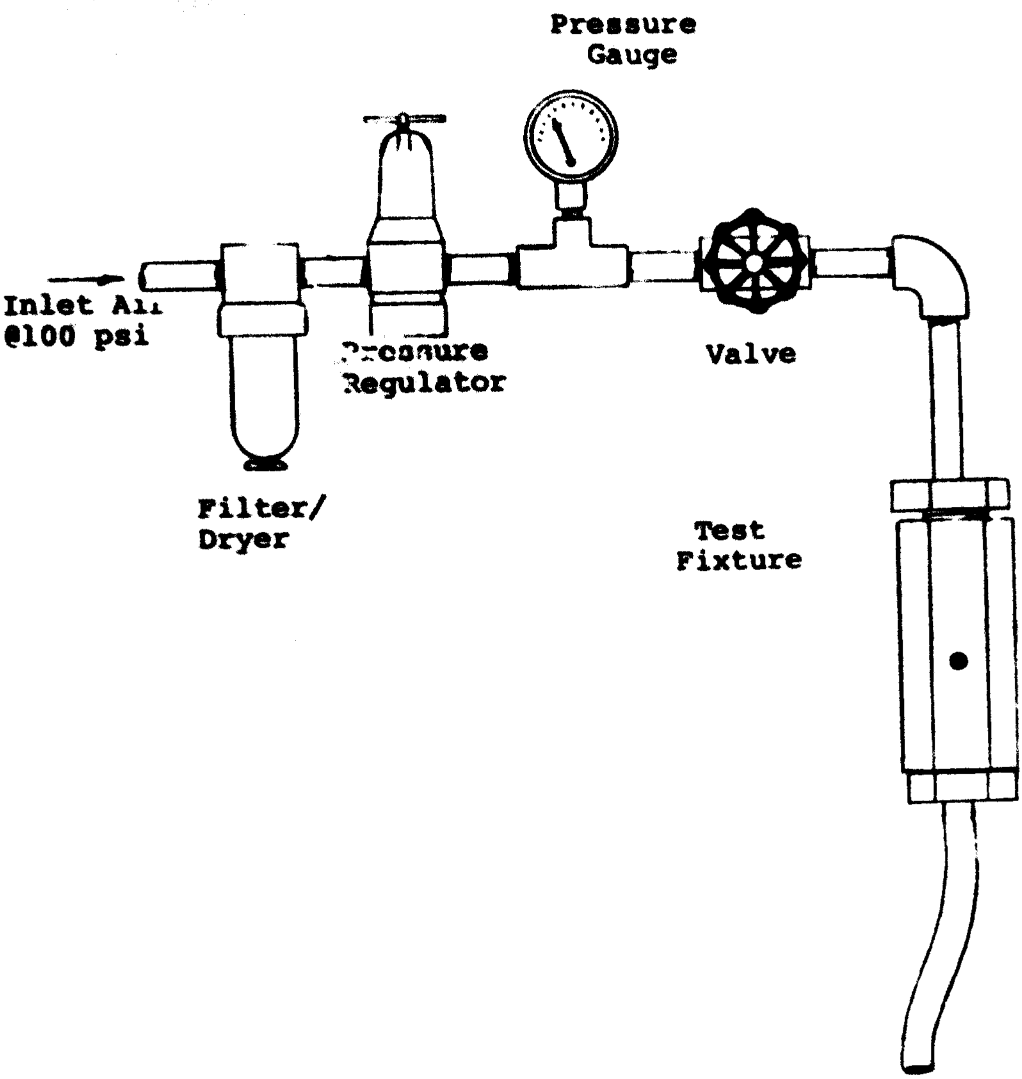

Figure F-2. Test apparatus.

Flow through the filter stack is measured in two ways. For water flow, the outlet line is inserted into a small, graduated cylinder. The volume of water flowing through the filter stack in a given amount of time then is measured. The volume of air passed through the filter in a given length of time is measured by displacing a water column in an inverted, graduated cylinder.

Test results are given in Table F-1. As shown, the airflow tests are conducted for stacks of two, three, and four layers of 1/16-inch filter disks. Also, flow rates for each of the above cases is recorded for 5-, 10-, and 15-psi pressure drops. As expected, the flow increases with decreasing stack height and increasing pressure drop. Note that the flow rates shown are well above the required 0.052 mole/day (0.0135 cm^3/s). Therefore, an increased stack thickness and/or a decreased pore size could be tolerated.

Results of the water flow test also are given. Results are for a stack of 4-1/15-inch-thick disks. The flow rate increases greatly between 10 and 20 psi. The water flow rate at 10 psi is below the allowable 0.36 cm^3/h, so that configuration could be used for pressures of 10 psi or lower. Decreasing pore size will allow higher pressure, but data are not sufficient to predict the allowable pressure versus pore size.

The airflow test data given in Table F-1 are used to predict the flow rate of the design vent assembly given in NuPac Dwg. EP-20-06D. Using four layers of 1/16-inch material, a flow rate of 0.26 cm^3/s is reached at a pressure of 10 psi. Extrapolating, using the flow values for two-, three-, and four-layer cases to define a curve, a value of 0.17 cm^3/s is calculated for a five-layer stack. That value is considerably above the required 0.0135 cm^3/s at 10 psi; therefore, it will allow use of 0.5-micron material instead of the 1-micron used for the above testing. Further testing was carried out using the design vent assembly with 1-micron material. Results of tests on prototype units are summarized in Table F-2.

TABLE F-1. TEST DATA

Filter Disk	Pressure (psi)	Flow (cm^3/s)
Air Flow		
2-layer	5	0.41
	10	0.94
	15	1.42
3-layer	5	0.17
	10	0.40
	15	0.60
4-layer	5	0.07
	10	0.26
	15	0.44

Filter Disk	Pressure (psi)	Flow (cm^3/h)
Water Flow		
4-layer	10	0.3
	20	3.0

TABLE F-2. PROTOTYPE TEST RESULTS

	S/N001	S/N002
Initial gas flow (cm^3/s)		
10 psi	0.470	0.093
40 psi	0.527	0.094
Final gas flow (cm^3/s)		
10 psi	0.464	0.038
Water flow (cm^3/h)		
10 psi	None	None
20 psi	0.042	None
30 psi	1.75	None
40 psi	5.25	None

Water infiltration rate to fill a HIC in 300 years is 0.33 cm^3/h (see Section 3.2 of main report). Interpolation of data for S/N001 gives:

Required pressure, psi	24
Hydrostatic head, ft (m)	55 (16.8).

APPENDIX G

SHIELDING ANALYSIS AND ANALYSIS OF RADIATION DOSE TO CONTAINER MATERIAL

Sam Swan

Consultant to Nuclear Packaging, Inc.

APPENDIX G

SHIELDING ANALYSIS AND ANALYSIS OF

RADIATION DOSE TO CONTAINER MATERIAL

G.1 Radiation Source

The radioactivity in each EPICOR-II liner is attributed to the following isotopes:[a]

^{90}Sr	70 Ci
^{134}Cs	272 Ci
^{137}Cs	1230 Ci.

The beta and gamma sources corresponding to these isotopes are listed in Table G-1. Five of the six gamma-energy groups are attributed to ^{134}Cs, with a half-life of 2.05 years. The 0.66-MeV energy group, however, is attributable to ^{137}Cs, with a half-life of 30 years. The latter energy group contains the highest gamma activity and is responsible for most of the gamma dose rate, both on the HIC interior and exterior. The beta-energy groups, with the exception of the 0.66-MeV group, are attributed to ^{90}Sr (and its daughter ^{90}Y) and ^{137}Cs, with half-lives of 28 and 30 years, respectively. Therefore, most dose rates from both beta and gamma activity are due to the longer-lived isotopes.

G.2 HIC Shielding Configuration

The geometry of the HIC is illustrated in Figure G-1, as modeled for shielding calculations. The ion-exchange media are contained within a 0.25-inch-thick EPICOR-II liner. Approximately 36 ft^3 of ion-exchange material is contained in the EPICOR-II liner. The HIC has a 0.25-inch-thick steel inner lining, which is coated with an organic sealant. The 6 inches of concrete (assumed 147 lb/ft^3) in the wall of the HIC, and 11 inches at top and bottom provide some shielding.

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a. This assumption is used to conservatively envelope the typical, or representative values given in Table 1 of EG&G Specification ES-60652B.

TABLE G-1. ASSUMED RADIATION SOURCE FROM AN EPICOR-II PREFILTER LINER

Gamma Source	
Energy (MeV)	Photons/s
1.365	3.4E11 x 10^{11}
1.17	1.9E11 x 10^{11}
1.04	1.0E11 x 10^{11}
0.80	9.9E12 x 10^{12}
0.66	3.9E13 x 10^{13}
0.61	9.8E12 x 10^{12}
Beta Source	
Energy (MeV)	Betas/s
2.27	2.6E12 x 10^{12}
1.18	3.2E12 x 10^{12}
0.66	1.0E13 x 10^{13}
0.55	2.6E12 x 10^{12}
0.51	4.6E13 x 10^{13}

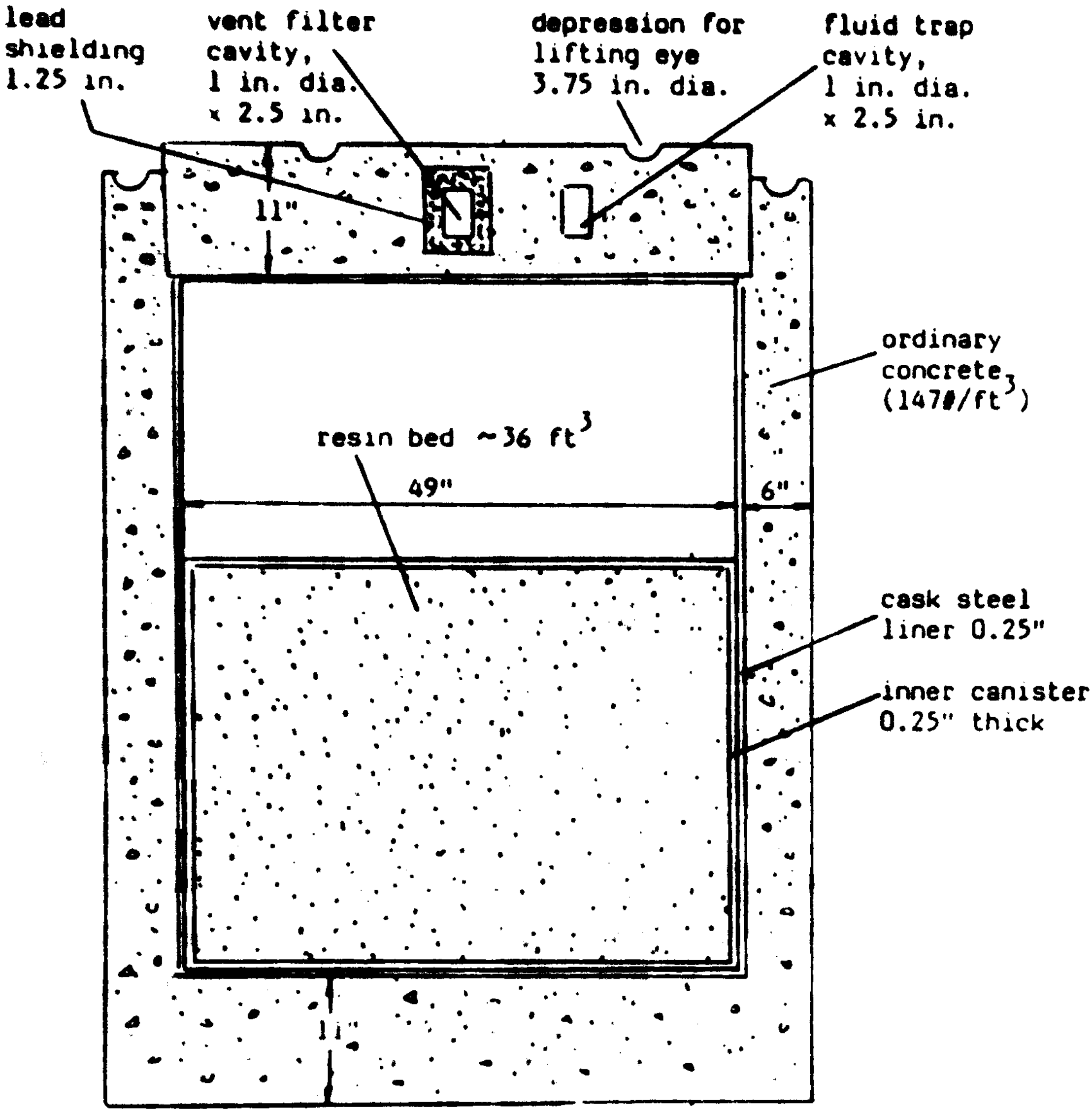


Figure G-1. High-Integrity cask shielding configuration.

The top of the HIC is a concrete lid sealed in place with a bonding agent. The lid is 11 inches thick and contains a vent system that includes two cylindrical cavities, each 1 inch in diameter by 2.5 inches long. One cavity is located along the HIC centerline and contains a filter assembly that is shielded on all sides by 1.25 inches of lead. The other cavity acts as a collection vessel for trapped fluid and is unshielded. Three depressions, located at the top of the lid (as shown in Figure G-1) provide clearance for the lifting eyes. The depressions are hemispheres 3.75 inches in diameter.

G.3 Source Configuration

Three cases were analyzed to ensure bounding of the actual source distribution:

1. A uniform activity distribution through the bed; the average density of the resin is specified as 0.865 g/cm^3

2. A concentration of the activity in a 15.24-cm (6-in.)-thick layer at the top of the bed, the layer consisting of zeolite at a density of 0.62 g/cm^3

3. A uniform concentration of activity in the upper half of the bed to match computations of dose rates by General Public Utilities Nuclear (GPUN) taken from bottom to top on a full EPICOR-II liner.

G.4. Calculated Dose Rates to the Coating of the HIC Inner Liner

The dose rate to the inner coating of the HIC was calculated to estimate the total integrated dose to that layer. All three source cases were considered. The steel EPICOR-II liner will effectively prevent any significant beta contribution to the HIC dose rate, but since the EPICOR-II liner may rust away, that liner was ignored and the dose contribution from beta radiation was also included.

Figure G-2 illustrates the calculated dose rates to the HIC interior coating for a uniform distribution of activity. For the uniformly distributed source case, dose-rate calculations for the top inner corner of the HIC, which represent the amount of radiation that would reach the lid bonding agent, are included. The maximum dose rate was calculated to occur along the HIC wall at the midpoint of the resin bed for that case.

Figure G-3 illustrates the calculated dose rates to the HIC interior for an activity concentration in the 6-inch-thick layer of zeolite at the top of the resin bed. Figure G-4 illustrates the dose rates calculated for an activity distribution in the upper half of the resin bed.

G.5 Calculated Dose Rates to the HIC Exterior

Figures G-5 through G-7 illustrate the dose rates calculated at specified points over the exterior of the HIC. The four lid points are at centerline, above the fluid-trap cavity, and in the depression of each lifting eye. Points along the container wall are evenly spaced between the top and bottom, and the three points on the bottom are at the edge, centerline, and halfway between.

The lowest dose rates to the exterior of the HIC were calculated for the uniform source distribution in the resin bed, with a maximum dose rate of 74 rads/h near the midpoint of the resin bed. The highest dose rates were calculated at a maximum of 172 rads/h for the source concentrated in the 6-inch zeolite layer, which is also the most realistic source to represent the 50 EPICOR-II liners.

G.6 Total Integrated Doses to the HIC Inner Coating

The total integrated doses to the inner HIC coating are summarized in Table G-2 for the three source distributions. The integrated doses are not in exact proportion to the calculated dose rates to the inner HIC coating, since the different half-lives of the contributing isotopes must be considered.

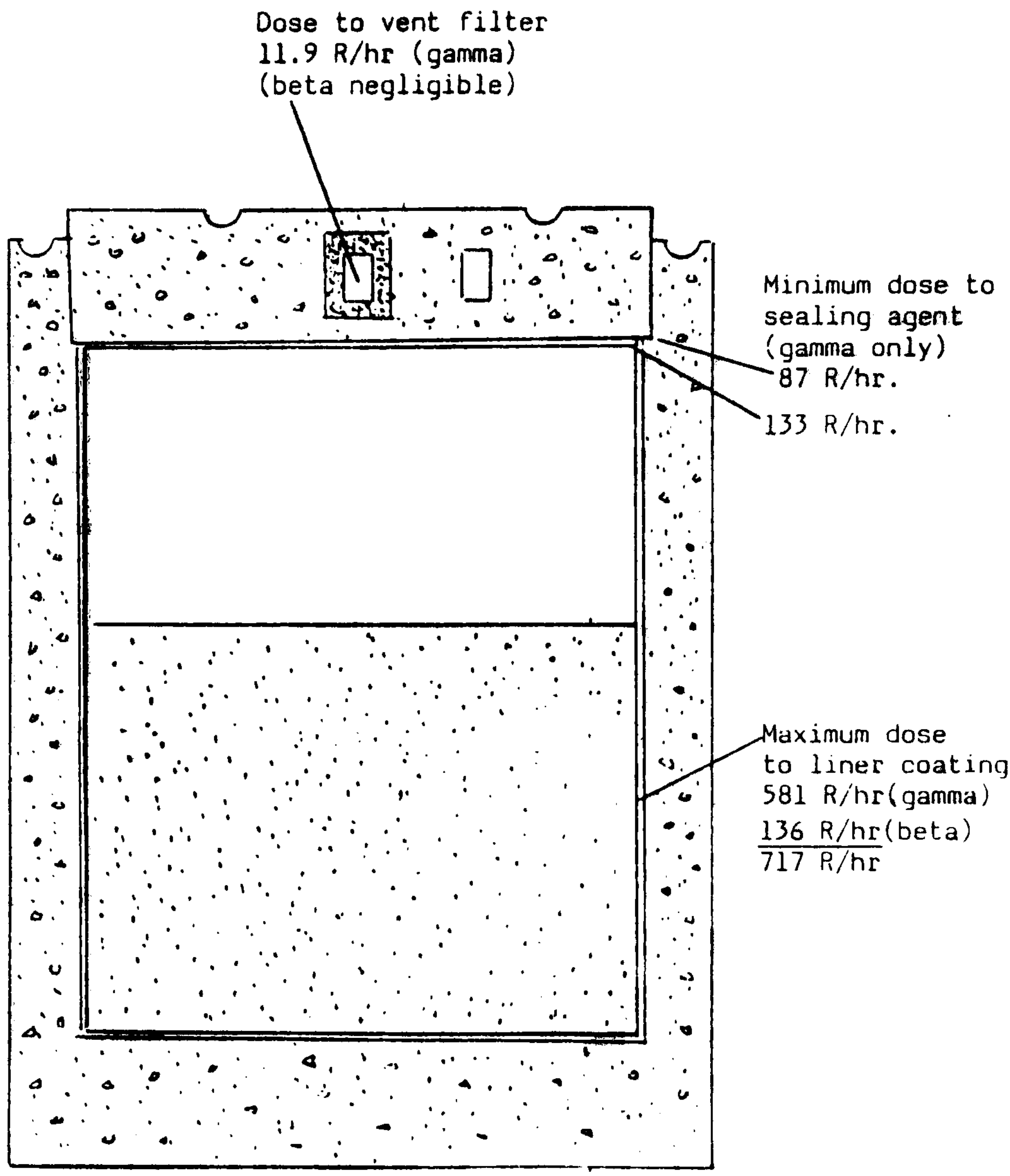


Figure G-2. Dose rates to coating of inner cask liner; source uniformly distributed through bed.

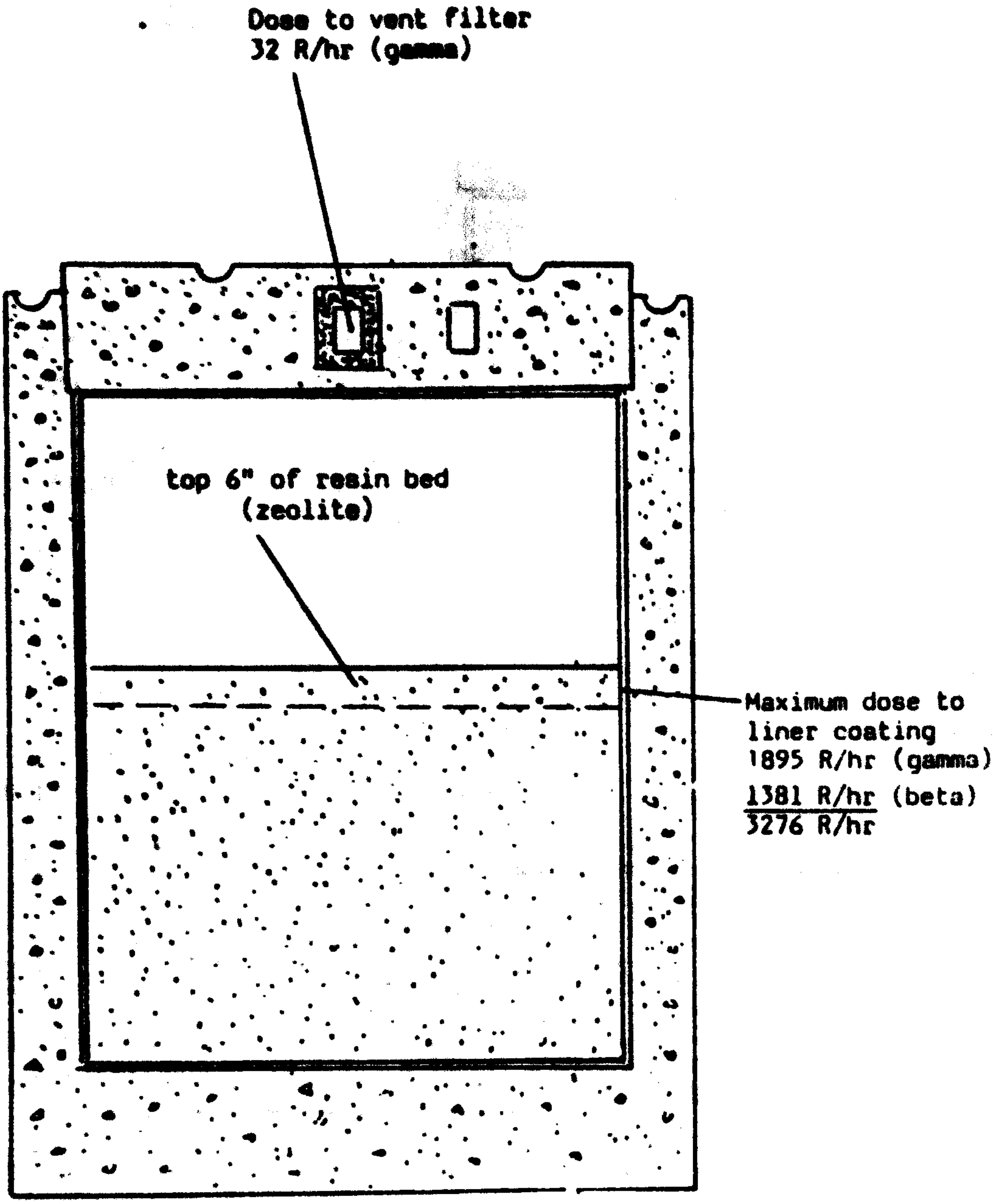
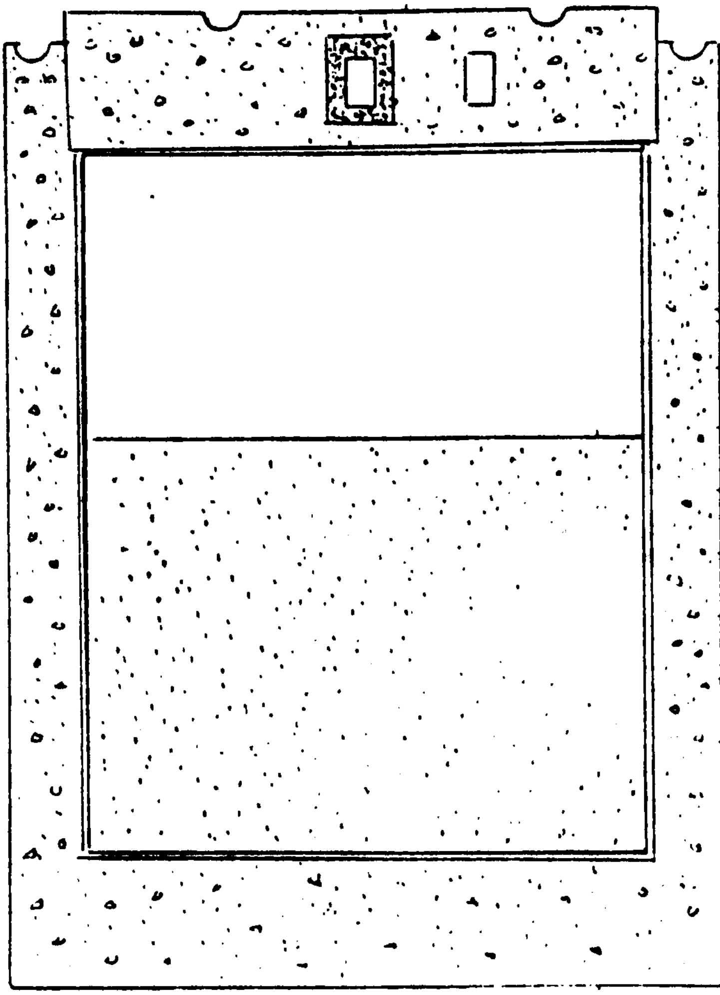


Figure 6-3. Dose rates to coating of inner cask liner; source concentrated in 6-inch-thick zeolite section at top of resin bed.



	Rad/Hour	
	Measured	Calculated
48"	0	372
42"	150	472
36"	350	593
30"	750	975
24"	950	1006
18"	650	653
12"	150	208
6"	0	71
0"	0	25

Figure G-4. Comparison of measured dose rates along wall of inner canister and calculated dose rates assuming activity is concentrated in the upper half of the resin bed.

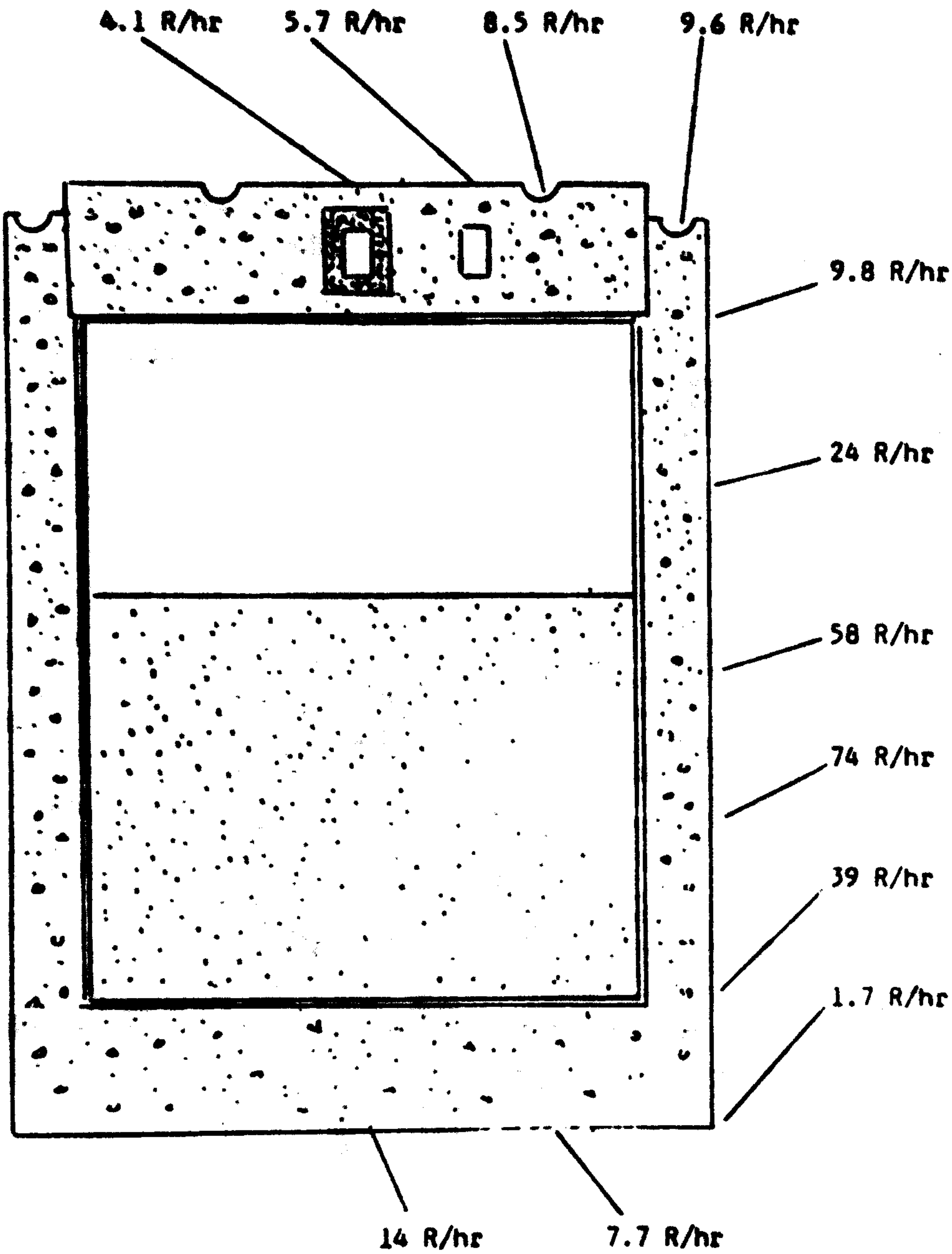


Figure G-5. Dose rates to HIC exterior (gamma only); source uniformly distributed through bed.

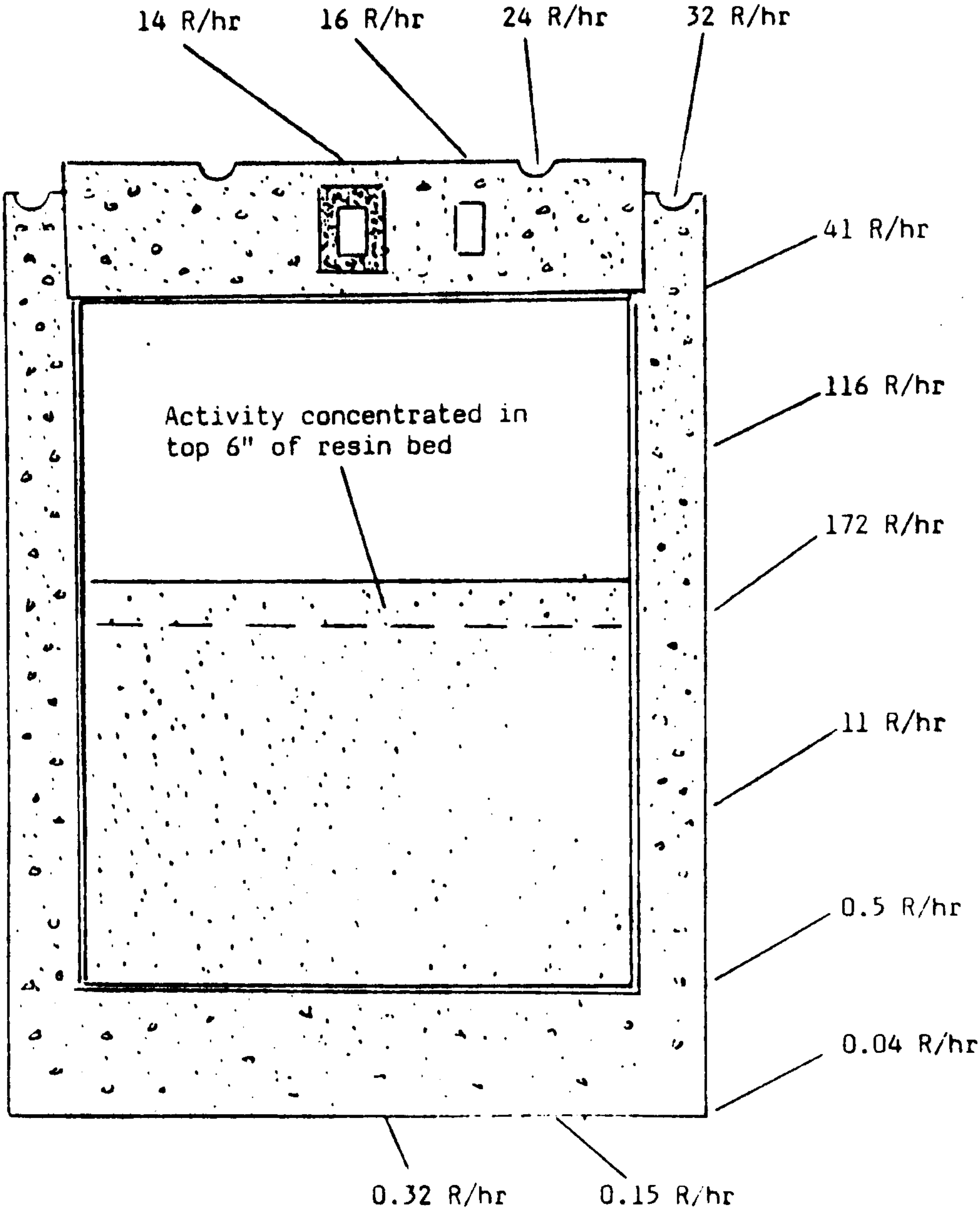


Figure G-6. Dose rates to cask exterior (gamma only); source concentrated in the 6-inch-thick zeolite section at the top of the resin bed.

