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

JUL 23 1991

Contracting Officer (Code 201)
Naval Supply Center
Puget Sound
Bremerton, WA 98314-5100

Attention: Suzanne Powers-Dexter

This is in response to your telephone inquiry on June 21, 1991 regarding NRC approved high-integrity containers (HICs) for use in the disposal of Class A, B and C (low-level) wastes. The following information is provided for your use.

A listing containing the identification of all topical reports submitted by vendors to the NRC for review under the requirements of 10CFR Part 61, Licensing Requirements for Land Disposal of Radioactive Waste, is enclosed showing the status of each report. The listing is dated July 15, 1991, with the three HIC basic designs that have been approved marked for identification. These are, by NRC docket number, as follows:

1.	WM-45 WM-85	by Nuclear Packaging (part of Pacific Nuclear)	Ferralium HICs of various sizes
2.	WM-81 Rev.2.1	by Chichibu Cement Co.	Concrete/Polymer HIC
3.	WM-93 Rev.1	by LN Technologies (now SEG, a subsidiary of Westinghouse)	Stainless Steel/ Polymer HIC

Also identified are three manufactures of high-density polyethylene (HDPE) HICs (WM-18, WM-76 and WM-80). These containers were disapproved, but are accepted at two of the currently operating low-level waste disposal facilities for Class B and Class C waste (Barnwell, SC and Hanford, WA) based on the use of concrete overpacks, which provide the structural stability that the HDPE container otherwise lacks. The Beatty, NV site accepts HDPE containers only for unstabilized Class A waste. Enclosed is a copy of the Technical Evaluation Report for these three HPDE HICs. Page 39 summarizes the conclusions.

The third enclosure provides more detail on each of the dockets. The question of how long the approval process may take can be estimated based on past experiences. For the approved HIC's (using 4 separate actions) the average time from submittal to approval was approximately 26 months. The last HIC to receive approval, however, required only about half that time for review.

413-7
WM-3
NL14 1/1

This information should assist you. If you have further questions, please contact Robert Shewmaker, (301) 492-0596.

(Original Signed by)

Paul H. Lohaus, Chief
Low-Level Waste Management Branch
Division of Low-Level Waste Management
and Decommissioning

Enclosures: As stated

Distribution: Central File # [redacted] NMSS r/f
RBangart ETen Eyck JAustin JSurmeier
JKennedy MTokar RShewmaker LLWM r/f
PDR YES X PLohaus
PDR NO ___ Category: Proprietary ___ or CF Only ___ ___
ACNW YES X NO ___ ___

SUBJECT ABSTRACT: TOPICAL REPORTS

OFC :LLWM	:LLWM Eaw	:LLWM	:
NAME:RShewmaker/sw	:MTokar for	:PLohaus	:
DATE: 7/19/91	:7/22/91	:7/22/91	:

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TOPICAL REPORT REVIEW STATUS SUMMARY
SOLIDIFIED WASTE FORMS AND HIGH INTEGRITY CONTAINERS (HIC's)

