SURVEY REPORT ON LOW-LEVEL WASTE SOLIDIFICATION PROCESSES
AND
HIGH INTEGRITY CONTAINERS (HICs)

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I. Introduction

The purpose of this report is to provide the subcommittee members with a reference document that presents summary information on LLW solidification processes and high-integrity containers used to dispose of B and C LLW. Only processes and containers that have been or are under active review by the NRC Staff are included in this summary. Further, the transportation of LLW and burial ground practices will not be addressed in this report. It is planned that separate reports on these two areas of LLW industry will be prepared in the near term.

Some sections of the report are not yet available because those vendors have not yet responded to inquiries for information. That information will continue to be sought and when available will be provided for insertion by the copyholders.

A detailed analysis of the regulations and staff guidance relating to the disposal of LLW will not be provided. However, some general comments on them follow. Part 61 and the Branch Technical Positions (BTPs) of interest are included in Appendix A.

Authorization to receive a specific type of waste form from any solidification process or HIC at a disposal site is, and was, the responsibility of the NRC or appropriate agreement state regulatory body. Since the promulgation of Part 61, the BTPs and other guidance, the NRC staff has acted as the states' technical review organization and has performed a coordinated review of the proposed solidification process or HIC designs. The general procedure is that the prospective solidification process or HIC vendor submits to the NRC a Topical Report which details the design of the process or HIC. Included in the Topical Report are the results of qualification tests on prototypical processes, materials or units and a justification of fully meeting all regulatory requirements. Upon completion of the NRC staff's technical evaluation report, with an acceptable finding, the individual states issue a Certificate of Compliance and the waste form or HIC may be used for disposal of LLW in licensed commercial facilities. In most cases in the states have issued interim approvals for the use of the HICs and the disposal of the solidified waste during the review process.

In NRC regulation 10 CFR 61, low level radioactive wastes (LLW) are classified by their radionuclide content. Sections 61.55(a)(2)(ii) and (iii) require that the stability provisions of section 61.56 be applied to the disposal of class B and C LWW respectively. Section 61.56(b) specifies that the wastes, as stabilized, or their containers have structural stability to withstand burial conditions for land disposal. These regulations are the reasons that require either the use of solidification processes or high integrity containers (HICs) for the disposal of LLW. Various branch technical position (BTP) papers and other NRC guidance have expanded and given further detail to the general requirements in 10 CFR Part 61. These detailed provisions are in large part a result of combining NRC requirements with industry experience to provide explicit information to guide future industry usage. For example, the BTP guidance that solidified waste be able to withstand a compressive load of originally 50 psi, and now 60 psi, is related to the industry practices of maximum burial depth at the Richland, WA site of originally 45 feet which has been changed to 55 feet.

Some other specific requirements are a result of operational incidents. Most notably an incident where a polyethylene (PE) HIC got jammed in its transportation cask, due to internal pressurization, resulted in the requirement that all HICs have passive venting to prevent the build-up of gases which may cause swelling or distortion of the HIC.

II. Solidification Processes

A. Background Discussion

Approximately 15 topical reports on various solidification processes and the resulting waste forms have been submitted to the NRC Staff for review and approval over the past 5 years. Of these, only one, the AZTECH process, developed by General Electric, has received official NRC approval. Note: Nuclear Packaging bought out all of G.E.'s activities in the low-level waste area in mid 1987, including the AZTECH process.

The various solidification processes may be divided into two general categories or classes. They are: 1) Solidification processes in which the waste itself is chemically involved in the process, that is to say that the waste itself forms a chemical bond with the solidification agent; and 2) Encapsulation techniques in which the waste itself is not chemically active in the process, but is, in fact, physically surrounded by the matrix material. The Portland and gypsum cement based processes are representative of the former group, while the bitumen and polymerization processes would be included in the latter.

It may be seen that in the first case the waste materials themselves help determine the physical and chemical properties of the final waste form. On the other hand, in the latter group, the waste materials probably do not materially affect the properties of the waste form, until very high waste loadings are reached. It is also worthy of note that some of the encapsulation processes either completely or largely drive off any water contained in the waste stream and may physically fracture the individual waste particles. Alternatively, the cement based processes must take into account the presence of variable fractions of water in the waste streams. Realization of these intrinsic differences between these two types of processes leads to an understanding of some of the reasons for the variable performance of the waste forms and processes themselves. It should be noted that in either case the resultant solid, the waste form, is not homogenous. The matrix or bonding phase surrounds discrete particles of waste which may or may not be chemically bound to the matrix. Thus in the case of the cementaceous processes the constitution and properties of the matrix may be quite variable. On the other hand in the encapsulation processes the matrix, and consequently the solidified mass, will tend to have reproducible and predictable properties, largely independent of the initial waste material.

B. Chemical Bonding Processes

As noted previously these processes are largely based upon the use of Portland cement. One process uses a gypsum cement, but the fundamental approaches are similar for all of the processes. The following sections will present significant aspects of several processes. All processes require small scale testing of the specific batch of waste to be solidified, prior to the start of the processing campaign. This procedure generally involves a through mixing of the waste, to enhance uniformity, followed by sampling and the preparation of laboratory scale samples of the waste form. Based upon this laboratory scale testing, additives, such as lime for pH control, or emulsifiers to break up oil contamination, may be added and re-testing performed. Upon determination of a "suitable" formulation the process campaign would then be initiated. It should be noted that the principal criteria for "suitability" is whether or not the formulation sets within 24 hours or so, without free standing liquid. Thus, it may be seen that each waste stream, during each solidification campaign, may produce a product that has no guaranteed similarity in either chemistry or physical properties to that prepared during another campaign or in the original testing program for the topical report data.

1. Westinghouse - Hittman (W-H)

Hittman was the original organization that developed and marketed a solidification process based upon urea formaldehyde (UF) in the 1970's. This process and variants of it were abandoned in the late 70's when it was discovered that a free liquid might result or be released from the solid upon aging. Hittman then shifted to a Portland cement based solidification process. Westinghouse subsequently acquired Hittman and provides both the solidification service and disposable cask liners or high-integrity containers (HICs) which will be discussed later.

Westinghouse-Hittman will either sell a utility a packaged solidification facility or provide a contract service upon request. In either case the process is a batch-type operation with mixing being performed in the final disposal containers. The general size of containers used is 100 cu ft in capacity and two such containers can be processed per 8 hour day. The mixing blades are left in the containers and are not reused. The basic formulation is determined as noted above, but adjustments and/or special additions may be made during the filling and mixing operations on an ad hoc basis.

2. LN Technologies Corporation

LN Technologies took over both the solidification and high integrity container (HIC) activities of NUS in late 1987. Their solidification process uses Portland cement and will be discussed here. The HIC work will be reviewed later in this report.

The management of LN were contacted directly, as were the other vendors' managements, to provide explicit information about their process. LN provided a very thorough commentary on their process which also gave considerable insight into the chemically bonded processes in general. For that reason the LN discussion included in its entirety as attachment 2-1.

Of particular interest are the paragraphs 2.3 and 2.4 where the variation in waste properties and the scale-up from labotatory sized samples to liners are discussed. Table 2 which presents the waste loadings attained by both weight and volume percentages is particularly interesting. The weight and volume percent figures are not calculated on the same basis for the several waste streams considered. Consequently, it is not possible to compare the figures directly. For example, the volume percent for 13% and 20% Sodium Sulfate is 69 and 68% respectively. This means that the final waste form from the 20% waste stream actually contains some 50% more Sodium Sulfate. Obviously, then the plants should evaporate the solutions to maximize the solids loading. Similar ambiguities exist in the data for the resins, since they are not necessarily fully dried.

LN SOLIDIFICATION PROCESS

LN provides low-level waste solidification services to ten power stations in the United States at the current time. A list of the types and volumes of wastes processed by LN is presented in Table 1. Waste loadings for the various waste formulations are summarized in Table 2.

The LN solidification process uses Portland Type I cement as the binder in stabilizing the wastes. The characteristics and process variables for the principal types of wastes solidified by LN are described in Secton 1. Curing procedures and the variations in waste characteristics are discussed in Section 2.

1. Waste Characteristics

1.1 Boric Acid Concentrates

Evaporator concentrates at PWRs generally contain boric acid in concentrations varying form 10 to 30%. Other dissolved and suspended solids are also generally present. LN has boric acid waste forms qualified to 10 CFR 61 stability criteria in the concentration range of 0 to 20%. Wastes with higher concentrations must be diluted down to ≤ 20% in order to use the LN formulations.

LN formulations for boric acid wastes use the following additives: hydrated lime, an absorbant, sodium metasilicate and Portland Type I cement. The lime and metasilicate are used to neutralize the boric acid to raise the waste pH to ≥ 10 prior to the addition of cement. The absorbant s a zeolite which has been found effective by LN and others in absorbing cesium and strontium, thereby increasing the leach indices for these radionuclides. Sodium metasilicate is used in some wastes to partially neutralize the boric acid and thereby reduce the amount of lime required. The metasilicate is particularly useful where the total solids of the waste is high and fewer solids can be added to the waste without adversely affecting mixability.

1.2 Sodium Sulfate Concentrates

Evaporator concentration of ion exchange regenerative chemicals results in sodium sulfate solutions ranging from approximately 15 to 35%. Other solids (primarily suspended materials) may also be present up to concentrations of up to 20%. LN has qualified sodium sulfate waste forms in the range of 13 to 20% to 10 CFR 61 stability requirements. At present, higher concentrations of sodium sulfates must be diluted down to ≤ 20% in order to use the LN formulation. Testing to increase the range of sodium sulfate concentrations is underway.

The following additives are used in the sodium sulfate waste form: hydrated lime, fly ash (Class F), and Portland Type I cement. As with other wastes, the lime is used as a neutralization agent while the fly ash is a pozzolan to decrease the permeability of the resulting waste form. The lower permeability results in lower leachability (higher leach indices).

1.3 Ion Exchange Resins

Bead-type ion exchange resins consist of cation, anion and mixed resins with various ratios of the cation to anion components. The greatest portion of resins used at power stations in contaminated water systems are strong-acid cation resins in the H^+ form and strong-base anion resins in the OH^- form. During ion exchange operations, the resins are loaded with the species removed from solution, i.e., lithium and boron in PWRs and various impurities. The resins typically contain 33 to 40% voids but fines and suspended materials may decrease the void space and the interstitial water.

During process control testing, LN filters resin samples to determine the volume of interstitial water, then adds the volume of "additional water" necessary to hydrate the cement used to solidify the waste. The pH of the resin slurry is then adjusted with lime to a pH of $\geq$ 10 and the cement added.

1.4 Filter Sludges

Filter sludges are defined as powdered resins, fibrous material, powdered activated carbon, etc., used to precoat filter septums. LN has qualified a number of filter sludge waste forms, in which lime and cement are used in the solidification process. As described above in the section on resins, samples of the sludge are filtered to determine the volume of interstitial water available to hydrate the cement binder. "Additional water" is then added, as necessary, to provide the required volume of water for hydration. Lime is added to a pH of 10 and then cement is added to complete the solidification.

2. Miscellaneous Discussion

2.1 Other Additives

Small amounts of a silicon-based antifoam and sodium metasilicate, used as a curing accelerator, are sometimes used for treating troublesome wastes. Testing has been completed which shows that these additives do not adversely affect the stability of the final waste form.

2.2 Curing Procedures

Cement hydration is an exothermic reaction which produces high temperatures in full-scale solidified billets. To approximate these high temperatures and accelerate the cure in small-scale samples, LN places the process control test samples in an oven at 160°F for 24 hours. Mindess and Young* have shown that curing samples at 140°F for 24 hours is equivalent to a 28-day cure for normally cured concrete.

Because the small PCP samples of 150 to 250 ml have a much higher surface-to-volume ratio than the full-scale billets, the samples are capped to prevent water loss during the curing period. Full-scale solidified billets are typically capped after one to three days when the exotherm has been completed and billet temperatures are decreasing.

* Concrete, S. Mindess, J.F. Young, Prent-Hall, Inc., Chapter 11, p. 312.

2.3 Variation in Waste Characteristics

There is considerable variation in waste characteristics between different plants. There is also significant variation in wastes over time with a specific plant. For example, bead resins from reactor letdown or waste processing ion exchangers and filter precoat materials from condensate polishers are often discharged to a common holdup tank. The ratio of bead to precoat materials, degree of exhaustion, amount of suspended materials, etc., may vary widely from week to week. The ingress of circulating water into contaminated systems at sea or brackish water plants can also upset normal waste stream characteristics.

LN's waste form qualification program has been expanded considerably to test waste formulations with broad variations in waste solids, oil contamination, deviations in quantities of solidification additives, etc. The result of this effort is a comprehensive database providing an improved understanding of the effects of variations in waste characteristics on stability. This information is incorporated in the Process Control Program (PCP) which controls actual waste solidifications performed at plant sites.

At the present time, variations in waste pH, water content, solids content and waste concentrations are measured and compensated for in the PCP. Oil is limited to a maximum of 1%, below which stability is unaffected.

2.4 Scale-up to Full-Scale Billets

The LN program for qualifying waste forms includes a two-step scale-up process: 1) first 55-gallon drums are solidified with a scaled down mixer, then 2) a full-scale liner is solidified. Core samples will be taken from the solidified billets after curing for 28 days then immersed for 90 days in demineralized or simulated seawater as specified in ANS Standard 16.1. The NRC has indicated that a full-scale billet of the "worst case" waste form, considered to be mixed ion exchange resins, is sufficient for the scale-up testing. LN will likely test other waste forms, however, to better support the scale-up of small samples to full-scale billets.

This portion of the LN waste form qualification program is scheduled to be completed over the next four months.

Table 1. LN Solidification Volumes*

No.	Reactor Type	Waste type	Waste Volume (ft^3/yr)
1	BWR	Sodium Sulphates	2389
		Bead Resin	1433
		Filter Sludge	664
		Waste Oil	242
2	PWR	Bead Resin	1167
		Activated Carbon	251
3	PWR	Boric Acid Conc.	1440
4	PWR	Bead Resin	774
		Boric Acid Conc.	1899
5	PWR	Boric Acid Conc.	2167
6	BWR	Filter Sludge	514
7	BWR	Filter Sludge	187
		Sodium Sulphates	175
8	PWR	Boric Acid Conc.	855
9	BWR	Filter Sludge	1253
		Sodium Sulfate	240
10	PWR	Boric Acid Conc.	2393
11	BWR	Bead Resin	120
12	PWR	Bead Resin	1524

* Volumes based upon wastes solidified in 1987 and volumes expected in 1988.

Table 2. Waste Loadings

Waste Type	Conc. wt. %	--Loading(wt %)-- Low	High	Ave	--Loading(vol %)-- Low	High	Ave
Boric Acid[1,2]	10	46	50	48	70	73	71
	10	49	54	52	70	74	72
Sodium Sulfate[1,2]	13	48	52	50	68	71	69
	20	48	52	50	67	70	68
Cation Resin[2,3]		33	36	34	67	73	70
Anion Resin[2,3]		38	43	40	75	83	79
Mixed Resin[2,3]		34	39	36	71	79	75
Powdex PCH[2,3]		42	48	45	74	83	78
Ecodex P202H[2,3]		18	22	20	69	79	74
Ecodex P203H[2,3]		16	19	17	67	75	71
Ecodex S502[2,3]		23	29	26	73	84	78

Notes:
1 weight % = (wt. of waste/wt. of final product)*100
2 volume % = (vol. of waste/vol. of final product)*100
3 weight % = (wt. of moist resin/wt. of final product)*100

3. Chem-Nuclear Services Inc. (CNSI)

CNSI has provided a detailed statement of their activities and capabilities which is attached as attachment 3-1. It describes, in general terms, the various formulations that they have developed to solidify the various LLW streams coming from a nuclear power plant. In addition, they have tabulated some of the additives that they may use. These additives were not specifically identified at my request since I did not wish to include proprietary information in this report.

It should be noted that where the term "certified" is used that it refers to certification by CNSI that to the best of their knowledge the formulation meets the NRC specifications. It does not mean that the NRC staff, specifically NMSS-DLLW, has certified the formulation.

CHEM-NUCLEAR SYSTEMS, INC.
220 Stoneridge Drive • Columbia, South Carolina 29210

January 20, 1988
RAPASS/5814r

Dr. Sidney J.S. Parry
ACRS Senior Fellow
United States Nuclear Regulatory
Commission
Advisory Committee on Reactor Safeguards
Washington, DC 20555

Dear Dr. Parry:

I appreciate the time you took the other day on the phone to explain the reasons for and needs of your review of various practices in the management of low level radioactive waste.

Chem-Nuclear Systems, Inc. (CNSI) is the largest single supplier of low-level radioactive waste processing and transportation services in the United States. CNSI provided full or partial waste processing services to approximately 35 of the operating 52 commercial utility sites in 1986 and 1987. More specifically, CNSI provided complete "stabilization" for aqueous wastes of 140,000 cubic feet of estimated 250,000 cubic feet requiring solidification or stabilization in 1986. CNSI "stabilizes" wastes using cross-linked polyethylene High Integrity Containers or certified cement based formulas. CNSI currently has 35 certified formulas certified to 10 CFR Part 61 Waste Form Branch Technical Position, Attachment #1. A variety of additives are used to meet the solidification stability requirements. Additives such as boric acid are used to slow the hydration and reduce exotherm which eliminates final product cracking and subsequent failures. Other additives are identified on the Attachment #2 with the specific purpose for each. Cement or cement and lime combinations alone without additives, have been proven ineffective in meeting the long term stability requirements in most waste forms unless the waste loading efficiency is reduced to such an extent as to render the process uneconomical, due to the extremely low waste loadings.

CNSI solidifies and stabilizes wastes with. Process Control Program and Equipment approved by the USNRC in Topical Report CNSI-2(P)4313-01354-01 Attachment #3, and operated by CNSI trained technicians.

Attachments #4 and #5 are the testing protocol and a generic drawing of our High Integrity Containers. For your information we utilize approximately 650 HIC's of various sizes per year.

(5814r)

I hope that this information and the attachments will be useful to you. If you have any questions or if I can be of any further assistance please feel free to contact me.

As I mentioned during our conversation, I would also like to take this opportunity to invite you, other staff members and the ACRS to visit our site and operations in Barnwell, South Carolina. We would be glad to show you in detail both HIC and waste form testing, the operator training and maintenance programs, as well as the other activities associated with the processing, packaging, transportation and disposal of low level radioactive waste.

Sincerely,

David G. Ebenhack
Vice President,
Regulatory Affairs and
Site Strategies

DGE/as

Attachment 1: CNSI List of Waste Forms Meeting 10CFR61 Stability Requirements
Attachment 2: CNSI Partial List of Additives Used In Stabilizing Aqueous Wastes With Cement To Meet 10 CFR Part 61 Waste Form Stability Requirements
Attachment 3: NRC Letter of Acceptance For Referencing of Licensing Topical CNSI-2(P) Rev.2, CNSI-2 NP Rev. 2 (4313-01354-01) Mobile Cement Solidification Plant
Attachment 4: HIC Qualification Testing
Attachment 5: Blueprint C-900-D-0010 Revision A

(5814r)

CHEM-NUCLEAR SYSTEMS, INC.