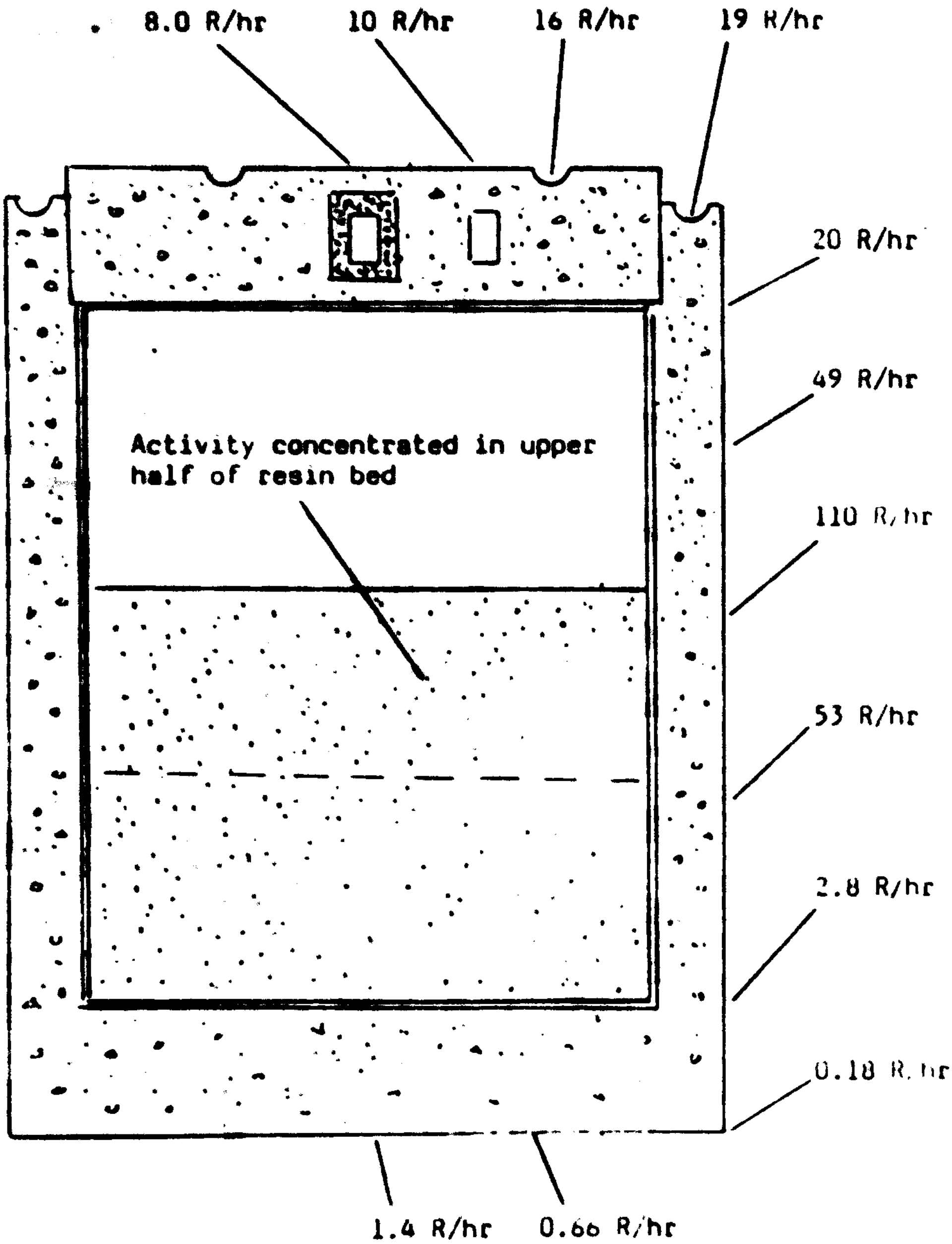


Figure G-7. Dose rates to cask exterior (gamma only); source concentrated in the upper half of the resin bed, based on measured dose rates at TMI.

TABLE G-2. SUMMARY OF TOTAL INTEGRATED DOSE TO HIC INNER COATING

Assumed Source Distribution	Integrated Dose (Mrads)
Uniform distribution over resin bed	170 (gamma) 42 (beta)
	212
Activity concentrated in the 6-in. zeolite layer	560 (gamma) 370 (beta)
	930
Activity concentrated in upper half of resin bed	300 (gamma) 85 (beta)
	385

APPENDIX H
ANALYSIS OF CONTAINER STRENGTH

V. K. Kumar

ABAM Consulting Engineers

CONTENTS

1. Strength Analysis (27 pages) H-5

2. Addendum #1: Aged Burst Assessment H-32

3. Addendum #2: 30-Foot Impact Evaluation (in Type "B" Package) H-34

APPENDIX H

ANALYSIS OF CONTAINER STRENGTH

These design analysis notes have been modified by two addenda at the end of the appendix. Addendum #1 reflects replacement of the three 4T Swift Lift Body anchors with two exposed stainless steel (316) fabricated eyes. Addendum #2 is a prediction of container strength increase with age.

Revision 1

ABAM CONSULTING ENGINEERS

PROJECT NUPAC TMI CASK | SHEET NO. 1 OF 18
DES. VK
SUBJECT DESIGN CRITERIA & REFERENCES | JOB NO. 81085
DATE 10/27/81

DESIGN CRITERIA

LOADS: EXTERNAL PRESSURE DIFFL. = 150 PSI (STATIC)
INTERNAL PRESSURE DIFFL. = 25 PSI (do)
PAYLOAD WEIGHT = 3250 #

LOAD FACTOR : 1.4 (ACI 318-77 SEC. 9.2.5)

STRENGTH REDUCTION FACTORS: 0.9 FOR FLEXURE ; 0.85 FOR SHEAR; 0.7 FOR AXIAL COMPRESSION (ACI 318-77, SEC 9.3.2)

LIFTING HARDWARE : F.S OF 3 ON YIELD LOADS
F.S OF 5 ON ULTIMATE LOADS

CONCRETE : NORMAL WEIGHT CONCRETE WITH $f_c' = 6000$ PSI

REINFORCING: $f_y = 60{,}000$ PSI

MIN. CONCRETE COVER : 1¼" (ACI 318-77 SEC 7.7.2)

EXPOSURE : -40°F TO 140°F, 60 CYCLES OF FREEZE/THAW

REFERENCES

1. BUILDING CODE REQUIREMENTS FOR REINFORCED CONCRETE ACI 318-77
2. SWIFT LIFT USERS MANUAL by SUPERIOR CONCRETE ACCESSORIES Co.
3. PCI DESIGN HANDBOOK, 2nd EDITION
4. THEORY OF PLATES & SHELLS BY S. TIMOSHENKO & S. WOINOWSKY-KRIEGER, McGRAW HILL, 2nd EDITION
5. MANUAL OF STEEL CONSTRUCTION, AISC 7th EDITION
6. THIN SHELL CONCRETE STRUCTURES, By BILLINGTON McGRAW HILL,
7. ACI 224 R-80, CONTROL OF CRACKING IN STRUCTURES.
8. BEHAVIOR OF MISSILE SILO CLOSURES BY W.L. GAMBLE ET. AL UNIVERSITY OF ILLINOIS PUBLICATION, MARCH, 68

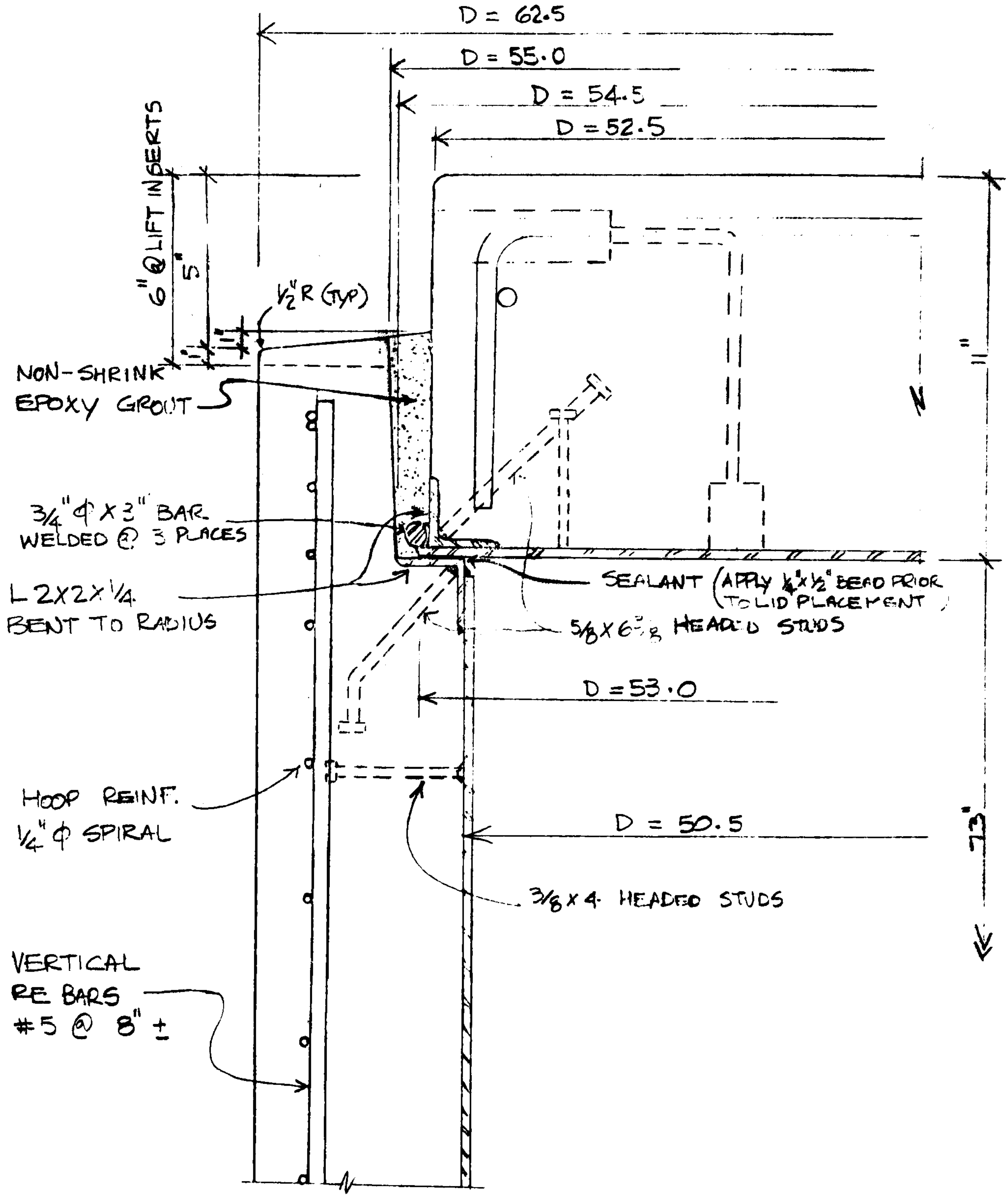
ABAM CONSULTING ENGINEERS
500 South 336th Street Federal Way WA 98003 (206) 952-6100

PROJECT NUPAC TMI CASK — SHEET NO. 2 OF 18

DES. VK

SUBJECT CONTAINER / LID JOINT — JOB NO. 81085

DATE 10/12/81



ABAM
CONSULTING ENGINEERS

SUBJECT NUPAC TMI CASK | SHEET NO. 3 OF 18
DES. VK
SUBJECT WEIGHTS | JOB NO. 81035
DATE 10/23/81

CONTAINER BODY:

STEEL SHELL	1/4 PL	$\frac{\pi \times 49.5 \times 62}{144} \times 10.2^{\#}$	= 683
	L 2x2x1/4	$\pi \times \frac{52}{12} \times 3.19^{\#}$	= 43
	3/8 x 4 STUDS	$96 \times 1.55^{\#}$	= 149
	5/8 x 6 3/8 STUDS	$24 \times 6.44^{\#}$	= 155
			1030
	WELDS	@ 5%	50
			1080 lbs.

CONCRETE SHELL $\frac{\pi \times 155}{144 \times 12}(56.5 \times 62 \times 6 + 58.5 \times 6 \times 4) = 6318$

$\frac{\pi \times 58.5 \times 8 \times 4}{144 \times 12} \times 155^{\#} = 527$

6845 lbs

STEEL BOTTOM 1/4" PL $\frac{\pi \times 51.25^2 \times 10.2^{\#}}{4 \times 144} = 146$

STUDS $43 \times 1.55 = 67$

213

WELDS @ 5% 10

$223^{\#}$

CONCRETE BOTTOM $\frac{\pi}{4} \times \frac{62.5^2}{144} \times \frac{10.75}{12} \times 155^{\#} = 2958$"

TOTAL CONTAINER BODY = $11{,}096^{\#}$

CONTAINER LID:

STEEL LID $\frac{\pi}{4} \times \frac{53^2}{144} \times 10.2^{\#} = 156.^{\#}$

L 2x2x1/4 $\pi \times \frac{52}{12} \times 3.19^{\#} = 44^{\#}$

STUDS (3/8" x 4") $43 \times 1.55^{\#} = 67^{\#}$

(5/8" x 6 3/8") $24 \times 6.44^{\#} = 155^{\#}$

$422^{\#}$

WELDS @ 5% $22^{\#}$

$444^{\#}$

CONCRETE LID $\frac{\pi}{4} \times \frac{52.5^2}{144} \times \frac{10.75}{12} \times 155^{\#}$ $2087^{\#}$

TOTAL CONTAINER LID = $2531^{\#}$

LIFT INSERTS FOR LID

REQUIRED LIFT CAPACITY $= \frac{5 \times 2531}{1000} = 12.7^K$ OR 6.35 TONS

FOR 3-POINT LIFTING, CAPACITY / ANCHOR $= \frac{6.35}{3} = 2.12$ TONS

USING 2 TON ($\frac{5}{16}'' \times 5\frac{1}{2}''$) SWIFT LIFT ANCHORS, (2)

STEEL STRENGTH $= \frac{15{,}300^{\#}}{2000} = 7.5$ TONS OK

CONC. STRENGTH $= \frac{\pi (6 + 1.38)\ 6.0 \times 4 \times \sqrt{6000}}{2000} = 21.4$ TONS OK

USE SL 467135 OR SL 467140

LIFT INSERTS FOR CONTAINER

THE LIFT INSERTS EMBEDDED IN THE CONTAINER IS DESIGNED FOR THE TOTAL LOAD AND WILL BE USED FOR STORAGE, HANDLING AND ULTIMATE BURIAL OF THE CONTAINER.

CONTAINER BODY	$= 11{,}096^{\#}$
CONTAINER LID	$= 2{,}531^{\#}$
PAY LOAD	$= 3{,}250^{\#}$
SEAL $\pi \frac{53.5}{12} \times \frac{1.25}{12} \times \frac{6}{12} \times 150^{\#}$	$= 110^{\#}$
	$16{,}987^{\#}$ SAY 17^K

REQUIRED LIFT CAPACITY $= 5 \times 17^K = 85^K$ ULTIMATE

$= 3 \times 17^K = 51^K$ WORKING

FOR 2-POINT LIFTING,

CAPACITY / INSERT $= \frac{85}{2} = 42.5^K$ ULTIMATE

& $\frac{51}{2} = 25.5^K$ WORKING

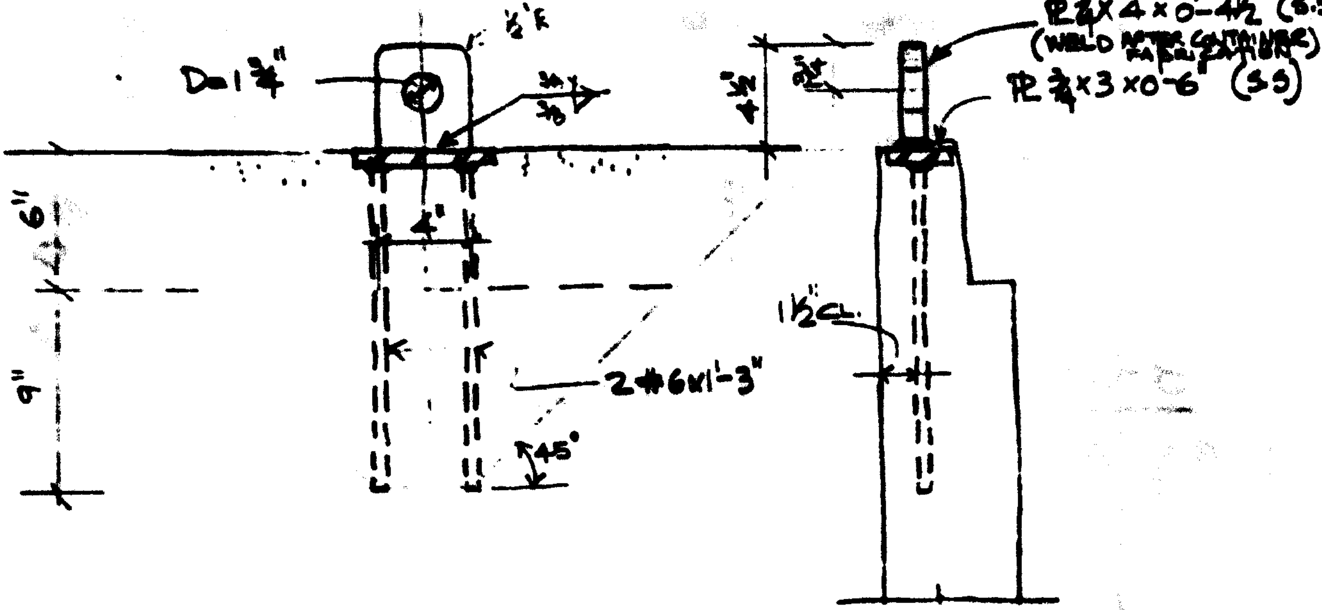
Revision 1

ABAM CONSULTING ENGINEERS

PROJECT NUPAC TMI CASK
SHEET NO. 5 OF
DES. VK
SUBJECT LIFTING INSERTS
JOB NO. 81085
DATE

NOTE: OPTION #1 NOT USED SEE OPTION #2, NEXT SHEET

OPTION #1 WELDED LIFTING EYE



FOR 304 STAINLESS STEEL

F_y : 30 KSI TABLE I-2.2 } ASME B & P.V CODE
F_u = 75 KSI TABLE I-3.2 } SECT III, APP. I

NET TENSION AREA @ EYE

$= (4 - 1\frac{3}{4}) \cdot .75 = 1.6875 \text{ in}^2$

$(f_a)_{ULT.} = \frac{42.5^k}{1.6875} = 25 \text{ KSI} < F_u = 75 \text{ KSI}$

OK

$(f_a)_{WRK} = \frac{25.5}{1.6875} = 15.1 \text{ KSI} < F_y = 30 \text{ KSI}$

WELDING REQUIRED

FOR 3/8 WELD AS SHOWN $L = 2 \times 4.0 = 8''$

$f_v = \frac{25.5}{8 \times .375 \times .707} = 12 \text{ KSI} < F_v = \frac{.4}{.6}(30) = 20 \text{ KSI}$

BACK-UP BARS

USING WELDABLE GRADE 40 REBARS (LOW CARBON)

$A_s = \frac{.25.5^k}{.9 \times 40} = 0.71 \text{ in}^2$ USE 2#6 A_s PROVIDED = $.88 \text{ in}^2$

CONCRETE CAPACITY:
FOR 15" EMBEDMENT

A_c = AREA OF (PARTIAL) SHEAR CONE $= (4 + 2\sqrt{2} \times 9)5 + 2(6\sqrt{2})4$

$= 147 + 68 = 215 \text{ in}^2$

PULL OUT CAPACITY $= \phi \cdot A_c \cdot 4\sqrt{f'_c}$

$= .85 \dfrac{\times 215 \times 4 \sqrt{6000}}{1000} = 56.7^k > P_u = 42.5^k$

OPTION #2 FORGED LIFTING EYE

316 FABRICATED EYE [P/N (8), DWG EP-20-0AD]

SWL = 9370 LB REF CAMPBELL CHAIN CATALOG
PATTERN M-28-ST
STOCK NR. CA0 5115

BASED UPON 5:1
S.F. ULTIMATE.

$F.S. = \dfrac{9370}{17000/2} = +1.10$

$\dfrac{(5)(9370)(2)}{17,000} = 5.5$ (ULTIMATE)

$1\frac{3}{4}$" ϕ CARBON STEEL SLEEVE NUT [P/N (9), EP-20-0AD]

NET AREA $= \frac{\pi}{4}\left[1.75^2 - 1^2\right] = 1.62 \text{ in}^2$

$(f_a)_{ULT} = \dfrac{42.5}{1.62} = 26.2$ ksi $< F_u = 60$ ksi

$(f_a)_{WORK} = \dfrac{25.5}{1.62} = 15.7$ ksi $< F_y = 36$ ksi

1" ϕ CARBON STEEL BAR [P/N (6), DWG EP-20-0AD]

AREA $= \pi/4 = .7854$

$(f_a)_{ULT} = \dfrac{42.5}{.7854} = 54.1$ ksi $< F_u = 60$ ksi

$(f_a)_{WORK} = \dfrac{25.5}{.7854} = 32.5$ ksi $< F_y = 36$ ksi

ABAM CONSULTING ENGINEERS

PROJECT NUPAC TMI CASK

SUBJECT LIFTING INSERTS

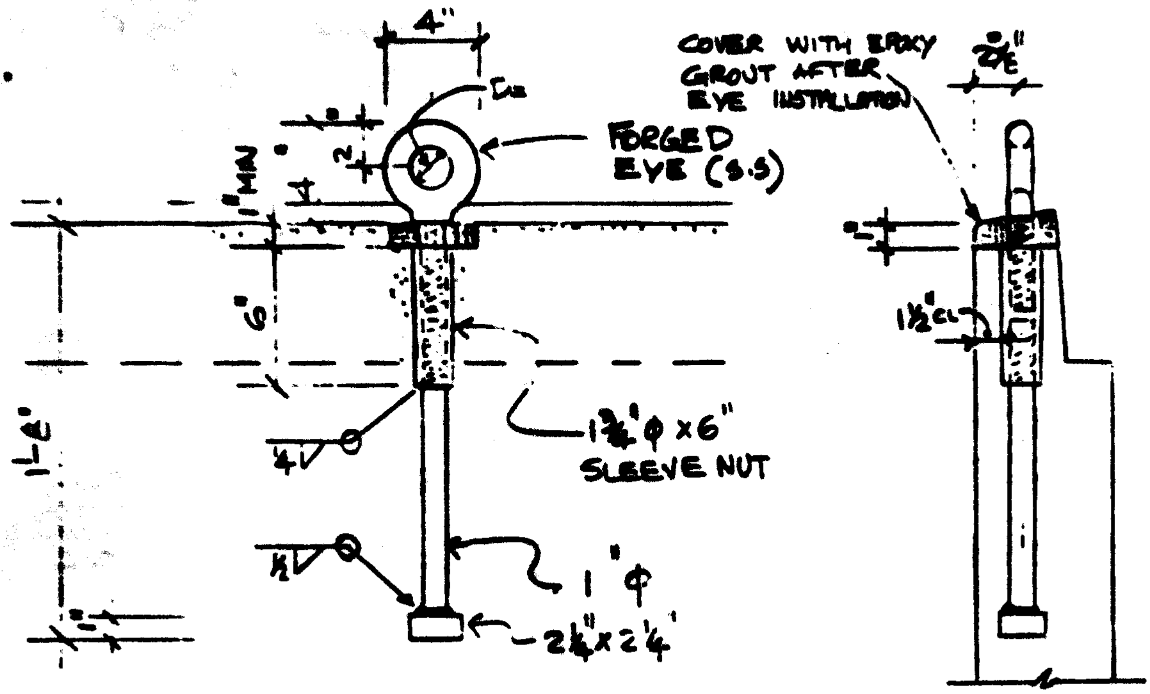
Revision 1

SHEET NO. 7 OF

DES. VK

JOB NO. B1085

DATE



CONCRETE CAPACITY:

FOR 16" TOTAL EMBEDMENT WITH 2¼" □ PL @ BOTTOM,

$A_c = (2.25 + 2\sqrt{2} \times 12)5 + 2(6\sqrt{2})4$

$= 181 + 68 = 249 \text{ in}^2$

PULL OUT CAPACITY $= \phi \cdot A_c \cdot 4\sqrt{f_c'}$

$= .85 \times \frac{249 \times 4}{1000} \sqrt{6000} = 65.6^k > P_u = 42.5^k$

$\frac{65,600}{71,000} = 1.7$

WELDING OF 2¼" x 2¼" x 1" PL

WELD LENGTH $= \pi \times 1.25 = 3.93'$

FOR ½" WELD ALL AROUND

$(f_v) = \frac{25.5}{3.93 \times .5 \times .707} = 18.4 \text{ ksi} < F_v = \frac{.4}{.6}(36) = 24 \text{ ksi}$

DESIGN OF LID

THE LID WORKS PRETTY MUCH AS A SIMPLY SUPPORTED CIRCULAR SLAB. SINCE THE STEEL CORROSION BARRIER IS BUILT COMPOSITE WITH THE CONCRETE, IT IS EXPECTED TO TAKE THE TENSION WHILE CONCRETE PICKS UP THE COMPRESSION

FOR $f'_c = 6000$ PSI USING HARD ROCK CONCRETE

$E_c = 155^{1.5}(33)\sqrt{6000} = 4933$ KSI

$E_s = 29{,}000$ KSI $\quad n = \frac{29000}{4933} = 5.88$ SAY 6

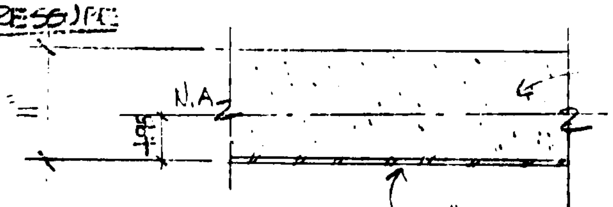
EQUIVALENT AREA $= .25 \times 6 + 10.75 = 12.25\ in^2/IN$

N.A. @ $\frac{.25 \times 6 \times .125 + 10.75 \times 5.625}{12.25} = 4.95"$ FROM BOTTOM

$I = .25 \times 6 \times 4.825^2 + \frac{10.75^3}{12} + 10.75(.425)^2 = 140.4$

$S_t = \frac{140.4}{6.05} = 23.2\ in^3/IN \qquad S_b = \frac{140.4}{4.95} = 28.4\ in^3/IN$

EXTERNAL PRESSURE



FLEXURE:

FROM P 56 OF REF. ⚠4

MAX MOMENT @ ℄ $M_r = M_t = \frac{qa^2}{16}(3+\nu)$ FOR A SIMPLY SUPPORTED CIRCULAR PL WITH UNIFORM LOAD

$q = 150$ PSI $\quad a = 25.75" \quad \nu = 0.2$

$M_℄ = \frac{150 \times 25.75^2}{16}(3+.2) = 19{,}506$ in-lb/IN

$(f_c)_{Top} = \frac{19{,}506}{23.2} = 840.8$ PSI (COMPRESSION) $< .45 f'_c = 2700$ PSI OK

$(f_t)_{Bottom} = 6\left(\frac{19{,}506}{28.4}\right) = 6(686.8)$ PSI $= 4121$ PSI (TENSION) $< .6 f_y = 21{,}600$ PSI OK

ONLY SHRINKAGE & TEMP. STEEL REQD. @ TOP

$A_s = .0018 \times 12 \times 10.75 = .23\ in^2/FT$ ⚠1 (ACI 318-77 7.12.2)

USE #3 @ 4"± $\quad A_s$ PROVIDED $= .11 \times \frac{12}{4} = .33\ in^2/FT.$ OK

EXTERNAL PRESSURE :—(CONTD.)