Office of Nuclear Material Safety and Safeguards

July 15, 1991

VENDOR	DOCKET NO	TOPICAL REPORT	DISPOSITION
• Nuclear Packaging	WM-45	HIC (Ferralium/FL-50)	APPROVED
• Chichibu	WM-81 Rev 2.1	HIC (Concrete/Poly)	APPROVED
DOW Chemical	WM-82	Solidification (Polymer)	APPROVED
• Nuclear Packaging	WM-85	HIC (Ferralium/Enviralloy)	APPROVED
General Electric	WM-88	Solidification (Polymer)	APPROVED
WasteChem	WM-90	Solidification (Bitumen)	APPROVED
• LN Technologies	WM-93	HIC (Stainless/Poly)	APPROVED
• LN Technologies	WM-93 Rev 1	HIC (Stainless/Poly)	APPROVED
Chem-Nuclear	WM-97	Solidification (Cement #2)	APPROVED *
Chem-Nuclear	WM-98	Solidification (Cement #3)	APPROVED *
Chem-Nuclear	WM-101	Solidification (Cement #1)	APPROVED *
— Chem-Nuclear	WM-18	HIC (HDPE)	NOT APPROVED
Pacific Nuclear	WM-51	Solid (Envirostone)	NOT APPROVED
— TFC Nuclear	WM-76	HIC (HDPE)	NOT APPROVED
— Westinghouse	WM-80	HIC (HDPE)	NOT APPROVED
VIKEM	WM-13	Solid (Oil/Cement)	DISCONTINUED
U.S. Ecology	WM-91	Solidification (Bitumen)	DISCONTINUED
Stock	WM-92	Solidification (Cement)	DISCONTINUED
U.S. Ecology	WM-100	Solid (NS1 Bitumen)	DISCONTINUED
Chem-Nuclear	WM-19	Solidification (Cement)	WITHDRAWN
Chem-Nuclear	WM-47	HIC (Fiberglass/Poly)	WITHDRAWN
LN Technologies	WM-57	HIC (HDPE)	WITHDRAWN
Nuclear Packaging	WM-71	Solid/Encap (Cement/Gypsum)	WITHDRAWN
Westinghouse	WM-79	Solidification (SG-95)	WITHDRAWN
Nuclear Packaging	WM-87	HIC (Stainless/SDS)	WITHDRAWN
Chem-Nuclear	WM-96	Solidification (Cement)	WITHDRAWN
SEG (LN Tech)	WM-20	Solidification (Cement)	UNDER REVIEW
SEG (W'house)	WM-46	Solidification (Cement)	UNDER REVIEW
Bondico	WM-94	HIC (Fiberglass/Poly)	UNDER REVIEW
Avancer (B&W)	WM-95	HIC (Coated Carbon Steel)	UNDER REVIEW
SEG (LN Tech)	WM-99	Solid (Cement/Decon)	UNDER REVIEW
U.S. Ecology	WM-102	Solidification (Bitumen)	UNDER REVIEW
Pacific Nuclear	WM-103	HIC (Enviroglass)	UNDER REVIEW
JGC Corp.	WM-104	Solidification (Cement)	UNDER REVIEW
Diversified Tech.	WM-105	Solidification (VERI)	UNDER REVIEW

* Interim (1-year) Approval granted for selected waste forms on July 2, 1991.

ENCLOSURE 1

US Nuclear Regulatory Commission
Washington, DC 20555

TECHNICAL EVALUATION REPORT

related to the Topical Reports on
High Integrity Containers made with
High-Density Polyethylene

submitted by:

Chem-Nuclear Systems, Inc.	(WM-18)
TFC Nuclear Associates, Inc.	(WM-76)
Westinghouse Hittman Nuclear, Inc.	(WM-80)

Technical Branch
Division of Low-Level Waste Management and Decommissioning
Office of Nuclear Material Safety and Safeguards
December 1988

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ENCLOSURE 2

ABSTRACT

This Technical Evaluation Report (TER) has been prepared by the Division of Low-Level Waste Management and Decommissioning of the Office of Nuclear Material Safety and Safeguards of the U.S. Nuclear Regulatory Commission for the Topical Reports filed by Chem-Nuclear Systems, Inc., TFC Nuclear, Inc., and Hittman Nuclear covering their high integrity containers manufactured from high-density polyethylene. The containers are proposed for use as a means of containing low-level radioactive wastes and meeting the structural stability requirements for waste in 10 CFR Part 61. The NRC staff concludes that the high integrity containers described in the Topical Reports do not meet the structural stability requirements of Part 61. They are not adequate for disposal of low-level radioactive wastes that require disposal in a structurally stable form as required under Part 61 unless the required structural stability is provided by some other means, such as an engineered structure or overpack. The NRC staff's findings thus do not preclude the use of HDPE as a component (for the purpose of providing corrosion resistance, for example) in systems where structural stability is provided by other means.