LIST OF WASTE FORMS MEETING 10CFR61 STABILITY REQUIREMENTS

PWR CONCENTRATES

	Waste Loading Percent (By Volume)	Waste Composition	Binder Type
"PWR-66"	66	12% Boric Acid	Cement
"PWR-66(P-20)"	66	12% Boric Acid	P-20
"PWR-72J"	72	12% Boric Acid	Cement
"30% Borate (PMC/A-27)"	74	30% Neut. BA	PMC
"50% Borate (N-24)"	85	50% Neut. BA	P-20
"12% Cold Borate (P-20)"	69	12% Neut. BA	P-20
"12% Hot Boric (H.B.R.)"	73	12% Boric Acid	Cement

BWR CONCENTRATES

"BWR-69"	69	25% Sodium Sulfate	Cement
"BWR-74"	74	15% Sodium Sulfate	P-20

RESIN BEADS

"Resin 'A'"	58	MR-3 Slurry	Cement
"72% Resin 'A', 10% M-5"	72	MR-3 Slurry	Cement
"72% Resin 'A', (P-20)"	72	MR-3 Slurry	P-20
"80% Beads (PMC)"	80	MR-3 Slurry	PMC
"50% Beads/50% Charcoal"	78	Charcoal/Resin Bead Slurry	P-20

PARTICLE WASTES

"Powdex 'B'"	68	Powdex Slurry	Cement
"Charcoal, (P-20)"	60	Charcoal Slurry	P-20
"D.E./Fe_2O_3"	74	D.E. Slurry	Cement
"90% Ecodex, 10% Powdex"	73	Ecodex/Powdex Slurry	P-20
"90% Powdex, 10% Ecodex"	73	Powdex/Ecodex Slurry	P-20
"90% D.E., 10% Ecodex"	78	D.E./Ecodex Slurry	P-20

NOTE: The waste loading values for resin bead or particulate slurries represent waste on a "settled" basis. Any water required above the settled solid for mixing purposes is not included.

CHEM-NUCLEAR SYSTEMS, INC.

LIST OF WASTE FORMS MEETING 10CFR61 STABILITY REQUIREMENTS

COMBINED BEADS AND CONCENTRATES

	Waste Loading Percent (By Volume)	Waste Composition	Binder Type
"100% RB/25S"	100	MR-3 Slurry & 5-25% Sodium Sulfate	P-20

CHELATE MATERIALS

"100% NS-1"	55	100% NS-1 (Liquid)	Cement
"NT-75"	70	NT-75 (Liquid)	Cement
"AP On Beads"	74	"AP" On Beads	P-20
"Citrox On Beads"	75	"Citrox" On Beads	P-20
"LOMI On Beads"	70	"LOMI" On Beads	P-20
"Special EPRI Beads"	75	Various Chelates	P-20

MISCELLANEOUS PRODUCTS

"Lubricating Oil (Drums)"	40	Lube Oil	Cement
"In-Situ Cement (Boric/S.4)"	N/A	N/A	Cement
"In-Situ PMC"	N/A	N/A	PMC
"Concentrated Floor Drains"	75	Conc., Salts, Soap, Dirt, Etc.	P-20
"Special IP-2 Sludge"	66	Dirt, Charcoal, Etc.	P-20
"33% West Valley Oil"	33	Fluid Organic Oil Blend	Cement
"TMI Sludge, React. Bldg."	74	Metal salts, silica, etc.	P-20
"TMI Sludge, Aux. Bldg."	73	Metal salts, silica etc.	P-20

Attachment 2

CHEM-NUCLEAR SYSTEMS, INC.
PARTIAL LIST OF ADDITIVES USED IN STABILIZING
AQUEOUS WASTES WITH CEMENT TO MEET 10 CFR PART
61 WASTE FORM STABILITY REQUIREMENTS

Cement (Normally Portland I)

Lime: Used to adjust pH (not always used)

P-20: Modified Portland Cement used for several reasons but needed to prevent swelling of solidified resins beads wher final product is long term contact with water. Also reduces leaching.

M-5: Additives used with Portland Cement to accomplish same effect as P-20, above, exhibits pozalonic activity.

PMC: Cementious formula used to stabilize very concentrated boric acid waste loadings. Also useful with bead resin.

N-24: (Patented) Allows high waste loadings of boric acid waste.

B-30: Used for decontamination solution acids to meet stability requirements, ie phosphoric acids.

A-27: Used for EDTA (DECON) solutions as a chelate treatment prior to stabilization.

S-3, S-7: Used for waste oil emulsification prior to stabilization.

S-4: Accelerator for normally slow setting wastes.

P-100: Pozalonic additive used to improve final cement product properties.

(5814r)

CHEM-NUCLEAR SYSTEMS, INC.

UNITED STATES ,
NUCLEAR REGULATORY COMMIS...
WASHINGTON, D. C. 20555

APR 11 1983

Mr. James P. Staehr, Director
Chem-Nuclear Systems, Inc.
P. O. Box 1866
Bellevue, WA 98009

Dear Mr. Staehr:

Subject: Acceptance for Referencing of Licensing Topical Report CNSI-2(P) Rev. 2, CNSI-2 NP Rev. 2, [4313-01354-01] "Mobile Cement Solidification Plant"

We have completed our review of the subject topical report submitted January 31, 1983 by Chem-Nuclear Systems, Inc., letter WPD-5036-3. We find this report is acceptable for referencing in license applications for Nuclear Power Plants to the extent specified and under the limitations delineated in the report and the associated (NRC) evaluation which is enclosed. The evaluation defines the basis for acceptance of the report.

We do not intend to repeat our review of the matters described in the report and found acceptable when the report appears as a reference in license applications except to assure that the material presented is applicable to the specific plant involved. Our acceptance applies only to the matters described in the report.

In accordance with established procedures (NUREG-0390), it is requested that Chem-Nuclear publish accepted versions of this report, proprietary and nonproprietary, within three months of receipt of this letter. The accepted versions should incorporate this letter and the enclosed evaluation between the title page and the abstract. The accepted versions shall include an -A (designating accepted) following the report identification symbol.

CHEM-NUCLEAR SYSTEMS, INC.

Should our criteria or regulations change such that our conclusions as to the acceptability of the report are invalidated, Chem-Nuclear and/or the applicants referencing the topical report will be expected to revise and resubmit their respective documentation, or submit justification for the continued effective applicability of the topical report without revision of their respective documentation.

Sincerely,

Cecil O. Thomas

Cecil O. Thomas, Chief
Standardization & Special
Projects Branch
Division of Licensing

Enclosure:
As stated

C. Encapsulation Processes

The encapsulation processes use organic binders rather than inorganic materials such as Portland cement. At the present time there are four such processes in use or proposed for use in the reactors. Only one of these, the AZTECH process, has been approved by the NRC Staff. There are two general groupings of binders, the asphaltic or bitumenous materials and the monomer/polymeric substances. In several of the processes the mixtures are heated and a vacuum is applied thus either wholly or largely removing the water contained in the waste. In all cases the resulting solidified material containing the waste consists of finely dispersed waste particles surrounded by an inert binder which forms a continuous matrix. Thus, the binder or matrix determines the general physical properties until very high loadings of waste are reached. As a consequence the reproducibility and uniformity of physical properties might be expected to be better than that of the chemically bonded materials. Further, since the aqueous portion of the waste streams is eliminated in several of these processes the volume of material placed in the disposal site is generally less than the initial volume of the waste.

1. Associated Technologies Inc. (ATI)

The Associated Technologies Inc. (ATI) process for solidifying low-level radioactive waste was developed by SGN (Societe Generale pour les Techniques Nouvelles), a French company. The process uses bitumen as the encapsulating or binder phase and the processing is performed in a vertical thin film evaporator. The waste stream and the bitumen are separately introduced into the evaporator, where the mixing occurs. The waste stream is homogenized and pre-treated in separate tanks prior to the evaporator. The evaporator operates at temperatures between 140° and 200°C. As a result all water and volatile constituents of the waste are driven off and the resultant waste material consist of a dry solid embedded in the bitumen, which solidifies upon cooling. A copy of descriptive literature provided by ATI is attached for further details (attachment 1-1). An alternative process using a screw extruder is described therein.

ATI has generally provided solidification services to utilities on a contract basis, using mobile equipment, but has a contract for the permanent installation of systems at Vepco's Surry and North Anna plants. It is worthy to note that ATI is a subsidiary of American Ecology who also owns U.S. Ecology, which operates the Hanford and Beatty disposal sites.

BITUMINIZATION PROCESS

SGN

The embedding into bitumen of sludges, concentrates, spent-ion-exchange resins and ashes encountered in radwaste treatment is one of the best methods for final disposal of waste. Provided that the chemical composition of the salts has been checked for safe operation, the bitumen process remains relatively independent of the waste composition.

The water is evaporated during the process so that high volume reduction and homogeneous dispersion of the salts in the bitumen are obtained.
Although using a cheap material for the immobilization of the radioactivity, the process produces blocks having excellent qualities in terms of leachability and ageing.

The CEA Group has developed a simple continuous one-step process based on a thin-film evaporator and using the "direct distillation" bitumen. It was first put into operation at Marcoule (France) in 1967 and has operated successfully since then in 7 different plants ; 3 more plants are being designed.

A new continuous two-step process under development in SGN laboratories operates with mixers which accept various types of coating agents, particularly the harder "blown" bitumens generally chosen for the more highly radioactive wastes. It can be installed more easily for versatile mobile units.

ADVANTAGES of BITUMINIZATION

- Efficiency
  . excellent leachability rates
  . excellent ageing
  . high volume reduction factors
- Flexibility
  . easily adaptable to the various wastes normally encountered in the nuclear industry
  . compatible with large pH variations
- Simplicity
  . minimal maintenance
  . highly reliable automated equipment
  . low cost and ordinary embedding material

Radwaste bituminization cell
Filling and capping station
Sydkraft Barsebeck, Sweden (1975)

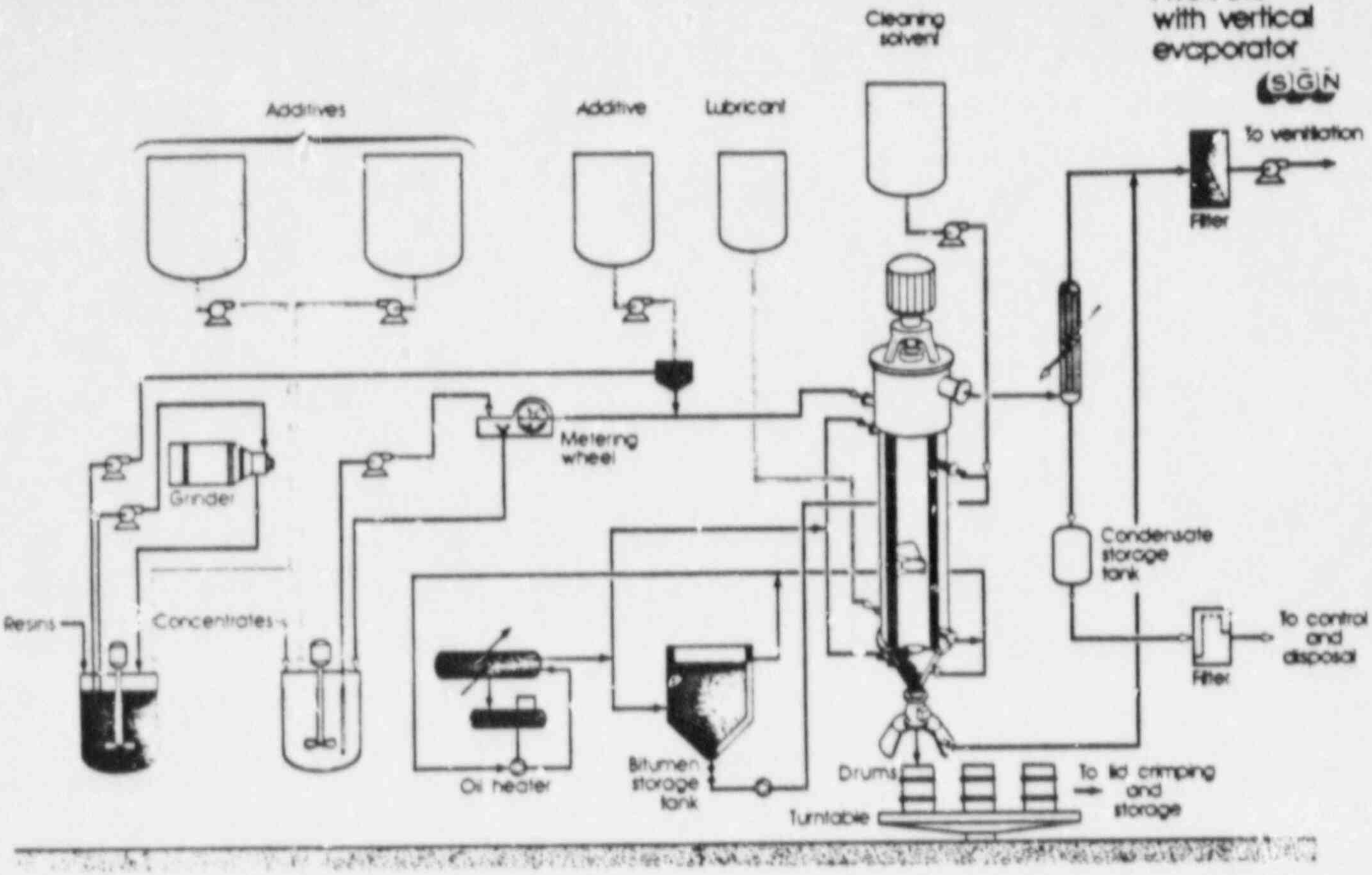
OPERATING PARAMETERS

- *Waste origins : various (nuclear power plants, enrichment and fuel reprocessing plants, research laboratories...)*
- *Effluent types : miscellaneous α, β, γ emitters (up to some Ci/l)*
- *Evaporation capacity : 50 to 250 l/hr larger capacities can be designed*
- *Equivalent decontamination factor > 10^3 (from feed to distillate) distillate usually needs secondary treatment or recycling*
- *Operating temperature : < 160°C (320° F) on product for thin-film evaporation*
- *Embedding performance* :*
  . for concentrates : up to 50 % salts in weight
  . for ion-exchange resins : 1 volume of embedded waste for 1 volume of 100 % settled resins
- *Drum filling performance :*
  . better than 90 %

** see embedded product quality on the last page*

CONTINUOUS BITUMINIZATION PROCESS with vertical evaporator

SGN



The bituminization process shown above is based on a vertical Luwa-type thin-film evaporator especially adapted to the nuclear industry.

WASTE FEEDING

Two tanks are installed for resin and concentrate storage, homogenization and sampling ; addition of reagents is possible whenever a pretreatment is needed. The bead resins are preferably ground before being fed into the evaporator.
The waste feeding rate is monitored by a metering system and the bitumen feeding rate is fixed according to a given ratio of dry extract - to - bitumen.

EVAPORATION

The evaporator is heated by a closed oil circuit for ease and versatility of operation. This oil is normally heated electrically.
The bitumen storage and melting tank may be heated by the same circuit or by steam.

The evaporator consists mainly of a vertical heated cylinder fitted with a droplet centrifugal separator on top. Rotor blades spread the mixture of waste and bitumen onto the heated wall where it flows downwards in a spiral path and undergoes a highly vigorous mixing.

The embedded waste is discharged through a special valve into the drums placed on a turntable. The temperature of the product is continuously monitored at discharge and is a good means of control of the embedding process.

DRUMMING

The drums are normally filled in two steps with an intermediate cooling stage to ensure a more complete use of the drum volume, the block retracting as it cools. The filling level is automatically controlled.
The turntable system can be replaced by a linear transport system if desired.

DISTILLATE RELEASE

The vapours are condensed and controlled before discharge or recycling. Residual oil entrainments are kept to a minimum by settling or filtration.

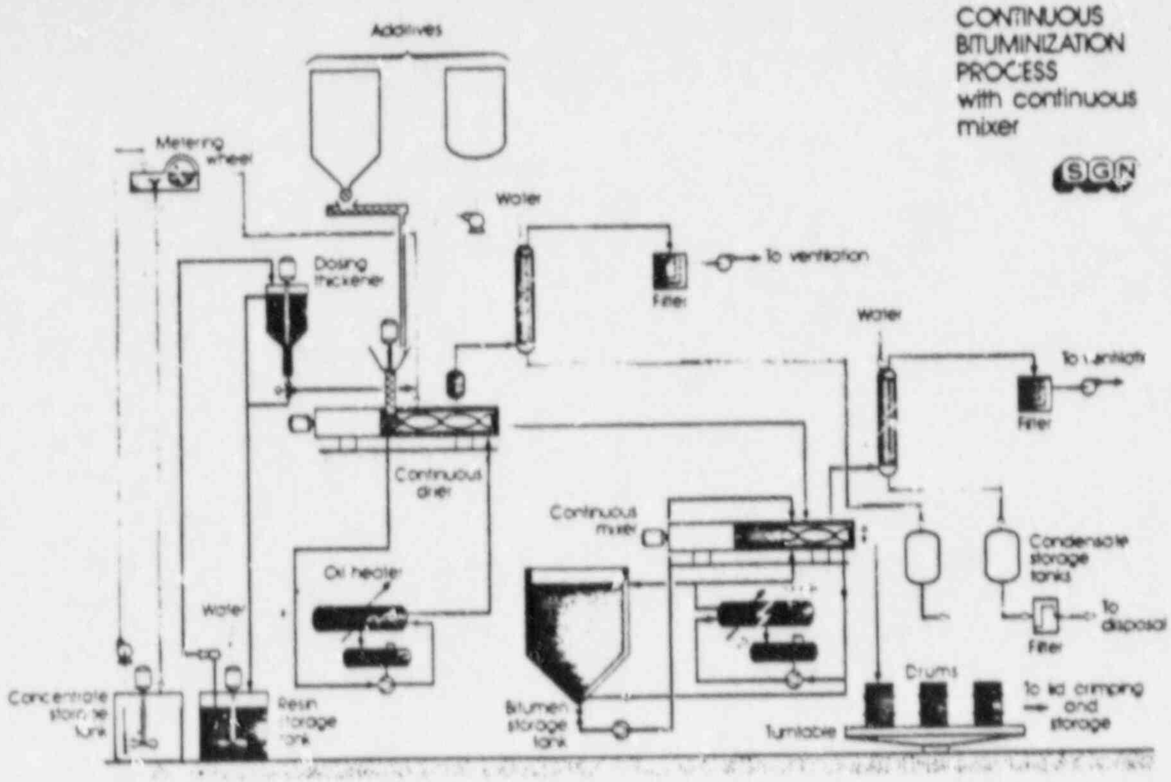
FIRE SAFETY

A fire protection system is included in the process.

MAINTENANCE

Periodic cleaning of the evaporation system is carried out by circulating pure bitumen. Solvent cleaning is possible prior to maintenance.