SHEAR :

• SHEAR FORCE ALONG WALL EDGE $= \frac{\pi \times r^2 \times 1}{2\pi r}$

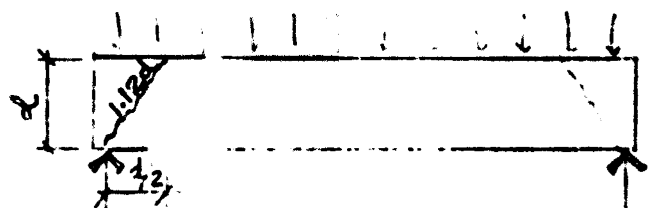
$= \frac{25 \times 150}{2} = 1874$ #/IN

IF ALL THE SHEAR IS TO BE TAKEN BY THE STEEL PL

$f_v = \frac{1874}{1 \times .25} = 7575$ PSI $< .4(36) = 14.4$ KSI OK

IF ALL THE SHEAR IS TO BE TAKEN BY CONCRETE IN A PUNCHING SHEAR MODE

$V_u = 1.4(1894) = 2652$ #/IN



FROM ACI 318-77 SEC 11.11 (1) $v_c = 4\sqrt{f'_c} = 4\sqrt{6000} = 310$ PSI

$V_c = \phi\, v_c \times 1.12\, d$

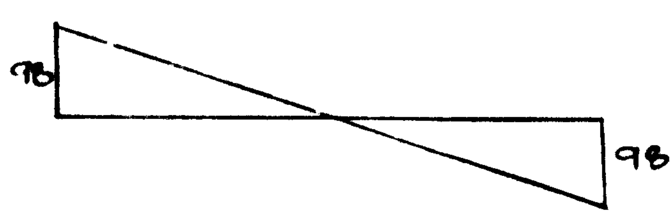
$= .85 \times 310 \times 1.12 \times 10.75 = 3273$ #/IN $> V_u$

HORIZONTAL SHEAR. M.S.$_{SHEAR}$ $= \frac{3273}{2652} - 1 = +0.23$

@ ② STEEL/CONC. INTERFACE $= .25 \times 6\,(4.95 - .125) = 7.24$

$v_{u\,max} = \frac{VQ}{Ib} = \frac{1874 \times 7.24}{140.4 \times 1} = 98$ PSI

THE HORIZONTAL SHEAR STRESS VARIES LINEARLY ALONG THE RADIUS DECREASING TO ZERO @ CENTER

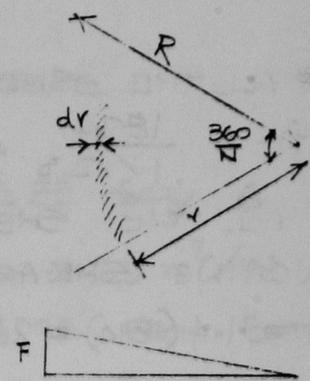


TOTAL HORIZONTAL SHEAR IS CALCULATED FOR A 60° SECTOR AND MEMBER STUDS ARE EVENLY DISTRIBUTED AS SHOWN

EXPRESSION FOR TOTAL HORIZONTAL SHEAR

$dA = \frac{2\pi r\,dr}{N}$

$dF = \frac{r}{R} F$



TOTAL FORCE $= \int_{r=0}^{r=R} dA \times dF$

$= \int_0^R \frac{2\pi r\,dr}{N} \frac{r}{R} F$

$= \frac{2\pi F}{NR} \int_0^R r^2 dr = \frac{2\pi F}{NR}\left[\frac{r^3}{3}\right]_0^R$

$= \frac{2\pi F}{NR} \frac{R^3}{3} = \frac{2\pi R^2 F}{3N}$

FOR. F = 98 PSI, $N = \frac{360}{(60)} = 6$ R = 26.25

TOTAL SHEAR $= \frac{2\pi \times 26.25^2 \times .098}{3 \times 6} = 23.6^k$

SHEAR CAPACITY REQD. $= 1.4(23.6) = 33^k$

STUDS FOR COMPOSITE ACTION

USING 3/8" X 4" STUDS, $\frac{t}{d} = \frac{.25}{.375} = .667 \simeq .68$ OK

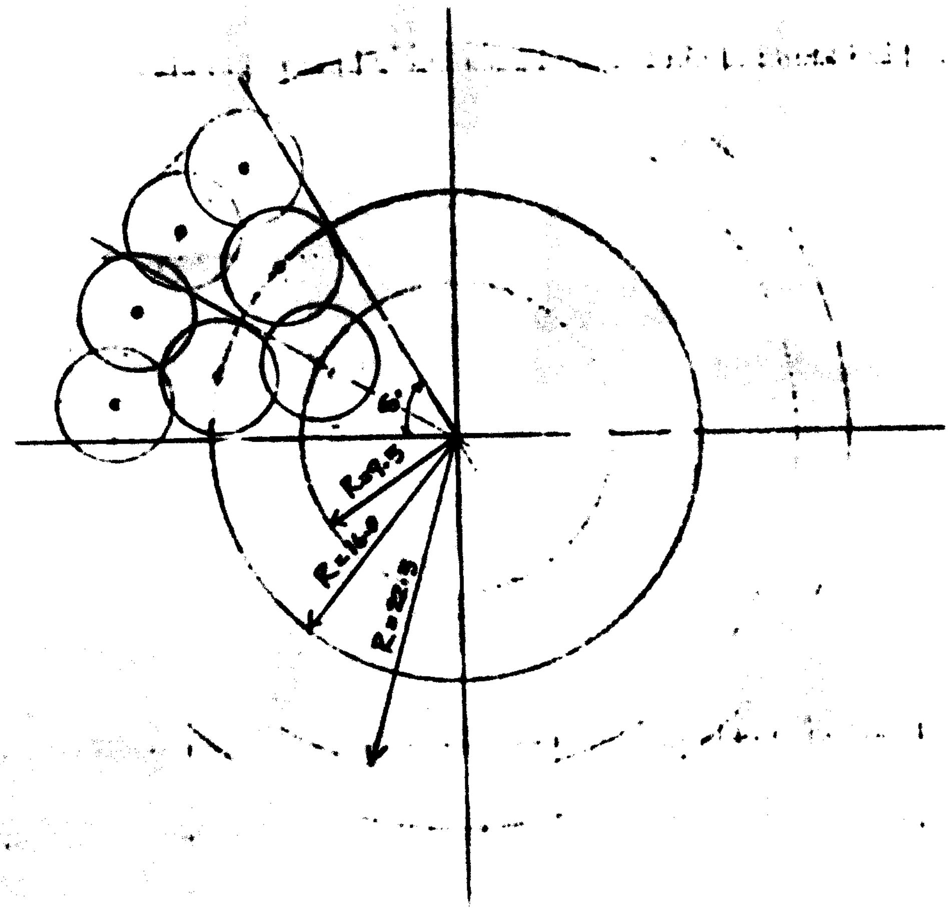
FROM PCI HANDBOOK TABLE 5.20.9, SHEAR STRENGTH OF ONE 3/8 X 4 STUD = 5.0 k (STEEL CONTROLS) ▽3

NO. OF STUDS REQD. $= \frac{33}{5} = 6.8$

USE 7 STUDS FOR A 60° SECTOR AS SHOWN.

THE SHEAR CONE OVERLAP IS LOW ENOUGH THAT CONCRETE WILL NOT CONTROL

FROM PCI TABLE 5.20.9 IT CAN BE FOUND THAT FOR 3/8" STUD WITH $d_e = 3"$ $\phi V_c = 5.1^k$, HENCE MIN SPACING BETW. STUDS SO THAT CONCRETE WILL NOT CONTROL IS 6" < 6.5" USED BETWEEN ROWS



STUD SPACING FOR LID

LID BEARING ON CONTAINER

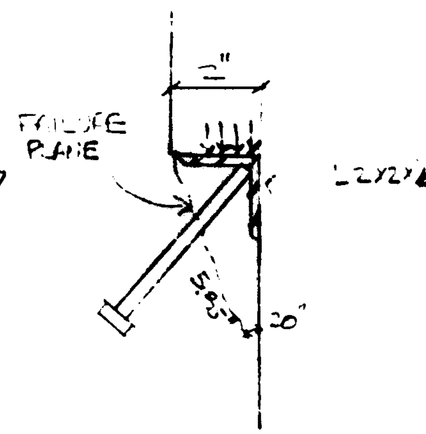
THE LID BEARING ON CONTAINER WALL LEDGE CREATES A VERY HIGH REACTION ON THE LEDGE.

SHEAR ALONG LEDGE = $\frac{26.25 \times 150}{2}$ = 1969 #/IN

$V_u = 1.4\ (1969) = 2.76^K/\text{IN.}$

FOR 24 STUDS EQUALLY SPACED ALONG A 26.25" RADIUS

$V_u = \frac{\pi \times 52.5}{24}(2.76) = 18.97^K$



USING SHEAR FRICTION APPROACH (AS PER PCI SEC. 5.6) 3

FOR $\mu = 1.4$ (CONCRETE CAST MONOLITHIC)

$f_y = 50$ KSI

$A_{vf} = \frac{.94(18.97)}{.85(50)1.4} = .30\ \text{in}^2$

USE 5/8" x 6 3/8 STUD $A_s = .51\ \text{in}^2$

SHEAR FORCE ON CRACK PLANE $= \frac{2.76}{5.85} = .472^{KSI}$ OR 472 PSI

$< 1000\lambda^2 = 1000$ PSI OK

BY SIMILAR REASONING, A L2x2x¼ WITH 24 - 5/8" x 6 3/8 STUDS EQUALLY SPACED WILL BE USED ON THE LID.

$M.S._{\text{LID SHEAR}} = \frac{1000}{472} - 1 = \underline{+1.12}$

INTERNAL PRESSURE

FLEXURE:

MAX. MOMENT @ ℄ $M_t = M_r = \frac{q a^2}{16}(3+\nu)$

$q = 25$ PSI $a = 25.25"$ $\nu = 0.2$

$M_℄ = \frac{25 \times 25.25^2}{16}(3+.2) = 3188$ in-lb/IN

$(f_t)_{TOP} = \frac{3188}{23.2} = 137$ PSI (TENSION) $\ll 6\sqrt{f_c'} = 465$ PSI

$(f_c)_{BOT} = 6\left(\frac{3188}{28.4}\right) = 6(112.2) = 674$ PSI (COMP)

DESIGN MOMENT FOR REINFORCING = 3188 × 1.4 = 4463 IN-# OR 4.46 FT-K/FT.

TRY #4 @ 4" $A_s = .6$ in²/FT

$a = \frac{.6 \times 60}{.85 \times 12 \times 6} = .588$ $d - \frac{a}{2} = 10.75 - \frac{.588}{2} = 10.46"$

$M_u = .9 \times .60 \times 60 \times 10.46 / 12 = 28.24$ FT-K/FT > M_u REQ. = 4.46

#4 @ 4" EA. WAY IS ADEQUATE FOR INTERNAL PRESSURE

SHEAR:

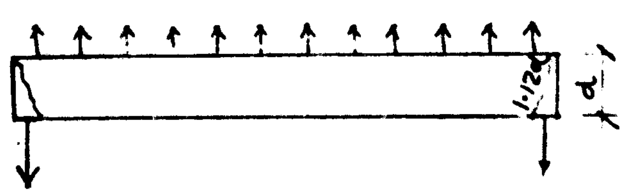
ASSUMING THAT THE GROUT CAN HOLD UP

$V_u = 1.7\left(\frac{25.25 \times 25^{\#}}{2}\right) = 537$ #/IN

$V_c = \phi\, v_c \times 1.155\, d$ $v_c = 4\sqrt{f_c'} = 4\sqrt{6000} = 310$ PSI

$= .85 \times 310 \times 1.12 \times 10.75 = 3273$ #/IN $> V_u = 537$

CONCRETE ALONE HAS SUFFICIENT SHEAR STRENGTH



HOOP DIRECTION

THE CONTAINER BODY IS BASICALLY UNDER HOOP COMPRESSION UNDER THE UNIFORM RADIAL PRESSURE. HOWEVER SOME BENDING DOES OCCUR AT THE WALL TO BASE JOINT DUE TO THE RESTRAINT.

FOR OPEN CYLINDER HOOP COMP. $= \frac{PD}{2} = \frac{150 \times 56.5}{2} = 4238^{\#}$

EQUIVALENT AREA $= 6 + .25 \times 6 = 7.5\ in^2/IN$

MAX. HOOP COMPRESSION $= \frac{4238}{7.5} = 565$ PSI FOR CONCRETE

$1.4(565) = 791^{PSI} < .7(6000) = 4200^{PSI}$ (ACI 9.3.2) OK

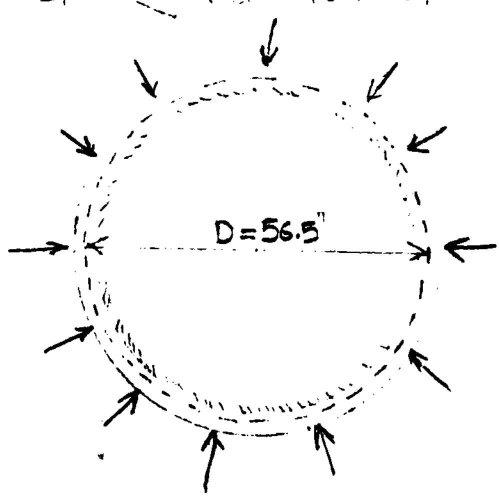
MAX HOOP COMPRESSION FOR 1/4" PL = 6(565) = 3390 PSI

CHECK PL BUCKLING BETWEEN STUDS

$\ell = \frac{\pi \times 50.5}{12} = 13.2''$ $r = \sqrt{\frac{.25^3}{12 \times .25}} = .144$ $K = .5$

$\frac{K\ell}{r} = \frac{0.5 \times 13.2}{.144} = 45.8 \longrightarrow F_a = 18.7$ KSI (5) AISC TABLE 1-36

$f_a = 3.39$ KSI $< F_a = 18.7$ KSI OK

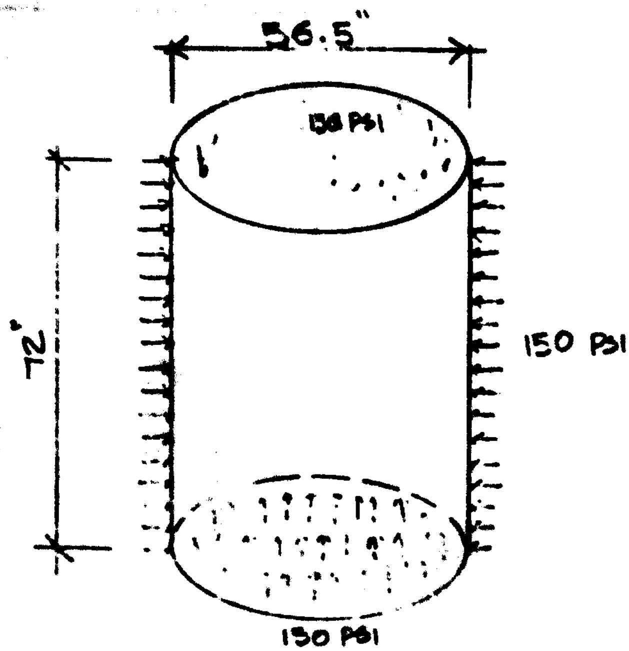


HOOP REINFORCING:

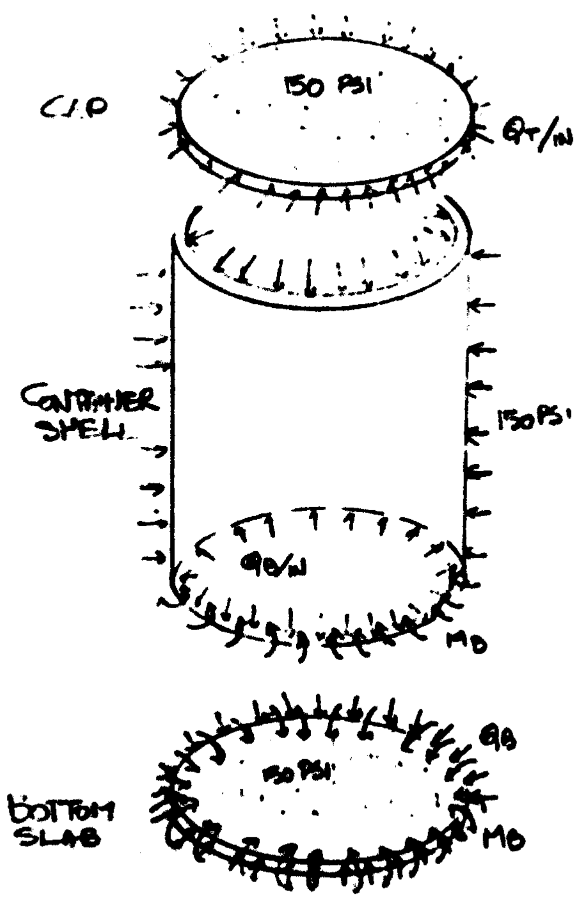
SHRINKAGE STEEL $= .0018 \times 6 \times 12 = .13\ in^2/FT$ (ACI 318 SEC. 7.12.2) ✓

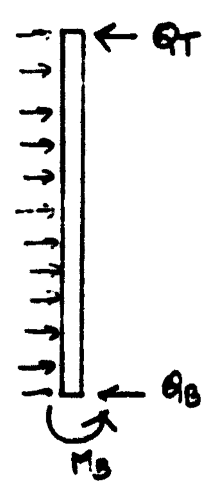
1/4" ϕ WIRE @ 4" PITCH PROVIDES $3 \times .05 = .15\ in^2/FT$ OK

USE 2" PITCH @ TOP & BOTTOM.



LOADING DIAGRAM.





FREE-BODY DIAGRAM

ANALYSIS FOR BENDING DUE TO TOP & BOTTOM RESTRAINT

COMPOSITE SECTION PROPERTIES

FOR BOTTOM SLAB $A = 12.25$

$I = 140.4$

FOR SHELL WALL $A = .25 \times 6 + 6 = 7.5\ in^2/in$

N.A @ $\frac{.25 \times 6 \times .125 + 6 \times 3.25}{7.5} = 2.625''$ FROM STEEL

$I = .25 \times 6 \times 2.5^2 + \frac{6^3}{12} + 6 \times .625^2 = 29.7$

$S_{OUT} = \frac{29.7}{3.625} = 8.19 \quad S_{IN} = \frac{29.7}{2.625} = 11.31$

FOR SLAB

$D_S = \frac{EI}{(1-\nu^2)} = \frac{E \times 140.4}{.96} = 146E$

$K_S = \frac{D_S(1+\nu)}{R} = \frac{146E\ (1.2)}{28.25} = 6.2E$ TABLE 3-2 OF ⑥

FOR WALL

$D_W = \frac{EI}{(1-\nu^2)} = \frac{E \times 29.7}{.96} = 30.3E$

$\beta^4 = \frac{EA_W}{4R^2 D_W} = \frac{E \times 7.5}{4 \times 28.25^2 \times 30.3E} = .0000775 \rightarrow \beta = .094$

$K_W = 2\beta D = 2 \times .094 \times 30.3E$ EQ. 3-33 OF ⑥

$= 5.7E$

$\pi/\beta = \frac{\pi}{.094} = 33.4'' < \frac{L}{2} = \frac{72}{2} = 36''$

HENCE THE REACTIONS @ TOP & BOTTOM WILL HAVE LITTLE INFLUENCE ON EACH OTHER. ANALYSE AS A LONG CYLINDER TO DETERMINE LOCAL EFFECTS.

RADIAL STRAIN FOR FREE CYLINDER

$\delta = \frac{585 \times 28.25}{4,700,000} = .0034''$

FROM PAGE 476 OF REF ④

RADIAL FORCE ON CYLINDER DUE TO LID $= 2\beta^3 D\delta$

$Q_T = 2\ (.094)^3\ 30.3 \times 4700000 \times .0034 = 816\ \#/in$

FROM PAGE [illegible] OF [illegible] REF (4)

FOR A CYLINDER WITH END BUILT IN

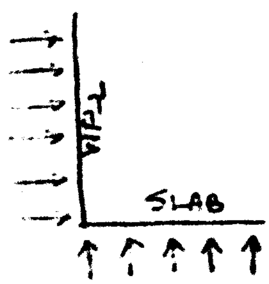
$M = -\frac{q}{2\beta^2} = -\frac{150}{2(.094)^2} = -8488$ IN-LB/IN

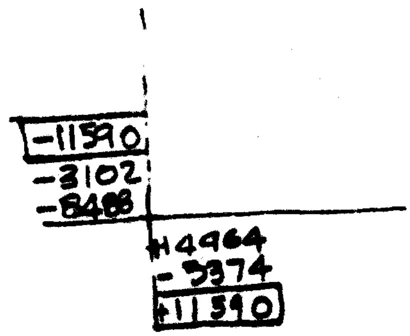
$Q_B = \frac{q}{\beta} = \frac{150}{.094} = 1596$ #

FOR A CIRCULAR SLAB WITH BUILT-IN EDGES,

$M = \frac{q\,r^2}{8} = 150 \times \frac{28.25^2}{8} = 14964$ IN-LB/IN

AS [illegible] IN THE ANALYSIS OF A CYLINDRICAL WALL [illegible] TO A CIRCULAR [illegible] IN pp. 77-103 OF [illegible], THE NET MOMENT @ THE WALL/BASE JOINT CAN BE RESOLVED BY MOMENT DISTRIBUTION





$K_S + K_W = 6.2E + 5.7E = 11.9E$

UNBALANCED MOMENT @ JOINT = 14964 − 8488 = 6476

INCREASE IN WALL MOMENT = $\frac{5.7E}{11.9E}(6476) = 3102$

DECREASE IN SLAB MOMENT = 6476 − 3102 = 3374

NET MOMENT @ JOINT = 11590 IN-LB

DESIGN MOMENT = 1.4 (11590) = 16226

d AVAILABLE = 6.25 − 1.5 − $\frac{.625}{2}$ = 4.313

$A_s = \frac{16226}{.9 \times 60 \times 4.313} = .070$ in²/IN OR .070 × 12 = .84 in²/FT

#5 @ 4¼" O.C. PROVIDES 0.88 in²/FT.

COMPRESSIVE STRESS IN STEEL PL

$$= \frac{11590}{4.375 \times .25} = 10.6 \text{ KSI} < F_b = 22 \text{ KSI}$$

CRACK CONTROL :

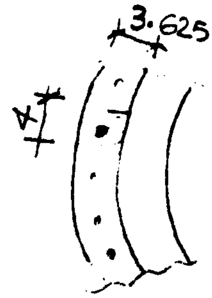
$d_c = 1.75$

$A = \frac{4 \times 3.625}{1} = 14.5$

$f_s = .6 f_y = .6(60) = 36$ KSI

$z = f_s \sqrt[3]{d_c A} = 36 \sqrt[3]{1.75 \times 14.5}$

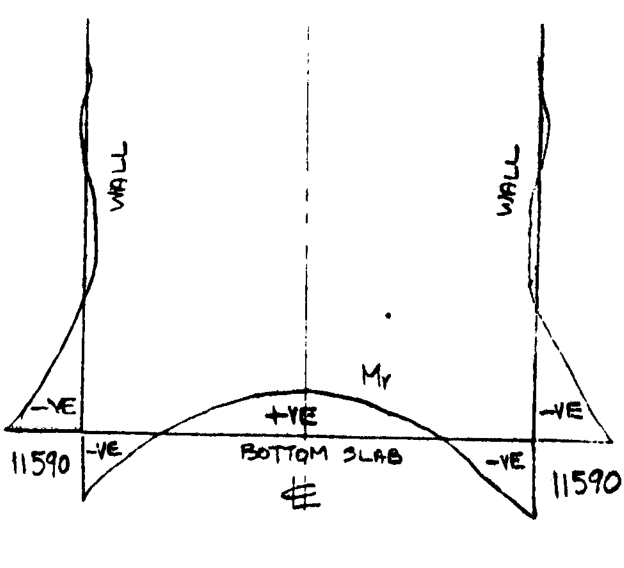
$= 105.8 < 145$



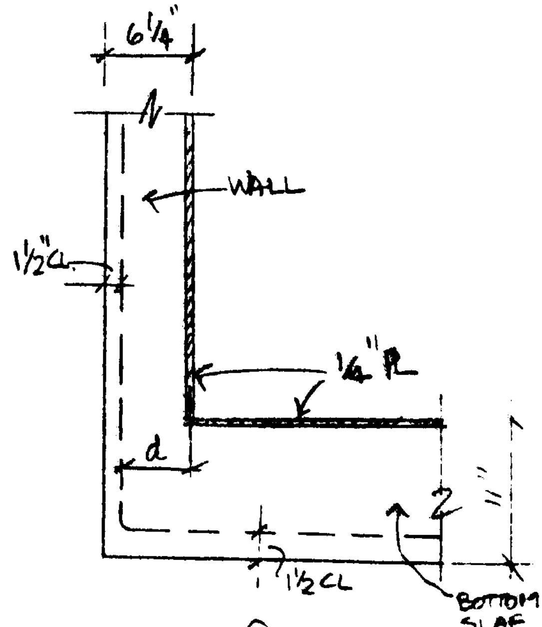
CRACK WIDTH = 0.076 β z = (ACI 10.6) ▽1

$= 0.076 \times 1.2 \frac{(105.8)}{1000} = .0096''$ SAY .01″

TOLERABLE MAX. CRACK WIDTH FOR EXPOSURE TO SOIL IS 0.012 IN — BY REF ▽7.
CRACK WIDTH OF 0.01 IN IS ACCEPTABLE



BENDING MOMENT DIAGRAM



DETAIL @ CORNER

THE MAX −VE BENDING MOMENT @ WALL/BASE JOINT QUICKLY DIES OUT WITHIN A SMALL HEIGHT. HENCE HALF THE REBARS CAN BE TERMINATED @ MIDHEIGHT.

A_s FOR TOP HALF OF CYLINDER FOR SHRINKAGE & TEMP

$= .0018 \times 12 \times 6 = .13 \text{ in}^2/\text{FT}.$

#5 @ 8½" PROVIDE $\frac{12}{8.5} \times .31 = .44 \text{ in}^2/\text{FT}$ OK

−VE STEEL FOR BASE SLAB @ ENDS

DESIGN MOMENT FOR BASE SLAB = 1.4 (11590) = 16226 IN-LB/IN

"d" AVAILABLE $= 10.75 - 1.5 - .625 - \frac{.625}{2} = 8.31 \text{ in}$

#5 @ 8" E W PROVIDES $\frac{.31}{8} = .039$

$a = \frac{60 \times .039}{.85 \times 6} = .46 \qquad d - \frac{a}{2} = 8.31 - \frac{.46}{2} = 8.08$

$M_u = .9 \times 60 \times .039 \times 8.08 = 17.02 \text{ K}$ OR 17,020 IN-LB/IN OK

+VE STEEL FOR BASE SLAB

THE ¼" STEEL PL WILL PROVIDE −VE STEEL AS FOR THE LID. HOWEVER SINCE IT MAY CORRODE AWAY SOME REBARS ARE TO BE PROVIDED.

FOR #4 @ 4" E.W $\qquad d = 10.75 - 1'' - \frac{.5}{2} = 9.0$

$a = \frac{.2 \times 60}{4 \times .85 \times 6} = .59$

$M_u = .9 \times 60000 \times \frac{.20}{4} \times (9.0 - \frac{.59}{2}) = 23,490$ IN-LB/IN

MAX MIDSPAN MOMENT = SS MOMENT − FIXED END MOMENT

= 19506 − 11590 = 7916 IN-LB/IN

REQUIRED $M_u = 1.4 (7916) = 11082 < M_u$ PROVIDED = 23,490 OK

−VE STEEL FOR BASE SLAB @ MIDSPAN

#5 @ 8" PROVIDES $\frac{.31}{8 \times 11} = .0035$ % > .002 REQUIRED FOR SHRINKAGE

HOOP DIRECTION

THE BEHAVIOR IS ONE OF HOOP TENSION WITH SOME BENDING AT WALL TO BASE JOINT

$$\text{HOOP TENSION} = \frac{PD}{2} = \frac{25 \times 56.5}{2} = 706^{\#}$$

SINCE CONCRETE IS NOT ASSUMED TO CARRY ANY TENSION THE HOOP TENSION IS TOTALLY RESISTED BY 1/4" STEEL PL & 1/4" φ WIRE SPIRAL. SINCE E_s IS SAME FOR BOTH,

$$\text{TOTAL STEEL } A_H = \frac{.25}{4} + .25 = .3125 \text{ in}^2/\text{IN}$$

$$(f_t)_{HOOP} = \frac{706}{.3125} = 2260 \text{ PSI} < F_T = .6(36{,}000) = 21{,}600 \text{ PSI FOR } 1/4 \text{ PL}$$

$$\& \; 1.4(2{,}260) < f_y = 60{,}000 \text{ PSI FOR REINF. STEEL}$$

CHECK CONCRETE STRESS

$$\text{EQUIVALENT AREA} = 6 + .3125 \times 6 = 7.875 \text{ in}^2$$

$$\text{TENSILE STRESS IN CONC.} = \frac{706}{7.875} = 90 \text{ PSI} < f_r = 6\sqrt{6000} = 465 \text{ PSI}$$

IT IS QUITE UNLIKELY THAT CONCRETE WILL BE CRACKED UNDER INTERNAL PRESSURE.

LONGITUDINAL DIRECTION

THE BENDING MOMENT OCCURING @ WALL TO BASE JOINT CAN BE FOUND BY PROPORTIONING RESULTS OBTAINED BY THE ANALYSIS FOR EXTERNAL LOADING. THE MOMENT CREATES TENSION INSIDE, & COMPRESSION OUTSIDE

$$(+M)_{LONGITUDINAL} = \frac{25}{150}(11590) = 1932 \text{ IN-LB/IN}$$

$$(f_b)_{CONC} = \frac{1932}{8.19} = 236 \text{ PSI COMP.}$$

$$(f_b)_{STEEL} = 6\left(\frac{1932}{11.31}\right) = 1025 \text{ PSI} < F_b = 24{,}000 \text{ PSI} \quad \text{OK}$$

BASE SLAB

- PROPORTIONING MOMENT VALUES OBTAINED FOR EXTERNAL PRESSURE

$M_{℄} = \frac{25}{150}(7916) = 1319$ IN-LB/IN TENSION OUTSIDE

$M_{ENDS} = \frac{25}{150}(11590) = 1932$ IN-LB/IN TENSION INSIDE

FOR #5 @ 8" $\quad d = 11'' - 1\frac{1}{2} - \frac{.31}{2} = 9.35$

$a = \frac{.31 \times 60}{8 \times .85 \times 6} = .46 \qquad \rho = \frac{.31}{8 \times 9.35} = .0041$

$M_u = .9 \times \frac{.31 \times 60}{8}\left(9.35 - \frac{.46}{2}\right) = 19{,}084$ IN-LB/IN

$> 1.4(1319) = 1845$ IN-LB/IN

$\rho_{MIN} = \frac{200}{60000} = .0033 < \rho_{PROVIDED} = .004$

M_{ENDS}

$(f_t)_{TOP} = \left(\frac{1932}{28.4}\right)6 = 408$ PSI $< .6 f_y = 21{,}600$ PSI

$(f_c)_{BOT} = \frac{1932}{23.2} = 83$ PSI $< .45 f'_c = 2700$ PSI OK

DESIGN OF LID / CONTAINER JOINT

TOTAL FORCE FROM INTERNAL PRESSURE

$$= \frac{\pi \times 50^2}{4} \times 25^{\#} = 49{,}087^{\#}$$

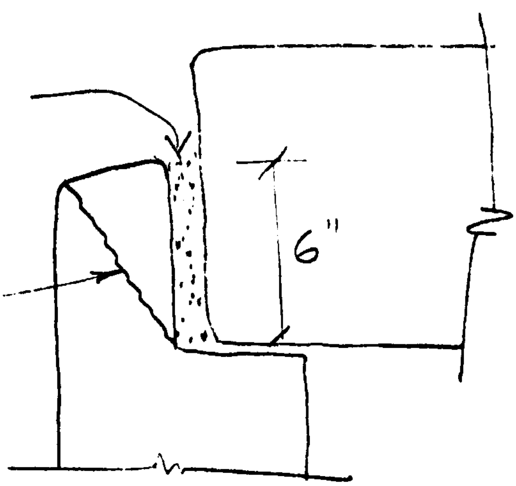
WT. OF LID	1,944
NET UPWARD FORCE	47,143 #

SHEAR STRENGTH OF CONCRETE BASED ON $4\sqrt{f_c'}$

$$= .85(\pi \times 54 \times 6 \times 4 \times \sqrt{6000}) = 268{,}000^{\#} > 1.4(47{,}143) = 66{,}000$$

$$F.S. = \frac{268{,}000}{66{,}000} = 4$$

THE GROUT MUST HAVE A MIN. $f_c' = 6000$ PSI TO PREVENT FAILURE IN GROUT



CONCRESIVE 1310* IF SELECTED A MORTAR BINDER HAS A SLANT SHEAR STRENGTH VALUE OF 3200 PSI UNDER WET CONDITIONS $> 4\sqrt{6000} = 310$ PSI OK

*NOTE: THE CONCRESIVE AEX-1512/-1513 MATERIALS USED ARE ESSENTIALLY IDENTICAL TO -1310 EXCEPT FOR CURE TIMES AND VISCOSITY.

THE MOST PROBABLE BURSTING PRESSURE WILL BE THE PRESSURE CORRESPONDING TO THE LOWEST OF THE FOLLOWING FAILURE MODES

(a) BLOW-OUT OF THE BASE SLAB

(b) BURSTING OF THE CONTAINER WALL FROM HOOP TENSION

(c) BLOW-OUT OF THE TOP LID.