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1.0 BACKGROUND

1.1 Regulations

By Federal Register Notice dated December 27, 1982 (47 FR 57466), the United States Nuclear Regulatory Commission (NRC) amended its regulations to provide specific requirements for licensing of facilities for the land disposal of low-level radioactive waste. The majority of these requirements are now contained in Part 61 to Title 10 of the Code of Federal Regulations (10 CFR Part 61) entitled "Licensing Requirements for Land Disposal of Radioactive Waste." (Ref. 1). Modifications have been made to other parts of the Commission's regulations, such as 10 CFR Part 20, "Standard for Protection Against Radiation." These regulations are the culmination of a set of prescribed procedures for low-level radioactive waste disposal that were proposed in the Federal Register on July 24, 1981. The effective date for the implementation of 10 CFR 20.311, which requires waste generators to meet the waste classification and waste form requirements in 10 CFR Part 61, was December 27, 1983.

1.1.1 10 CFR Part 61 - Structural Stability

The waste classification and waste form requirements in 10 CFR Part 61 are set forth in Sections 61.55 and 61.56, respectively. Wastes classified as Class B and C in accordance with Section 61.55 must meet the minimum waste form requirements set forth in Section 61.56(a) and the waste stability requirements set forth in Section 61.56(b). A structurally stable waste form, as defined in

Section 61.56(b)(1), "will generally maintain its physical dimensions and its form, under the expected disposal conditions." This section of the regulation goes on to explain that structural stability can be provided by the waste form itself by processing the waste to a stable form, or by placing the waste in a container or a structure that will provide the stability after disposal.

1.1.2 1983 Technical Position on Waste Form - Design Criteria

In May 1983, the NRC staff published technical positions (TP) on waste classification and waste form that provide guidance to generators and others on acceptable methods for meeting the classification and structural stability requirements of 10 CFR Part 61 (Ref. 2). The waste form TP includes guidance on processing waste into an acceptable stable form, designing acceptable high integrity containers, packaging cartridge filters, and minimizing radiation effects on organic ion-exchange resins. The guidance on designing acceptable high integrity containers (HICs) contains design criteria to be followed for acceptable design of the HIC and discusses properties of materials to be considered in the design of the HIC. The design criteria address the maximum allowable free liquid limits for HICs, the design goal of 300 year structural stability, load limits following burial, transportation requirements, and design of the HIC top, closure, and passive vent system. The properties of the materials that the TP says should be addressed include the corrosive and chemical effects from the waste and the burial environment, material creep, thermal loads, radiation stability, and biodegradation. The TP recommends that prototype testing be performed to demonstrate the performance of the HIC under burial and other conditions.

The TP states that these criteria will be used in the evaluation of a high integrity container to determine if the container is acceptable for compliance with the structural stability requirements of 10 CFR Part 61.

1.2 <u>Topical Report Submittals</u>

1.2.1 Chem-Nuclear Systems, Inc.

Chem-Nuclear Systems, Inc. (CNSI) submitted a Topical Report on December 23, 1983 (Ref. 3) to the NRC for the licensing of a family of sixteen (16) different high integrity containers made of high-density polyethylene (HDPE). The NRC docketed the Topical Report under File No. WM-18 for review by the technical staff. NRC transmitted the first formal set of requests for additional information (RAI#1) under the NRC topical report review process to CNSI on May 31, 1985 (Ref. 4). NRC transmitted additional information regarding the review of the Topical on June 25, 1986 (Ref. 5). The remaining review submittals for the CNSI Topical Report are covered in later sections in this TER.