CONTINUOUS
BITUMINIZATION
PROCESS
with continuous
mixer



The bituminization process using horizontal mixers shown above is being developed to offer a completely polyvalent system extending to higher specific activities and covering a large range of waste types. Moreover the mixers used are compatible with other solidification processes, such as concreting.
The first equipment shown on the diagram is a screw drier which directly accepts the various wastes to be dewatered and where pretreatments can be made at the same time. The second is a double screw mixer, mixing the dried or semi-dried waste to be embedded with the bitumen. The apparatuses are heated by separate oil loops and the annexes are similar to those of the process using a vertical evaporator.

EMBEDDED PRODUCT QUALITY

Water content for resins	2 to 3 %	Leach rate for PWR concentrates (measured after 3 years	137 Cs : 10^{-7} cm/d 60 Co : 3 10^{-5} cm/d
for concentrates	< 1 %		
Radiation resistance	no measurable effect up to 10^8 rad	Instantaneous fire point	> 350°C (662°F)
Softening point	> 70°C (158°F)	Resistance to micro-organism attack	no measurable effect

SGN has entrusted **ATI**, *(Associated Technologies Incorporated), for the commercialization of the thin-film evaporator bituminization process in the United States. Please contact them : 222 S. Church St, Charlotte, NC 28202 - Tel. (704) 376.5752 - Telex. 8106210336 ATISRO CHA*

SGN LIAISON OFFICES

In North America :

2560 M Street, NW
Suite 400
WASHINGTON, DC - 20037, U.S.A.
Tel. (202) 857-0713
Telex. 089 2805 - Cogema WSH

In Japan

Shin Ohtemachi bld 4 F
Ohtemachi 2 - Chome
CHIYODA - KU, TOKYO, 100 JAPAN
Tel. (3) 246 0028
Telex. 0222 80 74 SGN TKU

SGN 78184 SAINT-QUENTIN-YVELINES CEDEX - TEL. (3) 058.60.00 - TELEX 698 316 F

2. Pacific Nuclear

The AZTECH process was originally developed by the General Electric Co. They submitted the original topical report on the process which has been approved by the NRC Staff. This report is in fact the only topical report on a waste solidification process which has received NRC Staff approval. Subsequent to the approval of the report GE sold the process, with other LLW activities, to Pacific Nuclear who now markets the process.

The process consists of mixing a monomer, vinyl toluene (VT), with the waste and then heating the mixture and driving off the excess VT and contained water under a vacuum. A polyester and promoter are mixed with the VT coated waste and then a catalyst is added. Polymerization is initiated and the mixture is then poured into a disposal container to solidify.

3. DOW Chemical

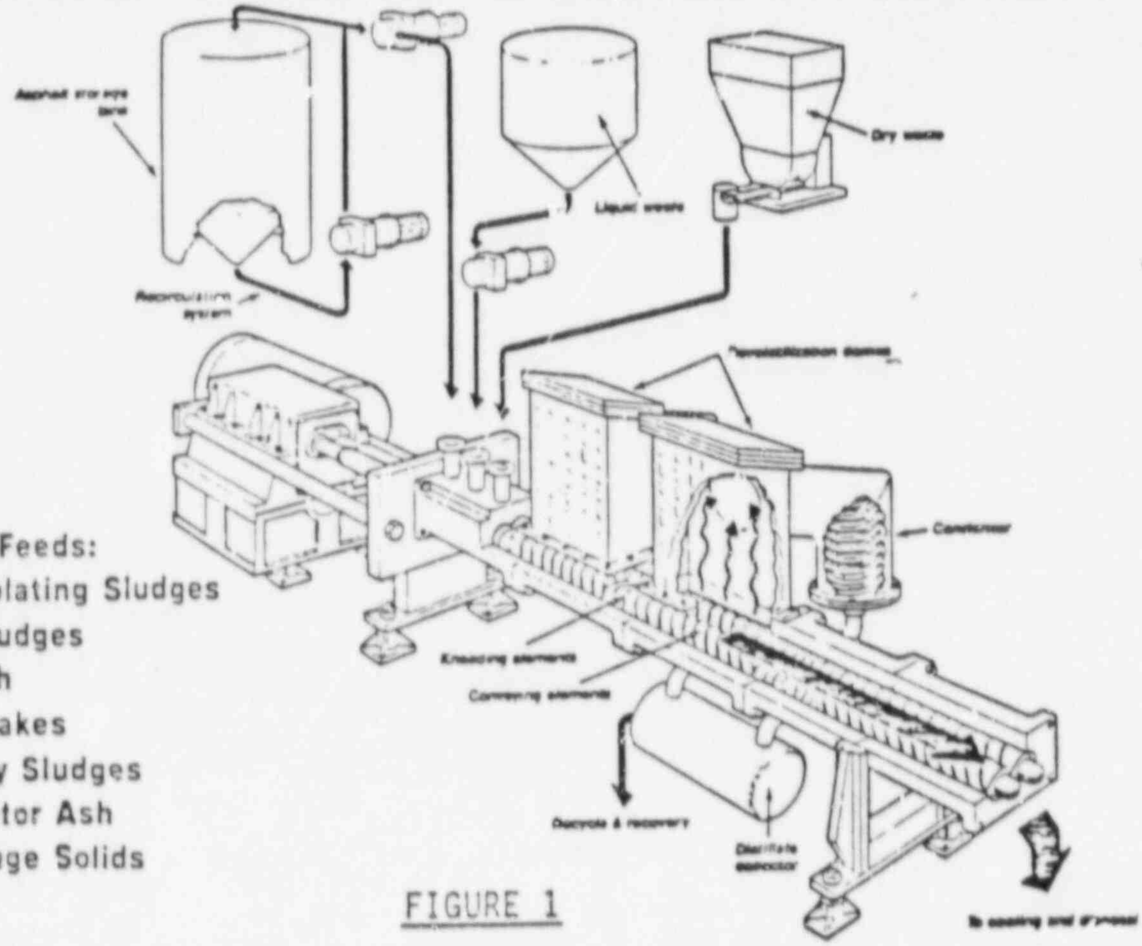
The DOW process uses a vinyl ester mixed with a styrene monomer as the basic binder. It is conventionally blended with the untreated waste in the disposal container. Once the mixture is homogenized a suitable catalyst and promoter are added and stirring is continued until polymerization is initiated. Then the stirrer is either disengaged and left in the mixture or it is withdrawn. The solidification proceeds and a monolithic solid results. A ratio of 1.5/1, waste to binder, has been demonstrated. This includes the water contained in the initial waste. Apparently the mixing operation requires visual observation and adjustment of the catalyst and promoter additions.

The process is licensed to the individual utilities by DOW. DOW will provide start-up assistance, but does not perform the solidification itself. The process is in use, or has been used in some four or five plants, both PWR and BWR. Waste loadings of 30 to 40% are normal. In several cases it is used in conjunction with an incinerator, solidifying the resultant ash. Because of the cost of the reagents it is a relatively expensive process. Generally the waste is cast into 55 gal drums but containers up to 6' high and 6' in diameter have been successfully used. The process is apparently straightforward to use and flexible in application.

4. Waste Chem

Attached is a schematic drawing of Waste Chem's process for solidifying LLW in bitumen. It is based on German technology and uses an imported extruder. It appears to be quite similar to the ATI alternative system described in ATI's literature. Like that process it appears that the product will be water free, highly uniform with a relatively high loading of waste. Also attached is some Waste Chem literature which provides some details. (see attachment 4-1).

VRS™–Volume Reduction and Solidification System



Typical Feeds:

- Electroplating Sludges
- Paint Sludges
- Kiln Ash
- Filter Cakes
- Refinery Sludges
- Incinerator Ash
- Centrifuge Solids

FIGURE 1

WasteChem

Services and Systems for Radioactive Waste Management

VOLUME REDUCTION & SOLIDIFICATION SYSTEM (VRS™)

WasteChem's Volume Reduction and Solidification (VRS™) system is a one-step, non-chemical process for the treatment of radioactive wastes. The system is available in two configurations:

- o Mobile VRS system, available on a service basis
- o Fixed VRS system, for installation and dedication at a single location

The VRS system uses an extruder-evaporator to remove the water from radwaste feeds by evaporation, while mixing the dried radioactive residues with an asphalt binder. The binder is a high-viscosity, oxidized asphalt that ensures compliance with the waste form requirements of 10CFR61.

WasteChem's operating VRS systems at nuclear facilities have been reducing waste volumes by a factor of approximately 10, compared with the volumes previously produced at these plants.

Benefits of the VRS system include:

- o Lower costs for waste storage, transport and disposal
- o Reduced volumes to meet burial allocations or extend on-site storage
- o Reliability based upon more than 150 system-years of operating experience
- o Regulatory approval of products

MOBILE VRS SERVICES

WasteChem will provide its Mobile VRS system to customers on a service basis with trained operating personnel. While the system can be dedicated to one plant, it is completely transportable so that it can be shared between plants for additional cost savings. The system's design simplicity promotes ease of operation and transport.

FIXED-INSTALLATION VRS SYSTEMS

The VRS systems which have been permanently installed in nuclear facilities offer the same volume reduction benefits as WasteChem's mobile system. WasteChem's scope of supply for permanently installed systems has varied greatly in scope, from basic VRS supply to complete, integrated radwaste facilities. Utilizing WasteChem's process engineering and materials handling expertise, such projects have included the design and supply of:

- o Liquid waste crystallizers
- o Container capping and monitoring equipment
- o Materials handling equipment including automated cranes, conveyors, turntables and carts
- o Waste collection, pre-treatment and feed systems

EXPERIENCE

VRS systems have been in operation since 1965. A total of 34 systems have been purchased worldwide, with 14 of these systems in the United States. Operating experience with over 200,000 system-hours of operation has resulted in an unparalleled reputation for high reliability and low maintenance.

SUPPORT SERVICES

WasteChem offers the following support services for all of its systems:

- Start-up and procedures development
- Installation supervision
- Training
- o Pilot plant testing

REGULATORY ACCEPTANCE

The VRS system Topical Report has been accepted by the NRC. WasteChem's Topical Report on 10CFR61 Waste Form Compliance has received interim acceptance. Burial site regulatory agencies have provided written acceptance of the VRS product. Testing for various government agencies has shown compliance with EPA limits for potentially toxic wastes, permitting use of the system for mixed waste applications.

WasteChem Corporation, One Kalisa Way, Paramus, NJ 07652 • 201/599-2900 • Telex: 6853631

III. High Integrity Containers (HICs)

A. Background Discussion

There are six specific vendors either supplying or planning to supply HICs who have formally interfaced with the NRC. Three vendors, Chem-Nuclear Services, Inc. (CNSI), Westinghouse-Hittman and TFC Nuclear Associates, Inc. (TFC), produce polyethylene (PE) units of comparable size and design, which are believed to be fabricated by the same rotational molding fabricator. The Nuclear Packaging (NUPAC) HIC is the only all metal unit in service and it is made of a special stainless steel. Nuclear Packaging also produces a PE HIC that is only suitable for use at Barnwell. (This limitation applies to all PE HIC's and will be discussed in detail later). LN Industries and Chichibu Cement produce composite HICs whose designs will be discussed below.

Only two of all of the above HICs have received formal NRC acceptance. They are one of Nuclear Packaging designs, the FL50 (50 ft^3 capacity), and the Chichibu designs for 200 and 400 liter units made of a special concrete. The LN composite design, a PE inner liner with a stainless steel outer shell recently was submitted to NRC for review. On the other hand, all of the PE designs and the other Nuclear Packaging designs have been under review by NRC for 2-3 years and still have not been formally accepted by the NRC. However, the PE HICs have been granted interim disposal authorization by South Carolina and NUPAC HICs other than the $50ft^3$ size have received a similar dispensation from Washington state.

The principal advantage of all the polyethylene HICs appears to be cost, when compared to the metallic and composite units. While they do demonstrate excellent corrosion characteristics with respect to groundwater and/or soil conditions, they do show sensitivity to various organic materials and care must be taken as to the composition of wastes put into polyethylene HICs.

Conversely, these units have several disadvantages which have held up their formal NRC acceptance. These are the continuing concerns over the tendency of polyethylene to deform or creep under applied stresses, causing buckling failures and stress cracking. As noted previously, one of these characteristics was first demonstrated when a polyethylene HIC deformed in a transportation cask and became wedged in the cask. The internal pressurization was caused by gas generated by either radiolysis or biological degradation. As a result of this incident all HICs are now required to have passive vents that will permit free movement of air or gases into and out of the HICs, while limiting ingress of water and egress of wastes. This is generally accomplished by the provision of passive vents in the wall or top of the HIC.

Structural analyses have been made of the long-term performance of polyethylene HICs. Appendix B is a Brookhaven National Laboratory (BNL) draft study for NRC that concluded that polyethylene HICs are not suitable for long-term disposal by burial in their present design, that is, unstiffened. An earlier report (Appendix C) by the Engineering Design and Testing Corp. for NUS Process Services, Inc. had previously reached the same conclusion. The PE HIC vendors have strongly opposed these opinions. For example, they have pointed out that the studies failed to take into account the strengthening effect of the contents of the HICs. Regardless of the conclusion of the analyses and presentations of the vendors considerable uncertainty as to the suitability of polyethylene as a material of construction still exists at NRC. It should be stressed that the concern is not initially over the expectation that the HICs would rupture and permit the waste to be leached by groundwater. The initial concern is that if the HICs deform, then the backfill above the HICs could settle and develop a "bathtub" shape, thus enhancing the collection and retention of water in the trenches. This, when coupled with failure of the HIC, will tend to enhance the movement of radionuclides into the ground water.

The NRC Staff is actively pursuing this matter and has provided further guidance on the use of PE HICs (see Appendix D). Further, the NRC has requested the PE HIC vendors to perform additional analyses of their designs and demonstrate that the HICs will perform properly (see Appendix E).

An important restriction on the design of HICs comes from the size and weight limitations of the transport casks used to contain the waste containers during transportation. This will be noted in the comparable size of the HICs from different vendors. A partial listing of the interior dimensions of commercial transportation casks is given in Table A-1.

Table A-1 -- Data for Standard Shipping Casks

Cask Designation	Inside Diameter, in.	Inside Height, in.
14-170	75.5	73
10-135	65.5	72
8-120	61	75
7-100	75.5	40.75

B. HIC Vendors

1. Chem-Nuclear Systems, Inc. (CNSI)

Chem-Nuclear has a unique position in the low-level radioactive waste disposal industry. It is the only company that 1) provides solidification systems or services on a lease or turn-key basis; 2) provides radwaste handling and disposal services; 3) markets HICs and other containers, and 4) operates a disposal facility at Barnwell, South Carolina. The operation of the Barnwell disposal facility is beyond the scope of this report.

Nominal wall thickness for the containers is 1/2-inch with the exception of the overpack lid which is 1/4-inch. The containers are manufactured from Phillips Chemical Company Marlex CL-100 cross-linked polyethylene using a rotational molding process. The shape of the HIC's is a right cylinder with a torospherical, or domed, head. Depending on the waste placed in the container the bottom may be flat or a 5 degree cone. In addition to the HIC's, Chem-Nuclear also offers liners made of polyethylene. Tables 1-1, 2, 3 presents a summary of the size and capacity data on the CNSI HICs and liners.

Table 1-1 -- CNSI HICs - Flat Bottom Size and Capacity

Designation	Diameter(in.)	Height(in.)	Vol (ft^3) inner	Vol (ft^3) outer	Gross Weight(lbs.)
PL 6-80	57	56	73	83	5,000
PL 7-100	72.5	39	70	94	6,250
PL 8-120	60	73	108	120	7,500
PL 14-170	72.5	71	150	171	10,800
PL 14-195	74	77.5	171	194	12,200
PL 21-300	80	107.5	285	314	18,750

Table 1-2 -- CNSI HICs - Conical Bottom Size and Capacity

Designation	Diameter(in.)	Height(in.)	Vol (ft^3) inner	Vol (ft^3) outer	Gross Weight(lbs.)
PL 4-85R	43	98	74	84	5,300
PL 6-80R	57	55	70	83	5,000
PL 7-100R	72.5	38	69	94	6,250
PL 8-120R	60	72	103	120	7,500
PL 14-170R	72.5	70	143	171	10,700
PL 14-195R	74	76.5	164	194	12,200
PL 21-300R	80	106.5	286	314	18,750

Table 1-3 -- CSNI Liners Size and Capacity

Designation	Diameter(in.)	Height(in.)	Vol (ft^3) inner	Vol (ft^3) outer	Gross Weight(lbs.)
Small	33	57	24	28	2,500
Medium	33	78	34	38	2,500
Large	33	85	37	42	3,500

Three different closure designs are utilized. The 1/4-inch fine thread closure consists of a 1/4-inch square thread, two threads per inch, with a double lead in. Sealing is accomplished by a lid lip that fits into a groove in the container throat. The groove is filled with 3M DS-800 duct sealer which provides an effective seal when cured. A second design, 3/4-inch coarse thread, employs a 3/4-inch course, single lead in thread. Sealing is accomplished by compressing a 1/2-inch polyethylene gasket. Gasket compression is achieved by utilizing polyethylene compression plates to transfer pressure from the lid to the gasket. The buttress thread design employs a 7-degree by 45-degree American National standard buttress thread. A double lead in thread is used. Sealing is accomplished by compressing a "U shape" EPDM gasket resting in a seal cup in the container throat. The 1/4-inch fine thread, 3/4-inch coarse thread, and buttress thread are employed on the standard containers. The overpack employs the buttress thread only.

The standard containers receive a polyurethene foamed flat top. This is required in order to provide a method of container stacking. The conical-bottomed vessels receive a foamed flat bottom equivalent to the foamed top. Lifting and handling of the vessels is accomplished by utilizing a carbon steel lifting basket and lifting cables. Passive venting is accomplished through the threaded plug.

In CNSI's recent submission, they noted that their annual use of HIC's is approximately 650 a year. In addition they provided a "testing protocol" which is attached as attachment 1-1.

HIC QUALIFICATION TESTING

Basic testing is required for Type "A" packages as given in 49 CFR 173.398(b).

Major test elements consist of:

1. Reduced pressure of 0.25 atmosphere absolute (simulate by pressurizing the container to achieve the equivalent pressure differential).

2. Drop test from 4 feet. Later changed to 20' - 25' per SC DHEC requirements. Containers are dropped flat bottom, flat top, side, bottom corner, and top corner. No loss of contents is allowed.

3. Compression test. This test is not required on package weighing more than 10,000 pounds but we performed this testing lieu of a burial test requested by South Carolina DHEC.

4. Penetration test. Standard drop of 40" by 1 1/2" diameter, 13 pound hemispherical end steel rod.

Other testing:

1. Heat - 130° F.

2. Cold - 40° F.

3. Hot water test - Container filled with water at 185° F and loaded into cask to demonstrate no slumping of container.

4. Lifting test - Abrupt lifting and free line fall with abrupt stop.

(5814r)

2. Westinghouse-Hittman Nuclear Inc. (W-H)

W-H produces the RADLOK line of HICs. They are similar to the Chem-Nuclear and TFC units in that they are right circular cylinders fabricated from rotationally molded polyethylene. Table 2-1 summarizes the sizes of the available W-H units.