(d) BENDING OF THE TOP LID

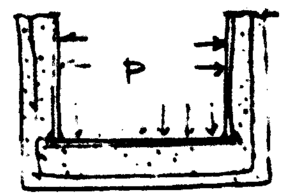
FAILURE MODES (a), (b) & (d) ARE EXPECTED TO BE DUCTILE AS THEY INVOLVE YIELDING OF STEEL LINER AND/OR REINFORCING BARS

FAILURE MODE (c) WILL BE BRITTLE AS IT INVOLVES CONCRETE FAILURE IN SHEAR / TENSION.

MODE (a)

BASEPLATE $f_u = 75$ KSI FOR REBARS

& $f_u = 60$ KSI FOR 1/4 PL



$$\left(\frac{\pi \times 50^2}{4}\right) p = \pi \times 50 \times .25 \times 60 + 44 \times .31 \times 75$$

$$p = \frac{3379}{1963} = 1.72 \text{ KSI} \quad \text{OR} \quad 1720 \text{ PSI}$$

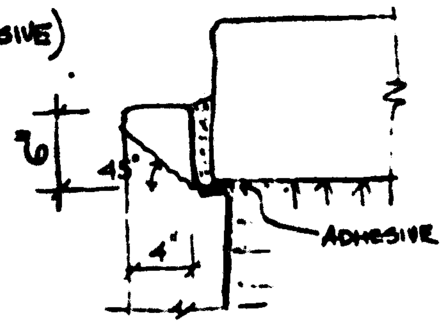
MODE (b)

$$p \frac{50}{2} = .25 \times 1 \times 60 + \frac{.05}{4} \times 75 \rightarrow p = .64 \text{ KSI}$$

OR 640 PSI

MODE (c) (ASSUME NO CONTRIBUTION FROM ADHESIVE)

FAILURE LIMITED BY CONCRETE



$$\left(\frac{\pi}{4} 50^2\right) p = \left(\pi \times 58.5 \times 4\sqrt{2}\right) \times 6\sqrt{6000}$$

$$p = (1040) \times 6 \times 77.5 = 246 \text{ PSI}$$

- FAILURE LIMITED BY MORTAR / BINDER

$$\left(\frac{\pi}{4} 50^2\right) p = \pi \times 52.5 \times 6 \times 3200$$ ← - - - SLANT SHEAR STRENGTH FOR CONCRESIVE 1310

$$p = 1613 \text{ PSI}$$

(d) BENDING FAILURE OF TOP LID

FOR #4 @ 4" TOP STEEL (GRADE 60)

TENSILE STRENGTH OF GRADE 60 = 75 KSI

$A_s = \frac{.2}{4} = .05 \text{ in}^2/\text{IN}$

$a = \frac{.05 \times 75}{.85 \times 1 \times 6} = .74$ $\quad d - \frac{a}{2} = 9.0 - \frac{.74}{2} = 8.63$

$M_u = .05 \times 75 \times 8.63 = 32.4$ IN-K/IN

IF LID IS ASSUMED TO BE SIMPLY SUPPORTED

$\frac{P r^2}{16}(3+\nu) = 32.4$

$p = \frac{32.4 \times 16}{3.2 \times 25.25^2} = .254$ KSI OR 254 PSI

CONCLUSION

THE MOST PROBABLE BURST PRESSURE IS 250 PSI & THE FAILURE MODE IS LIKELY TO BE THRU SHEARING OF THE TOP END OF THE CONTAINER BODY.

THE PROBABLE BURST PRESSURE WILL INCREASE AS THE CONCRETE GAINS STRENGTH FROM AGING. THIS IS ILLUSTRATED IN ADDENDA #1.

$M.S._{25 psi} = \frac{246}{25} - 1 = +8.84$

TASK: TO FIND THE ULTIMATE EXTERNAL LOAD APPLIED OVER A 24"ϕ CIRCULAR AREA OF LID

EQUATION (6.9) OF REF (8) GIVES A LOWER BOUND VALUE FOR THE TEST PROGRAM CONSISTING OF STEEL PLATE REINFORCED CONCRETE SLAB SUBJECT TO UNIFORM OVER PRESSURE.

ULTIMATE SHEAR STRESS @ SUPPORT

$f_c' = 6000^{psi}$; $\rho = .0227$
$f_y = 36^{ksi}$; $L = 50.5"$; $t = 11"$

$$V_u = .0076 f_y \sqrt{\frac{\rho f_c'}{(L/t)}}$$

$$= .0076 \times 36 \sqrt{\frac{.0227 \times 6000}{(50/11)}} = 1.5 \text{ KSI} \quad (\approx 20\sqrt{f_c'})$$

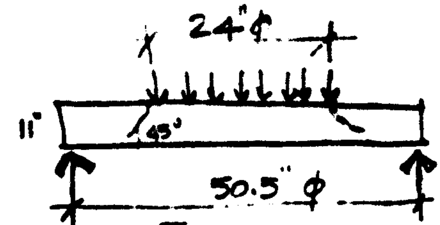
HOWEVER V_u @ A DISTANCE 't' FROM SUPPORTS ARE ONLY $12\sqrt{f_c'}$ OR $12\sqrt{6000} = .930$ KSI ⟵ USE

TOTAL LOAD THAT WILL PRODUCE THIS V_u ALONG A (24+11) = 35"ϕ CIRCLE

$$= \pi \times 35" \times 11" \times .93^{ksi} = 1124^{KIPS}$$

THIS AMOUNTS TO $\frac{1124}{(.7854)24^2} = 2.5$ KSI APPLIED IN 24"ϕ AREA

HOWEVER UNDER THIS LOAD FLEXURAL PROBLEMS MAY DOMINATE



$$M_{max} = \frac{\pi c^2 q}{4\pi}\left[(1+\nu)\log_e\frac{a}{c} + 1 - \frac{(1-\nu)c^2}{4a^2}\right] \quad (4)$$

$$= \frac{(12)^2 q}{4}\left[1.2\log_e\frac{25.25}{12} + 1 - \frac{(.8)12^2}{4 \times 25.25^2}\right] = 66.5\,q$$

FOR $q = 2.5$ KSI

$M_{max} = 2.5 \times 66.5 = 165$ "K/IN

BENDING STRENGTH OF SLAB

FOR $.25\ in^2/IN$ $\quad f_u = 60\ KSI$

$a = \dfrac{.25 \times 60^{KSI}}{.85 \times 1 \times 6} = 2.94$

$d - \dfrac{a}{2} = 10.875 - \dfrac{2.94}{2} = 9.4$

$M_u = .25 \times 60 \times 9.4 = 141\ ^{''}K/IN.$

PRESSURE CORRESPONDING TO THIS STRENGTH

$q_{max} = \dfrac{141}{165}(2.5) = 2.12\ KSI$

CONCLUSION

TOTAL LOAD ON 24" ϕ CIRCULAR AREA

$= .7854 \times 24^2 \times 2.12 = \underline{\underline{960}}^K$

NOTE: THE ABOVE COMPUTATIONS ASSUME LINEAR VARIATION OF STRAIN ACROSS DEPTH UPTO FAILURE AND USES ULTIMATE STRESS OF STEEL INSTEAD OF YIELD STRESS. HENCE THE RESULTS ARE ONLY BEST ESTIMATES.

ABAM CONSULTING ENGINEERS

PROJECT NUPAC TMI CASK

SUBJECT EXTERNAL RUPTURE LOAD FOR DYNAMIC LOADS

Revision 1

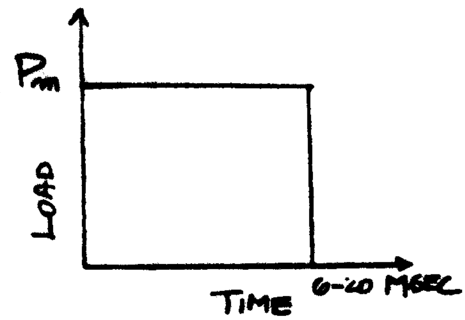
SHEET NO. 27 OF

DES. VK

JOB NO. B1085

DATE

TASK: TO FIND THE ULTIMATE EXTERNAL LOAD APPLIED DYNAMICALLY OVER A 24" ϕ CIRCULAR AREA OF LID.



AGAIN USING REF (B) AS GUIDE

$T = 3.11 \times 10^{-5} \frac{a^2}{t}$ a = RADIUS, t = THICKNESS OF SLAB

$= 3.11 \times 10^{-5} \frac{25.23^2}{11} = .0018$ SEC   SAY .2 MSEC.

$\frac{t_d}{T} = \frac{6}{.2}$ TO $\frac{20}{.2}$ OR 30 TO 100

FOR HIGH RATIOS OF $\frac{t_d}{T}$ SUCH AS ABOVE

$\frac{P_m}{Q_m} \longrightarrow 0.72$

P_m Peak Dynamic Load

Q_m Observed max. static resistance

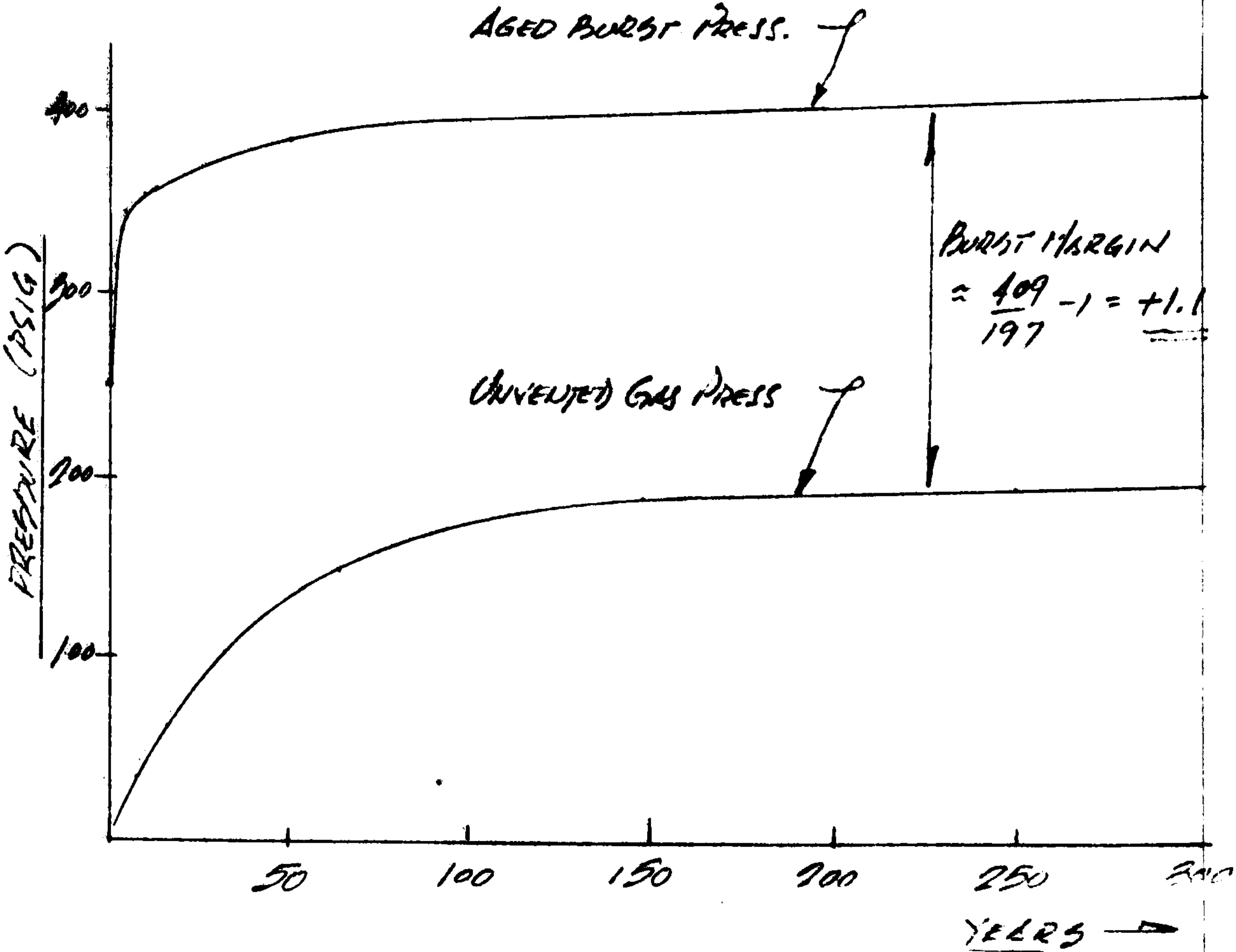
$P_m = .72(960^k) = 691^k$

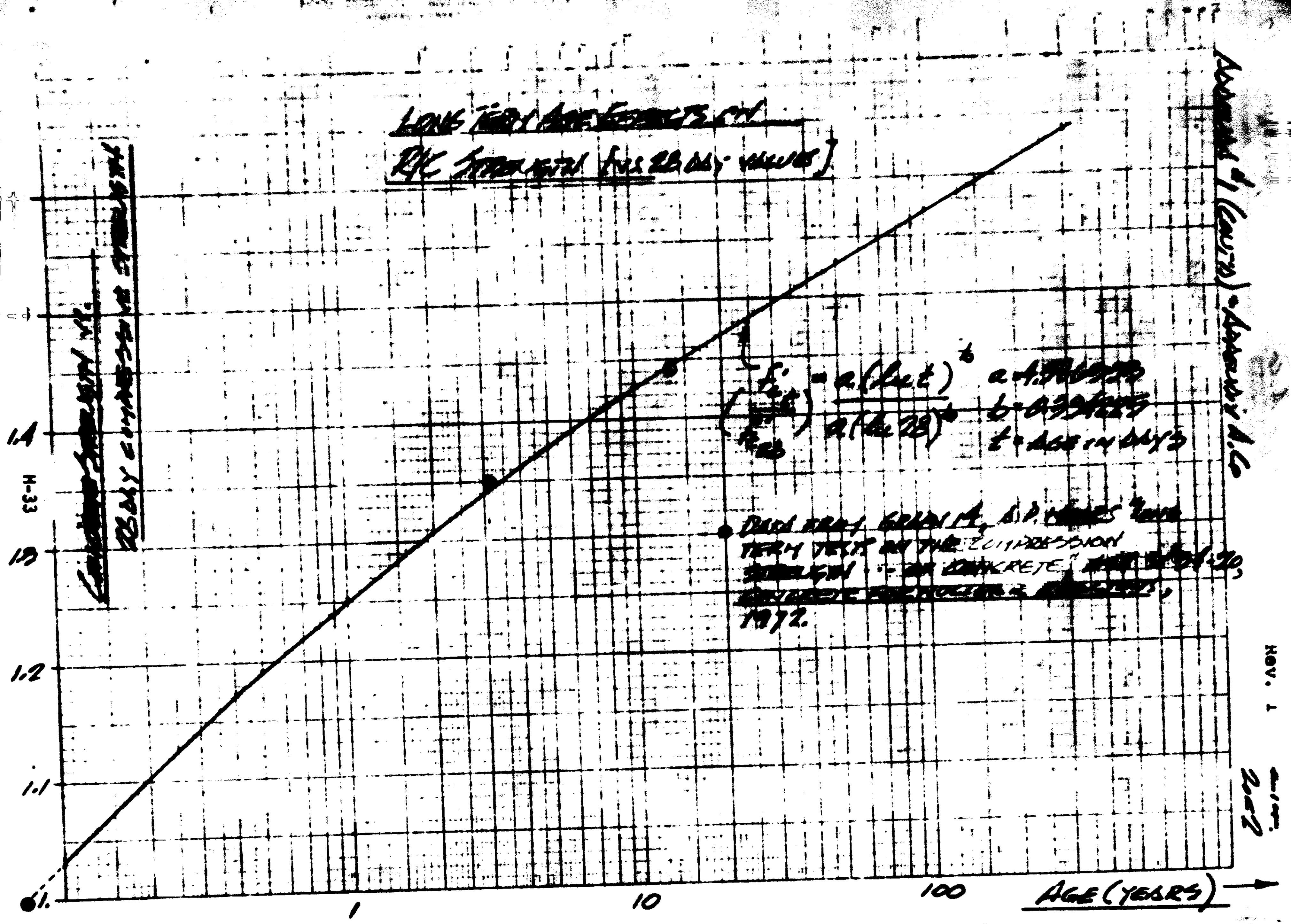
CONCLUSION

TOTAL RUPTURE LOAD OVER A 24" ϕ CIRCULAR AREA IF APPLIED DYNAMICALLY IN 6-20 MILLI SECONDS $= 691^k$

STRENGTH & BURST PRESSURE VS. AGE

PAGE 24 OF THE STRENGTH ANALYSIS PREDICTS A BURST PRESSURE OF 250psig AT 28DAY STRENGTH. CONCRETE INCREASES STRENGTH WITH AGE AS SHOWN ON THE NEXT SHEET. COMPARISON OF HIWDC BURST STRENGTH VS AGE IS PLOTTED BELOW VS. DESIGN BASE GAS PRESSURES, ASSUMING NO VENTING.




LONG TERM AGE EFFECTS ON
R/C STRENGTH (VS 28 DAY VALUES)
1.1
1.2
1.3
1.4
1
10
100
AGE (YEARS)
t = AGE IN DAYS
1972.

H-33

REV. 1

BONDED LID RETENTION - 30' HYPOTHETICAL ACCIDENT.

THIS ANALYSIS EVALUATES THE 'G' FORCES REQUIRED TO CAUSE THE BODY AND LID TO SEPARATE.

THERE ARE TWO POTENTIAL FAILURE MODES:
- ✓ IN THE EPOXY BOND
- ✓ IN THE ADJOINING CONCRETE

THE FORCE REQUIRED TO RUPTURE IS ESTIMATED AS FOLLOWS:

(1) EPOXY BOND

$$A = (6.75")(\pi)(52.5") = 1113.3\ IN^2$$

$$\text{EPOXY SHEAR STR} = \frac{1}{\sqrt{3}}(6000\ psi) = 3464\ psi$$

$$F_{RUP-EPOXY} = (1113)(3464) \doteq 3,856,000\ LBS.$$

(2) ADJOINING CONCRETE

PRESSURE TO RUPTURE = 246 psig [SEE p. 27 of A.6]

$$F_{RUP-CONC} = (246)\frac{\pi}{4}(50^2) \doteq 483,020\ LBS.$$

∴ FAIL. IS IN CONCRETE

THE COMBINED WEIGHT OF LID & PAYLOAD IS:

LID	2531 LBS
EPICOR II	3250
RUB. STRIPS.	139
TOTAL	5920 LBS

THE AXIAL 'G' FORCE @ RUPTURE IS:

$$\eta_g = 483,020/5920 = \underline{81.6g}$$

COMMENTS & CONCLUSIONS

1. 'G' VALUES OF THIS MAGNITUDE CAN DEVELOP UNDER END IMPACT - BUT - END IMPACT CANNOT IMPOSE FORCES THAT WOULD LOAD THE JOINT AS NEEDED TO CAUSE LID/BODY SEPARATION.

   a. BOTTOM END IMPACT - LID LOADS CARRIED VIA STEP TO BODY. BOTH LID & BODY HAVE HEAVY SHEAR KEYS.

   b. TOP END IMPACT - LID WOULD CONTACT FIRST. BODY WOULD THEN LOAD LID VIA STEP - SAME COMPRESSION LOAD PATH AS FOR BOTTOM END IMPACT.

2. SIDE IMPACTS WOULD NOT IMPOSE SEPARATION FORCES BETWEEN LID AND BODY.

3. CORNER IMPACTS COULD IMPOSE SEPARATION FORCES - BUT AXIAL ACCELERATIONS OF 82G'S ARE VERY UNLIKELY. TO ILLUSTRATE, A CRUSH OR CRUMPLE ZONE OF ONLY 4" WOULD REDUCE 'G' LOADS TO LESS THAN 82 G'S

$$\frac{30\,FT \times 12\,IN/FT}{81.6} = 4.4\ IN\ CRUSH.$$

∴ LID WILL NOT SEPARATE UNDER A 30' DROP WHEN CONTAINED IN A TYPE 'B' PACKAGE.

APPENUIX I
LIFTING AND HANDLING ANALYSIS

R. T. Haelsig

Nuclear Packaging, Inc.

APPENDIX I

LIFTING AND HANDLING ANALYSIS

I.1 Introduction

Lifting and handling equipment are defined on Dwgs. EP-70-01D, "Spreader Bar Fabrication Details," and EP-70-02D," Lift Links Fabrication Details."

I.2 Spreader Bar, Drawing EP-70-01D

The spreader bar has been checked for a fully loaded container weight of 17,200 pounds. The force imposed upon each of the beams (Item 1) under a normal lift is

$$\text{Shear, } V = \frac{17{,}200 \text{ lb}}{2} = 8{,}600 \text{ lb} \quad \text{(I-1)}$$

$$\text{Moment, } M = 8{,}600 \text{ lb } (57.75 \text{ in.}/2) = 248{,}325 \text{ in.-lb} \quad \text{(I-2)}$$

The beam, Item 1, is a W 10 x 26 with section properties of

$$S = 27.9 \text{ in.}^3 \quad \text{(I-3)}$$

$$A_v = (0.260)\ (10.33) = 2.69 \text{ in.}^2\ .$$

Stresses and margins of safety, using allowables from AISC, Section 1.5 for ASTM A-36 steel (Table I-1) are

$$f_b = \frac{248{,}325}{27.9} = 8{,}901 \text{ psi} \quad \text{(I-4)}$$

$$MS_b = \frac{12.76}{8.90} - 1 = +0.43$$

TABLE I-1. ALLOWABLE STEEL STRESSES

Stress Type	Symbol	Normal Lift Allowable Stress (psi)
Tension	F_t	$0.6\ F_s$ [a] $= 11,600$
Shear	F_v	$0.4\ F_s = 7,730$
Bending	F_b	$0.66\ F_s = 12,760$
Bearing	F_p	$0.9\ F_s = 17,400$

a. $F_s = \frac{1}{6} \cdot \text{Min}\ \frac{Fy}{3}, \frac{Fu}{5} = 19,330$ psi (A-36)

$$f_v = \frac{8600}{2.69} = 3,197 \text{ psi}$$

$$M.S._v = \frac{7.73}{3.20} - 1 = +1.42 \quad .$$

Connecting flange welds are full penetration, possessing the same stresses and allowables. Web welds are double fillets with greater strength than the full-beam-section capacity.

The primary lifting eye (Item 3) is a 6.6-inch-wide plate 1 inch thick, with a 1.5-inch-diameter hole and 2-inch margin. Using a conventional 40-degree tearout relation, the capability of the lug at limit stresses is

$$P_L = 2\ F_v t\ (E_m - d/2 \cos 40°) \qquad \text{(I-5)}$$

$$= (2)\ (7,730)\ (1.0)\ (2 - 0.75 \cos 40°) = 22,038 \text{ lb} \quad .$$

Net tensile area and associated limit tensile capacity are

$$A_T = (6.6 - 1.5)\ (1) = 5.10 \text{ in.} \tag{I-6}$$

$$P_L = (5.10)\ (11{,}600) = 59{,}200 \text{ lb} \quad . \tag{I-7}$$

Minimum primary lift lug margin is

$$M.S._L = \frac{22.04}{17.2} - 1 = +0.28 \quad . \tag{I-8}$$

Lift lugs of the container body (Item 2) are similar in lug shape excepting thickness is reduced to 0.50 inch, edge margin to 1.75 inches, and hole diameter to 1.44 inches. Three and one-half-inch-square cheek plates are provided on both sides of the lug. Limit capacity is

$$P_L = (2)\ (7{,}730)\ (1.25)\ (1.75 - \frac{1.44}{2} \cos 40°) \tag{I-9}$$

$$= 23{,}160 \text{ lb} \quad .$$

Net tensile area and associated limit tensile capacity are

$$A_T = (6.6 - 1.44)\ (0.5) + (3.5 - 1.44)\ (0.75) = 4.125 \text{ in.}^2 \tag{I-10}$$

$$P_L = (4.125)\ (11{,}600) = 47{,}850 \text{ lb} \quad . \tag{I-11}$$

Minimum body lift lug margin is therefore

$$MS_L = \frac{23.16}{8.6} - 1 = +1.69 \quad . \tag{I-12}$$

I.3 Lift Links, Drawing EP-70-02D

All elements shown on this drawing are standard components with safe working load ratings prescribed by manufacturers. Table I-2 presents margins of safety based upon those values. Manufacturers' data sheets follow the table.

TABLE I-2. MARGIN OF SAFETY

Item	Component	SWL[a] (lb)	Design Load (lb)	Margin of Safety
1	Wire rope, 0.50-in. ϕ	5,320	844	+5.30
2	Master link, 1-in. ϕ	20,300	2,531	+7.02
3	Socket, 0.50-in. ϕ	5,320	844	+5.30
4	Shackle, 3-1/4T	6,500	844	+6.70
5	Eye hook, 4-1/2T	9,000	8,600	+0.05
6	SL eye, 2T	4,000	844	+3.74
7	Link, 1/2-in. chain	11,250	844	+12.33
8	Socket, 0.75-in. ϕ	11,760	8,600	+0.37
9	Wire rope, 0.75-in. ϕ	11,760	8,600	+0.37
10	Socket, 0.75-in. ϕ	11,760	8,600	+0.37
11	Shackle, 4-3/4T	9,500	8,600	+0.10

a. Where breaking strength given, SWL = 1/5 break.

HUSKY Blue/white IWRC

Extra Improved Plow Steel — 15% Greater Strength

Pacific HUSKY Grade Blue/white Strand is properly Preformed, Internally Lubricated, and has an independent wire rope core. It is available in Regular Lay or Lang Lay.

The table below covers the 6 x 19 classification ropes of the following wire rope constructions:

6 x 25F IWRC, 6 x 21F IWRC, 6 x 19G IWRC, 6 x 26G IWRC

Diameter in Inches	Approx. Weight Per Foot	Breaking Strength in Tons of 2000 lbs.
1/4	.116	3.40
5/16	.180	5.27
3/8	.260	7.55
7/16	.35	10.2
1/2	.46	13.3
9/16	.59	16.8
5/8	.72	20.6
3/4	1.04	29.4
7/8	1.42	39.8
1	1.85	51.7
1-1/8	2.34	65.0
1-1/4	2.89	79.9
1-3/8	3.50	96.0
1-1/2	4.16	114.0
1-5/8	4.88	132.0
1-3/4	5.67	153.0
1-7/8	6.50	174.0
2	7.39	198.0
2-1/8	8.35	221.0
2-1/4	9.36	247.0
2-1/2	11.6	302.0
2-3/4	14.0	361.0

HUSKY Blue/white STRAND IWRC

Extra Improved Plow Steel

For extra heavy duty, providing a higher safety factor, "Husky Blue/white Strand" has 15% greater strength than listed for "Supersteel," and is used for similar purposes.

The wire used in "Husky Blue/white Strand" is drawn from special steel. Special drawing practice using the most modern scientific equipment assures superlative high strength, abrasion resistance, and fatigue resisting properties.

Pacific "Husky grade" is properly PREformed, Internally Lubricated, and has an independent wire rope core. It is available in Regular Lay or Lang Lay.

The table below covers the 6 x 37 classification ropes of the following wire rope constructions:

6 x 36G IWRC, 6 x 41F IWRC, 6 x 46F IWRC, 6 x 49FG IWRC, 6 x 49G IWRC

Diameter in Inches	Approx. Weight Per Foot	Breaking Strength in Tons of 2000 lbs.
1/4	.116	3.40
5/16	.180	5.27
3/8	.260	7.55
7/16	.35	10.2
1/2	.46	13.3
9/16	.59	16.8
5/8	.72	20.6
3/4	1.04	29.4
7/8	1.42	39.8
1	1.85	51.7
1-1/8	2.34	65.0
1-1/4	2.89	79.9
1-3/8	3.50	96.0
1-1/2	4.16	114.0
1-5/8	4.88	132.0
1-3/4	5.67	153.0
1-7/8	6.50	174.0
2	7.39	198.0
2-1/8	8.35	221.0
2-1/4	9.36	247.0
2-1/2	11.6	302.0
2-3/4	14.0	361.0
3	16.6	425.0
3-1/8	18.0	458.0

SUPER-7® Blue/white Strand IWRC

PATENTED—EXTRA IMPROVED PLOW STEEL

"SUPER-7" wire rope is a NEW concept in wire rope design. Essentially, it consists of seven rope strands (as the name implies) helically laid around a core.

Conceived as an intermediate rope between the usual 6-strand and 8-strand ropes, it has been proved by extensive field and laboratory tests to be an ideal ALL-PURPOSE rope.

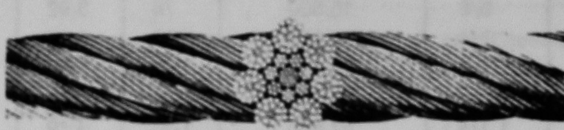
"SUPER-7" wire rope combines in ONE wire rope ALL the desirable characteristics one looks for in a wire rope — high strength and high abrasion with good fatigue life; flexibility and pliability with stability, ruggedness and resistance to crushing.

ALL-PURPOSE — "SUPER-7" comes closer to being an all-purpose rope than any wire rope ever manufactured. It is a true 7-strand wire rope plus an independent wire rope core. This approaches the flexibility of 8-strand rope, and the fatigue resistance of 6x37 rope, and the ruggedness of 6x19 rope.

SUPER-7® HUSKY GRADE IWRC

Diameter in Inches	Approx. Wt. Per Foot	Breaking Strength in Tons of 2000 lbs.
5/16	.18	5.19
3/8	.26	7.44
7/16	.35	10.1
1/2	.46	13.1
9/16	.59	16.5
5/8	.72	20.3
3/4	1.04	29.0
7/8	1.42	39.3
1	1.85	51.0
1-1/8	2.34	64.2
1-1/4	2.89	78.3
1-3/8	3.50	94.9
1-1/2	4.16	112.0
1-5/8	4.88	131.0
1-3/4	5.66	152.0

SUPER-7®
MONO-LAY EXCAVATOR ROPE
Lang Lay HUSKY IWRC



SUPER-7 Mono-Lay Ropes combine the proven SUPER-7 qualities, 37-wire flexibility, Mono-Lay IWRC construction and HUSKY Grade wire to produce a rope having the greatest balance of strength, flexibility, and stability of all the ropes in the Pacific family.

These ropes derive their optimum strength from the fact that the IWRC is so integrated with the outer seven rope strands that the latter are positively supported or cradled in the valleys of the seven outer strands of the IWRC. This feature gives maximum rope support and, consequently, greatest possible strength.

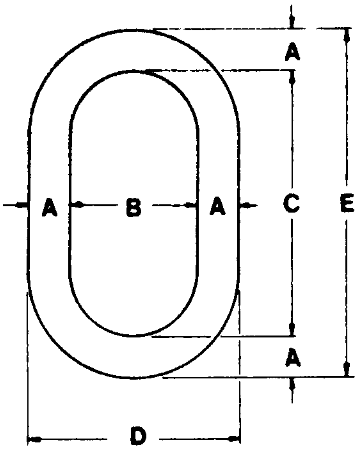
Principal uses for SUPER-7 Mono-Lay Ropes are for heavy-duty excavators, particularly as hoist ropes on shovels and draglines.

7 x 36F PREformed Lang Lay HUSKY MONO-LAY with Integrated 8-Strand IWRC

Diameter In Inches	Approx. Wt. Per Foot	Breaking Strength In Tons of 2000 Lbs.
1	2.01	55.8
1⅛	2.54	70.3
1¼	3.14	86.4
1⅜	3.80	104.
1½	4.52	123.
1⅝	5.31	144.