1.2.2 TFC Nuclear Associates, Inc.

TFC Nuclear Associates, Inc. (TFC) submitted a Topical Report on June 26, 1984 (Ref. 6) to the NRC for the licensing of one (1) high integrity container made of high-density polyethylene. Information on one (1) other size HDPE HIC was included in the Topical Report, but licensing of that HIC was not requested because TFC said that not all of the information on testing of the HIC was

included in the Topical Report. NRC docketed the Topical Report under File No. WM-76 for review by the technical staff. NRC requested additional information on the HDPE HIC Topical Report from TFC on December 27, 1984 (Ref. 7). Additional information was supplied by TFC on June 26, 1985 (Ref. 8), and October 2, 1985 (Ref. 9). The remaining review submittals for the TFC Topical Report are covered in later sections in this TER.

1.2.3 Westinghouse Hittman Nuclear Inc.

Westinghouse Hittman Nuclear Inc. (Hittman) submitted a Topical Report to the NRC on June 28, 1984 (Ref. 10) for licensing of three (3) different high integrity containers made of high-density polyethylene. The NRC docketed the Topical Report under File No. WM-80 for review by the technical staff. NRC transmitted the formal RAI#1 on their HDPE HIC Topical Report to Hittman on October 18, 1985 (Ref. 11). The remaining review submittals for the Hittman Topical Report are covered in later sections in this TER.

1.3 Descriptions of High Integrity Containers

1.3.1 Chem-Nuclear Systems, Inc.

The 16 HDPE HIC designs submitted in the CNSI Topical Report all have the prevailing shape of a right cylinder. The 16 HIC designs can be grouped into three categories; (1) flat bottom, torospherical head HICs, (2) 5-degree conical-bottom, torospherical head HICs, and (3) flat bottom, flat top overpacks. All of the HDPE HICs have a nominal wall thickness of 1/2 inch with

the exception of the overpack lid, which is 1/4 nch thick. The containers are all manufactured from Phillips Chemical Company Marlex CL-100 polyethylene by the rotational molding process. The three groups of containers are manufactured in a variety of sizes. Table 1 gives the dimensions, internal capacities, and gross weights of the CNSI HDPE HICs.

TABLE 1

SIZES OF CNSI HDPE HICs

Identification	Diameter(in)	Height(in)	Internal Capacity(cf)	Gross Weight(lbs)
Flat Bottom HICs				
PL6-80	57	56	72	5000
PL7-100	72½	39	75	6250
PL8-120	60	73	107	7500
PL14-170	72½	71	151	10800
PL14-195	74	77½	171	12200
PL21-300	80	107½	284	18750
Conical Bottom HICs				
PL4-85R	43	9[illegible]	75	5300
PL6-80R	57	55	69	5000
PL7-100R	72½	38	68	6250
PL8-120R	60	72	103	7500
PL14-170R	72½	70	144	10700
PL14-195R	74	76½	164	12200
PL21-300R	80	106½	[illegible]6	18750
Overpacks				
Small	33	57	2[illegible]	2[illegible]00
Medium	33	78	[illegible]	2500
Large	33	85	37	2500

1.3.2 TFC Nuclear Associates, Inc.

The 2 HDPE HIC designs submitted by TFC in their Topical Report are right cylinders and have essentially flat bottoms. The NUHIC-55 container is essentially the same size and shape as a standard 55 gallon drum, with a diameter of 23 inches and a height of 35 inches. The NUHIC-120 container is designed to hold approximately 125 cubic feet of material and has a diameter of 70 inches and a height of 72 inches. The NUHIC-55 container has a flat top, while the NUHIC-120 has a domed head with a slope of approximately 20 degrees. The NUHIC-55 container has an eight-inch diameter opening in the top for access and the NUHIC-120 is fitted with either an eight- or sixteen-inch opening for access in the top. The containers are rotationally molded from either Phillips Chemical Company Marlex CL-100 or Union Carbide G-PEP-805. The nominal wall thickness of the NUHIC-55 container is 3/8 inches and of the NUHIC-120 is 5/8 inches.