Table 2-1 -- W-H RADLOK HICs - Sizes and Specifications

Designation	Diameter(in.)	Height(in.)	Vol (ft^3) inner	Gross Weight(lbs.)
55 (1)	23	35.5	6	950
200 (2)	52	60	57	5,500
100 (2)	72	71	125	10,500

(1) stiffened ends

(2) dome head, flat or convex bottom

As noted above all HICs are subject to size limitations based on the capacities of the existing approved shielded transportation casks. As a result, there is a similarity between the W-H 100 and the CNSI PL 14-170 HICs. Also as with the other HIC suppliers the material of construction of the W-H HICs is Phillips' Marlex CL-100.

3. <u>TFC Nuclear Associates Inc.</u> (TFC)

TFC markets the NUHIC line of PE HICs which have the shape of a right circular cylinder. The available dimensions are given in Table 3-1.

Table 3-1 -- Size and Capacity of NUHIC HICs

Designation	Diameter(in.)	Height(in.)	Wall(in.)	External Volume (ft^3)
NUHIC 55	23.75	35	0.375	9
NUHIC 80	n/a	n/a	n/a	80
NUHIC 120	70	72	0.625	120

n/a - not available

Access to the HICs is through a cap in the top. Two cap diameters are available, 8" and 16". After filling, the caps are screwed into place and sealed by various adhesives. Venting is accomplished by 4-1/2" diameter vent plugs in the top of the HIC. The vent plugs use plastic milipore filter material to allow the passage of gases and to minimize water entering the HIC. Phillips' Marlex CL-100 is listed as a material of construction of the HIC. For this vendor, the size similarity between the NUHIC-120 and the W-H 100 and CNSI's PL 14-170 is also apparently based upon cask internal dimensions. Lifting and handling of the NUHIC units is accomplished by a lifting ring and wire cables in a manner similar to that used by either CNSI or W-H.

4. LN Technologies Corporation (formerly NUS Services)

LN Technologies Corporation (LN) is the most recent entrant into the HIC market. The predecessor of LN was NUS Process Services Corp. who developed a cementaceous process for solidifying LLW and also investigated the feasibility of using a polyethylene HIC. The NUS experience and LN position is summarized in letters of 3/20/87 and 9/16/87 (attachments 4-1 and 4-2). In summary LN concluded that unreinforced polyethylene would be unsuitable for HICs (see Appendix B) and they indicated that they would no longer pursue an all PE HIC design. As a result they proceeded to work toward developing a composite HIC consisting of a 316 stainless steel (SS) outer casing, lined with rotationally molded polyethylene. These activities and the logic behind the development effort are summarized in attachments 4-2 and 4-3.

The LN design is basically a right cylinder with domed top and bottom. Access is through the top. Two lids, an inner one of polyethylene and an outer one of 316 SS, provide closure. Venting of the interior is accomplished through two plug vents using carbon filters. One vent is in the polyethylene lid and the second is in the neck of the access hole in the SS shell. The lids are closed mechanically and no special sealing materials, such as gaskets, are used. The specifications for the LN composite HIC's are given in Table 4-2.

Table 4-2 -- LN Composite HICs - Dimensions and Capacities

HIC Desig.	Height in.	Diameter in.	Internal Volume, ft^3	Disposal Volume, ft^3	Empty Wt., lb	Max Gross Wt., lb
LN-1[illegible]	[illegible]4.5	72.5	158.2	179.2	2230	14,000
LN-131H	64.5	71	114.3	131.2	1880	10,000
LN-118H	60	74	100.4	118.3	1840	9,500
LN-96H	74.5	39.75	72.5	95.8	1450	7,000

LN has submitted its topical report on its composite HIC to the NRC in September, 1987. It is unknown whether or not they will attempt to obtain interim approval for the use of their units at Barnwell and Richland, pending NRC review, but it appears likely that they may do so.

ATTACHMENT 4-1

LN TECHNOLOGIES

...KEY ROAD COLUMBIA S... (803) 256-4355

WM DOCKET CONTROL
CENTER

March 20, 1987

'87 MAR 24 A10:12

WM Record File

WM Project 20
Docket No.
PDR ✓
LPDR

Distribution:
Peterson
Johnson

Mr. Timothy Johnson
US Nuclear Regulatory Commission
Low Level Waste Branch
Washington, DC 20555

RE: Polyethylene High Integrity Containers

Dear Sir:

This latter is intended to review the current status of polyethylene HICs, as LN Technologies understands it, and to aquaint you with our position regarding their use.

LN recognizes the conflicting opinions presented by various experts on the suitability of polyethylene as a HIC material. We further recognize that detailed designs and analyses for polyethylene HICs have been submitted. Unless it is determined that polyethylene is unsuitable as material of construction for HIC's, LN proposes to re-adopt the use of suitably licensed polyethylene HICs as part of our business.

Background

In 1984, NUS Process Services Corp. (NUSPSC), a predecessor company of LN Technologies Corporation (LN), approached a leading producer of high density polyethylene pipe regarding the fabrication of HICs for use in low-level radioactive waste disposal. The producer strongly indicated that polyethylene, in the thickness proposed, would be inadequate to survive burial under the conditions understood to be present in the burial trench.

NUSPSC then engaged a consulting firm, Engineering Design and Testing Corporation (ED&T), to analyze the NUSPSC HIC design for compliance with the disposal regulations requirements. It was expected that the analysis would, at worst, recommend minor design modifications. However, that analysis concluded that polyethylene, in the thickness proposed, is an unsuitable material for HICs because of the inadequate resistance of polyethylene containers to lateral forces (assuming no credit for HIC contents). The analysis concluded that the HICs would buckle in the burial trench.

Realizing the seriousness of this result, NUSPSC sought additional independent opinions from Mr. John O'Toole, a recognized expert on material properties of polyethylene and similar materials.

Mr. O'Toole wrote the Design Guide section of the Modern Plastics Encyclopedia. NUSPSC also consulted Dr. John Dickerson, Professor of Civil Engineering at the University of South Carolina. The opinions of both Mr. O'Toole and Dr. Dickerson confirmed the analysis of ED&T, i.e., polyethylene is an unsui'-ble material for HICs.

Faced with the same expert opinion from several sources, NUSPSC felt it had no option but to present the evidence to the licensing authorities, the Nuclear Regulatory Commission (NRC) and the South Carolina Department of Health and Environmental Control (SCDHEC). We also removed our Polyethylene "Barrier 55" HIC from the market, and refrained from using other commercially licensed HICs until this issue was clarified. NUSPSC did not have access to the analyses and detailed designs of these other HICs, so could not compare these designs and analyses with the one we had undertaken.

With our consent, SCDHEC passed the report prepared by LN, without the proprietary Appendix E, to the manufacturers of polyethylene HICs. It is our understanding that each of the current manufacturers subsequently submitted to SCDHEC their own analyses, which used some different assumptions and came to different conclusions than the ED&T analysis. We further understand that, after review of the LN report (with the ED&T analysis), and the other reports and analyses, SCDHEC has concluded that the current designs are satisfactory from a licensing point of view. LN accepts that conclusion and, as stated above, will re-adopt the use of properly licensed polyethylene HICs.

I hope this letter clarifies our position regarding the use of polyethylene HICs. Please contact us at LN Technologies if you have any questions on this matter.

Yours truly

J. E. Le Surf

J.E. Le Surf
President & CEO

ATTACHMENT 4-2

LN TECHNOLOGIES CORPORATION 1501 KEY ROAD, COLUMBIA, S.C. 29201 (803) 256-4355

September 16, 1987

FOR ENCLOSURES TO DOCUMENTS, REQUEST DURING FILE MATERIAL

WM Record File

WM Project 20

WM-20

Dr. Michael Tokar, Section Leader
Office of Nuclear Material Safety & Safeguards
Division of Low-Level Waste Management and Decommissioning
Technical Branch
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Distribution: M Tokar   T.C. Johnson

(Return to WM, 623-SS)

Dear Dr. Tokar:

As we discussed in our telephone conversation two weeks ago, I have enclosed the following report prepared for LN Technologies (formerly NUS Process Services) regarding the use of polyethylene in HICs:

> "An Assessment of Polyethylene as a Material for Use in High Integrity Containers", Engineering Design & Testing Corporation, July 7, 1986.

The report, which was transmitted to T. Johnson at the NRC, in October, 1986, indicates that HICs made of high density polyethylene have insufficient structural strength to withstand the stresses associated with burial. In particular, concerns are reported regarding buckling of the sides and top of the container at the time of burial, and environmental stress cracking over time.

Also included for your information is the following paper presented by ED&T's Dr. Tim Jur at Waste Management, '86, on the subject of HIC materials:

> "A Critical Review of Materials Selected for High Integrity Containers", T.A. Jur, W.M. Poplin, Engineering Design & Testing Corporation.

This paper was the first formal presentation of our concerns regarding the stability of polyethylene HICs. The recent Brookhaven work appears to reinforce these concerns.

Finally, we have observed over the past several years several items worthy of consideration regarding the burial of polyethylene HICs:

1. Drum size HICs "falling" off drum pallets into horizontal positions. This indicates that these small containers should be analyzed in a horizontal position in addition to the upright position.

2. Severe bulging of HICs (even without an overburden), indicating a very low structural strength of the container side wall.

3. Carbon steel containers are buried with poly HICs. Impingement of non-HIC, carbon steel containers on the sides of poly HICs has been observed. Such high localized stresses could lead to rapid failure of the poly HIC.

4. Impingement of the carbon steel lifting rings around the top circumference of poly HICs onto other poly HICs has also been observed. This can also result in high localized stresses and subsequent failure.

In addition to these items, it is clear the method of backfill (bulldozing dirt from the end of the trench) is not consistent with rigorous embedment and compaction techniques normally employed for polyethylene pipe and FRP tanks. Without proper installation underground poly and FRP structures will fail.

For these and other reasons, LN elected to design a composite HIC fabricated of stainless steel with a polyethylene lining. A topical report for the container was transmitted last week to Dr. Knapp for review by the NRC and we look forward to assisting the review by providing any additional information required.

I hope that the enclosed information is helpful to you, and I look forward to receiving the Brookhaven report on the poly HICs. Please contact me if you have any questions regarding this transmittal.

Sincerely,

Steven B. McCoy

Steven B. McCoy
Director, Developmental Engineering

cc: R. Voit

SBM:dab

ATTACHMENT 4-3

A CRICTICAL REVIEW OF MATERIALS SELECTED

FOR HIGH INTEGRITY CONTAINERS

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ABSTRACT

Under consideration is the selection of materials for the manufacture of High Integrity Containers (HICs). A study has been conducted in this regard, including review of material properties and structural analyses. As a result of this study, conclusions were reached recommending against the manufacture and use of either all plastics or all metal HICs. HICs manufactured entirely from plastic have demonstrated structural limitations. Metal HICs are subject to corrosion and are not expected to satisfy containment requirements. As an alternative design a HIC is recommended which uses both materials, plastic for containment and metal for structure.

INTRODUCTION

A recognized method for disposing of low level nuclear waste is to place these materials in special containers and then bury the containers underground at an approved disposal site. These containers are known as high integrity containers (HICs). This paper addresses the selection of materials used in the manufacture of HICs.

There are a number of government regulations concerning HICs. These regulations control, within certain limits, what waste material can be placed into a HIC and how burial is to be managed. Federal regulations are compiled in 10CFR61 "Licensing Requirements for Land Disposal of Radioactive Waste" [1] and a supplementary publication, the U. S. Nuclear Regulatory Commission "Technical Position on Waste Form" [2]. There are also additional regulations promulgated by each of the states where burial sites are located [3, 4]. Together the regulations set performance criteria for shipping, handling and burial. Material selection for fabrication of a HIC is left to the discretion of the design engineer, as long as compliance with regulations can be demonstrated.

The primary concern of this paper is the selection of a HIC material to survive burial underground. To be acceptable for burial, a HIC must have a demonstrated structural integrity and containment integrity sufficient for a 300 year life once it is buried. Manufacturers of HICs are required to establish performance criteria concerning structure and waste containment consistent with government regulations. The objective is to ensure that containers provide safe and secure disposal of nuclear waste products. Manufacturers and users of HICS must identify and account for all reasonably foreseeable waste forms and chemistries in the burial environment. This requires that careful attention be given to both the structural and environmental conditions at the burial sites.

Over the last three years the design requirements of HICs has been studied. In particular, this study has involved the selection of candidate materials from which HICs can be manufactured. Material properties and structural requirements have been reviewed. Effort has also gone into characterizing the nature of the waste products in terms of chemistry and form. As a result, it has become apparent that many factors which affect both structural integrity and containment integrity have not previously been fully and properly considered.

It is time to look more objectively at the issue of what constitutes good HIC design. From the onset, this has been the purpose of the study which underlies this paper. This paper includes a review of various factors, such as waste characterization and structural modeling, which significantly influence HIC design and material selection.

WASTE CHARACTERIZATION

Waste materials which are buried in HICs consist primarily of ion exchange resins and filter media. In addition, small amounts of free water (up to 1% of container volume) and small amounts of miscellaneous contaminants may be present with the waste.

Ion exchange resins used in nuclear power stations may be either bead-type or powdered resins, typically styrene divinyl benzene based resins. Bead or gel type resins are produced in small spheres approximately 0.5 mm in diameter (20-40 mesh) and contain approximately 50% water. Powdered resins are produced by grinding bead resin into fine particles typically 35-45 microns in size, which contain approximately 60% water by weight. This contained water may form "free" or pourable water if the resin structure breaks down.

The resin types used in power plants are nearly all strong-acid cation and strong-base anion or mixtures of these resins. In general, larger quantities of cation than anion resins are used due to ion exchange system design, resin capacity and applications typical of power stations. When placed into service, cation resins are typically in the hydrogren ion form while anion resins are typically in the hydroxide form.

In processing the wastes, the resins are converted to the ionic forms removed from the wastes. Although resins may be removed from service based on activity or radiation levels, radionuclides consume an insignificant portion of the resin capacity. As a result, resins are exhausted by normal water constituents such as sodium, magnesium, calcium, chlorides, sulfates and carbonates. These constituents may be found in the circulating or service water which provides the heat sink for the power cycle. The water leaks into the plant, is collected in a controlled drain system and consequently is processed as "radioactive" waste. It is not unusual, for example, to process wastes with high concentrations of sodium chloride at plants located on the seacoast. These ionic materials will be removed by the resins, then the resins are eventually placed into HICs and buried.

When the resins are removed from service, it is unlikely that all of the capacity has been exhausted. Unexhausted cation resin in the hydrogen form, for example, will produce low pH, acidic conditions while unexhausted anion will form high pH, alkaline conditions. For stainless steels, a highly corrosive enviornment will result when unexhausted cation resins in the hydrogen form is placed into a HIC with anion resin exhausted to the chloride form. Introduction of water to the resin during transfer to the HIC will form a dilute hydrochloric acid solution.

Irradiation of the resin results in resin breakdown by the release of functional groups and by changes in cross-linking [5, 6]. The side affects of this process are identified as release of free liquid, reduction in pH and gas generation. As an example of this behavior, irradiation of hydrogen form cation resins to $7x10^7$ rads resulted in pH values as low as 1.5 when 2.0 grams of this resin were placed in 10 ml of water [7]. In general, research has shown that the range of radiation induced chemical by-products is varied and includes many products which would be aggressive in a container environment.

Characterization of the conditions inside a HIC is further complicated by biodegradation. Bacteria growth on the resins used in radioactive waste treatment is well documented but the effect of biodegradation products on HIC materials is unclear.

In summary, the conditions inside of a HIC cannot be precisely defined. Conditions vary depending upon density of the waste water processed, the type or mixture of resins, radioactivity loading on the resins, the amount of water available in the container and the presence of biodegradation. Selection of the HIC materials must consider all of these factors in order to meet th objectives of HIC design.

DESCRIPTION OF HICs IN USE TODAY

HICs in general use today are fabricated of either polyethylene or ferralium stainless steel. These containers range in size from 208 liter (55 gallon drum size) containers up to relatively large containers, 2 meters tall by 2 meters in diameter. A representative range of container sizes and capacities is shown in Fig. 1.

The polyethylene containers are rotationally molded with wall thickness ranging from 11 mm to 19 mm. The smaller containers are typically provided with flat tops while the large HICs have elliptical heads and flat or conical bottoms. No other provisions to support the container under burial are provided other than the polyethylene material itself.

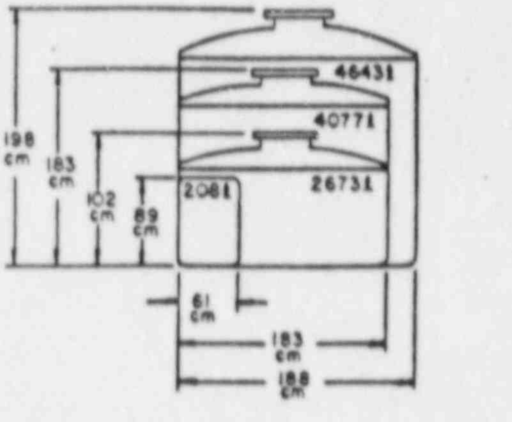

Fig. 1 Range of container sizes and capacities

A stainless steel container is now being manufactured using a specialty grade duplex material and employing conventional fabrication and welding methods [8]. The wall thickness is 6.4 mm. Information concerning thickness of the top and bottom is not available. There is no lining inside the container to protect against corrosive attack from the waste product within.

STRUCTURAL MODELING FOR UNDERGROUND BURIAL

Once radioactive waste product is placed in a HIC, the HIC now assumes the primary function of separating the waste from the surrounding environment. The ability of a HIC to perform this function is referred to herein as its "containment integrity". The HIC design should be such that containment integrity is insured during shipping, handling and burial.

Eventually the HIC is buried. When this occurs, it is now required to function as a structure, supporting the pressures exerted upon it by the surrounding soil. The ability of the HIC to perform this function is referred to herein as its "structural integrity". The properties of structural integrity and containment integrity are related. As a structure, a HIC is subject to failure by a variety of mechanisms which may cause cracking, rupture or damage resulting in a breach of containment. The importance of the structural function of the container must therefore be recognized in its fullest extent.

In this investigation, a HIC has been treated as a "buried structure". That is, an overburden of soil acts to create loads and pressures on the container. The container, in turn must be able to resist these loads and, in so doing, meet certain structural performance criteria [9, 10]. There are, however, certain considerations in the design of a buried structure which are different from structures in general. The design should consider not only performance of the container-structure but also the behavior of the soil around the container. The interaction is known as soil-structure interaction.

Two models of burial conditions are defined. Each of these burial conditions are described in the following sections. In addition, comment is also made concerning burial technique at a disposal site as it relates to soil compaction.