A-342
WELDLESS ALLOY MASTER LINKS

FORGED ALLOY STEEL — QUENCHED & TEMPERED



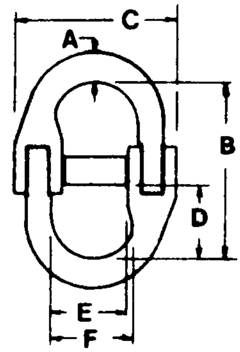
STOCK DIA. A	B	C	D	E	WEIGHT EACH	WORK LOAD* SINGLE PULL POUNDS
1/2	2.50	5.00	3.50	6.00	.81	4,100
5/8	3.00	6.00	4.25	7.25	1.5	5,500
3/4	2.75	5.50	4.25	7	2	8,600
1	3.50	7.00	5.50	9	4.6	20,300
1 1/4	4.38	8.75	6.88	11.25	9.2	29,300
1 1/2	5.25	10.50	8.25	13.50	15.7	39,900
1 3/4	6.00	12.00	9.50	15.50	24.5	52,100
2	7.00	14.00	11.00	18.00	38.1	81,400
†2 1/4	8.00	16.00	12.50	20.50	54.8	99,500
†2 1/2	8.00	16.00	13.00	21.00	71.6	122,750
†2 3/4	9.50	16.00	15.00	21.50	87.7	148,500
†3	9.00	18.00	15.00	24.00	115	190,000
†3 1/4	10.00	20.00	16.50	26.50	145	218,500
†3 1/2	12.00	24.00	19.00	31.00	200	232,500

*Minimum Ultimate Strength Six times working load limit.
†Welded Master Link.

A-336
LOK-A-LOY® 6
ALLOY CONNECTING LINK

FORGED ALLOY STEEL — QUENCHED & TEMPERED

(U.S. PATENT NO. RE-27620)

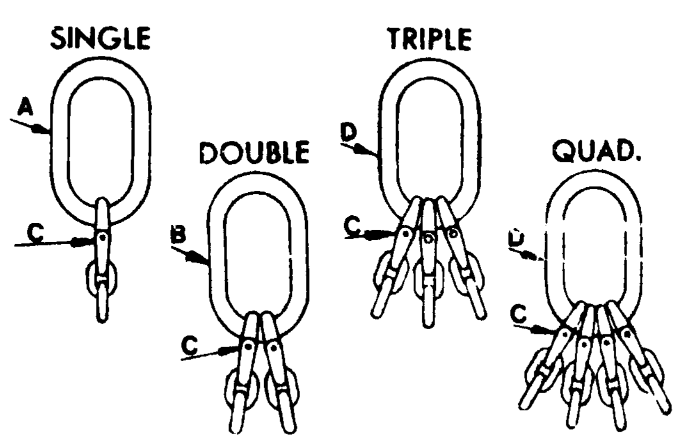


CHAIN SIZE INCHES	WORKING LOAD LIMIT POUNDS	A	B	C	D	E	F	DIA. HOLE TO ACCEPT MALE LEG	WEIGHT EACH POUNDS
1/4	3,250	.31	2.05	1.66	.87	.82	.90	.49	.25
3/8	6,600	.45	2.72	2.30	1.16	1.08	1.22	.65	.50
1/2	11,250	.58	3.33	3.13	1.42	1.40	1.56	.87	1.10
5/8	16,500	.78	3.92	3.94	1.67	1.67	1.86	1.05	2.20
3/4	23,000	.89	4.84	4.44	2.09	1.87	2.19	1.18	4.00
7/8	28,750	1.00	5.82	5.28	2.54	2.12	2.50	1.38	5.75
1	38,750	1.08	6.48	6.07	2.84	2.55	2.93	1.47	7.53
1 1/4	57,500	1.38	8.49	7.65	3.77	3.52	3.99	1.73	15.00

Ultimate Load is Four Times Working Load Limit.

Alloy Sling Chain Assembly Charts

ALLOY CHAIN SIZE	A MASTER LINK	B MASTER LINK	C LOK-A-LOY LINK	D MASTER LINK
1/4	A342- 1/2	A342- 1/2	G336- 1/4	A342- 3/4
3/8	A342- 3/4	A342- 3/4	G336- 3/8	A342-1
1/2	A342-1	A342-1	G336- 1/2	A342-1 1/4
5/8	A342-1	A342-1 1/4	G336- 5/8	A342-1 1/2
3/4	A342-1 1/4	A342-1 1/2	G336- 3/4	A342-1 3/4
7/8	A342-1 1/2	A342-1 3/4	G336- 7/8	A342-2
1	A342-1 3/4	A342-2	G336-1	A342-2 1/4
1 1/4	A342-2	A342-2 1/4	G336-1 1/4	A342-2 3/4

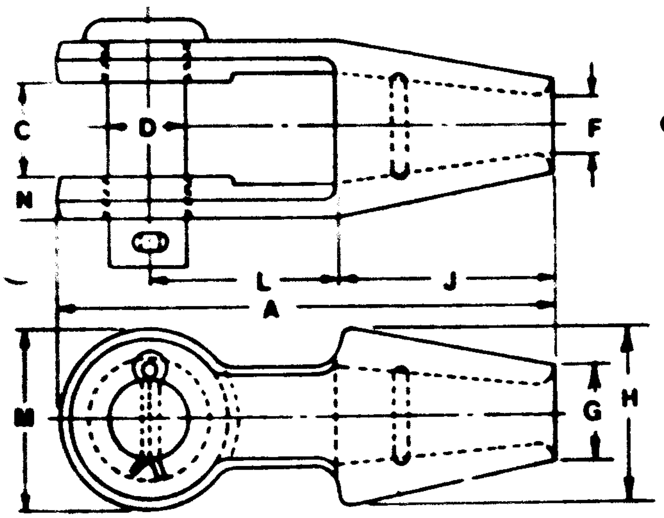


SPELTER SOCKETS — FORGED STEEL

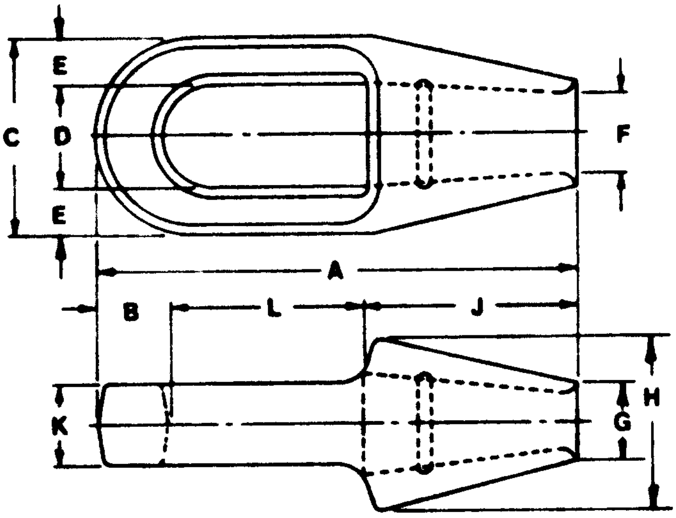
**et or exceed Federal Specification RR-S-550 Spelter socket terminations have an efficiency rating of 100% This rating ased on the catalog strength of wire rope

G-416 & S-416 OPEN SPELTER SOCKETS

ROPE DIA.	A	C	D	F	G	H	J	L	M	N	WT. LBS. EACH
1 4	4.31	69	69	31	63	1 31	2 00	1.56	1 31	.31	.9
5/16-3/8	4 63	81	.81	.44	75	1.63	2.00	1 75	1.56	.44	1.3
7/16-1/2	5 56	1 00	1 00	56	1.00	1.94	2 50	2 00	1 94	.50	2.3
9/16-5/8	6.75	1.25	1 19	69	1 13	2.25	3 00	2.50	2.25	.56	3.9
3 4	7 94	1 50	1.38	.81	1 25	2 69	3 50	3.00	2.63	.63	6
7 8	9.25	1 75	1 63	97	1.50	3.25	4.00	3.50	3.13	.75	10
1	10.56	2 00	2 00	1 13	1.75	3 75	4.50	4 00	3 75	88	15.5
1 1/8	11 81	2 25	2 25	1 25	2.00	4 25	5 00	4.50	4.13	1.00	24
1 1 4-1 3 8	13.19	2 50	2 50	1 50	2 25	4 75	5.50	5.00	4 75	1 13	32
1 1/2	15.12	3 00	2 75	1 63	2.75	5.25	6.00	6.00	5.38	1.19	46



416 (Open)



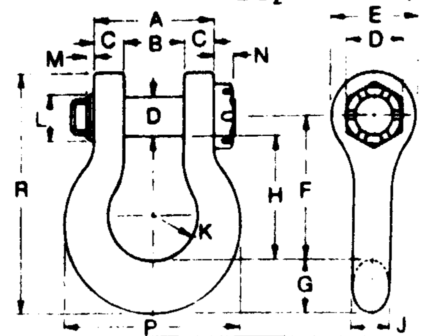
417 (Closed)

Note: Above drawings illustrate one groove used on sockets 3 4" and smaller Sizes 7 8" to 1 1/2" inclusive use 2 grooves Sizes 1 5/8" and larger use 3 grooves

G-417 & S-417 CLOSED SPELTER SOCKETS

ROPE DIA.	A	B	C	D	E	F	G	H	J	K	L	WT. LBS. EACH
1 4	4 25	44	1 44	81	31	31	63	1 31	2 00	50	1 81	5
5/16-3/8	4 63	56	1 69	94	38	44	75	1 56	2.00	.63	2.08	1
7/16-1 2	5 50	69	2 00	1 13	44	56	1 00	1 94	2 50	88	2 31	1 8
9/16-5/8	6 38	81	2 63	1 38	63	69	1 19	2.38	3.00	1.08	2.56	3.4
3/4	7 63	1 06	3 00	1 63	69	81	1 31	2 75	3 50	1 25	3 06	5 1
7/8	8 88	1 31	3.63	1 88	88	97	1 50	3.25	4.00	1.50	3.56	7 8
1	10 00	1 44	4 13	2 25	94	1 13	1 75	3 75	4 50	1 75	4 06	12
1 1/8	11.13	1.56	4.50	2 50	1.00	1 25	2.00	4.13	5.00	2.00	4.56	16
1 1/4-1 3/8	12 31	1 69	5 00	2 75	1 13	1 50	2 25	4 75	5 50	2 25	5 13	23
1 1/2	14 13	2 00	5 38	3.13	1.13	1 63	2.75	5 25	6.00	2.50	6.13	28

CAST ALLOY BOLT TYPE ANCHOR SHACKLES
G-2140 S-2140

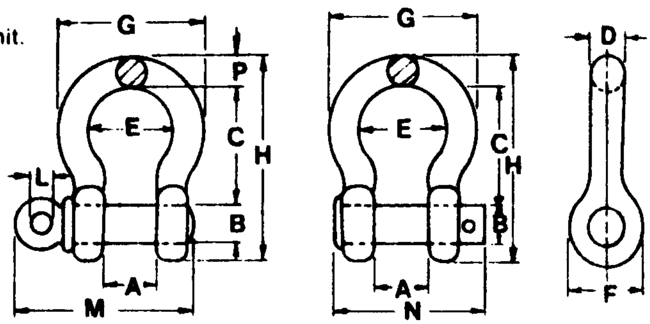


- Safe Working Load is shown on every shackle.
- Alloy bows, Alloy bolts.
- Quenched and Tempered.

Working Load* Limit Tons	DIMENSIONS IN INCHES																Weight Pounds Each
	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	R	
200	14 3/4	7 1/4	3 3/4	4 3/4	10 1/2	18	6	15 1/2	4 1/2	5 1/2	5 1/2	1	2	6	21	29 1/4	450
250	16	8 1/2	3 3/4	5	12	22 1/2	6 1/2	20	4 1/2	6 1/2	5 3/4	1	2	6 3/4	24 1/2	35	600
300	18	8 1/2	4 3/4	6	12	22 1/2	6 3/4	19 1/2	5	6 1/2	7	1	2	7 1/2	25	35 1/4	775
400	21 1/4	8 1/4	6 1/2	7	14	26	7 1/4	22 1/2	6	6 1/2	8	1	2	9 3/4	26	40 1/4	1100
†500	20 7/8	8 5/8	6 1/8	7 1/2	15	29	7 1/2	25 1/4	7 1/2	6 1/2	8	1 1/2	2	9 3/4	28	44	1550
†600	22 1/4	9 1/4	6 1/2	8 1/4	17	36	8 1/2	31 7/8	8 1/2	7	9	1 1/2	3	12 1/2	31	53	1900

*Proof Load is 2.2 times the Working Load Limit.
Minimum Ultimate Strength is 4 times the Working Load Limit.
†Maximum Proof Load is 1000 Tons.

G-209 & S-209 SCREW PIN ANCHOR SHACKLES
G-213 & S-213 ROUND PIN ANCHOR SHACKLES*



W. L. L. TONS	SIZE	A	B	C	D	E	F	G	H	L	M	N	P	TOLERANCE PLUS OR MINUS C	TOLERANCE PLUS OR MINUS A	WT. EACH LBS.
† 1/3	.19	.38	25	.88	.19	.69	.56	.98	1.47	.13	1.13	---	.19	.06	.06	.05
1/2	.25	.50	.31	1.13	.25	.78	.69	1.28	1.88	.16	1.44	1.34	.25	.06	.06	.12
3/4	.31	.53	.38	1.22	.31	.84	.81	1.47	2.13	.19	1.72	1.59	.31	.06	06	.18
1	.38	.66	.44	1.44	.38	1.03	.97	1.78	2.53	.22	2.06	1.88	.38	.13	.06	.3
1 1/2	.44	.72	.50	1.69	.44	1.16	1.06	2.03	2.91	.25	2.34	2.13	.44	.13	.06	.49
2	.50	.81	.63	1.88	.50	1.31	1.19	2.31	3.28	.31	2.72	2.38	.50	.13	.06	74
3 1/4	.63	1.06	.75	2.38	.63	1.69	1.56	2.94	4.22	.38	3.41	2.91	69	.13	.06	1.44
4 3/4	.75	1.25	.88	2.81	.75	2.00	1.88	3.50	5.00	.44	4.03	3.44	.81	.25	.06	2.16
6 1/2	.88	1.44	1.00	3.31	.88	2.28	2.13	4.03	5.75	.50	4.63	3.84	.97	25	.06	3.37
8 1/2	1.00	1.69	1.13	3.75	1.00	2.69	2.38	4.69	6.50	.56	5.31	4.53	1.00	.25	.06	5.3
9 1/2	1.13	1.81	1.25	4.25	1.13	2.91	2.63	5.16	7.31	.63	5.88	5.13	1.25	25	06	7
12	1.25	2.03	1.38	4.69	1.25	3.25	3.00	5.75	8.13	.69	6.44	5.50	1.38	.25	.06	9.6
13 1/2	1.38	2.25	1.50	5.25	1.38	3.63	3.31	6.38	9.03	.75	7.13	6.13	1.50	.25	.13	12.6
17	1.50	2.38	1.63	5.75	1.50	3.88	3.63	6.88	9.88	.81	7.66	6.50	1.62	.25	.13	17.3
25	1.75	2.88	2.00	7.00	1.75	5.00	4.31	8.50	11.88	1.00	9.19	7.75	2.12	.25	.13	27.8
35	2.00	3.25	2.25	7.75	2.00	5.75	5.00	9.75	13.38	1.13	10.34	8.75	2.00	.25	.13	41.1
† 55	2.50	4.13	2.75	10.50	2.62	7.25	6.00	12.50	17.75	1.38	12.97	---	2.62		25	83.5

† Furnished in Screw Pin Only

* Round Pin through 35 tons.

The Following Information Applies To All Shackles

RGED STEEL WITH ALLOY PINS — QUENCHED & .MPERED

Proof Load 2.2 times working load limit.

Ultimate Strength 6 times working load limit through 50 ton capacity.

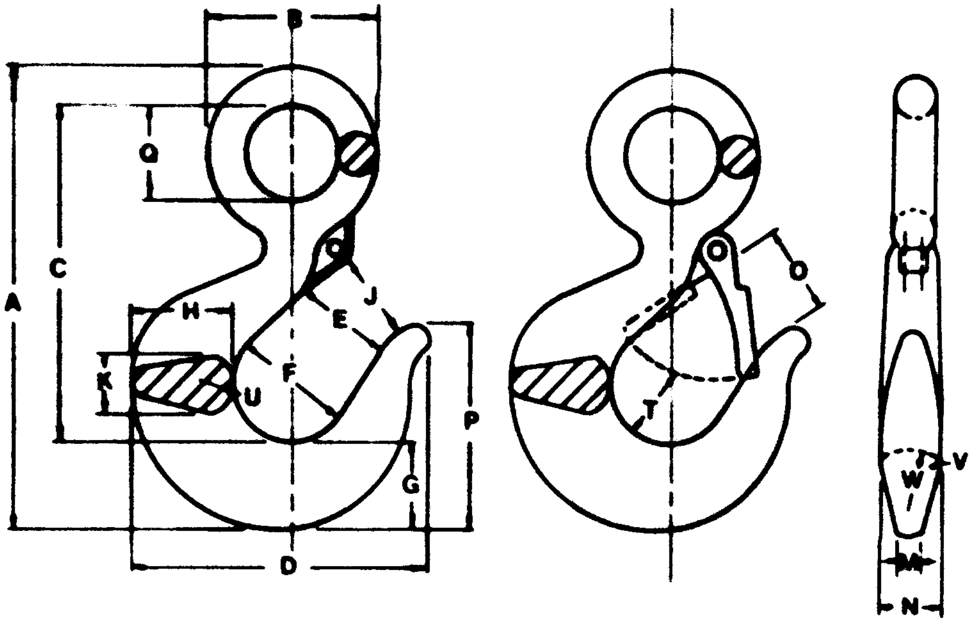
Ultimate Strength 5 times working load limit on 85 120 and 150 ton capacity

G-209, S-209 Screw Pin Anchor Shackles meet or exceed requirements of Federal Specification RR-C-271b, Type IV, Class 1.

G-213, S-213 Round Pin Anchor Shackles meet or exceed requirements of Federal Specification RR-C-271b, Type IV, Class 4.

NO. 320 EYE HOIST HOOKS

(AVAILABLE THROUGH 60 TONS)



• Latch Kit available for all sizes.

319C, 320C – FORGED CARBON STEEL, QUENCHED & TEMPERED

319A, 320A – FORGED ALLOY STEEL, QUENCHED & TEMPERED

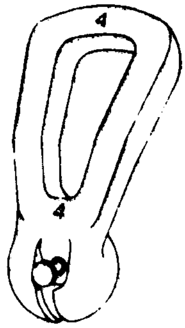
319B, 320B – FORGED BRONZE, HIGH STRENGTH

NO. 319 & NO. 320 HOOKS

W.L.L. — TONS			A	B	C	D	E	F	G	H	I	J	K	L	M
CARBON	ALLOY	BRONZE													
75	1	5	4 33	1 47	3 23	2 88	1 00	1 25	.75	81	50	94	56	5 00	25
1	1.5	.6	4 94	1 75	3 67	3.19	1.06	1.38	.84	94	56	1 02	62	5 62	28
1 5	2	1	5 55	2 03	4.09	3 62	1 12	1 50	1 00	1 16	62	1 02	75	6 19	31
2	3	1 4	6 39	2 41	4 69	4 09	1.25	1 63	1.12	1 31	.75	1 22	.84	6 94	38
3	4.5	2	7 89	2 94	5 77	4 94	1 50	2 00	1 44	1 62	1 00	1 50	1.12	8 47	44
5	7	3.5	10 09	3 81	7.38	6.50	1.88	2 50	1 81	2 06	1.25	1 88	1 38	10 31	.56
7 5	11	5	12 44	4 69	9 06	7 56	2 25	3 00	2 25	2 62	1 50	2.28	1 62	12 38	69
10	15	6 5	13 94	5.38	10 08	8 69	2 50	3.25	2.59	2 94	1 62	2 50	1 94	13 50	78
15	22	10	17 08	6 63	12 52	11 00	3 38	4.25	3 00	3 50	2 00	3 41	2 38	16 44	1 00
20	30	13	19 47	7 00	14 06	13 62	4 00	5 00	3 66	4 62	2 38	4 00	3 00	19.72	1.09
20	30					13 62	4 00	5 00	3 66	4 62	2 38		3 00	23 09	1 09
20	30					13 62	4 00	5 00	3 66	4 62	2 38		3.00	31.09	1.09
25	37		24 75	8 50	18 31	14 06	4 25	5 38	4 56	5 00	3 25	4 25	3 75	31.25	1 44
25	37					14.06	4.25	5 38	4.56	5 00	3.25		3 75	40 25	1 44
30	45		27 31	9.25	20 25	15.44	4 75	6 00	5 06	5 50	3 50	4 75	4 12	33 06	1 56
30	45					15.44	4.75	6 00	5 06	5 50	3 50		4 12	42 06	1.56
40	60		32.25	10 75	23 81	18 50	5 75	7 00	6 00	6 50	4 12	5 75	4 62	36 00	1 75
40	60					18.50	5 75	7 00	6.00	6 50	4 12		4.62	39 50	1.75
40	60					18 50	5 75	7 00	6 00	6 50	4 12		4 62	47 50	1 75
50	75					20 62	6 50	7.75	6 69	7 25	4 50		5 00	41 06	1.94
50	75					20 62	6 50	7.75	6 69	7 25	4 50		5 00	49 06	1 94
	100					23 13	5 88	7.00	8 63	9 88	5.50		5 50	42 12	3 00
	100					23 13	5 88	7 00	8 63	9 88	5 50		5 50	48 12	3 00
	150					24.38	6 00	7.00	9.13	10 88	6 00		6.00	45 63	3.25
	200					26 69	6 50	7 50	10 00	11 81	7 00		7.00	50 50	3 50
	300					30 12	8.00	9 50	10 94	12 94	7 25		7.25	54.69	4.25

TABLE CONTINUED ON NEXT PAGE

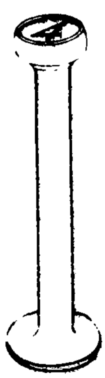
V. PARTS LIST



SL LIFTING EYES

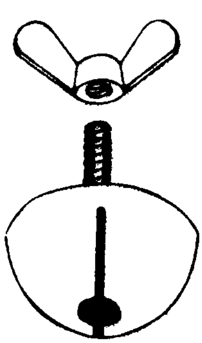
Part No.	Rated Load Tons	Weight/PC
467300	1	3 lbs.
467305	2	5 lbs.
467310	4	8 lbs.
467315	8	17 lbs.
467320	16	39 lbs.

6



SL ANCHORS

Part No.	Rated Load Tons	Length (in.)	Shaft Dia. (in.)	Weight Per 100
467100		2⅝		13.25
467105		3⅜		15.5
467110	1	4¾	⅜"	19
467115		8		29
467120		9½		38
467125		*2¾		32
467130	2	3⅜	9/16"	39
467135		5½		51.5
467140		6		55
467145		6¾		61
467150		11		96
467155		*3¾		83
467160		4¾		92
467165	4	7⅛	¾"	120
467170		9½		154
467172		14		212
467175		19		275
467180		6¾		280
467185	8	13⅜	1⅛"	465
467190		26¾		875
467200		10		807
467205	16	19¾	1½"	1306
467210		39⅜		2502



SL RECESS PLUGS

Recess Plug With Bolt/Nut	Recess Plug Only	Rated Load	Plug Dia. (in.)	Weight Per Piece	
				Plug With Bolt/Nut	Plug Only
467325	467350	1	2⅜	3.5 oz.	2 oz.
467330	467360	2	3	7.7 oz.	4 oz.
467335	467370	4	3¾	12.5 oz.	8 oz.
467340	467380	8	4¾	1.3 lb.	1 lb.
467345	467390	16	6⅜	3.6 lb.	3 lb.

*Consult SUPERIOR CONCRETE ACCESSORIES, INC. for safe capacities and concrete strength requirements.

APPENDIX J
COATING DATA SHEETS

CONTENTS

TEST DATA SUMMARY SHEET - PHENOLINE 300 SYSTEM J-5

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PRODUCT DATA SHEET - CARBOLINE 195 SURFACER J-11

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IRRADIATION/DECONTAMINATION TEST REPORT J-15

DBA TEST REPORT J-21

EXCERPTS FROM ORNL 3916 .... J-27

AREA CODE 314
644-1000

carboline®

CABLE-CARBOCO-ST. LOUIS
TELEX 44-7332

PROTECTIVE COATINGS
FOR CORROSION RESISTANCE • WATERPROOFING • FIRE PROTECTION • ROOFING

April 19, 1982

Mr. Dick Haelsig
Nuclear Packaging Inc.
815 S. 28th Street
Tacoma, WA 98409

Dear Dick:

The best system to use on the steel of the High Integrity Container (HIC) is the four coat Phenoline 300 Orange/Phenoline 302/Phenoline 300 Finish system. However, in our opinion, the Phenoline 300 Orange/Phenoline 302/Phenoline 302 system would show radiation tolerance comparable to the four coat system.

If you decide to use Phenoline 300 Finish as the topcoat, you should not be concerned about a pH range of 6-10. The Phenoline 300 Finish should not be affected.

If you need further clarification or if additional information is needed, please contact me.

Very truly yours,

Andy Bernard
Andy Bernard
Power Industry Specialist

nlf/l/630/
Haelsig/041582

cc: Mr. Dan McBride/Mr. Dave Muth/Mr. Bill Eggers/Mr. Tim Dolan/
Proj. File

CARBOLINE COMPANY • 350 HANLEY INDUSTRIAL COURT • ST. LOUIS, MISSOURI 63144

carboline

Phenoline 300 Orange/Phenoline 302/Phenoline 300 Finish

TEST DATA SUMMARY SHEET

CONCRETE SUBSTRATE

LOCA ORNL 340°F/70 psig/7-8 Days	NO DATA
LOCA ORNL 300°F/65 psig/10 Days	PASS
RADIATION RESISTANCE 1×10^9 RADS (AIR)	PASS
FLAME SPREAD (@ 32 mils DFT)	25
THERMAL CONDUCTIVITY $\left[\frac{(BTU)(Mil)}{(HR)(FT.^2)(°F)} \right]$	1,000 - 3,500
DECONTAMINATION FACTOR (OVERALL)	49
CHEMICAL RESISTANCE (Severe Exposure, ANSI N5.12)	
5% Disodium Phosphate	PASS
1.0 lb./gal. Trisodium Phosphate	PASS
0.3M Potassium Permanganate	FAIL
5% Ammonium Hydroxide	PASS
5% Sodium Borate	PASS
0.5M Sodium Fluoride	PASS
5% Sodium Hydroxide	PASS
.03M Hydrogen Peroxide	PASS
5% Sulfuric Acid	PASS
5% Hydrazine	PASS
5% Nitric Acid	PASS
5% Citric Acid	PASS
PHYSICAL PROPERTIES	
Adhesion (ANSI N5.12)	PASS (855 psi)
Abrasion (ANSI N5.12)	PASS (84 mg.)
Impact (ANSI N5.12)	PASS

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product data sheet

PHENOLINE® 300 ORANGE

350 HANLEY INDUSTRIAL COURT • ST. LOUIS, MO. 63144 • 314-644-1000

SELECTION DATA

GENERIC TYPE: Modified phenolic. Part A, Part B and Special Mica Filler mixed prior to application.

GENERAL PROPERTIES: A heavy-duty primer with excellent bond to most surfaces including steel and concrete. Special Mica Filler is always added to give maximum bond strength. Outstanding resistance to severe chemicals (except immersion in strong oxidizing acids), alkalies, salts and solvents. Excellent resistance to sub-film corrosion.

RECOMMENDED USES: Phenoline 300 Orange is used as a primer for Phenoline topcoats in heavy duty splash and spillage service, for lining of tanks and protection of floors.

NOT RECOMMENDED FOR: Lining steel tanks where the temperature exceeds 180°F (82°C) or where heating-cooling cycles occur. Not recommended for immersion service in strong oxidizing acids.

CHEMICAL RESISTANCE GUIDE:

Exposure	Immersion
Acids	Very Good
Alkalies	Excellent
Solvents	Very Good
Salt	Excellent
Water	Excellent

TEMPERATURE RESISTANCE: (Non-immersion)
Continuous: 200°F (93°C)

FLEXIBILITY: Poor **WEATHERING**: Good (chalks)

ABRASION RESISTANCE: Excellent

SUBSTRATES: Apply to properly prepared concrete, steel, stainless steel, aluminum or other surfaces as recommended.

TOPCOAT REQUIRED: May be topcoated with modified phenolics, catalyzed epoxies or others as recommended. Usual topcoats are Phenoline 300 Finish, Phenoline 300 Floor Finish, Phenoline 302 or others.

COMPATIBILITY WITH OTHER COATINGS: Apply directly to substrate. Use as a primer only.

SPECIFICATION DATA

THEORETICAL SOLIDS CONTENT OF MIXED MATERIAL:

	By Volume
Phenoline 300 Orange with Mica Filler	82% ± 2%

RECOMMENDED DRY FILM THICKNESS PER COAT: 8 mils (200 microns).

THEORETICAL COVERAGE PER MIXED KIT*:
(2.75 Gals. including Mica Filler)
4411 mil sq. ft. (32.8 m/l at 25 microns)
551 sq. ft. at 8 mils (4.1 m/l at 200 microns)

*NOTE: Material losses during mixing and application will vary and must be taken into consideration when estimating job requirements.

SHELF LIFE: Six months minimum.

COLORS: Orange only.

GLOSS: Medium.

ORDERING INFORMATION

Prices may be obtained from Carboline Sales Representative or Main Office. Terms – Net 30 days.

SHIPPING WEIGHT:

	2.5 Gal. Kit
Phenoline 300 Orange	53 lbs. (24.1 kg)
Phenoline Thinner	9 lbs. in 1's (4.1 kg)
	45 lbs. in 5's (20.4 kg)

FLASH POINT: (Pensky-Martens Closed Cup)

Phenoline 300 Orange Part A	77°F (25°C)
Phenoline 300 Part B	54°F (12°C)
Special Mica Filler	Over 200°F (93°C)
Phenoline Thinner	77°F (25°C)

Oct 80 Replaces Nov 76-N

APPLICATION INSTRUCTIONS

These instructions are not intended to show product recommendations for specific service. They are issued as an aid in determining correct surface preparation, mixing instructions, and application procedure. It is assumed that the proper product recommendations have been made. These instructions should be followed closely to obtain the maximum service from the materials.

SURFACE PREPARATION: Remove any oil or grease from surface to be coated with clean rags soaked in Carboline Thinner #2 or toluol.

Steel: For immersion service, dry abrasive blast to a White Metal finish in accordance with SSPC-SP 5 to a degree of cleanliness in accordance with NACE #1 to obtain a 2 to 3 mil (50-75 microns) blast profile. Weld slag must be removed and welds ground to a rounded contour.

For non-immersion service, dry abrasive blast to a Commercial Finish in accordance with SSPC-SP 6 to a degree of cleanliness in accordance with NACE #3 to obtain a 2 to 3 mil (50-75 microns) blast profile.

Concrete: Remove fins and other protrusions by stoning, sanding or grinding. Concrete must be cured at least 28 days at 70°F (21°C) and 50% R.H. or equivalent time. Remove form oils, incompatible curing agents and hardeners by abrasive blasting.

IMMERSION SERVICE – abrasive blast to open all voids and obtain a surface similar to medium grit sandpaper (horizontal surfaces may be acid etched). Blow or vacuum off sand and dust. Extremely rough concrete surfaces may require Carboline 195 Surfacer prior to application of Phenoline 300 Orange.

NON-IMMERSION SERVICE – Horizontal surfaces must be acid etched or abrasive blasted to remove laitance. For other surfaces blow off with compressed air to remove dust.