1.3.3 Westinghouse Hittman Nuclear Inc.

The 3 HDPE HIC designs submitted by Hittman in their Topical Report are right cylinders, and have two different shapes. The Radlok-55 HIC has stiffened and essentially flat ends, while the Radlok-100 has a domed head and a flat bottom, and the Radlok-200 has a domed head with a slightly convex bottom. The containers are manufactured with rotationally molded Phillips Chemical Company Marlex CL-100. The nominal wall thickness of the Radlok-55 is 2/5 inches and of the Radlok-100 and Radlok-200 is 5/8 inches. The containers all have an eight-inch diameter fill port closure, and the Radlok-100 and Radlok-200 sizes have a sixteen-inch diameter manway closure. Table 2 shows

the dimensions, internal capacities, and gross weights of the three Hittman HDPE HICs.

TABLE 2

SIZES OF HITTMAN HDPE HICs

Identification	Diameter(in)	Height(in)	Internal Capacity(cf)	Gross Weight(lbs)
Radlok-55	23	35½	6	950
Radlok-100	52	60	57	5500
Radlok-200	72	71	125	10500

1.4 Topical Report Review Events

Many events have taken place that have played a role in the technical review of the three HDPE HIC Topical Reports. Some of these events have occurred outside of the actual topical report review process, but they have played a role in the review. The important review events are described in the following sections.

1.4.1 10 CFR Part 61 Promulgation Events

Prior to the promulgation of 10 CFR Part 61, HDPE HICs were being accepted for disposal at the Barnwell, SC Low-Level Waste Disposal Facility. Beginning in 1979, the State of South Carolina began issuing Certificates of Compliance for HDPE HICs that indicated that the containers met South Carolina's regulatory requirements for high integrity containers (Certificates of Compliance for HDPE HIC designs have been issued to; Chem-Nuclear Systems, Inc., Philadelphia Electric Company, Westinghouse Hittman Nuclear, Inc., NUS Corporation (now LN Technologies, Inc.), TFC Nuclear Associates, Inc., Nuclear Packaging, Inc., and

Vermont Yankee Nuclear Power Corporation). With the promulgation of 10 CFR Part 61 and its implementation, it was agreed to by the NRC and the States with operating low-level waste disposal facilities that the NRC would perform a centralized review of topical reports to determine if the new Part 61 requirements would be met by waste forms and high integrity containers being used and proposed for use. It was also agreed to that during the review of topical reports submitted on waste forms and high integrity containers already in use at the operating disposal facilities that these waste forms and containers could continue to be accepted for disposal while awaiting the NRC's evaluation of the topical reports. The NRC announced the topical report review process and a temporary fee waiver for submittal of topical reports in the Federal Register on September 8, 1983 (48 FR 40512) (Ref. 12). The three HDPE HIC Topical Reports that are the subject of this TER were submitted in response to this Notice.

1.4.2 Other Topical Report Reviews

NUS Process Services Corporation (NUS) submitted a Topical Report on June 21, 1984 (Ref. 13) to the NRC for the licensing of the Barrier-55 polyethylene high integrity container. The NRC docketed the Topical Report under File No. WM-57 for review by the technical staff. NUS withdrew the Topical Report from the NRC review process on May 13, 1985 (Ref. 14). No Topical Reports on the HDPE HICs that received certificates of compliance from the State of South Carolina from manufacturers other than CNSI, TFC, Hittman, and NUS have been submitted to the NRC for licensing.