Cluster Burial

A sketch depicting cluster burial is shown in Fig. 2. The model assumes that multiple containers are placed at the bottom of an excavated site at some repeated inter-container spacing, d. The distance d is such that a masonry arch develops over the soil located between containers. As a result, the container sees a vertical load due not only to a cylindrical column of soil over the container but also shares a portion of the soil load over the masonry arches which develop between itself and its neighbors. This model results in a vertical pressure on the container greater than otherwise developed by a cylindrical column of soil directly over the container. However, lateral pressure on the walls of the container would be non-existent. The following expressions for vertical and horizontal pressure would apply:

$$p_v = C_o \lambda h \qquad (1)$$
$$p_h = 0$$

where: p_v = vertical pressure on the container
p_h = lateral (horizontal) pressure on the container
λ = soil density
h = height of soil overburden
C_o = factor greater than 1.0 which accounts for increase loading due to development of masonry arches between containers

$$C_o = A_o/A_c$$

where: A_c = cross-sectional area of container
A_o = cross-sectional area of slug of soil supported by container

The exact intercontainer spacing d is outside the control of the designer. Ideally, the spacing would be minimized. However, soil conditions can develop a masonry arch between containers should less efficient arrangements be employed.

Isolated Burial

It is conceivable that conditions at the disposal site may result in the isolated disposal of a single container. Further, this model is considered herein to offer interpretation of the local conditions on a container at the periphery of a cluster burial arrangement.

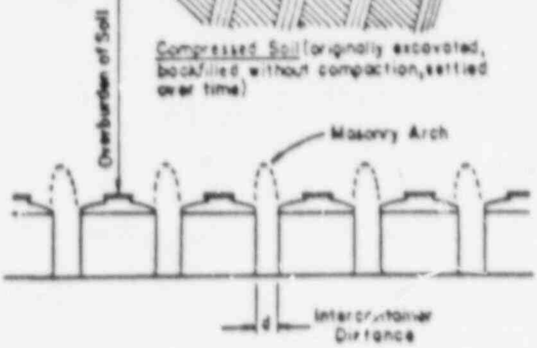

Fig. 2 Cluster burial of high integrity containers

Analysis has been conducted which compares the compressibility of a single isolated vertical container with the compressibility of the surrounding soil. The results indicate that, upon initial burial, a masonry arch <u>does not</u> develop over the container. Therefore the container must carry the burden of soil overhead. For this load condition, the expressions for vertical and lateral pressures are written as follows:

$$p_v = \lambda h \qquad (2)$$
$$p_h = K \lambda (h + \ell/2)$$

where: λ = soil density
h = height of soil overburden
ℓ = height of container
K = factor relating lateral pressure to vertical pressure and to a given overburden height (in this case a height equal to $(h + \ell/2)$ which gives an average lateral pressure on the container); K would be 0.5 for soils that have not been preloaded or preconsolidated[11] (uncompacted, as in the case at a disposal site).

Soil Condition Upon Burial

Disposal techniques are such that burial of HICs takes place without compaction. Under such circumstances, an engineering definition of soil condition upon disposal is difficult at best. Various design parameters upon which an analysis of loading due to soil-structure interaction is based cannot, therefore, be evaluated accurately. The reliability of the analysis is therefore decreased. Under such circumstances greater margins of safety are required than would otherwise be the case.

POLYETHYLENE HICs -- PROBLEMS

Polyethylene is a thermoplastic material commonly used in the shipping and storage of many chemicals. It is also inexpensive. Based on these criteria alone, PE is a candidate for a HIC material. However, the structural properties of unreinforced plastics, specifically polyethylene, are simply insufficient to handle the high external loads associated with burial. There is no assurance that survival to 300 years can be obtained unless structural features are added which make the container undesirably expensive and complex relative to other alternatives.

A major part of the study involved an attempt to design and justify an all plastic cylindrical container. This design was expected from the start to be similar to other plastic HICs in service. As a basis for design, a container having the dimensions 198 cm tall by 188 cm in diameter was selected. The attempt to design such a container proved unsuccesful. Plastic HICs, it was found, proved to have insurmountable structural limitations. The primary factors controlling design include environmental stress cracking, stress rupture and buckling of the container wall.

Environmental Stress Cracking (ESC)

Although a variety of materials may be placed in a HIC, the predominant waste product is spent ion exchange resin. This material is wet when it is removed from service. Even though the resin is dewatered prior to placement in the HIC, the product is not totally dry. The bottom of the container is expected to collect what moisture is available due to (a) eventual settling out of residual moisture left behind in the resin after dewatering, and (b) irradiation induced breakdown of the resin. The makeup of this liquid can be expected to contain ESC promoters such as surfactants. Further, the container is placed on an earthen base formed by simply scraping the bottom of the burial trench. Once buried, the bottom of the container will embed into the earthen trench thereby creating tensile stresses in the container bottom. Conditions for ESC are now in place due to the combination of tensile stress and the expected presence of harmful chemicals[12, 13]. Exact predictions are not possible. In engineering design situations, a lack of information concerning an expected failure mechanism naturally biases judgment to the side of caution. A recommendation would therefore be made against such a design.

Stress Rupture

Plastics are viscoelastic materials and are subject to the time dependent effects of stress and deformation [13]. This factor must be considered as part of the design. Once placed in the ground and buried, the sidewalls of the container, the lid and the bottom are now stressed due to soil-structure interaction as described earlier in this paper.

Due to pressures developed by the surrounding soil the container lid and bottom are now deformed. At the depths HICs are buried, the soil loads and pressures are tremendous considering the relative strength and stiffness of polyethylene.

The best properties among polyethylene materials are obtained using high density polyethylene. Regardless of density, the material is classified as viscoelastic. For such materials, when subject to a state of stress over a long period of time, the appropriate design criterion is stress rupture. Fig. 3 shows stress rupture curves in generalized form. The term "rupture" implies just what it says, a tearing apart of material — a structural failure. The stress rupture curve provides information to the design engineer concerning threshold levels of stress corresponding to structural failure as a function of time in service. Referencing Fig. 3, Curve B represents a material which exhibits a change in failure mechanisms during its lifetime. The result of such a behavior is a lowered threshold stress level for failure at prolonged lifetime. Curve A represents a material which does not manifest this behavior.

For most viscoelastic materials, including polyethylene, stress rupture data is in limited supply. A required design life of 300 years further aggravates this problem. For example, it cannot be known whether the material will behave in a manner exhibited by Curve B. Recognizing that the container itself is irradiated during service, a real possibility exist that a behavior change could occur.

In the absence of limited data or no data at all, the development of a stress rupture curve or the extrapolation of existing data to longer service life, is an exercise in engineering judgement. The approach employed here involved bringing together what is known about the static properties of the material, available data for creep and stress rupture of polyethylene, stress rupture behavior for other viscoelastic plastics and knowledge of viscoelastic materials in general.

From a standpoint of failure by stress rupture, locations on the HICs subject to tensile stress would be the lid, the bottom, and locations of secondary stresses where the lid and bottom join to the container sidewall. The unrealistic nature of such a

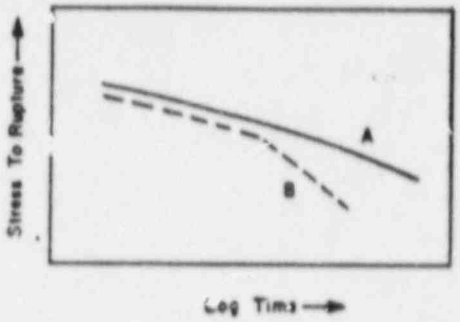

Fig. 3 Schematic representation of stress rupture behavior

design becomes apparent when the stresses resulting from soil loads on the lid and bottom are compared with the allowable stress. Flat lids and bottoms up to 25 mm thick proved to be unsatisfactory. Various dome shaped lids were also examined and proved unsatisfactory.

Buckling

A HIC designed as a cylindrical shell and placed upright in a burial site experience pressure from the surrounding soil on the top and the bottom. For the case of an isolated container there exists horizontal pressure on the sides of the HIC as well. Under this condition of loading, the HIC is modeled as an externally pressurized cylinder. The sidewalls are subject to buckling.

Procedures for analyzing sidewall buckling of externally pressurized cylinders are readily available[14]. The procedures involve specifying wall thickness and then calculating the soil overburden required to buckle the container. The relationships between soil overburden, p_h and p_e are established using Eqs. (1) for the case of cluster burial, and Eqs. (2) for the case of isolated burial.

Figs. 4 and 5 represent, in part, the results of this analysis for isolated burial and cluster burial respectively. A controlling factor in resistance to buckling is not only the thickness of the sidewall but also the elastic properties (elastic modulus) of the material of construction. Figs. 4 and 5 are plots of the sidewall thickness required to resist buckling as a function of soil overburden and elastic modulus of the HIC material. In both figures Curve A corresponds to a HIC made of high density polyethylene (elastic modulus = $7x10^{2}$ mPa) buried in a trench 8.2 meters deep (overburden of approximately 6.2 meters for a HIC 198 cm tall). [redacted] Curve B corresponds to a container made of stainless steel (elastic modulus = $2x10^{5}$ mPa). The difference in wall thickness required to resist buckling is very much a function of the material from which the HIC is made. This feature is strikingly evident in Figs. 4 and 5. It is also evident from these figures that the critical condition for buckling of the sidewall is the case of isolated burial, Fig. 4.

A word on factor of safety is appropriate at this point. Experimental results from tests on thin walled

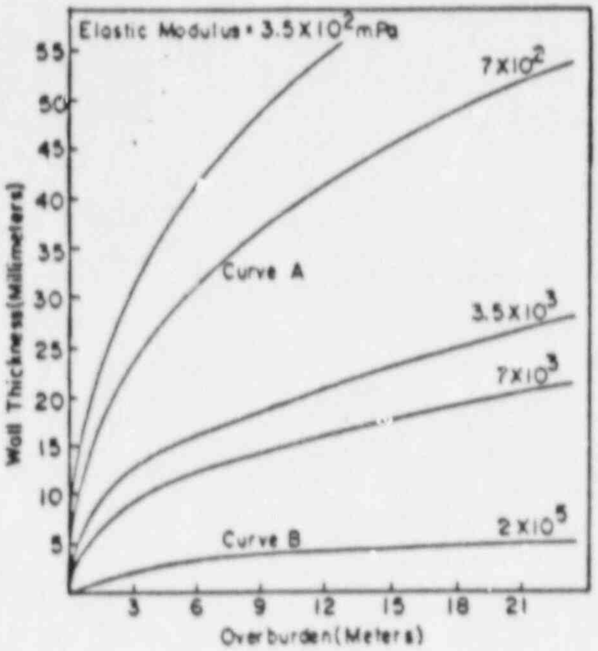

Fig. 4 Wall thickness required to resist buckling for a container in isolated burial

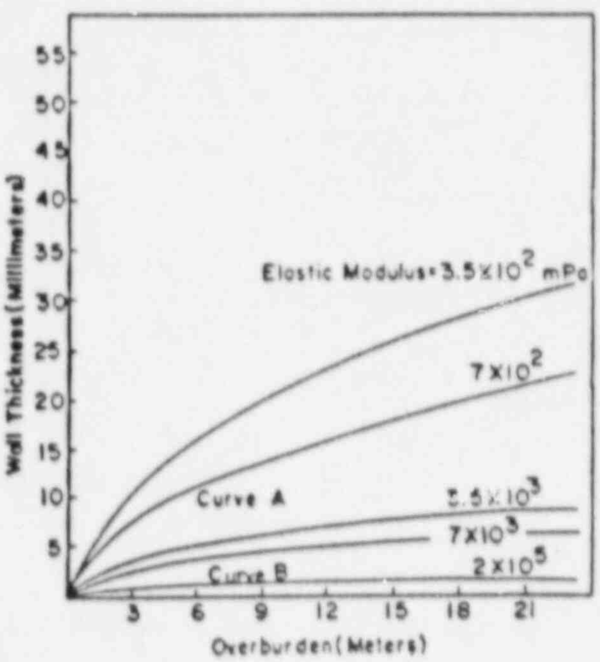

Fig. 5 Wall thickness required to resist buckling in cluster burial

cylinders have shown that theoretical analyses overstate the actual loads at which failure occurs. Failure is expected at loads 40-60% of what is predicted. Furthermore, there are differences between laboratory test results and conditions as they exist at the burial site. It has already been noted that the loads on the bottom of a HIC would not be expected to be uniform. Also, the backfill surrounding the HIC is not carefully compacted into place. Variations in burial conditions indicate a need to apply factors of safety in the range of 4.0 to 5.0 applied to theoretically calculated loading. It is evident that the required wall thickness of an unreinforced plastic container would be unacceptably high.

STAINLESS STEEL HICS — PROBLEMS

As a result of a study of plastic materials, in particular polyethylene, the conclusion has been reached that an unreinforced all plastic HIC would not provide in all cases the required structural integrity necessary for burial. Various other possible materials were examined with an emphasis on metals. Fabrication of metal storage containers is established technology. Metals, of course, do not suffer from the structural problems of low strength and low stiffness exhibited by plastics. A conventional fabricated metal vessel of relatively thin wall would resist even the soil pressures developed upon burial in 17 meter trenches at the Richland site.

For reasons of economy and practicality, candidate metals were restricted to stainless steels. Other metals noted for corrosion resistance, such as titanium alloys and the noble metals were rejected outright on the basis of cost. Conventional structural steels were rejected due to an expected lack of corrosion resistance in the burial environment.

Considerations of Corrosion from Within

The most important consideration in using metals for fabrication of a HIC is corrosion. Corrosion may occur from outside the container due to the surrounding soil environment. However, the more severe corrosive environment exists inside the container. Corrosion of an all metal container from within is a serious problem.

Waste form was discussed earlier in this paper. For waste placed in a HIC, regulations limit total irradiation prior to disposal. These same regulations, however, place virtually no controls on the chemistry of the contents. A typical waste product is ion exchange resin, usually a mixture of cation and anion resins. The pH is often neutral and the quantity of potentially harmful chemicals often small. Unfortunately, there can be no assurance that this description of waste product is always going to apply. The range of waste product chemistry may never be known. However, as already described, it is probable and therefore foreseeable that waste product placed in a HIC can have a low pH and can have chemical contents, such as chlorine, at levels considered harmful to stainless steel, regardless of the grade of stainless steel involved. It is also probable that contents placed in a HIC will be more corrosive than surrounding soils. The difference in corrosiveness may be several orders of magnitude.

Stainless steel HICs in use as of this writing have been evaluated for corrosion in soils. However, the available literature does not address corrosion from within. Recognizing the increased potential from corrosion due to the container contents, attempts to qualify an all metal stainless steel HIC as offering containment integrity over a life of 300 years cannot be justified.

Consideration of Corrosion from Without

Regarding the corrosion behavior of stainless steel and soils reference is made to two studies conducted by the National Bureau of Standards . The earlier of these two references concern data and conclusions available as a result of field tests conducted by NBS from 1910 to 1955. Many different materials were tested including nine different stainless steels exposed to different soils for 14 years. The later of the two references specifically concerned stainless steels. A greater variety of stainless steel grades and a variety of specimen treatment conditions were involved. Results of exposures up to eight years are reported. Together, these two reports are the best information available for assessing the corrosion behavior in soils of a stainless steel HIC.

For purposes of comparison, Table I has been prepared which lists the characteristics of test soils in the most recent of NBS studies. The table also includes corresponding characteristics of the backfill sands at both the Barnwell and Richland burial sites. An examination of the information in these tables reveals that the pH of backfill sand is within the range of pH of the test soils. Particular attention is given to Table I where it is seen that the chloride content of the backfill sands are noticeably less than the NBS test soils, in particular soil types C, E and G. Examination of the NBS results indicates that the aggressiveness of the soil is independent of pH in the range reported, but is distinctly related to the chloride concentration. In this sense, the soils at both burial locations are considered to have a very low potential as corrosive environments.

The following observations are based upon a consideration of all of the reported data in both NBS studies:

(a) Corrosion is not dependent on soil pH in the pH range observed.

(b) Corrosion is highly dependent upon the presence of chlorides and sulphates in the soil. On this basis, existing site backfill sands, regardless of the grade of stainless steel involved, would not be considered aggressive environments.

(c) There are a variety of grades of stainless steels for which very little corrosion would be expected in a backfill sand environment.

(d) Sensitization detracts from corrosion resistance[17]. In the NBS study, sensitization was produced by specially heat treating the steels to produce a sensitizied microstructure. Ordinary fabrication of containers from these metals results in sensitization due to a condition of inherent heat treatment in the heat affected zone surrounding a weld. For comparison, the NBS study tested welded samples as well as sensitized samples. In such cases, the corrosion behavior was similar.

(e) Manufacture of a HIC from stainless steel would necesarily involve welding. Today, grades of stainless steel are available through alloying which are routinely welded without sensitizaton.

(f) There is a need to consider a 300 year life in comparison with the eight year life test data available. Fourteen year test data is reported in the earlier NBS study. These data show discernably small increases in weight loss and pitting over the eight year data taken from the later study. Further, the earlier NBS study demonstrates that corrosion damage in metals proceeds at a decreasing rate as exposure time increases.

The data available from NBS and an application of metallurgical principles of stainless steels virtually guarantees structrual integrity for the lifetime of a HIC manufactured from an appropriate grade of stainles steel. However, from the standpoint of containment integrity, the data also shows that, regardless of the grade of stainless steel involved, penetration of the container wall is possible. Corrosion of stainless steel in soils, when it occurs, is in the form of "pitting" and not in the form of "uniform attack". In other words, although total corrosion may be very minor, what does occur will tend to concentrate at isolated locations in the form of pits. Depending upon the wall thickness, pitting eventually results in perforation. Such an event is possible, given wall thicknesses dictated by structural and economic requirements. Such an event extends to even the expensive specialty grades of stainless steels.

TABLE I
COMPARISON OF NBS TEST SOILS (REF. 16) WITH SOILS AT BURIAL SITES

NO.	TYPE	LOCATION	DRAINAGE	pH	Ca	Mg.	CHLORIDES	SULPHATES
	Barnwell Backfill Sand	Barnwell, SC	--	5.6	--	200ppm	5.2ppm	135ppm
A	Sagemoor Sandy Loam	Toppenish, WA	good	8.8	108ppm	23	330	216
B	Hagerstown Loam	Loch Raven, MD	good	5.3	--	--	--	--
C	Clay	Cape May, NJ	poor	4.3	540	754	3529	6768
D	Lakewood Sand	Wildwood, NJ	good	5.7	--	--	--	--
E	Coastal Sand	Wildwood, NJ	poor	7.1	302	329	5765	1133
G	Tidal Marsh	Patuxent, NJ	poor	6.0	140	165	3259	1709
	Richland Backfill Sand	Richland, WA	--	7.8	--	--	1 max	4 max

Structural integrity of a metal HIC is a relatively easy achievement. There are a number of choices of stainless steels, including relatively common and inexpensive grades which can be used to accomplish this task. Containment integrity, however, is another matter. Regardless of the stainless steel employed, a review of available data (or lack thereof) demonstrates that perforation of containers is expected. For an all metal HIC, structural integrity upon burial is a certainty. Loss of containment integrity due to corrosion is possible and is, therefore, a problem to be addressed.

Consideration of Hydrogen Related Damage

Slow general or localized corrosion of metals as well as the general breakdown of ion exchange resins due to irradiation are mechanisms accompanied by available hydrogen at exposed metal surfaces along the inside of an all metal HIC. For many metals, including many stainless steels, this situation is accompanied by diffusion of hydrogen into the metal and a potential for hydrogen embrittlement. The result could be premature failure [18].