MIXING: Mix separately, then combine and mix in the following proportions:

	2.5 Gal. Kit
Phenoline 300 Orange Part A	Two–1 Gal Cans
Phenoline 300 Part B	1/2 Gal
Special Mica Filler (6-1/2 lbs.)	1 Gal

Thin up to 30% by volume with Phenoline Thinner.

POT LIFE: 1 hour at 75°F (24°C) and less at higher temperatures. Pot life ends when coating loses body and begins to sag.

APPLICATION TEMPERATURES:

	Material	Surfaces
Normal	65-85°F (18-29°C)	65-85°F (18-29°C)
Minimum	60°F (16°C)	60°F (16°C)
Maximum	85°F (29°C)	100°F (38°C)

	Ambient	Humidity
Normal	65-85°F (18-29°C)	30-70%
Minimum	50°F (10°C)	0%
Maximum	110°F (43°C)	85%

Do not apply when the surface temperature is less than 5°F (2°C) above the dew point.

Special thinning and application techniques may be required above or below normal condition.

SPRAY: Use adequate air volume for correct operation. Hold gun 8-10 inches from the surface and at a right angle to the surface.

Use a 50% overlap with each pass of the gun. On irregular surfaces, coat the edges first, making an extra pass later.

NOTE: The following equipment has been found suitable, however, equivalent equipment may be substituted.

Conventional: Use 1/2" minimum I.D. material hose.

Mfr. & Gun	Fluid Tip	Air Cap
Binks #18 or #62	67	67 PB
DeVilbiss P-MBC or JGA	D	64
	approx. .086" I.D.	

Airless: Not recommended (abrades tip).

BRUSH: Use short bristled brush and work material into all corners and crevices.

DRYING TIMES:

Between coats:	Minimum	Maximum*
60°F (16°C)	36 hours	14 days
75°F (24°C)	18 hours	7 days
90°F (32°C)	12 hours	3 days

NOTE: Before topcoating, scrub surface with bristle brushes and clean water. Allow to dry thoroughly before topcoating.

*IF MAXIMUM DRYING TIME BETWEEN COATS IS EXCEEDED, PRIMER MUST BE THOROUGHLY CLEANED WITH CARBOLINE SURFACE PREPARATION #1 PRIOR TO TOPCOATING.

CLEAN UP: Use Carboline Thinner #2 or xylol.

STORAGE CONDITIONS:
Temperature: 40-100°F (4-43°C)
Humidity: 0-100%

For more detailed information please consult specific Carboline Application Guides.

CAUTION: CONTAINS FLAMMABLE SOLVENTS. KEEP AWAY FROM SPARKS AND OPEN FLAMES. IN CONFINED AREAS WORKMEN MUST WEAR FRESH AIRLINE RESPIRATORS. HYPERSENSITIVE PERSONS SHOULD WEAR GLOVES OR USE PROTECTIVE CREAM. ALL ELECTRIC EQUIPMENT AND INSTALLATIONS SHOULD BE MADE AND GROUNDED IN ACCORDANCE WITH THE NATIONAL ELECTRICAL CODE. IN AREAS WHERE EXPLOSION HAZARDS EXIST, WORKMEN SHOULD BE REQUIRED TO USE NONFERROUS TOOLS AND TO WEAR CONDUCTIVE AND NONSPARKING SHOES.

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PHENOLINE® 302

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SELECTION DATA

GENERIC TYPE: Modified phenolic. Part A and Part B mixed prior to application.

GENERAL PROPERTIES: Phenoline 302 is the most resistant topcoat of the Phenoline series for immersion service. Has very good resistance to abrasion, including slurries. After the final cure there is no leaching of resins or catalyst. Excellent general tank lining material because of its overall chemical resistance.

RECOMMENDED USES: As a tank lining for tanks holding moderate concentration acids, caustics, salts or solvents. Excellent tank lining material for acid-solvent and alkali-solvent solutions. Recommended as a heavy duty maintenance coating for severe exposures to splash, spillage and fumes. Also for protection of floors exposed to chemical spillage. Generally used where other lining systems have proved unsuitable.

NOT RECOMMENDED FOR: Immersion in strong acids.

CHEMICAL RESISTANCE GUIDE:

Exposure	Immersion
Acids	Very Good
Alkalies	Excellent
Solvents	Excellent
Salt	Excellent
Water	Excellent

TEMPERATURE RESISTANCE: (Non-immersion)

Continuous:	200°F (93°C)
Non-continuous:	250°F (121°C)

Immersion temperature resistance is dependent on solution, but should not exceed 180°F (82°C). Metal tanks must be insulated when temperatures exceed 140°F (60°C).

FLEXIBILITY: Fair

WEATHERING: Good

ABRASION RESISTANCE: Very Good

SUBSTRATES: Use over properly primed steel, concrete, aluminum or others as recommended. Acceptable primers are Phenoline 300 Orange, or Phenoline 300 Surfacer.

TOPCOAT REQUIRED: Normally none. May be topcoated with Phenoline 300 Finish for change of color. 0604

COMPATIBILITY WITH OTHER COATINGS: May be applied over recommended modified phenolic or catalyzed epoxy primers or surfacers.

SPECIFICATION DATA

THEORETICAL SOLIDS CONTENT OF MIXED MATERIAL:

	By Volume
Phenoline 302	88 ± 1%

RECOMMENDED DRY FILM THICKNESS PER COAT: 8 mils (205 microns)

THEORETICAL COVERAGE PER MIXED KIT* (1.25 gals):
1764 mil sq. ft. (34.5 m²/ℓ @ 25 microns)
220 sq. ft. at 8 mils (4.3 m²/ℓ @ 205 microns)

***NOTE:** Material losses during mixing and application will vary and must be taken into consideration when estimating job requirements.

SHELF LIFE: 24 months minimum

COLORS: Black and green only

GLOSS: Flat

ORDERING INFORMATION

Prices may be obtained from Carboline Sales Representative or Main Office. Terms — Net 30 days.

SHIPPING WEIGHT:

	1's	5's
Phenoline 302 Black	18 lbs. (8.2 kg)	82 lbs. (37.2 kg)
Phenoline 302 Green	19 lbs. (8.6 kg)	90 lbs. (40.9 kg)
Phenoline Thinner	9 lbs. (4.1 kg)	45 lbs. (20.4 kg)

FLASH POINT: (Pensky-Martens Closed Cup)

Phenoline 302 Part A	120°F (49°C)
Phenoline 302 Part B	53°F (12°C)
Phenoline Thinner	77°F (25°C)

June 78 Replaces Apr. 77-N

APPLICATION INSTRUCTIONS

These instructions are not intended to show product recommendations for specific service. They are issued as an aid in determining correct surface preparation, mixing instructions, and application procedure. It is assumed that the proper product recommendations have been made. These instructions should be followed closely to obtain the maximum service from the materials.

SURFACE PREPARATIONS: Remove any oil or grease from surface to be coated with clean rags soaked in Carboline Thinner #2 or Toluol

Steel: Apply to clean, dry recommended primer.

Concrete: Apply over clean, dry properly primed or surfaced concrete.

MIXING: Mix separately, then combine and mix in the following proportions:

	1-Gal. Kit	5-Gal. Kit
Phenoline 302 Part A	1-Gal. Can	1-5 Gal. Can
Phenoline 302 Part B	1-Qt. Can	1-5 Qt. Can

Thin up to 25% by Volume with Phenoline Thinner.

POT LIFE: 1 hour at 75°F (24°C) and less at higher temperatures. Pot Life ends when coating loses body and begins to sag.

APPLICATION TEMPERATURES:

	Material	Surfaces
Normal	60-85°F (16-29°C)	60-85°F (16-29°C)
Minimum	55°F (13°C)	50°F (10°C)
Maximum	90°F (32°C)	120°F (49°C)

	Ambient	Humidity
Normal	60-85°F (16-29°C)	30-70%
Minimum	50°F (10°C)	0%
Maximum	120°F (49°C)	85%

Special thinning and application techniques may be required above or below normal condition.

Do not apply when the surface temperature will be less than 5°F (2°C) above dew point.

SPRAY: Use adequate air volume for correct operation. Hold gun 8-10 inches from the surface and at a right angle to the surface.

Use a 50% overlap with each pass of the gun. On irregular surfaces, coat the edges first, making an extra pass later.

NOTE: The following equipment has been found suitable, however, equivalent equipment may be substituted.

Conventional: Use ⅜" I.D. Mat'l. Hose.

Mfr. & Gun	Fluid Tip	Air Cap
Binks #18 or #62	67	67PB
DeVilbiss P-MBC or JGA	D	64
	Approx. .086" I.D.	Approx. 11 cfm @ 30 psi

Airless: Not recommended. (Abrades tips)

BRUSH OR ROLLER: Brush out well, using full strokes. Avoid rebrushing.

DRYING TIMES:

	Minimum Temp.	Maximum Dry*
Between coats:	72 hrs. @ 50°F (10°C)	4 days
	36 hrs. @ 60°F (36°C)	3 days
	18 hrs. @ 75°F (24°C)	2 days
	12 hrs. @ 90°F (32°C)	1 day
Final cure:	28 days @ 50°F (10°C)	
	14 days @ 60°F (36°C)	
	7 days @ 75°F (24°C)	
	5 days @ 90°F (32°C)	

Force curing is suggested for all tank linings.

*If this time is exceeded, special surface preparation will be necessary for recoating.

CLEAN UP: Use Carboline Thinner #2 or Xylol

STORAGE CONDITIONS:

Temperature: 45-110°F (7-43°C) **Humidity:** 0-100%

NOTE: Excessive film thickness or poor ventilating conditions require longer dry times and in extreme cases may cause premature failure. Excessive humidity or condensation on the surface during curing may result in a surface haze or blush; any haze or blush should be removed by water washing before recoating.

For more detailed information please consult specific Carboline Application Guides.

CAUTION: CONTAINS COMBUSTIBLE SOLVENTS. KEEP AWAY FROM SPARKS AND OPEN FLAMES. IN CONFINED AREAS WORKMEN MUST WEAR FRESH AIRLINE RESPIRATORS. HYPERSENSITIVE PERSONS SHOULD WEAR GLOVES OR USE PROTECTIVE CREAM. ALL ELECTRIC EQUIPMENT AND INSTALLATIONS SHOULD BE MADE AND GROUNDED IN ACCORDANCE WITH THE NATIONAL ELECTRICAL CODE. IN AREAS WHERE EXPLOSION HAZARDS EXIST WORKMEN SHOULD BE REQUIRED TO USE NONFERROUS TOOLS AND TO WEAR CONDUCTIVE AND NONSPARKING SHOES.

Carboline 195 Surfacer/Carboline 191 HB

TEST DATA SUMMARY SHEET

CONCRETE SUBSTRATE

LOCA ORNL 340°F/70 psig/7-8 Days	PASS
LOCA ORNL 300°F/65 psig/10 Days	PASS
RADIATION RESISTANCE 1×10^9 RADS (AIR)	PASS
FLAME SPREAD (@ 24 mils DFT)	40 (E)*
THERMAL CONDUCTIVITY $\left[\frac{(BTU)(Mil)}{(HR)(FT.^2)(°F)}\right]$	1,000 - 3,500
DECONTAMINATION FACTOR (OVERALL)	20
CHEMICAL RESISTANCE (Severe Exposure, ANSI N5.12)	
5% Disodium Phosphate	PASS
1.0 lb./gal. Trisodium Phosphate	PASS
0.3M Potassium Permanganate	FAIL
5% Ammonium Hydroxide	PASS
5% Sodium Borate	PASS
0.5M Sodium Fluoride	PASS
5% Sodium Hydroxide	PASS
.03M Hydrogen Peroxide	PASS
5% Sulfuric Acid	PASS
5% Hydrazine	PASS
5% Nitric Acid	PASS
5% Citric Acid	PASS
PHYSICAL PROPERTIES	
Adhesion (ANSI N5.12)	PASS (370 psi)
Abrasion (ANSI N5.12)	PASS (51 mg.)
Impact (ANSI N5.12)	PASS

*(E) - Estimate

product data sheet

carboline

CARBOLINE 195 SURFACER

350 HANLEY INDUSTRIAL COURT • ST. LOUIS, MO. 63144 • 314-644-1000

942

SELECTION DATA

GENERIC TYPE: Modified epoxy-polyamide. Parts A and B mixed prior to application.

GENERAL PROPERTIES: High build epoxy coating for sealing and surfacing irregular cementitious surfaces. Particularly recommended for nuclear plants where concrete surfaces must be prepared for ease of decontamination.

RECOMMENDED USES: As a primer-surfacer on concrete under Carboline 191 HB, Phenoline® 305 Finish or other Carboline topcoats as recommended:

NOT RECOMMENDED FOR: Immersion service without recommended topcoats.

CHEMICAL RESISTANCE GUIDE: (Consult topcoat for Chemical Resistance Guide).

Exposure	Splash and Spillage
Acids	Very Good
Alkalies	Excellent
Solvents	Excellent
Salt	Excellent
Water	Excellent

TEMPERATURE RESISTANCE: (non-immersion)

Continuous:	200°F (93°C)
Non-continuous	300°F (149°C)

FLEXIBILITY: Very Good

WEATHERING: Good (chalks, discolors)

ABRASION RESISTANCE: Very Good

SUBSTRATES: Concrete, or other surfaces as recommended.

TOPCOAT REQUIRED: May be topcoated with catalyzed epoxies, modified phenolics, modified polyurethanes or others as recommended. Carboline 191 HB or Phenoline 305 Finish is normally used for nuclear application. Other acceptable topcoats are Carboline 193 Finish, Carboline 190 HB, Phenoline 300 Finish or Phenoline 302.

COMPATIBILITY WITH OTHER COATINGS: Should be applied directly to concrete substrate or over Carboline 1340 clear if a curing compound is desired.

SPECIFICATION DATA

THEORETICAL SOLIDS CONTENT OF MIXED MATERIAL:

	By Volume
Carboline 195 Surfacer	97 ± 2%

RECOMMENDED DRY FILM THICKNESS PER COAT: 10-60 mils as required. Typical average is 20 mils (500 microns)

THEORETICAL COVERAGE PER GALLON:*
1556 mil sq. ft. (38.8 sq. m/l @ 25 microns)
78 sq. ft. at 20 mils (1.9 sq. m/l @ 500 microns)

***NOTE:** Material losses during mixing and application will vary and must be taken into consideration when estimating job requirements.

SHELF LIFE: 24 months minimum

COLORS: Off-white

GLOSS: Low

ORDERING INFORMATION

Prices may be obtained from Carboline Sales Representative or Main Office. Terms – Net 30 days.

SHIPPING WEIGHT:

	2 Gal. Kit	10 Gal. Kit
Carboline 195 Surfacer	30 lbs. (13.6 kg)	140 lbs. (63.6 kg)
Carboline Thinner #2	9 lbs. in 1's (4.1 kg)	43 lbs. in 5's (19.5 kg)

FLASH POINT: (Pensky-Martens Closed Cup)

Carboline 195 Surfacer Part A	130°F (54°C)
Carboline 195 Surfacer Part B	198°F (92°C)
Carboline Thinner #2	30°F (-1°C)

Aug 80 Replaces July 79

APPLICATION INSTRUCTIONS

These instructions are not intended to show product recommendations for specific service. They are issued as an aid in determining correct surface preparation, mixing instructions, and application procedure. It is assumed that the proper product recommendations have been made. These instructions should be followed closely to obtain the maximum service from the materials.

*Comprehensive Application Instructions are available. Consult Carboline Technical Service Department for a copy.

SURFACE PREPARATION: Remove any oil or grease from surface to be coated with clean rags soaked in Carboline Thinner #2 or toluol.

Concrete: Concrete floors should be at least as rough as medium grit sandpaper. The surface should be free of laitance. This can be accomplished by finishing technique, acid etch or mechanical abrasion. Concrete walls normally require only vacuuming or air blow-off. Do not coat concrete treated with hardening solutions (except for Carboline 1340 Clear) unless test patch indicates satisfactory adhesion. Do not apply coating unless concrete has cured at least 28 days @ 70°F (21°C) and 50% RH or equivalent.

MIXING: Mix separately, then combine and mix in the following proportions:

	2 Gal. Kit	10 Gal. Kit
Carboline 195 Surfacer Part A	1 Gallon	5 Gallons
Carboline 195 Surfacer Part B	1 Gallon	5 Gallons

Thin up to 18% by volume with Carboline Thinner #2.

POT LIFE: 1-1/2 hours at 75°F (24°C) and less at higher temperatures. Pot life ends when coating becomes too viscous to use.

APPLICATION TEMPERATURES:

	Material	Surfaces
Normal	60-75°F (16-24°C)	60-75°F (16-24°C)
Minimum	55°F (13°C)	50°F (10°C)
Maximum	90°F (32°C)	90°F (32°C)

	Ambient	Humidity
Normal	60-75°F (16-24°C)	30-70%
Minimum	45°F (7°C)	0%
Maximum	95°F (35°C)	95%

Do not apply when the surface temperature is less than 5°F (2°C) above the dew point.

Special thinning and application techniques may be required above or below normal condition.

SPRAY: Hold gun 12-14 inches from the surface and at a right angle to the surface. Squeegee surfacer into all holes. Apply second coat at full thickness.

NOTE: The following equipment has been found suitable; however, equivalent equipment may be substituted.

Conventional: Not recommended.

Airless: Use a 1/2" minimum I.D. material hose.

Mfr. & Gun	Pump*
Use either model below	Huskie (DeVilbiss)
Graco 207-300	Bulldog 30:1
Binks Model 520	Jupiter 8D

*Teflon packings are recommended and available from pump manufacturer. Use a .031" to .035" tip with 2200-2400 psi. A reversible tip is recommended.

BRUSH OR ROLLER: Thin up to 25% by volume per gallon with Carboline #2. Brush only for touch-up. **ROLLER**: Useful where spraying is impractical. Immediately after rolling, squeegee surfacer into all holes. Apply second coat at full thickness.

DRYING TIMES:

To Recoat: May be recoated with itself as soon as firm, generally allowed to cure overnight.

To Topcoat:

Temperature	At 20 Mils*
50°F (10°C)	12 Days
60°F (16°C)	6 Days
75°F (24°C)	3 Days
90°F (32°C)	1 Day

*Carboline 195 Surfacer which has been applied at thicknesses greater than 20 mils will require longer cure times, especially if applied thinned.

Note: If exposed to sunlight in excess of two weeks, surface contamination must be removed by wiping with Carboline Surface Preparation #1 before recoating.

CLEANUP: Use Carboline Thinner #2 or xylol.

STORAGE CONDITIONS:

Temperature:	40-100°F (4-38°C)
Humidity:	0-95%

For more detailed information, please consult specific Carboline 195 Surfacer Application Instructions.

CAUTION: CONTAINS COMBUSTIBLE SOLVENTS. KEEP AWAY FROM SPARKS AND OPEN FLAMES. IN CONFINED AREAS WORKMEN MUST WEAR FRESH AIRLINE RESPIRATORS. HYPERSENSITIVE PERSONS SHOULD WEAR GLOVES OR USE PROTECTIVE CREAM. ALL ELECTRIC EQUIPMENT AND INSTALLATIONS SHOULD BE MADE AND GROUNDED IN ACCORDANCE WITH THE NATIONAL ELECTRICAL CODE. IN AREAS WHERE EXPLOSION HAZARDS EXIST, WORKMEN SHOULD BE REQUIRED TO USE NONFERROUS TOOLS AND TO WEAR CONDUCTIVE AND NONSPARKING SHOES.

product data sheet

carboline

CARBOLINE 191 HB

350 HANLEY INDUSTRIAL COURT • ST. LOUIS, MO. 63144 • 314-644-1000

978

SELECTION DATA

GENERIC TYPE: Epoxy-polyamide. Part A and Part B mixed prior to application.

GENERAL PROPERTIES: A high performance epoxy-polyamide topcoat for use over suitably primed steel and sealed or surfaced concrete. Meets the stringent performance requirements of the American National Standards Institute. ANSI N101.2-1972 and ANSI N5 12-1974. Has performed satisfactorily in radiation resistance and decontamination testing at Oak Ridge National Laboratories. Has been successfully evaluated under typical Loss of Coolant Accident (LOCA) exposure criteria specified by the nuclear industry.

RECOMMENDED USES: Carboline 191 HB is an excellent topcoat for the protection of steel and concrete surfaces in nuclear power plants. Suitable for use in areas which are exposed to chemicals, steam and abrasion inherent in a nuclear generating facility. Carboline 191 HB may be used where resistance to nuclear radiation and decontamination procedures are a requirement. When applied over an appropriate primer, Carboline 191 HB is an excellent tank lining for potable water, meeting FDA formulation requirements and FDA EPA extraction criteria.

NOT RECOMMENED FOR: Immersion in water over 140°F (60°C), strong acids, or solvents.

CHEMICAL RESISTANCE GUIDE:

Exposure	Immersion	Splash and Spillage
Acids	NR	Good-Excellent
Alkalies	Excellent to 150°F (66°C)	Excellent
Solvents	NR	Fair-Good
Salt	Excellent to 150°F (66°C)	Excellent
Water	Excellent to 140°F (60°C)	Excellent
Sugar Solutions	Excellent to 150°F (66°C)	Excellent

TEMPERATURE RESISTANCE: (non-immersion)

Continuous	200°F (93°C)
Non-continuous	250°F (121°C)

FLEXIBILITY: Good **WEATHERING:** Very good (chalks)

ABRASION RESISTANCE: Very good

SUBSTRATES: Apply over suitably prepared metal or cementitious surfaces.

TOPCOAT REQUIRED: Normally none

COMPATIBILITY WITH OTHER COATINGS: May be applied over inorganic zincs, catalyzed epoxies, modified phenolics or others as recommended. Acceptable primers are Carbo Zinc® 11, Carbo Zinc 12, Carboline 191 Primer, Carboline 195 Surfacer, Carboline 295 WB Surfacer, Phenoline® 307 or others. A mist coat may be required when topcoating inorganic zinc primers.

SPECIFICATION DATA

THEORETICAL SOLIDS CONTENT OF MIXED MATERIAL:

	By Volume
Carboline 191 HB	59% ± 2%

RECOMMENDED DRY FILM THICKNESS PER COAT: 4-6 mils (100-150 microns)

THEORETICAL COVERAGE PER MIXED GALLON:*
946 mil sq. ft. (23.6 sq.m/1 @ 25 microns)
189 sq. ft. at 5 mils (4.7 sq.m/1 @ 125 microns)

***NOTE:** Material losses during mixing and application will vary and must be taken into consideration when estimating job requirements.

SHELF LIFE: 24 months minimum

GLOSS: Low

COLORS: Standard colors are White C800 and Gray C703. Other colors are special order and not returnable.

ORDERING INFORMATION

Prices may be obtained from Carboline Sales Representative or Main Office. Terms — Net 30 days

SHIPPING WEIGHT:	2's	5's
Carboline 191 HB	27 lbs (12.3 kg)	133 lbs (60.4 kg)
Carboline Thinner #15	9 lbs in 1's (4.1 kg)	45 lbs in 5's (20.4 kg)
Carboline Thinner #2	9 lbs in 1's (4.1 kg)	45 lbs in 5's (20.4 kg)

FLASH POINT: (Pensky-Martens Closed Cup)

Carboline 191 HB - Part A	68°F (20°C)
Carboline 191 HB Part B	43°F (6°C)
Carboline Thinner #15	77°F (25°C)
Carboline Thinner #2	30°F (-1°C)

June 80 Replaces April 80

APPLICATION INSTRUCTIONS

These instructions are not intended to show product recommendations for specific service. They are issued as an aid in determining correct surface preparation, mixing instructions, and application procedure. It is assumed that the proper product recommendations have been made. These instructions should be followed closely to obtain the maximum service from the materials.

SURFACE PREPARATION: Remove any oil or grease from surface to be coated with clean rags soaked in Carboline Thinner #2 or toluol.

Steel/Concrete: Apply over clean, dry recommended primer or surfacer. Application over inorganic zincs may require a mist coat.

MIXING: Mix separately, then combine and mix in the following proportions:

	2 Gal. Kit	10 Gal Kit
Carboline 191 HB - Part A	1 Gal.	5 Gals.
Carboline 191 HB - Part B	1 Gal.	5 Gals.

Thin up to 25% by volume with Carboline Thinner #15. For temperatures below 65°F (18°C) use Carboline Thinner #2.

POT LIFE: Four hours at 75°F (24°C) and less at higher temperatures.

APPLICATION TEMPERATURES:

	Material	Surfaces
Normal	60-95°F (16-35°C)	60-95°F (16-35°C)
Minimum	40°F (4°C)	40°F (4°C)
Maximum	90°F (32°C)	110°F (43°C)

	Ambient	Humidity
Normal	60-95°F (16-35°C)	35-65%
Minimum	40°F (4°C)	0%
Maximum	110°F (43°C)	95%

Do not apply when the surface temperature is less than 5°F (2°C) above the dew point.

Special thinning and application techniques may be required above or below normal condition.

SPRAY: Use adequate air volume for correct operation. Hold gun 8-10 inches from the surface and at a right angle to the surface.

Use a 50% overlap with each pass of the gun. On irregular surfaces, coat the edges first, making an extra pass later.

NOTE: The following equipment has been found suitable. However, equivalent equipment may be substituted.

Conventional: Use a 3/8" minimum I.D. material hose.

Mfr. and Gun	Fluid Tip	Air Cap
Binks #18 or #62	66	66 PB
DeVilbiss P-MBC or JGA	E	704
	Approx. .070" I.D.	Approx. 9-10 cfm @ 30 psi

Airless: Use a 3/8" minimum I.D. material hose. A 30 mesh inline filter is recommended.

Mfr. and Gun	Pump*
DeVilbiss JGB-507	QFA-514
Graco 205-591	President 30:1 or Bulldog 30:1
Binks Model 500	Mercury 5C

*Teflon packings are recommended and available from the manufacturer.

Use a .021 - .025" tip with 2400 psi.

Brush: For touch-up only.

DRYING TIMES:

Temperature	Dry to Handle	Between Coats	For Immersion Service
40°F (4°C)	2 days	3 days	*
60°F (16°C)	16 hours	24 hours	14 days
75°F (24°C)	8 hours	12 hours	7 days
90°F (32°C)	4 hours	6 hours	3 days
110°F (43°C)	2 hours	3 hours	1 day

Force curing is suggested for all tank linings.

*Final cure below 60°F (16°C) is not recommended for tank lining service.

CLEAN UP: Use Carboline Thinner #2 or ketone solvent.

STORAGE CONDITIONS:
Temperature: 40-110°F (4-43°C)
Humidity: 0-100%

For more detailed information please consult specific Carboline Application Guides.

CAUTION: CONTAINS FLAMMABLE SOLVENTS. KEEP AWAY FROM SPARKS AND OPEN FLAMES. IN CONFINED AREAS WORKMEN MUST WEAR FRESH AIRLINE RESPIRATORS. HYPERSENSITIVE PERSONS SHOULD WEAR GLOVES OR USE PROTECTIVE CREAM. ALL ELECTRIC EQUIPMENT AND INSTALLATIONS SHOULD BE MADE AND GROUNDED IN ACCORDANCE WITH THE NATIONAL ELECTRICAL CODE. IN AREAS WHERE EXPLOSION HAZARDS EXIST, WORKMEN SHOULD BE REQUIRED TO USE NONFERROUS TOOLS AND TO WEAR CONDUCTIVE AND NONSPARKING SHOES.

Analytical Chemistry Division
Oak Ridge National Laboratory
Date: December 17, 1976

Report of Irradiation, Decontamination, and DBA Testing
Carboline, St. Louis, Missouri

The Irradiation, Decontamination, and Design Basis Accident (DBA) tests are conducted, respectively, in accordance with Bechtel Corporation Standard Specification Coatings for Nuclear Power Plants, Spec. Nos. CP-951, CP-952, and CP-956. The tests are designed also to meet the specifications set in both A.N.S.I. Report N 101.2-1972, Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities, and N 5.12-1974, Protective Coatings (Paints) for the Nuclear Industry. The DBA test spray solution and the test conditions are listed in Tables 1 and 2. After both the DBA and the irradiation tests, the coatings are examined for signs of chalking, blistering, cracking, peeling, delamination, and flaking, according to ASTM standards where applicable. All except the decontamination test panels are returned to the coating manufacturer.

The irradiation tests are run using a spent fuel assembly, removed from the High Flux Isotope Reactor (HFIR) at ORNL, as the source of radiation. These fuel assemblies are stored under 20 feet of demineralized water. The fuel is 93% enriched U^{235} as U_3O_8 combined with aluminum. The spent fuel assemblies are removed after each 23-megawatt day period. Irradiation is done using the gamma energy from the accumulated mixed fission products. This more readily simulates conditions around a reactor than does a cobalt source. Also, the higher gamma activity affords shorter irradiation time to achieve accumulated doses. The dose rate four days after removal of a fuel assembly from the reactor is 1×10^8 rads/hour.

The fuel assembly is 20 inches high. A 20-foot long, 3 1/2-inch diameter pipe, with one end capped, is used for the air irradiation tests. The capped end is lowered into the four-inch opening of the center of the fuel assembly. The open end, above the water level, is covered with an "O" ring sealed flange to which is attached a steel cable and an air outlet hose. The air inlet is located at the bottom of the pipe. The test specimens are connected

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Approved [signature]

to the bottom of the cable and lowered into the radiation field. Also at the center of the fuel assembly is a stainless steel clad cadmium tube used as a neutron absorber. This prevents contamination of the test specimens by induced radiation.

The decontamination procedure is as follows: a mixture of fission product nuclides (aged greater than 90 days and less than three years) is neutralized to pH 4 and immediately applied to the test specimens. The specimens are previously degreased in alcohol. After the contaminated spot is air dried, the activities of four of the nuclides are measured by counting with a Ge(Li) detector and a multichannel pulse height analyzer. The specimens are then suspended in a beaker of water at 25°C and washed by stirring for 10 minutes. The specimens are removed, the backs rinsed in water, air dried, and counted as above. The ratios of the activities before, to those after the decontamination are reported as decontamination factors for water. The decontamination and counting steps in 25°C and 80°C acids are repeated, and the respective decontamination factors calculated. The "total overall D. F." is calculated as the ratio of the total activity at the beginning of the test to the total activity at the completion of the three washing steps. All activities are corrected for decay between counts. A computer has been programmed to do all the calculations.

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Manufacturer: Carboline

St. Louis, MO

Analytical Chemistry Division
Oak Ridge National Laboratory
Date: December 17, 1976

Table 1. DBA Solution Composition, Distilled Water.

0.28 M boric acid (3,000 ppm boron)
0.064 M sodium thiosulfate
Adjusted to pH 9.6 with sodium hydroxide

Table 2. DBA Test Conditions.

Time	Temperature (°F)	Pressure (psig)	Comments
Start	170		Autoclave preheated.
20 seconds	340	70 (10 sec)	Steam injected.
6 hours		70	Pressure maintained by relief valve.
20 seconds	220	30	Spray solution added at 75°F.
15 minutes	220-250	30	
4 days	250	30	
20 seconds	180	-15	Fresh spray solution added at 75°F after draining autoclave.
15 minutes	180-200	10	
3 days	200	10	
End of test			

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Manufacturer: Carboline

St. Louis, MO

Analytical Chemistry Division
Oak Ridge National Laboratory
Date: December 17, 1976

System Identification: ___Steel X Concrete Block

CBCS-13
195/191HB

DBA Test Results:

ORNL Master Analytical Manual Method No. 2 0922;
Bechtel Corp. Spec. No. CP-956;
ORNL Log Book No. A 7562; 11-29-6

Sample No.	DBA Phase	Comments**
*70	spray	Coatings intact; no defects.
*71	spray	Coatings intact; one small crack, bottom side.
72	spray	Coatings intact; no defects.
73	spray	Coatings intact; no defects.
74	spray	Coatings intact; no defects.
75	spray	Coatings intact; one crack at bottom edge of top side.