1.4.3 Brookhaven National Laboratory Studies

In June 1985, the NRC initiated work with Brookhaven National Laboratory (BNL) to review the structural analyses presented in the three Topical Reports. The results of the reviews by BNL were submitted to the NRC in three technical reports, one report for each of the Topical Reports (Refs. 15,16,17). In general, the results of the BNL structural analyses reviews of the three topicals indicated major problems with the analyses as presented. In all three Topical Reports, a complete analysis is presented on only one design, when more than one design is being submitted for licensing. Also, the BNL reviews pointed out that in all three Topical Reports the nonlinear behavior of the polyethylene is not being considered in the analysis. Following these reviews of the three Topical Reports by BNL, the NRC initiated work with BNL to: (1) develop acceptance criteria to provide a better base for the reviews of the Topical Reports; (2) analyze existing data on creep of polyethylene; and, (3) develop a methodology in the form of a computer code to perform structural analysis of the HDPE HIC designs presented in the Topical Reports that would facilitate determining whether the designs would meet the acceptance criteria. BNL submitted the results of their work in two technical reports to the NRC in April 1987, entitled, "Review of the High Integrity Cask (sic) Structural Evaluation Program (HICSEP)" (Ref. 18) and "Users Manual for the High Integrity Cask (sic) Structural Evaluation Program (HICSEP)" (Ref. 19) that document the computerized structural analysis methodology and the recommended acceptance criteria for HDPE HIC designs. The acceptance criteria reported in the study are in the form of maximum allowable values for membrane stress, creep, and buckling stress. Additionally, the HICSEP model was run on several actual HDPE HIC designs using information from the Topical Reports from CNSI, TFC, and Hittman. The results of these HICSEP runs indicated that there may be a potential for large polyethyene HICs to experience excessive membrane stresses

and to exceed the proposed maximum allowable buckling stress. The NRC reported the results of the BNL study in a paper that was presented at the Ninth Annual DOE Low-Level Radioactive Waste Management Conference held in Denver, CO in August 1987 (Ref. 20).

1.4.4 Engineering, Design, and Testing Corp. Report

In March 1986, Engineering, Design, and Testing Corp. (EDT) submitted a paper to the NRC that was presented at the Waste Management '85 conference in Tucson, AZ (Ref. 21) that is critical of materials being used for designs of high integrity containers. Briefly, the paper states that HICs made of plastics have structural limitations, that HICs made of metals are subject to corrosion and would not be expected to meet containment requirements, and it recommends a design of a HIC that uses both materials. In July 1986, EDT submitted a report to NUS entitled, "An Assessment of Polyethylene as a Material for Use in High Integrity Containers," (Ref. 22) which documents findings on the suitability of HDPE for use as a material for HICs. In short, EDT concludes in the report that polyethylene is not suitable for use in a HIC that has a structural requirement and that the existing HDPE HIC designs on the market today do not meet published requirements. In October 1986, NUS, now LN Technologies, Inc., submitted this EDT report to the NRC (Ref. 23), and stated that, based on the results of this study, they designed a HIC which incorporates both stainless steel and polyethylene as materials of construction. On October 30, 1987 (Ref. 24) LN Technologies submitted comments provided to them by EDT to the NRC regarding the BNL HICSEP study . In summary, EDT said that the results of the BNL study were very consistent with their own findings on polyethylene as a material for use in HICs.

1.4.5 Vendor Submittals Regarding BNL Studies

On May 28, 1987, and on September 17, 1987, the NRC met with Hittman [illegible] discussed the results of the BNL studies. The NRC met with CNSI a[illegible] discussed the results of the BNL studies on September 15, 1987 (Ref. 25). On October 1[illegible], [illegible]987 (Ref. 26,27,28), the NRC submitted a letter to CNSI, TFC, and Hittm[illegible] that discussed the results of the BNL study and enclosed the BNL techn[illegible]l reports, the computer code listing of HICSEP, and an example output from [illegible] code. The letter states that, as a result of the BNL work and the ana[illegible]es performed using the HICSEP code, it was the position of the NRC staff [illegible] HICs should be designed so that they do not experience excessive membrane stresses, buckling, or tertiary creep. The letter requests that the three vendors submit complete information that demonstrates that their HIC design will meet the NRC acceptance criteria. The letter says that the vendors can demonstrate this by (1) modifications to the current designs, (2) their own analysis, and/or (3) administrative procedures. The letter tells the vendors that failure to submit the complete information would result in the discontinuance of the review of the Topical Report. In response to the NRC letter, CNSI submitted information on February 2, 1988 (Ref. 29), TFC submitted information on February 22, 1983 (Ref. 30), and Hittman submitted information on February 29, 1988 (Ref. 31). The CNSI response to the NRC request was to perform their own structural analyses using the ANSYS computer code. The TFC submittal argued against purely theoretical evaluations of the structural capability of their HDPE HIC, said that design changes were possible but not feasible, and argued that test results in their Topical Report and the experience with their HIC demonstrated its structural capability. Hittman proposed an administrative procedure that

would result in a complete fill of the HIC prior to disposal that would ensure structural stability of their HDPE HICs.