The conclusion drawn from this investigation is that there is a basis to expect, given the environment within a container, a reasonable probability of hydrogen damage over a 300 year life in a stainless steel container fabricated as a welded structure. This expected problem of hydrogen damage is further reason to question the use of an all metal container.

DISCUSSION

An investigation of suitable thermoplastic materials has resulted in a conclusion that unreinforced plastics are unable to withstand soil pressures which develop upon burial. On the other hand, polyethylene offers the necessary corrosion and radiation resistance to conditions which are foreseeable in the waste material placed in a HIC. In other words, polyethylene is able to satisfy the requirement of containment integrity, but is not expected to economically provide structural integrity.

Investigation of suitable metals has resulted in a conclusion that metal HICs can be designed which provides the required structural integrity with a comfortable factor of safety. Modest wall thicknesses and conventional fabrication technology would be involved. To offer resistance to anticipated corrosive environments, metal HICs would be expected to be fabricated from stainless steels. However, analysis has also shown that a stainless steel HIC would not be expected to offer containment integrity in the long-term burial environment. Identified problems are corrosion and hydrogren embrittlement. Corrosive attack is most foreseeable at exposed metal surfaces along the inside of the container. Isolated perforation of the container due to corrosion from the surrounding soil environment is also a possibility. In other words, an all metal HIC can be designed to satisfy the requirement of structual integrity, but is not expected to provide the containment integrity required.

Based on the study conducted, it has been concluded that neither polyethylene nor stainless steel alone would be suitable for use as HIC materials. However, the potential exists for the use of these materials together to take advantage of the better properties of both. This alternative is currently under investigation.

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5. Nuclear Packaging Inc. (Nu Pac)

Nuclear Packaging Inc. (Nu Pac) submitted its initial topical report on a stainless steel 50 ft^3 HIC in March of 1984. Interim approval for the use of this unit, FL50, was granted within seven months by the state of Washington. South Carolina issued a formal certificate of compliance a year later in October of 1984. The initial approval of the FL50 was made by the NRC staff in October of 1985 and the final approved Topical Report was accepted by NRC in June, 1987. An application for approval for generic class of similar HICs over a range of sizes is still pending in the NRC. Interim approval of some of these units is being granted by the State of Washington on a calendar quarter by quarter basis. While certain questions were raised during the review process, the certification of this design by the states proceeded quite rapidly.

But due to its high cost, relative to the PE HICs, the use of the metallic HIC cannot be justified at Barnwell where the burial depth is only 25 feet and PE HICs are accepted by South Carolina. Thus use of these units is limited to the Hanford and Beattie sites where the burial depth, 55 feet, requires the additional strength of the Nu Pac metallic HICs.

The Nu Pac basic design is an all-metal right cylinder. Five basic sizes are available. These sizes are comparable to those provided by other vendors and are limited by the internal dimensions of the available transport casks.

Table 5-1 -- Nu Pac HIC Dimensions

Model	Outer Diameter (in.)	Overall Height (in.)	Outer Volume (ft^3)
210	75.25	78.50	200
190	73.50	71.63	170
140	64.00	71.25	134
142	64.00	70.00	128
50	46.50	50.70	50

The material of construction is Ferralium Alloy 255, a proprietary alloy developed in England and marketed by Cabot Corporation. This alloy is classed as a duplex stainless steel. It is highly resistant to general corrosion, but does not have the sensitivity to chloride induced stress corrosion cracking of the 300 series stainless steels. A commercial brochure describing the material is provided as Attachment 5-1.

As noted above the basic shape of the HICs is a right cylinder. The larger size units are internally stiffened by braces either from top to bottom or by circumferential rings welded to the walls. The top and bottom surfaces are strengthened by external braces. Closure is provided by either a full diameter lid or a 24" diameter access lid. Sealing is accomplished by the use of flat gaskets and bolts or a series of tapered wedges. Lifting lugs are welded to the side or top of the units.

Among the advantages that the Nu Pac HICs demonstrate are structural strength, corrosion resistance and a high ratio of waste volume to total container volume. While simple in its basic design it appears that significant variations in design are not readily available. This appears to be due to the limited range of structural shapes in which the Ferralium 255 alloy is available and the lead time required in obtaining this special alloy. As noted above the principal factor limiting the use of this line of HIC appears to be its cost relative to other HICs, particularly those fabricated from polyethylene. Thus, this HIC is only used at the Richland, WA or Beatty, NV disposal facilities.

ATTACHMENT 5-1

CABOT HIGH TECHNOLOGY MATERIALS DIVISION

FERRALIUM® ALLOY 255

A high strength, super stainless steel with outstanding corrosion resistance

Contents

Properties Data

The properties listed in this booklet are average values based on laboratory tests conducted by the manufacturer. They are indicative only of the results obtained in such tests and should not be considered as [illegible] minimums. Materials must be tested under actual service conditions to determine their suitability for a particular purpose. All data represent the average of four or less tests unless otherwise noted. The secondary units (metric) used in this booklet are those of the SI system.

PRINCIPAL FEATURES

[redacted]

Outstanding Corrosion Resistance

The corrosion resistance of FERRALIUM alloy 255, under most conditions of service, is superior to that of the fully austenitic type 304, 316 and 317L stainless steels. [redacted]

Alloy 255 is highly resistant to acetic, formic and other organic acids and compounds. [redacted]

Like the austenitic stainless steels, FERRALIUM alloy 255 is not generally suitable for handling hydrochloric acid and other severely reducing acids and chemicals.

Resists Chloride Stress-Corrosion Cracking

Alloy 255 has improved resistance to stress-corrosion cracking, crevice corrosion and pitting when compared to austenitic stainless steels such as types 304, 316, 317L and even the 20Cr-25Ni grades. [redacted]

Heat-Treatment

Optimum properties are achieved by a simple heat-treatment which does not involve martensitic transformation. FERRALIUM alloy 255 is solution heat-treated at 1900°F (1038°C) and rapid cooled.

Availability

FERRALIUM alloy 255 is available from High Technology Materials Division in the form of plate, sheet, strip, billet, bar, wire, covered electrodes, tubing and pipe.

Physical Metallurgy

FERRALIUM alloy 255 is a duplex alloy with approximately [redacted] sile properties of alloy 255 are nearly isotropic while the impact properties show significant directionality.

The microstructure of alloy 255 in the annealed condition is shown in Figure 1. The alloy forms a variety of secondary phases such as chromium-rich $M_{23}C_6$ carbides, M_2N nitrides and sigma phase when aged in the 1000-1800°F (538-982°C) temperature range. Aging in this range should be avoided.

Although the precipitation of sigma phase does not have a significant effect on the corrosion resistance of alloy 255 in oxidizing environments (represented by nitric acid and ferric sulfate tests), the ductility and impact strength of the alloy are drastically reduced.

Another phase which is detrimental to the impact properties of alloy 255 is the chromium-rich alpha prime phase which forms around 885°F (474°C). The maximum continuous operating temperature for FERRALIUM alloy 255 in the ASME Boiler and Pressure Vessel Code Case is 500°F (260°C).

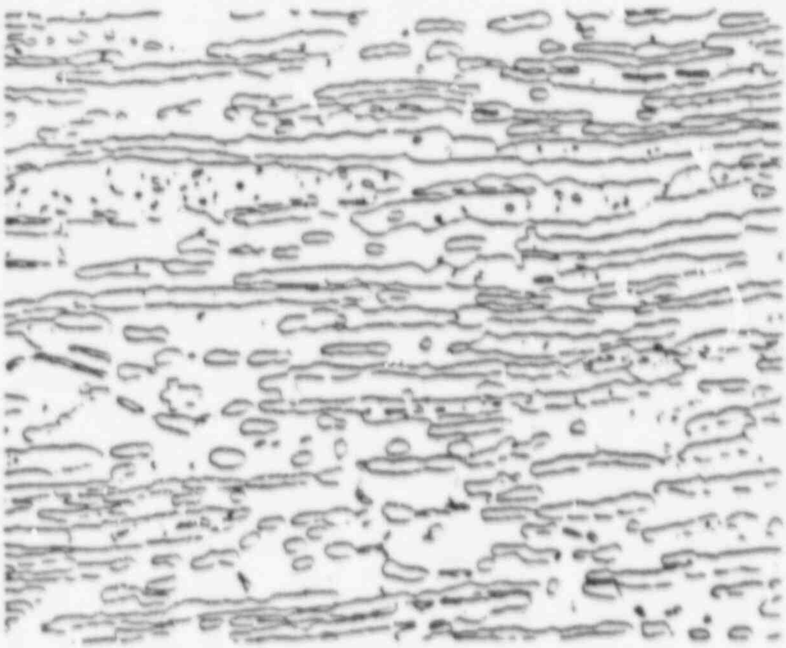


Figure 1—Annealed microstructure of alloy 255 at 500X.

Applications

Because of its resistance to chloride pitting and stress-corrosion cracking, FERRALIUM alloy 255 is finding wide use in place of austenitic stainless steels for handling solutions with chlorides present such as in marine scrubbers. As a result of its wear, erosion and corrosion resistance, alloy 255 is particularly suitable for pumps, agitators and other critical components handling hot corrosive slurries.

Special mention should be made of its performance in the production of fertilizer grade phosphoric acid by the "wet" process where the alloy finds extensive application.

Some of the areas of present or potential use for FERRALIUM alloy 255 products follow:

Chemical Process Industry

- Equipment Handling Fatty Acids, Terephthalic Acid and Polythеonic Acid
- Nitric Acid-Hydrofluoric Acid Solutions—125 deg. F (52 deg. C) max.
- Sulfuric Acid Production
- Tank Internals, Rakes, Fasteners in Uranium Extraction

Copper Smelting

- Sulfuric Acid Production
- Leaching Area
- Precipitators
- I. D. Fans
- Wet Scrubbers
- Tuvere Bars

Marine

- Propeller Shafting
- Cutlass B[illegible]
- Seals
- Rudders
- Desal[illegible]ment
- Pump Pa[illegible]
- Feed Wate[illegible]s
- Fasteners for Off-Shore Platform Gauges

Oil and Gas Industry

- Injection Pumps
- Processes for Treating Crude Oil, i.e. Desalting, Desulfurization and Distillation
- Mild Sour Gas Wells

Petrochemical Industry

- Styrene Monomer Wash Acid Equipment
- PVC Film Extrusion Dies
- Solvent Recovery Absorbers
- Low Density Polypropylene Dryer Baffles
- Entrainment Separators
- Handling Hot Organic Acids, i.e. Acetic, Formic, Oxalic Acids With or Without Chlorides Present

Pollution Control

- Centrifuges (Waste Water Clarification)
- Venturi Scrubbers for Sewage Incinerators
- SO_2 Scrubbers
- Roast Gas Scrubbers (Fan and Vessels)
- Fans for Garbage Incinerators
- Sodium Hypochlorite Scrubbers

Pulp and Paper Industry

- Black Liquor Heater Tubes
- Digester Blow Valves
- Rotary Feed Valves
- I. D. Fans
- Brownstock Washers
- Digester Strainer Plates
- Cyclone Target Plates
- Precipitators
- Wet Scrubbers
- Pump Parts
- Recovery Furnace Boiler Tubes
- Bleach Agitator Shafts
- Agitator Assemblies (Bleach Plant Mixer)

Wet Phosphoric Acid Production

- Digester Agitators
- Mixing Tees
- Vortex Breakers
- Centrifuge Parts
- Pump Parts
- Valves
- Piping

Urea Production

- Decomposer Tubes
- Pump Parts
- Valves
- Bolts

Patents and Licenses

FERRALIUM* alloy 255 is covered by U.S. Patent No. 3,567,434 and British Patent No. 1158614 issued to Bonar Langley Alloys, Limited, Slough, Berks. SL3 6EA England. High Technology Materials Division, Cabot Corporation is licensed by Bonar Langley Alloys, Limited to produce and sell wrought FERRALIUM alloy 255 products in North and South America, with the exception of Cuba, and in Australia, India and Japan.

ASME Boiler and Pressure Vessel Code Case

FERRALIUM alloy 255 sheet, strip, plate, bar, pipe and tubing are covered by ASME Code Case No. 1883.

Specifications

FERRALIUM alloy 255 is covered by the following ASTM specifications:

A240-82	Sheet, plate and strip
A479-82	Bar
A789-82	Seamless and Welded Tubing
A790-82	Seamless and Welded Pipe

American Bureau of Shipping

FERRALIUM alloy 255 has been accepted by the American Bureau of Shipping for use as propellers, shafts and in other marine applications.

UNS Number

The UNS number for FERRALIUM alloy 255 is S32550.

CHEMICAL COMPOSITION, PERCENT*

Fe	Cr	Mo	Ni	Si	Mn	C	N	Cu	Others
Bal	24.0-27.0	2.0-4.0	4.5-6.5	1.0**	1.5**	0.04**	0.10-0.25	1.5-2.5	P-0.04** S-0.03**

*The undiluted deposited chemical composition of covered electrodes may vary beyond the limits shown.
**Maximum

AVERAGE PHYSICAL PROPERTIES

Physical Property	Temp., °F	British Units	Temp., °C	Metric Units
Density	Room	0.282 lb/in.³	Room	7.81 g/cm³
Electrical Resistivity	77	33.1 microhm-in.	25	0.84 microhm-m
	212	34.6 microhm-in.	100	0.88 microhm-m
	392	36.6 microhm-in.	200	0.93 microhm-m
	572	38.6 microhm-in.	300	0.98 microhm-m
	752	40.6 microhm-in.	400	1.03 microhm-m
	932	42.5 microhm-in.	500	1.08 microhm-m
	1112	43.7 microhm-in.	600	1.11 microhm-m
Mean Coefficient of Thermal Expansion	68-200	6.1 microinches/in.-°F	20-93	11.0 × 10⁻⁶m/m-K
	68-300	6.3 microinches/in.-°F	20-149	11.3 × 10⁻⁶m/m-K
	68-400	6.5 microinches/in.-°F	20-204	11.7 × 10⁻⁶m/m-K
	68-500	6.6 microinches/in.-°F	20-260	11.9 × 10⁻⁶m/m-K
	68-600	6.7 microinches/in.-°F	20-316	12.1 × 10⁻⁶m/m-K
	68-700	6.8 microinches/in.-°F	20-371	12.2 × 10⁻⁶m/m-K
	68-800	6.9 microinches/in.-°F	20-427	12.4 × 10⁻⁶m/m-K
	68-1000	7.2 microinches/in.-°F	20-538	13.0 × 10⁻⁶m/m-K
Thermal Conductivity	77	94 Btu-in./ft.²-hr.-°F	25	13.5 W/m-K
	212	105 Btu-in./ft.²-hr.-°F	100	15.1 W/m-K
	392	119 Btu-in./ft.²-hr.-°F	200	17.2 W/m-K
	572	123 Btu-in./ft.²-hr.-°F	300	19.1 W/m-K
	752	145 Btu-in./ft.²-hr.-°F	400	20.9 W/m-K
	932	156 Btu-in./ft.²-hr.-°F	500	22.5 W/m-K
Specific Heat	77	0.113 Btu/lb.-°F	25	475 J/kg-K
	212	0.119 Btu/lb.-°F	100	500 J/kg-K
	392	0.127 Btu/lb.-°F	200	532 J/kg-K
	572	0.134 Btu/lb.-°F	300	561 J/kg-K
	752	0.140 Btu/lb.-°F	400	587 J/kg-K
	932	0.155 Btu/lb.-°F	500	647 J/kg-K

AVERAGE DYNAMIC MODULUS OF ELASTICITY*

Form	Condition	Test Temp., °F (°C)	Average Dynamic Modulus of Elasticity, psi × 10⁶ (MPa)
Plate	Solution heat-treated	Room	30.5 (210,000)
		200 (93)	29.9 (206,000)
		400 (204)	28.7 (198,000)
		600 (316)	27.4 (190,000)
		800 (427)	25.9 (179,000)
		1000 (538)	24.0 (165,000)

*Average of three tests at each temperature.

EFFECT OF ORIENTATION ON IMPACT STRENGTH

Condition	Sample Orientation	Average Charpy V-Notch Impact Strength, ft-lb.	J
Solution heat-treated	"Transverse"	169	229
	"Longitudinal"	123	167

The impact properties of alloy 255 show significant directionality. In the table above, the toughness of the specimens with cracks propagating on the same planes is averaged. Thus the toughness values for "Longitudinal" specimens refer to the average of the toughness values for T-L and T-S specimens and "Transverse" toughness values refer to the average of toughness values for the L-T and L-S specimens. (See Figure 2.)

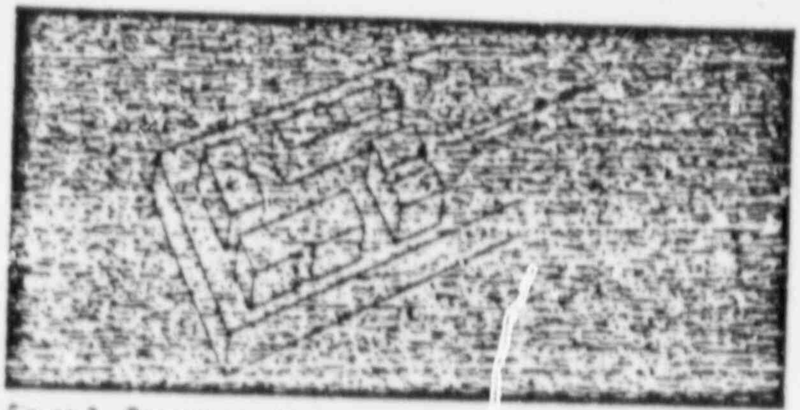


Figure 2—Orientation of specimens for impact strength tests

AVERAGE HARDNESS AND TENSILE DATA, ROOM TEMPERATURE[a]

Form	Ultimate Tensile Strength Ksi (MPa)	Yield Strength at 0.2% offset, Ksi (MPa)	Elongation in 2 in. (50.8mm), percent	Hardness, Rockwell
Sheet, 0.028-0.084 in. (0.71-2.1 mm), thick[b]	129.5 (893)	94.7 (653)	25	C-25
Sheet, 0.095-0.141 in. (2.4-3.6 mm), thick[c]	129.7 (894)	101.5 (700)	22	C-26
Plate, 3/16-3/8 in. (4.8-9.5 mm), thick[d]	131.6 (907)	107.7 (743)	23	C-28
Plate, ½-1¼ in. (12.7-31.8 mm), thick[e]	125.5 (865)	97.7 (674)	30	C-22

[a]Solution heat-treated
[b]Average of 25 tests
[c]Average of 6 tests
[d]Average of 18 tests
[e]Average of 13 tests

EFFECT OF ORIENTATION ON ROOM TEMPERATURE TENSILE PROPERTIES*

Sample Orientation	Ultimate Tensile Strength, Ksi (MPa)	Yield Strength at 0.2% offset, Ksi (MPa)	Elongation, in 2 in. (50.8mm), percent
Long Transverse	124 (855)	105 (724)	27
Short Transverse	125 (862)	102 (703)	27
Rolling Direction	126 (869)	107 (738)	27

*Solution heat treated plate 1 in. (25.4mm) thick.