*Irradiated.

**(SA) = sand blast; (SH) = shot blast; (GR) = grit blast.

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Manufacturer: Carboline
St. Louis, MO

Analytical Chemistry Division
Oak Ridge National Laboratory
Date: December 17, 1976

System Identification: ___ Steel X Concrete Block

CBCS-10
195/305

DBA Test Results:

ORNL Master Analytical Manual Method No. 2 0922;
Bechtel Corp. Spec. No. CP-956;
ORNL Log Book No. A 7562; 11-29-6

Sample No.	DBA Phase	Comments**
*82	spray	Coatings intact; no defects.
*83	spray	Coatings intact; no defects.
84	spray	Coatings intact; no defects.
85	spray	Coatings intact; no defects.
86	spray	Coatings intact; cracked at bottom edge of bottom side.
87	spray	Coatings intact; cracked at right edge of top side.

*Irradiated.

**(SA) = sand blast; (SH) = shot blast; (GR) = grit blast.

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Approved [signature]

Manufacturer: Carboline
St. Louis, MO

Analytical Chemistry Division
Oak Ridge National Laboratory
Date: December 17, 1976

System Identification: ___ Steel X Concrete Block

CBCS-12
Phenoline 2303-15

DBA Test Results:

ORNL Master Analytical Manual Method No. 2 0922;
Bechtel Corp. Spec. No. CP-956;
ORNL Log Book No. A 7562; 11-29-6

Sample No.	DBA Phase	Comments**
52	spray	Coating intact; no defects.
53	spray	Coating intact; no defects.
*54	spray	Coating intact; no defects.
*55	spray	Coating intact; no defects.
56	spray	Coating intact; no defects.
57	spray	Coating intact; no defects.

*Irradiated.

**(SA) = sand blast; (SH) = shot blast; (GR) = grit blast.

Evaluated [signature]

Approved [signature]

Report of DBA Testing of Coating Systems
from Carboline, St. Louis, Missouri

Systems of both coated steel panels and concrete blocks were submitted for Design Basis Accident (DBA) testing. The test was conducted in accordance with the manufacturer's recommendations which included reference to ANSI Report N101.2-1972, Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities and to a Babcock & Wilcox, Westinghouse, Combustion Eningeering Composite. A description of the systems, their total film thickness, and placement within the autoclave are listed in Tables 1., 2.. The DBA spray solution and the test conditions are listed in Tables 3., 4.. After the test, the coatings were examined for signs of chalking, blistering, cracking, peeling and delamination as per ASTM standards where applicable. All the systems were considered to have passed these test criteria except where otherwise noted in the comments listed in Tables 1., 2..

After the DBA test the panels and blocks were half immersed in spray solution which was kept at 200°F for a 10 day period under static conditions. The samples were again examined after this second test. There was no change in the condition of the coatings for any of the systems. The panels were 2" x 5" x 1/8" in size, scribed diagonally on one side. The blocks were 1" x 2" x 5" in size. The panels and blocks have been returned to Carboline.

Analytical Chemistry Division
Oak Ridge National Laboratory
December 5, 1975

Evaluated [signature]

Approved [signature]

Table 1.

Carboline Systems Submitted for Testing;

Steel Panels

System Designation	System Description	Total Film Thickness, mils
1A	Carbo zinc 11	3.5
1B(1)	"	3.4
2A	CZ 11/C-191HB	12.3
2B	"	13.7
3A	CZ 11/C-290WB	9.4
3B	"	6.8
5A	CZ 11/2 coats C-X2191-154	8.2
5B	"	6.5
6A	CZ 12/C-191HB	8.9
6B	"	10.1
7A	CZ 12/C-290WB	8.7
7B	"	9.9
8A	CZ 12/2 coats C-X2191-154	8.9
8B	" "	8.3
9A	Carbo Weld 11/C-X2191-154HB	5.5
9B	" "	4.9
10A	CW 11/Phenoline 305 finish	4.6
10B	" "	5.0
11A	C-X3904-72	3.2
11B	"	3.4
12A	CZ 11/C-X3910-17	3.5
12B	"	3.4
13A	CZ 11/Phenoline 368 WG	12.2
13B	" "	11.8
14A	C-193 Primer/C-191HB	10.3
14B	" "	9.7

Analytical Chemistry Division
Oak Ridge National Laboratory
December 5, 1975

Evaluated ____________

Approved ____________

Table 1. Cont'd

Steel Panels

Designation	Description	Thickness, mils
15A	C-193 Primer/C-190HB	6.7
15B	"	7.0
16A	C-X2191-149/C-290WB	7.0
16B	"	7.4
17A	P-368FD/Phenoline 368 finish	6.5
17B	"	7.5
18A	P-368FD/Phenoline 368 WG finish	8.8
18B	"	9.8

* A samples - spray phase-DBA.

* B samples - Immersed phase-DBA.

(1) Coating beginning to deteriorate.

Analytical Chemistry Division
Oak Ridge National Laboratory
December 5, 1975

Evaluated ____________

Approved ____________

Table 2.

Carboline Systems Submitted for Testing;
Concrete Blocks

System Designation*	System Description	Film Thickness, mils
20A	Phenoline 306TG	1/16 in.
20B	"	"
21A	P-306TG/C-191HB	1/16 in./4
21B	"	"
22A	C-195 Surfacer/C-191HB	25-40/4
22B	"	"
23A	C-295WB Surfacer/C-191HB	25-30/4
23B	"	"
24A	C-295WB Surfacer/C-290WB	25-30/4
24B	"	"
25A	C-295WB Surfacer/C-X2191-154	25-30/2
25B	"	"
26A	C-191HB/C-191HB	5/5
26B	"	"
27A	C-290WB/C-290WB	5/5
27B	"	"
28A	Phenoline 305 Concrete Primer/C-191HB	4/4
28B	"	"
29A	Phenoline 300 Orange/P-302/P-300 finish on one side only	8/8/8
29B[(1)]	"	"
30A[(2)]	P-300 Surfacer/P-300 finish	25-40/8
30B[(2)]	"	"
31A	C-295WB Surfacer/P-305 finish	25-30/4
31B	"	"

*A samples - spray phase DBA
*B samples - Immersed phase DBA

(1) A few cracks noted on all surfaces.

(2) Cracks at bottom of block; apparently due to mode of coating application. No other defects.

Evaluated [signature]

Approved [signature]

Analytical Chemistry Division
Oak Ridge National Laboratory
December 5, 1975

Table 3.

DBA Solution Composition; Distilled Water

0.28 M Boric Acid (3,000 ppm Boron)

0.064 M Sodium Thiosulfate

Adjusted to pH 9.5 with Sodium Hydroxide

Table 4.

DBA Test Conditions

Time	Temperature (°F)	Pressure (psig)
Start	90	--
0-2 minutes*	220	20
2-30 minutes	220-300	65
30-70 minutes	300-250	35
4 days	250	35
90 minutes	250-100	10
End of first part of Test		
10 days	200	--
End of test		

*Added spray solution at 300°F and began dynamic spray cycle.

Analytical Chemistry Division
Oak Ridge National Laboratory
December 5, 1975

Evaluated ____________

Approved ____________

3/26/82 - COPY TO RAY CHAPMAN, EG&G

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TELEX 44-7332

PROTECTIVE COATINGS
FOR CORROSION RESISTANCE • WATERPROOFING • FIRE PROTECTION • ROOFING

March 16, 1982

Mr. Dick Haelsig
Nuclear Packaging Inc.
815 S. 28th Street
Tacoma, WA 98409

Subject: Nuclear Waste Packaging

Dear Dick:

Here are the ORNL test results which you requested. In Table 7.1 you see that there is no effect on the coating at 1 x 10^{10} RADS. Since the HIC application is over steel, and the exposure will be in air, the 1 x 10^{10} RAD figure is the one to use.

I hope this helps to answer your questions. If you need anything further, please call.

Very truly yours,

Andrew K. Bernard
Power Industry Specialist

nlf/1/630/
Haelsig/031582

Enclosure

cc: Mr. Dave Muth/Mr. Bill Eggers/Mr. Dan McBride/Mr. Michael Salater/
Mr. Tim Dolan

CARBOLINE COMPANY • 350 HANLEY INDUSTRIAL COURT • ST. LOUIS, MISSOURI 63144

Revision 1
September, 1982

ORNL-3916

Contract No. W-7405-eng-26

UNIT OPERATIONS SECTION QUARTERLY PROGRESS REPORT

July-September 1965

M. E. Whatley

P. A. Haas
R. W. Horton
A. D. Ryon
J. C. Suddath
C. D. Watson

MARCH 1966

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
Operated by
UNION CARBIDE CORPORATION
U. S. ATOMIC ENERGY COMMISSION

Radiation Resistance of Protective Coatings (Paints)[a]

G. A. West

Tests to evaluate some protective coatings (paints) for use in reactor containment vessels, spent-fuel processing plants, and laboratories were conducted by exposing (a) some specimens to gamma radiation, (b) other specimens to the fallout of radioactive fission products from the plasma-jet volatilization of irradiated UO_2 in a 1,350-ft^3 vessel, and (c) selected coatings to a tentative standard decontamination test. The Nuclear Safety Pilot Plant group conducted the volatilization test with coating specimens supplied by the Unit Operations Section.

Radiation-Tolerance Testing

Protective coatings were exposed to ^{60}Co gamma radiation at an intensity of 1×10^6 rads/h at 40-50°C in air and in demineralized water. Several manufacturers submitted special formulations of their coatings in an attempt to discover a coating with unusual or outstanding resistance to gamma radiation in the presence of deionized water.

Three such coatings surpassed the previous high (5×10^9 rads) resistance in demineralized water: (a) Carboline Co's. System K, a modified phenolic (Phenoline 368) containing embedded glass cloth, and Phenoline 368 seal coat failed at 8.3×10^9 rads by blistering and loss of adhesion; (b) Varni-Lite Corp's. No. S-0900 epoxy system failed at 8.0×10^9 rads by blistering; and (c) Amercoat No. 1762 with No. 66 epoxy seal coat failed at 7.9×10^9 rads by chalking (Table J-1). There is evidence of greater radiation tolerance in air since 19 of 79 coatings appear serviceable after an exposure of 10^{10} rads.

---

a. Excerpted from ORNL-3916, Unit Operations Quarterly Progress Report, July-September 1965, Contract No. W-7405-ang-26, March 1966.

TABLE J-1. RADIATION RESISTANCE RATING OF SEVERAL PROTECTIVE COATINGS (Radiation Source: ^{60}Co at 1 x 10^6 rads/h Temperature: 40 to 50°C Manufacturers are listed alphabetically, with the coatings listed in decreasing order of resistance to radiation)

Manufacturer	Coating	Substrate	Exposure under Demineralized Water (rads)	Effect	Exposure in Air (rads)	Effect
Carboline Company	Modified phenolic, System K (Phenoline 368)	conc.	5.8×10^9	C,D	1×10^{10}	
		steel	8.3×10^9	C,D	1×10^{10}	
	Modified phenolic, System C	conc.	3.6×10^9	C,D	8.3×10^9	B,C
	Modified phenolic, System H (Phenoline 368)	conc.	2.6×10^9	C	1×10^{10}	
		steel	6.3×10^9	C	1×10^{10}	
	Modified phenolic, System G (Phenoline 368)	conc.	4.7×10^9	C	1×10^{10}	
		steel	4.7×10^9	C	1×10^{10}	
	Modified phenolic, System I (Phenoline 368)	conc.	4.7×10^9	C	1×10^{10}	
		steel	3.6×10^9	C	1×10^{10}	
	Modified phenolic, System F (Phenoline 368)	conc.	No test		7.8×10^9	C
		steel	3.6×10^9	C	6.8×10^9	C
	Modified phenolic, System J (Phenoline 368)	conc.	2.1×10^9	A	4.7×10^9	B,C
		steel	2.1×10^9	A	1×10^{10}	
	Modified phenolic, System A (Phenoline 368)	conc.	4.3×10^9	A,C	3.2×10^9	C
		steel	4.7×10^9	C	7.1×10^9	B,C
	Modified phenolic, System B (Phenoline 368)	conc.	2.6×10^9	C	5.6×10^9	B,C
		steel	3.6×10^9	C	7.1×10^9	C
	Modified phenolic, System D	conc.	2.1×10^9	A,E	6.0×10^9	C
	Modified phenolic, System E (Phenoline 368)	conc.	2.1×10^9	A	6.0×10^9	C
		steel	2.1×10^9	A	6.8×10^9	B

Studies of Contamination due to a Simulated Reactor Excursion

Protective-coating specimens and controls were exposed to an atmosphere contaminated with radioactive fission products from the plasma-jet volatilization of natural UO_2 that had been irradiated at an average neutron flux of 4.5×10^{10}. This resulted in about 0.6 Ci of total mixed fission product gamma activity after cooling for seven days. In tests simulating a reactor excursion and the volatilization of fuel, the amount of radionuclides deposited on the exposed surface was measured and compared. Radionuclides were identified and measured by scanning the specimens with a gamma-ray spectrometer before decontamination.

Coatings exhibiting the least retention of the 10 radionuclides measured are listed below:

Modified Phenolics

Phenoline 300, Carboline Company
Phenoline 305, Carboline Company
No. 7122, 7133X, Wisconsin Protective Coating Company.

APPENDIX K
SEAL MATERIAL DATA SHEETS

APPENDIX K

SEAL MATERIAL DATA SHEETS

CONTENTS

1. Adhesive Engineering Technical Bulletin AE-441/1 Concresive 1077 Type I and Type II[a] K-4

2. Adhesive Engineering Technical Bulletin AE-455, "A Discussion of Nuclear Radiation Resistance of Epoxies with Particular Reference to the Class Including Concresive Type 1077 Improved (Types I and II) and Concresive 1305 and 1310"[a] K-9

3. Adhesive Engineering Technical Bulletin A/E 470 Concresive AEX-1512[a] Chemical/Radiation Resistant Mortar Binder (used for lid seal) K-22

4. Adhesive Engineering Technical Bulletin AE-402/2 Concresive 1310[a] Chemical Resistant Mortar Binder (used for lift lug grouting) K-25

5. Adhesive Engineering Memorandum, September 14, 1982; Subject: The Durability of Concresive 1512[a] Grout and Concresive 1513[a] Gel Seal K-27

---

a. The Concresive 1077, 1310, 1512, and 1513 products are similar, differing only in cure times and consistency.

ADHESIVE ENGINEERING COMPANY

1411 INDUSTRIAL ROAD
PHONE (415) 592-7900

SAN CARLOS, CALIFORNIA 94070
TELEX 34-8459

A MEMBER OF THE JEFFERSON CORPORATION FAMILY

CONCRESIVE® 1077 TYPE I & TYPE II

CONCRESIVE 1077 Type I and II are two closely related epoxy adhesives which are primarily used to restore cracked Portland Cement Concrete (PCC) and to fill voids in concrete structures. The products are particularly suitable for use in structures which are exposed to high levels of nuclear radiation.

CONCRESIVE 1077 Type I and II replace two older products, CONCRESIVE 1077-1 and 1077-12. The principal improvements incorporated in the new products are:

greatly increased storage life; simple volumetric mix ratio; ability to bond to damp concrete.

CONCRESIVE 1077 Type I is a low viscosity, two component, room temperature curing epoxy adhesive for restoring cracked Portland Cement Concrete (PCC) primarily in applications where high levels of nuclear radiation may be encountered and for bonding steel to PCC. The product is best applied by using Adhesive Engineering Company's SCB Process® which provides accurate metering, mixing and injection of the material.

CONCRESIVE 1077 Type II is intended for filling large voids in PCC, rock or wood structures. Due to its slow cure rate, the product can be applied in a large mass without undo build-up of heat and the attendant high degree of shrinkage or possible decomposition. Due to its long working life, CONCRESIVE 1077 Type II may be extended with sand or gravel and installed using conventional cement grout pumps. Prepacking of the space to be filled in a concrete structure with sand or gravel and subsequent injection of the liquid material is an alternate technique which has been successfully used.

CONCRESIVE 1077 Type II is not recommended for applications involving thin bond lines. The product may be employed in load bearing applications when at least partial confinement of the product can be achieved.

CONCRESIVE 1077 Type I and Type II represent a matched pair of products with common A and compatible B components. This allows mixing of the two B components and makes possible the adjustment of pot life and set time. The B components of CONCRESIVE 1077 Type I and II are stable on storage and may be used with the equally stable A component of Type I or Type II in the same volume ratio. Upon cure such blended products exhibit properties intermediate of Type I and II alone. Care has to be taken in the use of the blended products to avoid an undesirable exotherm which can occur when a high percentage of CONCRESIVE 1077 Type I B is present. Use of blended products is not recommended in filling large voids.

CONCRESIVE 1077 Type I will cure in the presence of moisture and at temperatures down to 35°F. Due to the large increase in viscosity, application below 50°F is not practical. The same limitations apply to CONCRESIVE 1077 Type II. In addition, the cure time of a small mass of Type II below 65°F is very long (more than two weeks).

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Water and chemical resistance of both types of CONCRESIVE 1077 is outstanding and similar to that of CONCRESIVE 1305 and 1310. Both materials have excellent physical properties compared to PCC. In structural applications, use of the products at ambient temperatures exceeding the heat deflection temperature (HDT) is not recommended.

PRODUCT DESCRIPTION

	TYPE I	TYPE II
Form	Two component, very low viscosity liquid	
Color		
Part A	Clear Amber	
Part B	Black	
Mixed	Black	
Typical Properties @ 77°F		
Density		
Part A	9.5	9.5
Part B	9.3	9.2
Mixed	9.4	9.4
Viscosity, Poise		
Part A	5.0	5.0
Part B	6.0	4.0
Mixed	6.0	5.0
Mix ratio, A:B	2:1, by volume	
Shelf Life	One year minimum in sealed containers at ambient temperatures of less than 120°F.	

TYPICAL CURING PROPERTIES AT 77°F

	TYPE I	TYPE II
Pot Life, minutes		
One Quart Mass	60	300
One Gallon Mass	50	120
Thin Film Tack Free Time, hours	5	N/A*
Full Cure Time, days	10	22

*Not available

TYPICAL PHYSICAL PROPERTIES OF CURED MATERIAL AT 77°F

The properties listed below are typical of CONCRESIVE 1077 Type I and II after a cure time of two weeks at 77°F. Prolonged cure times or short exposure to higher temperatures will increase the physical properties of Type II material to those of Type I.

For applications in a nuclear radiation environment, it should be noted that irradiation itself post-cures the epoxy indirectly by causing an increase in temperature of the material and directly by promoting further cross-linking of the polymer.

CONCRESIVE 1077

PROPERTY	TYPE I	TYPE II
Tensile Strength, psi (ASTM D638)	6,000	5,000
Elongation at Break, % (ASTM D638)	2.0	2.5
Compressive Yield Strength, psi (ASTM D695)	10,000	9,000
Compressive Modulus, psi (ASTM D695)	1.4×10^5	1.2×10^5
Flexural Strength, psi (ASTM D790)	10,000	8,000
Flexural Modulus, psi (ASTM D790)	3.5×10^5	3.0×10^5
Heat Deflection Temperature, °F (ASTM D648)	120	112

ADHESIVE PROPERTIES OF CONCRESIVE 1077 TYPE I AT 77°F

Slant shear strength (AASHTO T-237; for wet test, PCC was immersed in water at 77°F for 24 hours, removed, bonded with the epoxy adhesive and cured in air at 77°F).

	CURED PCC	
CURE TIME, days	DRY, psi	WET, psi
2	2000	1000
7	7000	5500
14	8000	6000

EFFECT OF AGGREGATE EXTENSION

CONCRESIVE 1077 Type I is an injection material for the repair of cracked concrete and is designed for application with SCB Process equipment, therefore, the use of fillers and aggregates in the filling of large voids is not recommended.

CONCRESIVE 1077 Type II and Type I/II blends containing a major proportion of Type II may be employed as mixtures with sand or gravel or as casting systems. It is also possible to prepack large voids with graded pea gravel followed by injection of the epoxy material. The effect of aggregate on CONCRESIVE 1077 Type II is indicated in the table below which shows properties of specimens containing 3.5 volumes of sand after a two week cure at 77°F.

PROPERTY	TEST VALUE
Compressive Yield Strength, psi (ASTM D695)	10,500
Compressive Modulus, psi (ASTM D695)	2.7×10^5

EXOTHERM TEMPERATURE ON CURE

In void filling applications, it is essential that the maximum temperature which develops on cure remains moderate (100-120°F) to avoid shrinkage after the gel state of the epoxy system has been reached. This condition can be met by providing a heat sink for fast reacting systems, the use of slowly reacting systems or the employment of a adhesive system in combination with a sufficient amount of aggregate to minimize the exotherm. Aggregate prepacking is often not possible which leaves only the slowly reacting epoxy system as a practical solution to a void filling problem. CONCRESIVE 1077 Type II is such a system. In a one gallon mass, when surrounded by air, this product develops an exotherm of approximately 350°F within three hours after mixing. The same mass surrounded by concrete shows no appreciable exotherm because the heat of reaction is absorbed by the environment.

CHEMICAL, WATER AND SOLVENT RESISTANCE

Chemical, water and solvent resistance of CONCRESIVE 1077 Types I and II is equivalent to that of CONCRESIVE 1305 and 1310. Please refer to the corresponding bulletins.

NUCLEAR RADIATION RESISTANCE

CONCRESIVE 1077 Types I and II are specifically designed for use in nuclear radiation environments. A pamphlet on the behavior of the materials manufactured by Adhesive Engineering Company in radiation environments is available upon request.

LIMITATIONS

	CONCRESIVE 1077	
	TYPE I	TYPE II
Minimum Application Temperature, °F		
Liquid	50	65
Mortar	60	65
Minimum Cure Time Before Functional Use, days	7	20
Application in Thin Bond Lines	recommended	not recommended

CLEAN-UP

All tools and equipment must be immersed or cleaned with toluene or acetone before curing occurs.

HANDLING AND TOXICITY

A and B Components for Industrial Use Only! Warning! Skin Contact May Cause Serious Delayed Dermatitis. Avoid inhalation of vapor. Use ventilation particularly if heated or sprayed. Prevent all contact with skin. If contact occurs, wash immediately with soap and water. Part A - SPI Classification 2; Part B - SPI Classification 4.

The use of barrier creams, such as Kerodex No. 71 or Indco Labs No. 211, 213 or 214 is recommended. Clean rubber gloves or disposable polyethylene gloves provide the best protection. Should skin contact occur, wash immediately with soap and water, or Adhesive Engineering Company's EPOCLEANSE ® 6001 skin cleaner.

Good ventilation is necessary for indoor work, and great care should be taken to avoid splashes which would endanger the face and eyes.

FOR LIMITED DISTRIBUTION

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A DISCUSSION OF NUCLEAR RADIATION RESISTANCE OF EPOXIES WITH PARTICULAR REFERENCE TO THE CLASS INCLUDING CONCRESIVE® 1077 IMPROVED (TYPES I AND II) AND CONCRESIVE 1305 AND 1310

Introduction

Epoxy resins have been employed in nuclear applications from the start [1]. It was recognized even in 1957 [2] that aromatic amine cured conventional epoxies were considerably more radiation resistant than systems with aliphatic amines.

One of the first specifications covering pressure injected epoxies to restore cracked PCC to be subjected to radiation was developed in 1963 for repair of the Stanford Linear Accelerator (SLAC) in Menlo Park, California after construction and prior to use and specified an aromatic amine cured epoxy for the purpose. CONCRESIVE 1077 met this specification and was used for the contract.

Since that time CONCRESIVE 1077 has been used for concrete repair and restoration at the following nuclear facilities in the USA:

Structure Name	Function
Brown's Ferry Nuclear Power Plant Decatur, Georgia	Electrical generation
Turkey Point Station Florida City, Florida	Electrical generation
Pilgrim Station Plymouth, Massachusetts	Electrical generation
Allied Gulf Nuclear Plant	Nuclear fuel
Sterling Nuclear: Unit I Oswego, New York	Electrical generation
Surry Power Station Gravel Neck, Virginia	Electrical generation
McQuire Nuclear Station Charlotte, North Carolina	Electrical generation
Vallecitos Nuclear Plant Livermore, California	Research and isotope manufacture

® [illegible] Trade Name, Adhesive Engineering Company

Structure Name	Function
Washington Public Power Supply System Units 3 & 5 Satsop, Washington	Electrical generation

Measurement of Radiation and Its Effects on Construction Materials

Types of Radiation

Radiation can be divided into the following categories:

(a) X-rays and gamma-rays -- emissions due to profound changes in the shell and nucleus of the atom.

(b) Fast neutrons and slow (thermal) neutrons -- streams of neutral particles.

(c) Alpha-rays, electron beams (beta-rays), protons, deuterons, positively charged nuclei of other elements and other fission fragments -- streams of charged particles, either positive or negative.

General Effect of Radiation Type

In terms of the effect of radiation on organic materials, such as epoxy resins, it is categories (a) and (b) above that possess great penetrating power and of these, in general, gamma-rays and fast neutrons are the most damaging.

In the case of category (c), the energy of these charged particles diminishes during passage through materials, thus the effect of radiation is observed primarily at the surface of the material in contrast to (a) and (b) where the effect is uniform through a substantial volume.

It is, therefore, important to take account of the thickness of the epoxy as well as any covering materials when considering radiation in category (c), both of which reduce damage.

General Effect of Radiation on Polymers

a. Chemical Effect -- The general chemical effect of radiation on polymers such as epoxy is to simultaneously increase the degree of cross-linking or cure and, where irradiation is carried out in air (oxygen), to promote oxidation (deterioration) by free-radical production, i.e., to activate the oxygen.

b. Thermal Effect -- Irradiation causes instantaneous temperature rise in the material or part of the material affected. The temperature rise increases with the intensity of the irradiation to a depth affected by the type of radiation. By conventional thermal conductivity, heat is transferred from any covering material or section of epoxy being irradiated to areas not under irradiation. Thus irradiation may cause deterioration by conventional heat aging (oxidation) in addition to the chemical effects discussed above.

Conclusion

In theory the total dosage (amount) of radiation of any type absorbed by an epoxy will have the same effect (2, 3 and 4). However, the degree of penetration, already mentioned, must be considered. Also it is common practice to simulate many years of lower level radiation by short-time tests of higher level radiation. This may be satisfactory for a comparative rating of a number of candidate materials, but care should be exercised in interpretation of these effects for establishment of performance criteria. The rate of dosage used in testing should not be so high as to cause an unrealistically high degree of oxidation in the epoxy that does not correlate with long-term field conditions or one-time disaster conditions.

The difference in dose rates conveniently available from different types of radiation sources, and the thickness effect for charged and uncharged types, appear to be the main reasons for different conclusions by separate investigative programs as to the degree of radiation absorption that a particular epoxy system can withstand.

It can generally be stated that the more resistant an epoxy system is to ordinary heat aging the greater will be its radiation resistance. This correlates with the observed fact that conventional (Bisphenol A) epoxy resin cured with aromatic amines are more radiation resistant than when cured with aliphatic amines; they are also more resistant to thermal aging especially above their Heat Deflection Temperature (HDT) or Glass Transition Temperature (Tg).

It should be noted the structural capability of any epoxy system is limited at and above its HDT due to a significant reduction in modulus with increasing temperature. In general the modulus will be regained upon cooling below the system's heat cured HDT. Sealing and waterproofing qualities are usually maintained at the elevated temperature despite loss of modulus. Also the modulus reduction may not be significant where a high degree of confinement, due to surrounding materials, is present.

Units of Radiation Measurement

Units of radiation resistance for this purpose may be divided into two categories:

(a) Measurements of emission (density of the radiant field), including emission through air, e.g., flux density or emission intensity in ergs/cm^2 - sec or Mev/cm^2 - sec or neutrons/cm^2 - sec; or in air roentgens or Mev/g of air. Also nvt; and

(b) Measurements of absorption by materials (other than air), e.g., absorbed dose in reps, rems, and rads.

Apart from the qualifications indicated above regarding dose rate, the significant units, from the viewpoint of effect on materials, is the absorbed radiation dose (from any type of radiation). Of the units in (b) above the rep and rem refer to absorption by biological tissue thus the rad is the most suitable unit for use with epoxies.

Some of the earlier published work on materials state dosage in terms of roentgens or nvt's (slow thermal) neutron flux X irradiation time). In order to make use of such data some correlation factors have been developed.

Roentgen

This unit refers to the quantity of x-rays or gamma-rays only required to produce a fixed degree of ionization in 1cc of air. The quantity of radiation required to produce the same intensity in 1cc of polymer (i.e., the energy equivalent) is approximately proportional to their respective densities.

When dosage of a polymer is given in roentgens, the radiation source must have been x- or gamma rays and a close approximation may be used to convert to rads:

$$1 \text{ rad} = 0.88 \text{ roentgens}$$

n.v.t.

The absorbed dose in the polymer is considered here to be proportional to the emission intensity (density X velocity) of slow (thermal) neutrons only (in neutrons/cm^2/sec) multiplied by a fixed period of time (in seconds). For specific polymers, conversion coefficients to rads have been developed[5], e.g.,

Acrylic	1 nvt = 7.0×10^{-8} rads
Nylon	1 nvt = 1.0×10^{-9} rads
Neoprene	1 nvt = 2.5×10^{-7} rads

nvt units are slow (thermal) neutrons/cm^2

Rad

As indicated above, this is the most desirable unit for both total absorbed dose and comparisons of dose rates obtained by back-calculation (total dose divided by irradiation time in hours or days equals rads/hr. or rads/day).

$$1 \text{ rad} = 100 \text{ ergs/g or } 6.25 \times 10^{13} \text{ ev/g of irradiated polymer}$$

Threshold Radiation Value (TRV)

This is the dosage in rads, required to start degradation of a polymer as determined by the physical, thermal, electrical or chemical resistance property being monitored.

In practice, the designer may allow up to 50% loss of a particular property depending upon the safety factor employed in the design.

Typical TRV's for conventional Bisphenol A epoxy resins cured with the various classes of amines are as follows:

Unmodified Aromatic Amines (heat cured) $1 - 2 \times 10^9$ rads

Modified Aromatic Amines (room temp. cured) $5 - 6 \times 10^8$ rads

Aliphatic Amines (room temp. or heat cured) $5 - 9 \times 10^7$ rads

It should be noted that the description "aliphatic amines" also covers amine-adducts, amido-amines and polyamide hardeners for epoxy resin.

It is noted in Reference 6 that aromatic amines are 4-9 times more stable than aliphatic amines and that basic curing agents (amines) are more stable than acidic types (e.g., anhydride curing agents).

Specific Studies

The results of two specific studies carried out by independent investigators are given below. They were selected on the basis of close chemical similarity or equivalency of the epoxy/aromatic systems tested to CONCRESIVE 1077, Type I and Type II (as well as CONCRESIVE 1305 and 1310).

Study No. 1

Application: Nuclear Reactor Pool Lining (with glass cloth in coating) - presumed use of pool is storage of spent reactor fuel rods.

Estimated Design Dosage: 1×10^9 roetgens would be received by coating over 30 years.

Test Dosage: 1×10^9 roetgens total over 25 hours.

Assumed Test Radiation: Gamma (since does is given in roetgens and application is pool lining).

Conversion: 1 rad = 0.88 roetgens. Therefore:

Total Dosage: $[0.88] \times [1 \times 10^9] = 8.8 \times 10^8$ rads (in 25 hours)

Back-Calculated Dose Rate: 8.45×10^8 rads/days or 3.52×10^7 rads/hour

Temperature During Test: Not Known

Result: Free films reinforced with glass cloth were not deteriorated. Tear strength of film actually increased after irradiation. A decrease was noted for some of the other (epoxy) systems tested.