AVERAGE TENSILE DATA, PLATE*‡

Test Temperature °F	°C	Ultimate Tensile Strength, Ksi (MPa)	Yield Strength at 0.2% offset, Ksi (MPa)	Elongation, in 2 in. (50.8mm), percent
Room	Room	125.5 (865)	97.7 (674)	30
200	93	114.6 (790)	89.3 (616)	30
400	204	109.7 (756)	79.9 (551)	30
600	316	106.0 (731)	76.4 (527)	31

*Solution heat treated plate ½ in. (12.7mm) thick.
‡Average of 10 tests at room temperature and 7 tests at each other temperature.

COMPARATIVE TENSILE DATA AT ROOM TEMPERATURE

Alloy	Ultimate Tensile Strength, Ksi (MPa)	Yield Strength at 0.2% offset, Ksi (MPa)	Elongation in 2 in. (50.8mm), percent
FERRALIUM alloy 255	126 (869)	98 (676)	30
Type 304L Stainless Steel	81 (558)	39 (269)	55
Type 316L Stainless Steel	81 (559)	42 (290)	50
Type 317L Stainless Steel	86 (593)	38 (262)	55

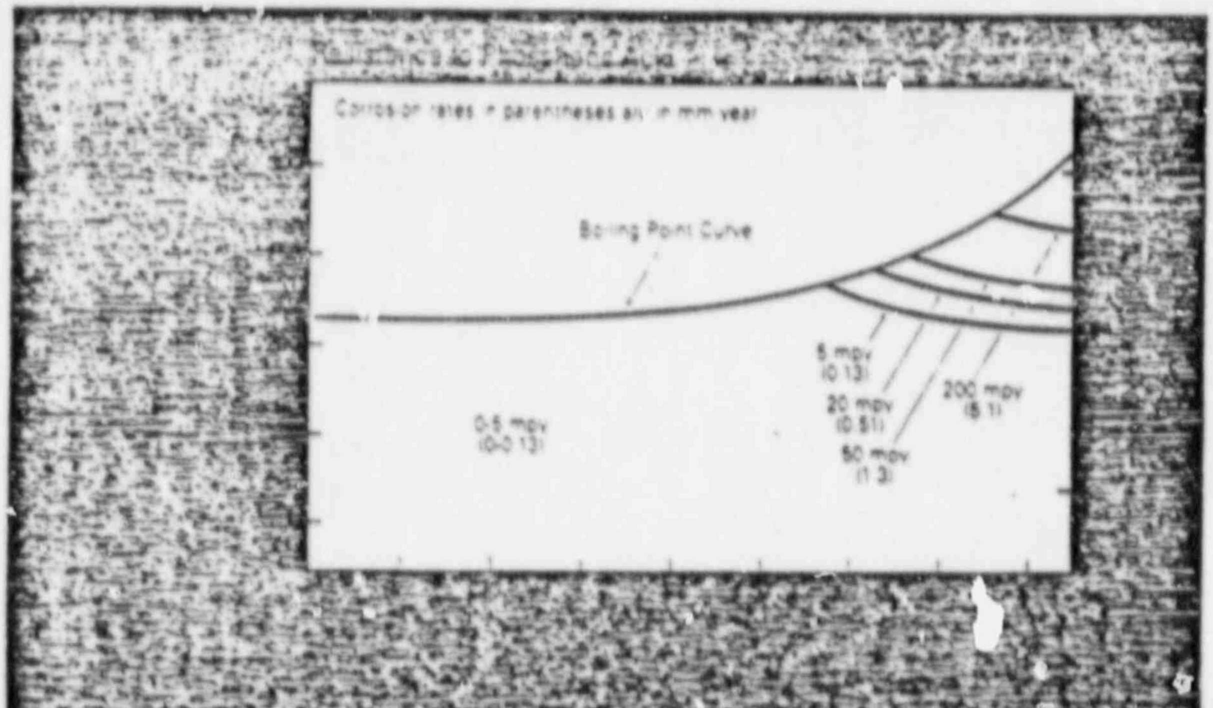
COMPARATIVE AQUEOUS CORROSION DATA

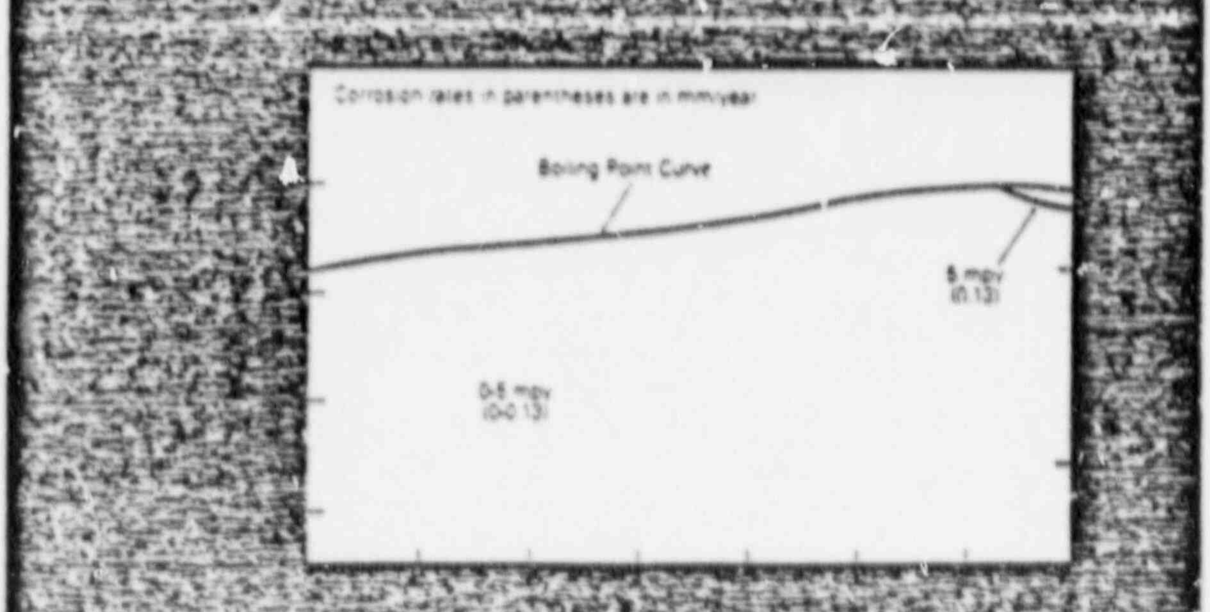
Media	Concentration, percent by weight	Test Temp., °F (°C)	Average Corrosion Rate, mils (mm) per year FERRALIUM alloy 255	Type 317L Stainless Steel
Acetic Acid	10	Boiling	0.2 (<0.01)	0.2 (<0.01)
	50	Boiling	Nil	0.2 (<0.01)
	Glacial	Boiling	0.1 (<0.01)	2.9 (0.07)
Citric Acid	50	Boiling	Nil	0.2 (<0.01)
Formic Acid	20	Boiling	0.4 (0.01)	8.5 (0.22)
	40	Boiling	0.4 (0.01)	17 (0.43)
	60	Boiling	0.1 (<0.01)	22 (0.56)
	88	Boiling	18 (0.46)	9.2 (0.23)
Hydrochloric Acid	1	Room	Nil	Nil
	2.5	Room	Nil	11 (0.28)
Nitric Acid	10	Boiling	19 (0.48)	—
	65	Boiling	8.0 (0.20)	—
Phosphoric Acid	10	150 (66)	Nil	Nil
	10	Boiling	Nil	Nil
	30	150 (66)	0.1 (<0.01)	Nil
	30	Boiling	0.2 (<0.01)	6.7 (0.17)
	55	150 (66)	Nil	0.1 (<0.01)
	55	Boiling	0.1 (<0.01)	1.2 (0.03)
	85	150 (66)	0.1 (<0.01)	0.2 (<0.01)
Sodium Chloride	3	Boiling	0.4 (0.01)	—
Sodium Chloride plus 200 ppm Cu	3	Room	0.4 (0.01)	—
Sodium Chloride plus 0.5% Acetic Acid	0.8	Boiling	0.2 (<0.01)	0.3 (<0.01)
Sodium Chloride plus 0.5% Citric Acid	0.8	Boiling	1.2 (0.03)	31 (0.79)
Sodium Chloride plus 0.5% Oxalic Acid	0.8	Boiling	0.5 (<0.02)	22 (0.56)
Sodium Chloride plus 0.5 % Ammonium Chloride	0.8	Boiling	Nil	Nil
Sodium Chloride plus 0.5% Phosphoric Acid	0.8	Boiling	Nil	0.1 (<0.01)
Sodium Chloride plus 0.1 N Sulfuric Acid	5	Boiling	1.0 (<0.03)	148 (3.8)
Sodium Hydroxide	50	Boiling	1.8 (0.05)	29 (0.74)
Sulfuric Acid	5	150 (66)	Nil	Nil
	5	Boiling	12 (0.30)	200 (5.1)
	10	150 (66)	Nil	8.9 (0.23)
	10	Boiling	40 (1.0)	490 (12)
	20	150 (66)	Nil	50 (1.3)

—not tested

ISOCORROSION DIAGRAMS*

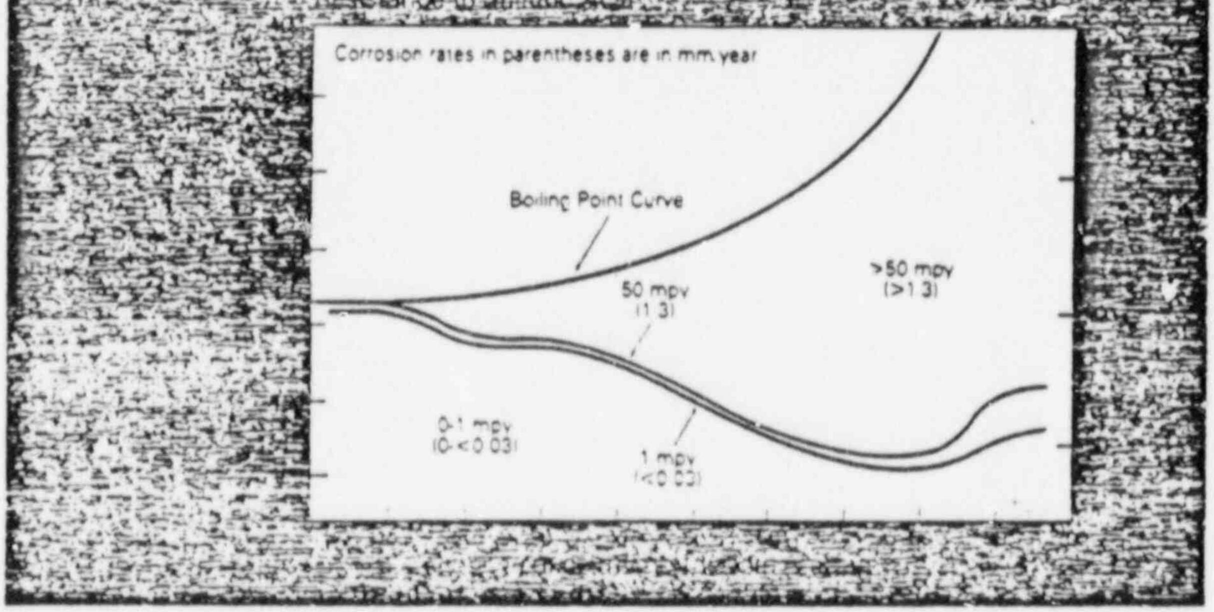
The isocorrosion diagrams shown on this and subsequent pages were plotted using data obtained in laboratory tests in reagent grade acids. These data should be used only as a guide. It is recommended that samples be tested under actual plant conditions.





*All test specimens were solution heat treated and in the unwelded condition.

Resistance to Sulfuric Acid



PHOSPHORIC ACID FIELD DATA

Location	Media	Average Corrosion Rate, mils (mm) per year
Seal Tank	0.2% to 1.0% H_3PO_4 with some fluoride ions at 85°F (29°C)	2.1 (<0.06)
Storage tank (at top)	30% H_3PO_4 with fluoride ions at 90°F (32°C)	1.0 (<0.03)
Holding tank for aging (at top)	3% H_2SO_4 and 30% H_3PO_4 with some fluoride ions at 150°F (66°C)	1.7 (<0.05)
Digester	3% H_2SO_4 and 30% H_3PO_4 with some fluoride ions at 160°F (71°C)	6.1 (0.16)

EFFECT OF CHLORIDE IONS ON AVERAGE CORROSION RATE IN 28% P_2O_5 AT 185°F (85°C)*

Alloy	Average Corrosion Rate, mils (mm) per year	
	No chloride ions	2000 ppm chloride ions
FERRALIUM alloy 255	0.5-0.8 (<0.02-0.02)	0.5-0.7 (<0.02-<0.02)
Type 316 Stainless Steel	3.0-4.4 (<0.08-<0.1[illegible])	110-151 (3.0-3.8)

*Agitated 96-hr test

CORROSION DATA IN SEAWATER

Media	Test Temp. °F	°C	Average Corrosion Rate, mils (mm) per year
ASTM Synthetic Seawater*	68	20	Nil
	95	35	Nil
	122	50	0.1 (<0.01)
	140	65	0.1 (<0.01)
	176	80	Nil
	194	90	Nil
ASTM Synthetic Seawater Saturated with Chlorine Gas*	68	20	2 (0.05)
	95	35	0.8 (0.02)
	149	65	7 (0.18)**
ASTM Synthetic Seawater Saturated with SO_2 Gas	150	66	Nil

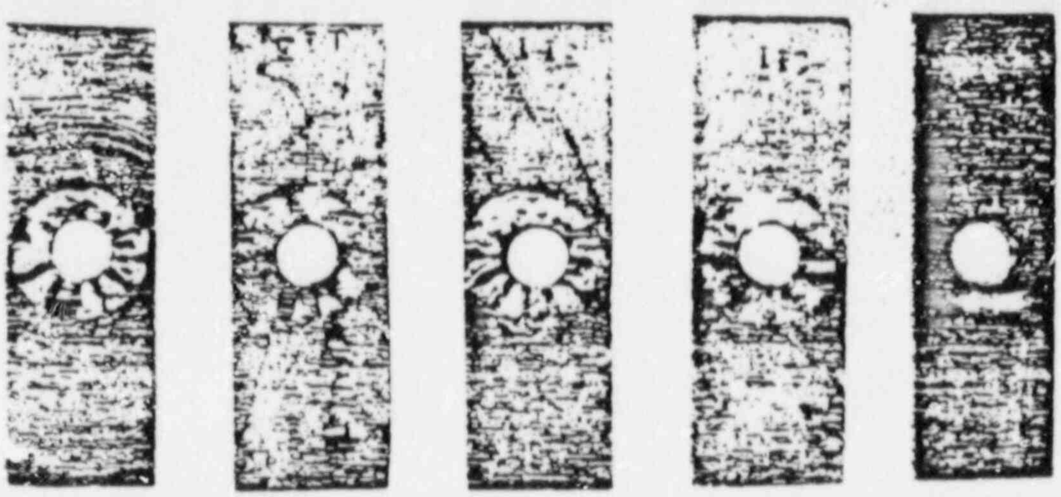
*Average of duplicate smooth specimens 96-hr exposure
**Initiation of pits

CREVICE CORROSION DATA IN NATURAL SEAWATER

Alloy	Test Duration, Days	Test Temp., °F	°C	Percent Crevices Initiated*	Maximum Depth of Attack, mm
FERRALIUM alloy 255	29	57	14	0	<0.01
Type 316 Stainless Steel	29	57	14	81	1.2
FERRALIUM alloy 255	30	86	30	1.6	<0.08
Type 316 Stainless Steel	30	86	[illegible]	28	1.9
Type 317 Stainless Steel	30	86	30	76	1.9
Type 317LM Stainless Steel	30	86	[illegible]	97	1.1
20 Cb-3** Alloy	30	86	30	41	3.1
FERRALIUM alloy 255	30	126	52	0.8	<0.01
Type 316 Stainless Steel	30	126	52	28	0.10

* Number of Crevices Initiated / Number of Crevices Possible (12)
**Trademark of Carpenter Technology Corporation

CREVICE-CORROSION IN 10% FERRIC CHLORIDE AT ROOM TEMPERATURE*



20 Cb-3 ALLOY | TYPE 317L STAINLESS STEEL | TYPE 316 STAINLESS STEEL | TYPE 304 STAINLESS STEEL | FERRALIUM ALLOY 255

*All samples were immersed in 10 percent ferric chloride for 240 hours in a bolted crevice-corrosion block (similar to ASTM G 48-76) at 77°F (25°C).

CREVICE-CORROSION DATA IN 10% FERRIC CHLORIDE AT ROOM TEMPERATURE FOR 10 DAYS

Alloy	Number of Attacked Crevices*	Maximum Depth of Penetration, mils	mm
FERRALIUM alloy 255	0	0	0
Type 317LM Stainless Steel	20	12	0.30
Alloy No. 904L	23	19	0.48
Type 317L Stainless Steel	16	77	2.0
20 Cb-3 alloy	24	76	1.9
Type 316 Stainless Steel	24	76	1.9 (Perforated)

*Maximum possible number of crevices was 24

CREVICE-CORROSION TESTS IN SIMULATED SO_2 SCRUBBER ENVIRONMENT*

Alloy	Corrosion Rate per year mils	mm	Number of Attacked Crevices**	Maximum Depth of Crevice Attack, mils	mm
FERRALIUM alloy 255	0.4	0.01	0	0	0
Alloy No. 904L	57	1.4	24	6	0.15
Type 317LM Stainless Steel	179	4.5	24	10	0.25
Alloy No. 825	216	5.5	24	10	0.25

*45,000 ppm Cl⁻***, 150°F (66°C), pH 2, SO_2:O_2 (1:1) bubbled through solution
**Maximum possible number of crevices was 24
***0.003% $FeCl_3$, 0.11% KCl, 0.5% $MgCl_2$, 1.1% $CaCl_2$, 5.6% NaCl, 0.02% CaF_2 and 200g/l $CaSO_4 \cdot 2H_2O$

COMPARATIVE LOCALIZED CORROSION TEMPERATURE DATA IN OXIDIZING NaCl-HCl SOLUTION*

Alloy	Pitting Temperature, °C	°F	Crevice-Corrosion Temperature, °C	°F
FERRALIUM alloy 255	50	122	35	95
Alloy No. 904L	45	113	20	68
Type 317LM Stainless Steel	35	95	15	59
Type 317L Stainless Steel	25	77	10	54
CABOT alloy No. 825	25	77	≤ −5	≤23
20 Cb-3 alloy	20	68	≤ −5	≤23
Type 316 Stainless Steel	20	68	≤ −5	≤23

*4% NaCl + 0.01M HCl + 0.1% $Fe_2(SO_4)_3$

COMPARATIVE STRESS-CORROSION CRACKING DATA

Media	Test Temp., °F	°C	Time to Failure, hrs: FERRALIUM alloy 255	Type 316L Stainless Steel	Type 317L Stainless Steel
50% NaOH Saturated with NaCl	290	143	NC	NC	NC
70% NaOH Saturated with NaCl	350	177	NC	200.648	1031.1031

NC-No failure in 1000 hours. All tests were run on duplicate specimens.

COMPARATIVE STRESS-CORROSION CRACKING DATA

Media	Test Temp., °F	°C	Type 316 Stainless Steel	FERRALIUM alloy 255
ASTM Synthetic Seawater	176	80	NC[a]	NC
0.8% NaCl + 0.5% Oxalic Acid*	286	141	NC	NC
0.8% NaCl + 0.5% Acetic Acid*	286	141	C	NC
0.8% NaCl + 0.5% Citric Acid*	286	141	C	NC
Modified Wick Test*[b]	212	100	C	NC
25% NaCl***	393	200	—	NC
30% NaCl**	Boiling		—	NC
0.8% NaCl + CO_2*	286	141	—	NC
4% NaCl + 1% H_3PO_4*	Boiling		—	NC
0.8% NaCl + 0.2% H_3PO_4*	286	141	C	C
45% Magnesium Chloride	Boiling		C	C

*U-bend specimen, 30-day exposure
**U-bend specimen, 100-day exposure
***U-bend specimen, 504-hr. exposure
NC-No Cracks
C-Cracked
—Not tested
[a]Localized attack
[b]1000 ppm Cl⁻ (as NaCl) and 500 ppm $FeCl_3$

COMPARATIVE STRESS-CORROSION CRACKING DATA*

Alloy	Test Temp., °F / °C	Calcium Chloride** 250 / 121	300 / 149	350 / 177	400 / 204	Sodium Chloride** 250 / 121	300 / 149	350 / 177	400 / 204
FERRALIUM alloy 255		NC	NC	NC	C	NC	NC	NC	C
Alloy No. 904L		NC	NC	C	C	NC	NC	C	C
20Cb-3 alloy		NC	NC	NC	C	NC	NC	C	C

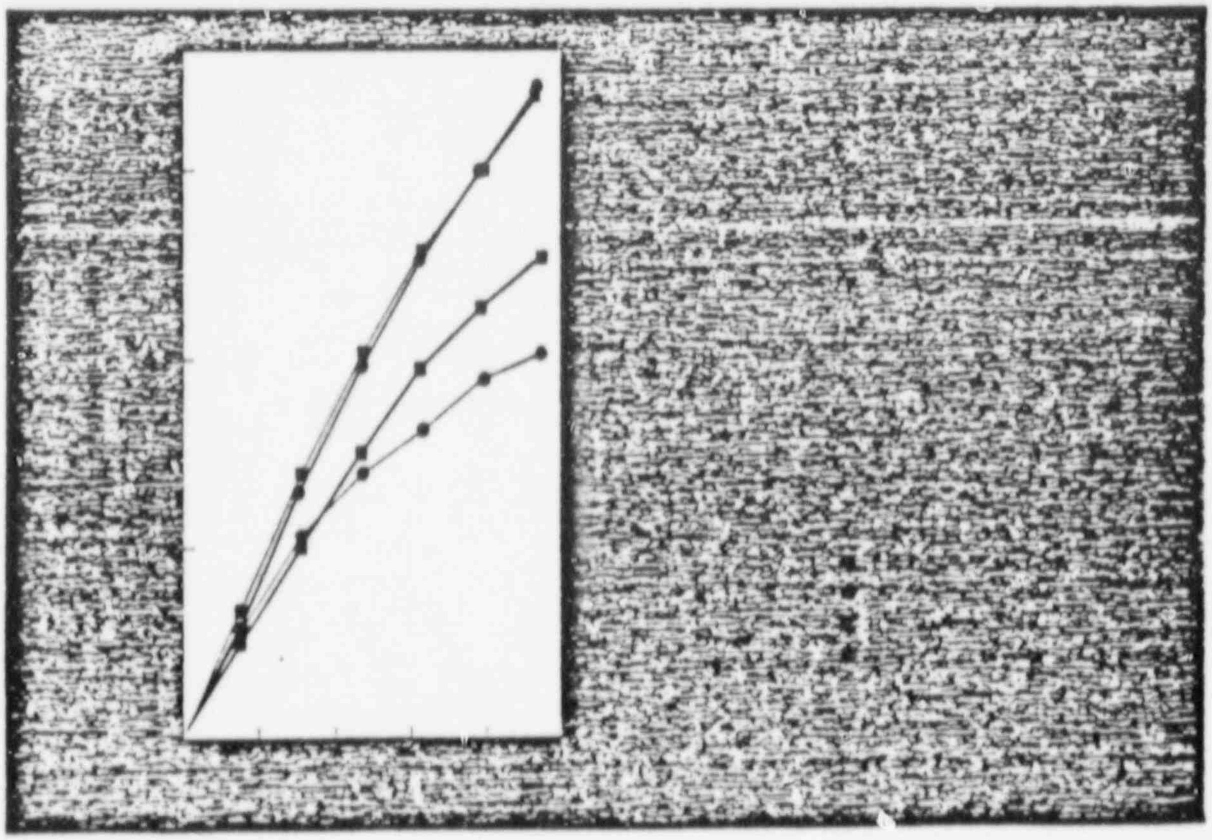
*1-week exposure. C-shaped specimens, like alloy holder.
**Compositions were selected to provide the same chloride content as a 25% NaCl solution.
NC-No cracks
C-Cracked

COMPARATIVE RESISTANCE TO ABRASIVE WEAR*

Alloy	Orientation	Volume Loss, mm³**
FERRALIUM alloy 255	Transverse	97.5
FERRALIUM alloy 255	Longitudinal	101.9
22% Cr-Duplex Stainless Steel	Transverse	110.9
317L Stainless Steel	—	123.3
316L Stainless Steel	—	127.0

*Dry sand rubber wheel abrasion test. Tested in accordance with ASTM G 65-80
**Average of 2 measurements

COMPARATIVE RESISTANCE TO CAVITATION EROSION



WELDING AND MACHINING

Gas Tungsten Arc Welding (GTAW)

FERRALIUM alloy 255 is readily weldable by the GTAW process using standard procedures for stainless and high alloy materials. Shielding and backing gas is normally 100% argon. Helium can be added to the shielding gas to increase heat input and travel speed in automatic welding. Thoriated tungsten electrodes with D.C., straight polarity are used. A gas diffuser screen is recommended.

Gas cup size should be as large as practical, [illegible] in (12.7mm) minimum (No. 8), if possible. Flow rates with argon should be 15-25 cfh (7.1-11.8 l/min.) for manual welding. High frequency arc starting and current decay equipment will minimize tungsten inclusions and crater cracking problems. Each pass should be throughly cleaned with a stainless steel wire brush.

Gas Metal Arc Welding (GMAW)

Both short arc and spray arc welding have been used for FERRALIUM alloy 255. One hundred percent argon is used for spray transfer, while argon-helium mixtures are used for the short arc mode. A large gas cup is desirable with flow rates around 45 to 55 cfh (21.2-26 l/min.). Interpass cleaning with a stainless steel wire brush, is recommended.

Shielded Metal Arc Welding (SMAW)

FERRALIUM alloy 255 coated electrodes are provided with a slightly higher nickel content to improve the weld metal microstructure and more closely match the structure of the base metal. An interpass temperature of around 200°F (93°C) is desirable. The opened electrodes should be stored at about 300°F (149°C) to prevent excessive moisture pickup.

Slag should be removed from each pass by grinding and stainless steel wire brushing.

Welding Dissimilar Alloys

FERRALIUM alloy 255 welding products are used for joining this material to itself and a variety of dissimilar combinations. Both stainless and carbon steel dissimilar joints have been welded successfully with FERRALIUM alloy 255. Higher alloys, such as HASTELLOY alloys C-276 and G-3, are joined with the high alloy welding product. Type 316 stainless steel filler metal has been used successfully to join FERRALIUM alloy 255 to Type 316 stainless steel.

Machining

FERRALIUM alloy 255 can be readily machined using conventional techniques. Although considerably harder than the austenitic stainless steels, the same practices can generally be employed. High speed tools are normally found to be satisfactory but machining speeds can often be substantially increased by the use of carbide-tipped tools.

For more detailed information on the fabrication of FERRALIUM alloy 225 and other CABOT Corrosion-Resistant alloys, ask for bulletin H-2010.

AVERAGE TRANSVERSE TENSILE DATA, WELDED PLATE

Test Temp., °F (°C)	Welding Process	Ultimate Tensile Strength, Ksi (MPa)	Yield Strength at 0.2% Offset, Ksi (MPa)	Elongation in 2 in. (50.8mm), percent	Reduction of Area, percent
Room	GTAW	124.6 (859)	103.0 (710)	20	53
	GMAW	125.0 (862)	104.0 (717)	25	58
	SMAW	126.9 (875)	108.8 (750)	21	54
400 (204)	GTAW	105.4 (727)	78.9 (544)	18	47
800 (427)	GTAW	101.7 (701)	69.1 (476)	17	40

AVERAGE TENSILE DATA, ALL WELD METAL

Test Temp., °F (°C)	Welding Process	Ultimate Tensile Strength, Ksi (MPa)	Yield Strength at 0.2% Offset, Ksi (MPa)	Elongation in 2 in. (50.8mm), percent	Reduction of Area, percent
Room	SMAW	137.5 (920)	114.6 (767)	22	39
	GMAW	134.9 (902)	116.5 (779)	24	47
	GTAW	133.2 (891)	109.9 (758)	22	51
400 (204)	GTAW	109.2 (753)	85.6 (590)	21	44
	SMAW	117.5 (786)	94.4 (631)	20	41
800 (427)	GTAW	103.7 (715)	71.8 (495)	23	—

EFFECT OF LONG-TIME EXPOSURE ON TENSILE DATA, ALL WELD METAL

Welding Process	Exposure Temperature °F	°C	Time hrs.	Ultimate Tensile Strength, Ksi, (MPa)	Yield Strength at 0.2% offset, Ksi (MPa)	Elongation, in 2 in. (50.8mm), percent	Reduction of Area percent
GTAW*			None	133.2 (918)	109.9 (758)	22	51
	500	260	4000	134.0 (924)	114.9 (792)	21	49
	600	316	4000	177.4 (1223)	160.6 (1107)	4.4	2.4
	700	371	4000	188.3 (1298)	177.5 (1224)	0.5	1.6
	800	427	4000	189.4 (1306)	151.6 (1045)	3	2

*Welded in flat position

TYPICAL TRANSVERSE BEND TEST DATA, WELDED PLATE*

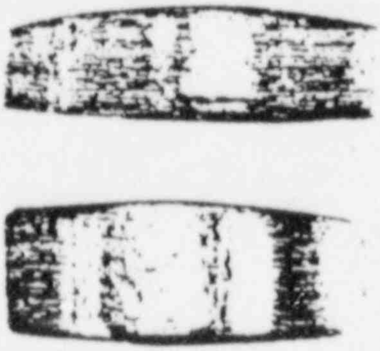
Welding Process	Type of Bend	Bend Radius	Results**
GTAW	Face	1½ T	Passed
GTAW	Root	1½ T	Passed
GMAW	Side	2T	Passed
SMAW	Face	1½ T	Passed
SMAW	Root	1½ T	Passed

*See Figure 3 for photographs of two bend-test specimens
**ASME Boiler and Pressure Vessel Code, Section IX, used as a guide

TYPICAL LONGITUDINAL BEND TEST DATA, DISSIMILAR ALLOYS

Base Material	Process	Filler Metal	Bend Ductility: Type of Bend	Bend Radius	Results
FERRALIUM alloy 255/ Type 316 stainless steel	SMAW	FERRALIUM alloy 255	Face	2T, 1½T	Pass
			Root	2T, 1½T	Pass
FERRALIUM alloy 255/ A-36 carbon steel	SMAW	FERRALIUM alloy 255	Face	2T, 1½T	Pass
			Root	2T, 1½T	Pass

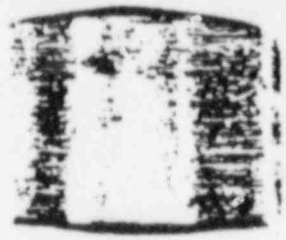
See Figure 4 for photograph of longitudinal bend test specimen



GMAW—Spray
2T Radius
Transverse—
Side Bend

GTAW
1½T Radius
Transverse—
Face Bend

Figure 3—Bend test specimens of FERRALIUM alloy 255.



SMAW
1½T Radius
Longitudinal—Face Bend

Figure 4—Bend test specimen of FERRALIUM alloy 255 A-36 Carbon Steel.

AVERAGE IMPACT STRENGTH, NOTCH IN WELD METAL*

Welding Process	Test Temperature, °F	°C	Average Charpy V-Notch Impact Strength, ft. lb.	J
SMAW	−80	−62	4	5
	−40	−40	8	11
	−20	−29	13	18
	0	−18	14	19
	32	0	18	24
	70	21	26	35
	140	60	32	43
	212	100	41	56
GTAW	−80	−62	5	7
	−40	−40	12	16
	−20	−29	13	18
	0	−18	20	27
	32	0	25	34
	70	21	59	80
GMAW**	70	21	25	34
GMAW***	70	21	26	35

*Welded in flat position **Short-arc mode ***Spray mode

EFFECT OF LONG TIME EXPOSURE ON AVERAGE IMPACT STRENGTH, NOTCH IN WELD METAL*

Welding Process	Exposure: Temperature °F	°C	Time, hrs.	Average Charpy V-Notch Impact Strength, ft. lb.	J
GTAW	As welded			59	80
	400	204	1000	54	73
	400	204	4000	48	65
	500	260	1000	42	57
	500	260	4000	22	30
	600	316	1000	2.5	3.4
	600	316	4000	2	2.7
	800	427	1000	1	1.4
	800	427	4000	0.7	0.9
SMAW	As welded			26	35
	400	204	1000	26	35
	500	260	1000	20	27
	600	316	1000	1.7	2.3

*Welded in flat position

AVERAGE AQUEOUS CORROSION RESISTANCE OF WELDMENTS*

Media	Test Temp., °F (°C)	Average Corrosion Rate Per Year, mils (mm): Base Metal	½ in. (12.7mm) Plate, SMAW	⅛ in. (3.2mm) Plate, GTAW	½ in. (12.7mm) Plate, GTAW
75% Acetic Acid	Boiling	0.1 (<0.01)	Nil	0.2 (<0.01)	0.2 (<0.01)
2.5% Hydrochloric Acid	Room	0.1 (<0.01)	Nil	1.7 (<0.05)	Nil
10% Ferric Chloride	86°F (30°C)	0.2 (<0.01)	0.6 (<0.02)	0.7 (<0.02)	—
6% Ferric Chloride (With Crevice)	Room	Nil	Nil	Nil	Nil
65% Nitric Acid	Boiling	4.7 (0.12)	8.3 (0.21)	7.6 (0.19)	11 (0.28)
10% Nitric Acid + 3% Hydrofluoric Acid	Room	2.3 (0.06)	—	6.8 (0.17)	—
55% Phosphoric Acid	Boiling	1.4 (0.04)	1.6 (0.04)	4.1 (0.10)	1.3 (<0.04)
10% Sulfuric Acid	Boiling	37 (0.94)	73 (1.9)	49 (1.2)	66 (1.7)
50% Sulfuric Acid + 42 g/l of Ferric Sulfate	Boiling	13 (0.33)	19 (0.48)	18 (0.46)	23 (0.58)

FERRALIUM alloy 255 to itself.

CABOT

High Technology Materials Division
Cabot Corporation
1020 West Park Avenue, Kokomo, Indiana 46901

Condensed Product List

ALLOYS

High-Performance Alloys
- HASTELLOY® alloy B-2
- HASTELLOY® alloy C-[illegible]
- HASTELLOY® alloy C-276
- HASTELLOY® alloy G
- HASTELLOY® alloy G-3
- HASTELLOY® alloy N
- HASTELLOY® alloy [illegible]
- HASTELLOY® alloy W
- HASTELLOY® alloy X
- HAYNES® alloy No. 25
- HAYNES® alloy No. 31
- CABOT® alloy No. R-41
- CABOT® alloy No. 75
- HAYNES® alloy No. 188
- CABOT® alloy No. 263
- HAYNES® alloy No. 556
- CABOT® alloy No. 625
- CABOT® alloy No. 718
- CABOT® alloy No. X-750
- MULTIMET® alloy
- WASPALOY® alloy

Super Stainless Steels
- FERRALIUM® alloy 255
- CABOT alloy No. 904L

Nickel Alloys
- CABOT alloy No. 200
- CABOT alloy No. 201
- CABOT alloy No. 400
- CABOT alloy No. 600
- CABOT alloy No. 800
- CABOT alloy No. 800H
- CABOT alloy No. 825

Titanium and Titanium Alloys
- CABOT Ti-25
- CABOT Ti-40
- CABOT Ti-55
- CABOT Ti-70
- CABOT Ti-3Al-2.5V
- CABOT Ti-6Al-4V

Electrical/Magnetic/Expansion Alloys
- CABOT alloy No. 4-79
- CABOT alloy No. 4-79S
- CABOT alloy No. 22-3
- CABOT alloy No. 29-17
- CABOT alloy No. 36
- CABOT alloy No. 49
- CABOT alloy No. 49L
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- CABOT alloy No. 72
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Tel: 714-978-1775

Elmsford, New York 10523
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6. Chichibu Cement Co., Ltd. (CCC)

The CCC design was the first of what might be called the "composite" designs. [illegible]'s PE lined steel container is the second such design which takes advantage of the structural support of a metallic outer casing during fabrication, handling and burial, which is lined with a chemically inert material that resists internal corrosion.

In the case of CCC this inert material is a steel fiber reinforced polymer impregnated concrete, labelled SFPIC. The initial sizes of this HIC are nominally 200 and 400 liters (55 and 110 gal.) CCC is developing designs for larger size HICs. The HIC has a inner flat lid of SFPIC which fits inside the outer steel shell and is sealed to the liner of SFPIC by an epoxy cement after the waste is loaded. A passive vent of a porous ceramic material is provided in a plug in the SFPIC lid. Closure of the outer steel drum for handling and transportation purposes is accomplished by using a standard drum lid and hoop ring over the inner SFPIC lid.

The effect of the CCC composite design is to permit the outer casing to be included in analyses for the predisposal conditions, such as handling and transportation, while only the inner, SFPIC, liner is considered for the disposal conditions. In this manner the advantages of the individual parts of the system can be applied to the greatest effect.

The key dimensions and capacities of the currently available CCC HICs are given in Table 6-1.

Table 6-1 -- Size and Capacity of CCC HICs

Item	200 li.	400 li.
Inside Diameter, in.	19.8	24.6
Wall thickness, in.		
side	1.1	1.5
lid and bottom	1.5	1.8
Overall height, in.	32.3	40.8
Volume, (ft^3)		
inner	3.1	10.0
outer	8.8	16.8

The Topical Report (TR) for the 200 and 400 liter HICs was submitted to the NRC in June of 1984. It was approved by NRC in June 1986 and the final approved TR was accepted by NRC in July of 1986.