Reference: "Irradiation Resistance of Araldite 6005/DP-131H/DP-136 System" (now 6005/830/850). Ciba-Geigy, Basle, Switzerland, Lab. Report, 1963 Summary reprinted in Ciba-Geigy, USA "Coatings Technical Newsletter, No. 6, Dec. 16, 1963 - (Item #3).

Chemical Description:

Bisphenol A diglycidyl either (Araldite 6005) cured with liquified methylene dianiline (MDA), modified with dibutyl phthalate and accelerated with a trace of aromatic acid (Araldite Hardeners HY830 and HY850).

Study No. 2

Application: Proton Synchroton Vacuum Chamber Construction

Source: Nuclear Reactor Pile

Type of Radiation: Slow neutrons plus gamma rays and fast neutrons

Flux Density: 1.2×10^{12} slow (thermal) neutrons/cm^2/sec.

Pile Factor (nvt) = flux density x 24 hours = $(1.2 \times 10^{12}) \times (8.64 \times 10^4) =$
1.0×10^{17} nvt

Conversion Coefficient used for epoxy (back-calculated) was 1 nvt =
7×10^{-10} rads, therefore:

Pile Factor = $(7 \times 10^{-10}) \times (1 \times 10^{17}) = 7 \times 10^7$ rads

Therefore, back-calculated - dose rate = 7×10^7 rads/day or
2.92×10^6 rads/hour

Therefore, cumulative dose at 5 days = $5 \times (7 \times 10^7) = 3.50 \times 10^8$ rads

10 days = $10 \times (7 \times 10^7) = 7.00 \times 10^8$ rads

15 days = $15 \times (7 \times 10^7) = 1.05 \times 10^9$ rads

20 days = $20 \times (7 \times 10^7) = 1.50 \times 10^9$ rads

Temperature During Immersion: 70°C (158°F)

Specimen Size: 2" x 1/2" specimens cut from 1/8" thick cast sheet

Tests: Ultimate Flexural Strength, Hardness and Shrinkage vs. radiation dose.

TABLE I

EFFECT OF RADIATION ON AN AROMATIC VS. AN ALIPHATIC AMINE CURED EPOXY

Cumulative Dose (rads)	Modified Aromatic Amine (AERE System #16)					Typical Aliphatic Amine (AERE System #1)				
	Flexural Strength		Hardness [1]		Shrinkage [2]	Flexural Strength		Hardness		Shrinkage
	Value (psi)	% Change	Value	% Change	% Change	Value (psi)	% Change	Value	Change	% Change
0	18,500	0	46	0	0	19,300	0	32	0	0
3.50×10^8	18,100	-2.2	--	--	-0.3	9,600	-50.3	35	+9	Badly blistered -
7.00×10^8	15,700	-15.1	51	+11	-0.3	1,500	-92.2	34	+6	not possible to run
1.05×10^9	11,700	-36.8	--	--	-0.3	Sample destroyed				
1.40×10^9	7,100	-61.6	42	-7	-0.3	Sample destroyed				

(1) Vickers Hardness Number

(2) Percent change in thickness. Negative value indicates increase in cross-link density.

Identification of Systems Employed in Table I.

AERE Report R-3085 does not identify fully all systems evaluated, presumably for security reasons at that time. Due to the comprehensive and valuable nature of this report, the chemical compositions are provided below:

System #1

Resin - Epikote[R] 815 (Shell Chemical Co. Ltd., U.K.) same as
Epon[R] 815 (Shell Chemical Co., USA)
Composition: Diglycidyl ether of Bisphenol A (Epon 828) 88%
n-butyl glycidyl ether 12%

Hardener - Epikure[R] T (Shell Chemical Co. Ltd., U.K.) also
Hardener Q18814 (Bakelite Ltd., U.K.)
In USA: Epon Curing Agent T (Shell Chemical Co., USA)
Composition: 1:1 molar adduct of diethylene triamine and ethylene oxide. (N-hydroxyethyl diethylene triamine)

System #16

Resin - Araldite[R] D (Ciba ARL Ltd.)
In USA Araldite 502 (Ciba-Geigy, Inc.)
Composition: Diglycidyl ether of Bisphenol A (Araldite 6020) 84%
dibutyl phthalate 16%

Hardener - 4,4'-diamino diphenyl methane (UK) or 4,4'-methylene dianiline (MDA) in USA.

Note that 25 phr of hardener was used in System #16 rather than 22 phr, thus amine stoichiometry was in excess at 113.6%. (Exact, i.e., 100%, stoichiometry would be expected to result in even greater resistance)

Other Systems

Resins - System Nos. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 18 used Epikote 815.

Systems No. 12, 13, 14, and 15 used Epikote 828

System No. 16 used Araldite D.

Hardeners - System No. 2 - Epikure K61B (UK) or in USA Epon Curing Agent D

System No. 3 - Epikure Z (UK) or in USA Epon Curing Agent Z

System No. 12 - Nadic[R] Methyl Anhydride (methyl endomethylene tetrahydrophthalic anhydride).

AERE Conclusions

Among the conclusions of the above study were the following:

1. Aromatic amine cured epoxy producted considerably more radiation resistant systems than aliphatic amine cured systems.

2. Breakdown, in the case of aliphatic amines, consisted of a rapid fall-off in flexural strength and formation of gas blisters.

3. Diamino diphenyl methane (methylene dianiline) is the most radiation resistant, commercially available hardener.

Reference: AERE Report R-3085 entitled "Some Effects of Radiation in Cast Epoxide Resin Systems", by I.D. Aitkin and K. Ralph. Atomic Energy Research Establishment, Harwell, England, 1960.

Summary and Comments:

CONCRESIVE 1077 type systems (including CONCRESIVE 1305 coating and CONCRESIVE 1310 mortar) based on modified aromatic amine hardeners, are probably the most radiation resistant, room temperature curing epoxy systems available. The TRV appears to be of the order of 5 to 6 x 10^8 rads while useful service is provided up to 7 x 10^8 to 1 x 10^9, depending upon the design criteria involved.

Despite the well documented superior radiation resistance or aromatic amine cured conventional epoxy resins, coatings currently used for protecting nuclear power plants are generally based on aliphatic amines, amine adducts, amido amines and polyamide resins and, exhibit relatively poorer radiation resistance than the available state-of-the-art.

APPENDIX

SYSTEM FOR CONVERSION OF RADIATION UNITS

Given	Electron-Beam Energy	Gamma-Radiation Flux (1.0-Mev Rays)					Neutron Flux	
	Electron Density at 1.0 Mev, A (electrons/cm^2)	Absorbed Dose, B (rads)	Roentgen Equivalent Physical, C (reps)	Absorbed Energy per Gram Air, D (roentgens)	Absorbed Energy per Gram, E (ergs/gm)	Gamma Photons per cm^2, F	Fast Neutrons (over 0.1 mev) Neutrons/cm^2, G (nvt)	Thermal Neutrons (below 0.1 mev) H (nvt)
				Electron-Beam Energy				
Electrons/cm^2	----	$Bx5x10^{7}$	$Cx4.6x10^{7}$	$Dx4.4x10^{7}$	$Ex5x10^{5}$	$Fx2.5x10^{-2}$	$Gx1.5x10^{-1}$	$Hx3x10^{-2}$
				Gamma-Radiation Flux				
Rads	$Ax2x10^{-8}$	----	Cx0.93	Dx0.877	$Ex10^{-2}$	$Fx5.0x10^{-2}$	$Gx3.0x10^{-9}$	$Hx6.0x10^{-11}$
Reps	$Ax2.15x10^{-8}$	Bx1.075	----	Dx1.05	$Ex1.075x10^{-2}$	$Fx5.4x10^{-10}$	$Gx3.2x10^{-9}$	$Hx6.4x10^{-11}$
Roentgens	$Ax2.28x10^{-8}$	Bx1.14	Cx0.95	----	$Ex1.14x10^{-2}$	$Fx5.7x10^{-10}$	$Gx3.4x10^{-7}$	$Hx6.8x10^{-11}$
Ergs/gm	$Ax2x10^{-6}$	$Bx10^{2}$	Cx93	Dx87.7	----	$Fx5.0x10^{-8}$	$Gx3.0x10^{-7}$	$Hx6.0x10^{-3}$
Photons/cm^2	Ax40	$Bx2.0x10^{9}$	$Cx1.86x10^{9}$	$Dx1.75x10^{9}$	$Ex2.0x10^{7}$	----	Gx6.0	Hx1.2
				Neutron Flux				
Fast nvt	Ax6.6	$Bx3.3x10^{8}$	$Cx3.1x10^{8}$	$Dx2.92x10^{8}$	$Ex3.3x10^{8}$	Fx0.17	----	Hx0.2
Thermal nvt	Ax33	$Bx1.66x10^{9}$	$Cx1.56x10^{9}$	$.37x10^{9}$	$Ex1.66x10^{7}$	Fx0.83	Gx5.0	----

Reference: Pendelton, W.W., "System for Conversion of Radiation Units," Electro-Technology, October, 1963

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August 1980

Technical Bulletin A/E 470
July 14, 1982

Revision 1
September, 1982

ADHESIVE ENGINEERING COMPANY

1411 INDUSTRIAL ROAD
PHONE (415) 592-7900

SAN CARLOS, CALIFORNIA 94070
TELEX 34-8459

A MEMBER OF THE JEFFERSON CORPORATION FAMILY

CONCRESIVE [R] AEX-1512

CHEMICAL/RADIATION RESISTANT MORTAR BINDER

Description: Solventless, long pot life, room temperature curing epoxy mortar binder. Designed for mixing with suitable aggregate to produce mortars and grouts with good resistance to most highly corrosive chemicals and superior resistance to radiation exposure.

Uses:
- Grouting machine bases and sole plates where resistance to chemicals is required.
- Grouting voids where resistance to radiation is required.
- Patching and grouting where a long working time is required.

UNCURED CHARACTERISTICS OF BINDER

Form: Two-component, low viscosity liquid

Mix Ratio, A:B 2:1, by volume

Standard Packaging: One gallon unit

	Part A	Part B	Mixed
Color:	clear amber	dark green	dark green
Density, lb/gal:	9.52	9.22	9.40
Viscosity, poise:	7.0	10.5	8.0

Shelf Life: One year minimum in sealed containers at ambient temperatures of less than 120°F.

[R] Registered Trade Name, Adhesive Engineering Company

CURING CHARACTERISTICS OF BINDER[1)]

Pot Life, minutes: 60
225 g mass

Full Cure Time, days: 16

Strength Development @ 77°F:

Cure Time	Compressive Yield Strength, psi (ASTM D695)
25 hrs	1,600[2)]
40 hrs	6,300[2)]
48 hrs	7,400
9 days	12,000

CURED CHARACTERISTICS OF BINDER[3)]

Tensile Strength, psi	ASTM D638	6,000
Elongation at Break, %	ASTM D638	2.0
Compressive Yield Strength, psi	ASTM D695	10,000
Compressive Modulus, psi	ASTM D695	2.4×10^5
Flexural Strength, psi	ASTM D790	8,000
Flexural Modulus, psi	ASTM D790	3×10^5
Heat Deflection Temperature, °F	ASTM D648	118
Expansion Coefficient, 1/°F (strain gauge)		4×10^{-5}

CHARACTERISTICS OF CONCRESIVE AEX-1512 GROUT

Proportion of grout mix (one standard unit):

CONCRESIVE 1512	1 gallon	9.4 lbs
A/E SPECIAL GROUT BLEND	1 bag	44.3 lbs
Total Weight :		53.7 lbs
Yield	3 gallons	0.4 cubic feet

Peak Exotherm (1 quart mass)[1]:

	In air	In water bath
Time, minutes	100	No exotherm developed.
Temperature, °F	87	

Strength Development @ 77°F:

Cure Time	Compressive Yield Strength, psi (ASTM D695)
30 hrs	5,400[2]
10 days	15,000

Linear Curing Shrinkage: less than 0.1%

Coefficient of Thermal Expansion, 1/°F: 1.2×10^{-5}
(strain gauge)

1) @ 77°F
2) 2% Offset Yield
3) Cured 14 days @ 77°F

Description

Solventless, room-temperature curing epoxy mortar binder. Designed for mixing with suitable aggregates to produce mortars resistant to most highly corrosive chemicals. Standard color is brick red.

Uses

- Indoor flooring and patching on PCC where high chemical resistance is required. May be used in facilities manufacturing or using strong chemicals including plating rooms, acid etching rooms, dairies, breweries, canneries, slaughter houses, paper pulp plants, and nuclear power plants.

Features

Provides outstanding protection of concrete and other substrates against chemical deterioration, mechanical abuse and wear. Withstands steam cleaning, high temperatures and nuclear radiation. By selection of a suitable aggregate type and grading, CONCRESIVE 1310 mortars can provide high skid-resistance and resistance to mechanical abuse and wear.

Product characteristics

Form: Two-component, low-viscosity liquid

Color: Part A - red, Part B - clear brown, Mixed - red. Special dark colors available upon request.

Typical Density*, lb./gal. (kg/m³): Part A - 10.2 (1220), Part B - 9.3 (1117), Mixed - 9.9 (1186)

Typical Viscosity*, poise (Pa·s): Part A - 8.0 (0.80), Part B - 12.0 (1.20), Mixed - 10.0 (1.00)

Mix Ratio: 2 parts A to 1 part B by volume

Standard packaging: 1 gallon (3.8 dm³) and 15 gallon (56.8 dm³) units

Shelf life: One year minimum in sealed containers at 90°F (32°C) or below

*At 77°F (25°C)

Top: Machinery cleaning room floor resurfaced, skid-proofed and protected from corrosive chemicals by CONCRESIVE® 1310 mortar.

Bottom: Application by trowel and screed.

Effect of temperature on cure (typical)

	Material Temperature 50°F (10°C)	77°F (25°C)
Pot Life:		
1 gallon mass	70 minutes	30 minutes
1 gallon (3.8 dm³) mass of mortar with 3.5 volumes graded sand	3 hours	2 hours
Tack Free Time	13 hours	7 hours
Open Time to Light Traffic	20 hours	9 hours
Open Time to Normal Traffic	35 hours	18 hours
Final Cure Time (for maximum chemical resistance)	14 days	7 days

Typical properties of cured mortar*

	CONCRESIVE 1310	PCC (for comparison)
Compressive Yield Strength, psi (MPa) (ASTM D 695)	10,000 (68.9)	5,500 (37.9)
Compressive Modulus, psi (MPa) (ASTM D 695)	2.7 x 10⁵ (1861.0)	3.1 x 10⁶ (21371.0)

*CONCRESIVE 1310 with 3.5 volumes graded sand cured 7 days at 77°F (25°C) and tested at 77°F (25°C)

Typical mechanical properties of cured binder*

Tensile Strength, psi (MPa)	ASTM D 638	6,500 (44.8)
Ultimate Elongation, %	ASTM D 638	4
Compressive Yield Strength, psi (MPa)	ASTM D 695	10,000 (68.9)
Compressive Modulus, psi (MPa)	ASTM D 695	1.4 x 10⁵ (965.0)
Heat Deflection Temperature, °F (°C)	ASTM D 648	115 (47)
Slant Shear Strength, psi (MPa)	AASHTO T-237	
Dry Concrete		>4,000 (>27.5)
Water Saturated Concrete		>3,200 (>22.0)

*Cured 7 days at 77°F (25°C) and tested at 77°F (25°C)

Chemical resistance properties of cured binder:

The following data is based on continuous total immersion of the binder without aggregate coated on metal panels at the temperatures and concentrations indicated. This is considered the most serious attack condition; thus, where only fume, splash or spill is involved, the protection afforded by Concresive 1310 will be greatly extended. Please contact Adhesive Engineering Company for advice on chemicals and conditions not listed. This data should be used as a guide and a test patch installed in case of doubt.

Acids (diluted with water, % by weight)

Acetic acid - 10% at 77°F (25°C), 158°F (70°C) (excellent) - 20% at 77°F (25°C) (excellent) - 100% at 77°F (25°C) (not resistant)

Citric acid - 10% at 77°F (25°C) and 140°F (60°C) (excellent)

Chromic acid - up to 3% at 77°F (25°C) (attack after 6 months) - between 5% and 10% up to 158°F (70°C) (limited resistance) - 20% and 30% (not resistant)

Formic acid - 5% at 77°F (25°C) (limited resistance)

Chemical resistance properties of cured binder (continued)

Hydrochloric (muriatic) acid - up to 10% to 158°F (70°C) (excellent) - up to 15% to 140°F (60°C) (excellent - 37% (concentrated) (not resistant)

Linseed oil fatty acid at 77°F (25°C) (excellent)

Nitric acid - 3% at 77°F (25°C) (surface attack only after 10 months) - up to 10% at 77°F (25°C) (surface attack only after 4 months) - 50% at 77°F (25°C) (not resistant)

Phosphoric acid - up to 30% to 158°F (70°C) (excellent) - 43% at 77°F (25°C) (blistered after 18 months) - 43% at 140°F (60°C) (limited resistance)

Silo acid at 77°F (25°C) (excellent)

Sulfuric acid - up to 60% to 140°F (60°C) (excellent) - up to 10% at 158°F (70°C) (excellent) - 20% to 30% at 158°F (70°C) (limited resistance) - 70% (not resistant)

Alkalis (Bases) diluted with water

Ammonium hydroxide (ammonia) - up to 28% at 77°F (25°C) (excellent) - 10% at 122°F (50°C) (limited resistance) - 10% at 158°F (70°C) (not resistant)

Sodium hydroxide (caustic soda) - up to 50% at 77°F (25°C) (excellent) - up to 30% to 158°F (70°C) (excellent) - 50% at 140°F (60°C) (excellent) - after 1 month (probably much longer)

Waters

Sea water, tap water, distilled water and deionized water up to 158°F (70°C) (excellent)

Salt solutions

Sodium chloride (table salt) - up to 20% (excellent)

Sodium sulfate - 30% (excellent)

Bleaches

Sodium sulfite (1%), spent sulfite liquor, zinc hydrosulfite (1%), calcium hypochlorite (5%), sodium hypochlorite (Chlorox®) - 5% at 77°F (25°C) (all excellent)

Paper bleaching solution at 77°F (25°C) (not resistant)

Solvents

Ethyl alcohol (in water) - up to 40% to 158°F (70°C) (excellent) - 50% at 77°F (25°C) (excellent) - 95% at 77°F (25°C) (not resistant)

Normal and secondary butyl, iso-propyl and diacetone alcohols at 77°F (25°C) (limited resistance)

Toluene at 77°F (25°C) (not resistant)

Heptane - toluene (25/75) at 77°F (25°C) (limited resistance)

Heptane - toluene (50/50 and 75/25) at 77°F (25°C) (excellent)

Xylene (limited resistance)

Gasoline and kerosene at 77°F (25°C) (excellent)

Carbon tetrachloride at 77°F (25°C) (excellent)

Ethyl acetate, methyl iso butyl ketone (MIBK), acetone, methyl ethyl ketone (MEK), trichloroethylene, nitrobenzene, o-dichlorobenzene, ethyl ether (ether), methylene chloride, chloroacetyl chloride at 77°F (25°C) (not resistant)

Attack by these solvents is not strictly chemical but a softening or swelling action. If the floor does not receive heavy traffic while the solvent evaporates, most of the original strength is regained.

Miscellaneous materials

Sour crude oil, fuel oil, mineral oil, edible oil, lard, cotton-seed oil, dioctyl phthalate, dibutyl phthalate, tricresyl phosphate, pine oil, ethylene glycol at 77°F (25°C) (excellent)

Mineral oil at 140°F (60°C) (excellent)

Hydrogen peroxide - 20% at 77°F (25°C) (excellent)

Formaldehyde - 37% (excellent)

Styrene at 77°F (25°C) (not resistant)

Epichlorohydrin at 77°F (25°C) (not resistant)

Phenol (in water) - 7% and 95% (not resistant)

Sodium monochloroacetate (in water) - 45% at 77°F (25°C) (limited resistance)

Detergent solution .5% at 77°F (25°C) (excellent)

Limitations

Application of CONCRESIVE 1310 is not recommended when the ambient and/or substrate temperature is below 50°F (10°C) during application and cure. Although cure will take place down to 35°F (1°C), the mortar becomes very difficult to trowel due to increasing viscosity of the binder with decreasing temperatures. CONCRESIVE 1310 mortars should not be installed in areas subjected to freeze-thaw cycles.

Instructions for use

Surface preparation: Surfaces must be free of dirt or dust, paint, grease, oil, rust or other contaminants. Surface may be damp if unavoidable. Sandblasting, water blasting, flame blasting, chipping, scarification, or etching and rinsing the surface of the old concrete is recommended to expose clean sound surfaces.

Aggregate selection: *Proper aggregate selection is essential for a high quality, non-porous patch or overlay.* High quality silica sands—washed, graded, and bagged—are commercially available and are most commonly employed.

The coarse fractions of the aggregate should be sub-angular in shape, because the coarse round particles tend to "roll" under trowel compaction. The fine fraction should be round to assure proper particle packing and ease of finishing.

The ratio of aggregate to binder should be from 6.5:1 to 7:1 by *weight*. "Rich" mixes (those with excess binder) are sticky and difficult to finish, while "lean" mixes result in a porous overlay which can lead to failure.

The following aggregate gradation is recommended.

Std. Sieve No.	% Weight Passing
8	100
10	80-100
30	53-73
50	26-46
100	8-24
200	1-8
270	0-3
325	0

By calculation, select three or four sand sizes in proportions such that the blend falls within the gradation limits. Then, calibrate containers to proportion the various loose *volumes* corresponding to the *weights* required for the batch size of the mortar. Two adjacent sizes can be pre-blended off-site, but not the complete gradation since separation will occur during transportation and handling.

Planning your aggregate mix ahead of time will save time and money and prevent failures. Consult Adhesive Engineering or your local aggregate plant for assistance in this procedure.

Mixing: Mix only the amount of material that can be used before the end of the pot-life. Measure the material carefully and add Part B to Part A. Mix thoroughly, using a paint stirrer (e.g., a Jiffy® Mixer, Jiffy Mixer Co., Irvine, CA) attached to a low speed (450-750 rpm) electric or pneumatic drill. Carefully scrape the sides and bottom of the container while mixing. Proper mixing will take about three minutes, and the mixed material must be streak-free. To prepare mortar, pour mixed binder into a mortar mixer (e.g., KOL Mixal®, Model M60, GE-8, ¼ HP, equipped with a Model R paddle from Man-U-Fab Inc., Minneapolis, MN) and add the calibrated quantities of the different sand sizes. Mix an additional three minutes after adding all the sand.

Application of mortars: The substrate should be primed with a thin coat of CONCRESIVE 1310 before applying the mortar. The mortar is then applied evenly over the desired area. After distribution is complete, trowel finishing is required to obtain a compact overlay. Most applications require a minimum compacted thickness of ¼ inch (6 mm). Occasional wiping of the trowel face with a cloth dipped in toluene or lacquer thinner will prevent excessive sticking of the mortar. Care must be taken not to transfer solvent to the surface of the mortar.

Handling and toxicity: This bulletin does not accompany the product when sold. For specific hazard warnings and first-aid instructions READ THE CONTAINER WARNING LABELS CAREFULLY.

® CONCRESIVE is a registered trade name of Adhesive Engineering Co.

ADHESIVE ENGINEERING COMPANY

1411 Industrial Road, San Carlos, CA 94070/(415)592-7900/Telex 34-8459

A MEMBER OF THE JEFFERSON CORPORATION FAMILY

August 1979

Printed in U.S.A.

Revision 1
September, 1982

ADHESIVE ENGINEERING COMPANY

memorandum

From Brian Carr

Date September 14, 1982

Subject The Durability of CONCRESIVE® 1512 Grout and CONCRESIVE 1513 Gel Seal

Replaces Memo dated 8/19/82

To Bob Rioux

Copies W. Eisenhut
Anthony Gaffney

At your request, a literature review (limited in scope to publications on hand) on the subject of the durability of aromatic amine cured epoxy resins in various environments was carried out to indicate the background for the selection of CONCRESIVE 1512 and 1513 as promising candidates to submit for simulated life testing by a potential customer attempting to design storage containers to safely contain aqueous radioactive waste when stored underground for 300 years.

Durability could be described as the ability of material to resist the various adverse environments to which it is exposed thereby determining its useful service life.

Such effects may include the permanence of the adhesive seal and grout seal in adhesion and their impermeability when exposed to oxidation, elevated thermal degradation, low temperatures, sunlight, radiation, water, chemical reagents, oils and biodeterioration.

Radiation Resistance

The nuclear radiation resistance of liquid aromatic epoxy resins (conventional Bisphenol A type) cured with aromatic polyamines has been demonstrated and described in Adhesive Engineering's Technical Bulletin No. 315. References 1 through 6 (page 12), Study #1 (page 5) indicates durability as a cooling pond lining in the presence of both water and radiation amounting to about 1×10^9 rads to be received over 30 years. Further details of this study are now available in a Swiss technical bulletin on pages 4 and 5 (enclosed) published by Ciba-Geigy. The use of glass (silica) reinforcement or filler improves resistance in absence of excessive air bubble entrapment.

Study #2 (page 6) compares an aromatic amine cured epoxy resin with a typical conventional (aliphatic) amine, data generated during material studies for construction of a 7 GeV Proton Synchrotron in Harwell, UK. A further description of construction is given in Ciba Technical Notes #227 (Nov. 1961) and of other nuclear engineering studies through October 1967 in Ciba Technical Notes for this month.

Adhesion

Due to the presence of polar hydroxyl and ether groups combined with low cure shrinkage of epoxy resins, adhesive strength is perhaps the best obtainable in plastics technology (ref. Lee & Neville, Handbook of Epoxy Resins, McGraw-Hill (1967), P. 1-5).

Resistance to Water and Chemicals

Lee & Neville (p. 8-2) state that aromatic amine cured systems are very resistant to chemical (including water) attack being superior to the conventional room temperature cured systems (which employ aliphatic amines and polyamido amines) and to the anhydride-curing agents (which require an elevated temperature cure even when modified).

Heat Resistance and Long Term Aging

Reference same page 8-2 above. The aromatic amine cured epoxies are superior in both those properties to the aliphatic polyamines (and polyamido amines) which are considered the standard room temperature curing agent types.

Diluent Migration

The minor quantity of dibutyl phthalate (DBP) present to obtain cure at ambient temperature does not exhibit migratory tendencies on aging (Lee & Neville p. 13-3). Data exists showing the minimal effect of vacuum (space) on the volatility of DBP diluted castings, however, we have been unable to retrieve the reference to date. When not encapsulated in resin, the vapor pressure of DBP is 1 mm Hg at 148.2 deg. C according to the "Handbook of Chemistry and Physics".

Biodeterioration

Cured epoxy resins, in the absence of polyamido amines or vegetable oil modifiers show excellent resistance to fungus and the like (reference Lee & Neville, p. 6-52).

Low Temperatures

Cured epoxy resins expand and contract more than PCC or steel. Expansion due to a rise in the ambient temperature is not generally a problem since thermally induced stress relief (lowered modulus) occurs concurrently with the expansion. Contraction due to low ambient temperatures is to be considered at the design stage. Thermal contraction and expansion are greatly reduced via introduction of fillers (which also serve to reduce any exothermic heat of reaction or cure). The blend of, e.g., silica sand or filler and resin may be treated as a composite of reduced coefficient of thermal expansion (CTE) and calculations made knowing the probable low exposure temperature, the CTE, of cured resin and fillers and the concentration of each, the shape of the grout/seal and the tensile strength of the substrates. A safety factor for fatigue of the bond line is allowed if thermal cycling is present.

Sunlight & Oxidation

Oxidation can cause deterioration often by initiation of numerous micro-cracks which may propagate. One class of antioxidants and antiozonants are the substituted para-phenylenediamines which cause large increases in the critical energy required for the propagation of cracks. (Reference Weathering and Degradation of Plastic, a book edited by S. A. Pinner, Lender published by Gorden and Breach; Science Published, Inc. - page 45.)

These materials are usually incorporated into various plastics as additives. In the case of epoxy resins cured with aromatic polyamines, such as MDA and MPDA, the entire thermoset polymer network contains molecular segments that are analogous to substituted para-phenylenediamines.

This is believed to be a principal factor in both the high resistance to heat and oxygen as well as radiation of the systems.

On exposure to direct sunlight and oxygen, the UV component of the light acts as a catalyst oxidizing an extremely thin outer layer of cured resin causing the well known phenomenon of "epoxy-chalking". It has been speculated that, with most epoxy coatings, their longevity may be associated with this "protective chalk" in a manner similar to the oxidation of galvanized steel.

A greenish surface coloration may first appear since MDA (curing agent) is a dye base. This disappears between two and six months with the onset of the build-up of a tan "chalk" and loss of gloss.

Since the material is to be buried and, therefore, not exposed to direct sunlight, much of the above may be moot.

Heat Aging Extrapolation Methods

One of the classic methods used by materials engineers to similate heat aging/oxidation for many years was described in "Heat Resistant Encapsulating Resins" by Lee, Proceedings Soc. of Plastic Eng., 15th Annual Technical Conference, New York, January 1959.

This work is also summarized in some detail in the book "Electronic Packaging With Resins" by Charles A. Harper (McGraw Hill Book Co., pp 241-246). Lee first prepared graphs of a large number of systems, including the aromatic amine curing agents MPDA, Curing Agent Z (Shell Chemical Co.) and DDS and determined weight loss in air with time for 1000 hours. Temperatures were 175°C, 200°C, 225°C and 250°C. "Useful life" was defined as 16% maximum permissible weight loss on original specimen weight.

Arrhenius type master curves were then prepared with the percent weight loss per 1000 hours of "useful life" against aging temperature. Linear relationships were derived for the majority of systems including the three aromatic amines used to cure a conventional unmodified epoxy. From the 1000 hour data, reasonable extrapolations were made to 18.3 years continuous operation at 140°C in the case of an aromatic amine (MPDA = metaphenylenediamine) which is generally similar to MDA and also (although not plotted in the enclosure), in the case of Curing Agent Z, a blend of MPDA and MDA modified with a monoepoxide to lower the crystallization point.

A method of this type might be considered an evaluation of the Container's epoxy grout, seal and internal coating, although criteria other than percentage weight loss, e.g., time to a specific degree of substrate rusting or film blistering, would be more appropriate considering the nature of the application and the lower test temperatures required to extrapolate data for the unusually long design life. Extrapolation of Lee's data beyond his present order of magnitude would not be valid due to the high margin of error.

History

Fortunately, we were able to recover a copy of the original Ciba, UK, bulletin on System #16 described in the Adhesive Engineering Bulletin AE-455 (page 8).

As can be seen from the back page, the system (under its experimental designation) was introduced on the first of September, 1958, while the supplement indicates that six months chemical resistance data as a coating on steel panels had been collected for publication on November 1, 1958. Note on page 2 of this bulletin that Resin X83/8 eventually became Araldite D and Hardener X83/8 is 4,4' MDA. Accelerator X83/8 is a mild carboylic acid in a plasticizer, used in small quantities to accelerate the cure rate if desired. An abstract of the analysis performed in 1961 by a third party is enclosed to demonstrate the point that systems very similar to CONCRESIVE 1512 and 1513 have been in use for about 24 years.

The composition used in Study #1 will be found on page 5 of the A/E bulletin. Note its similarity to X83/8. A May 1964 Ciba, UK, bulletin demonstrates that the slightly revised version has been in use since at least May 1964, and used for bonding both new and cured concrete.

Frequent references have been made to Ciba-Geigy, a large Swiss multinational Corporation who, apart from their well-known activity as a pharmaceutical manufacturer, also manufacture and formulate epoxy resins and hardeners. Being a large concern, their documentation is more comprehensive and the systems' referenced are so chemically similar to our own that we believe the data to be essentially interchangeable. However, A/E's advantage is its ability to custom tailor these basic systems to meet the performance needs of a specific project combined with practical application characteristics.

B.J.C.