1.4.6 Brown University Study (Silling Report)

In March 1988, the NRC initiated work with Dr. Stewart Silling, Assistant Professor of Engineering at Brown University, to review the vendor submittals regarding the structural stability of the HDPE HIC designs. Dr. Silling submitted his findings on June 10, 1988 (Ref. 32) in a report entitled, "Review of the Structural Designs of Polyethylene High Integrity Containers," (Silling Report). The Silling Report details problems regarding HDPE HICs and their capability in meeting the 300-year structural stability requirement and attaches as Appendices his review of each of the vendor submittals. The problems detailed in the Silling Report and the Appendices include: (1) that polyethylene may undergo a ductile/brittle transition over time, leading to crack growth, (2) creep of polyethylene, (3) creep leading to buckling, (4) irradiation causing embrittlement of the polyethylene, (5) creep was not properly considered in the HDPE HIC designs, (6) buckling analysis was flawed, (7) credit for the waste in the HDPE HIC to support against buckling was flawed, and (8) compression test procedures were not appropriate because of the incompressible material inside the HIC during the test.

1.4.7 Vendor Submittals Regarding Silling Report

On June 14, 1988 (Refs. 33,34,35), the NRC submitted a letter to CNSI, TFC, and Hittman transmitting the Silling Report to them and asking for any comments that they had on the report. The Silling Report was also transmitted to the

State of South Carolina for comment. The NRC then met with each of the vendors during a series of meetings held July 13 and 14, 1988 (Ref. 36) to discuss the Silling Report and any comments the vendors had to that date. The NRC asked the vendors to supply written information responding to the Silling Report following the meetings. CNSI submitted information regarding the Silling Report on August 8, 1988 (Ref. 37) and Hittman submitted information on August 25, 1988 (Ref. 38). South Carolina also submitted comments on the Silling Report on June 29, 1988 (Ref. 39). The CNSI transmittal includes information that disputes the findings of the Silling Report in several areas: (1) data used by Silling showing the ductile/brittle transition problem was inappropriate, (2) more recent data collected by the Phillips Chemical Company indicated the ductile/brittle transition was not as conclusive for Marlex CL-100, (3) actual radiation dose a HIC might experience was well below 1.0E+8 rads, (4) several aspects of the buckling analysis performed by Silling were weak and/or inappropriate, (5) creep was properly considered in the designs of their HDPE HICs, and (6) a threshold stress level exists for which creep is not a problem if actual stress is below it. The Hittman submittal also disputes the findings of the Silling Report primarily based on the approach of taking credit for the waste material in the HIC supporting the HIC and preventing buckling, the onset of creep, and crack growth. The Hittman submittal also questions many aspects of the theoretical approaches in the Silling Report regarding buckling, and the use of data other than Marlex CL-100 data for indicating a problem of a ductile to brittle transition. NRC sent the CNSI and Hittman submittals on the Silling Report to Dr. Silling for his review. Dr. Silling submitted a review of the CNSI information on August 19, 1988 (Ref. 40) and on the Hittman information on September 24, 1988 (Ref. 41). TFC did not submit any additional information about the Silling Report following the July 1988 meetings.

1.4.8 ACNW Meetings

The technical issues arising from the HDPE HIC Topical Report reviews were discussed with the NRC's Advisory Committee on Nuclear Waste (ACNW) at ACNW meetings held on June 28, 1988 and September 13, 1988. At the June meeting, Dr. Silling presented his findings regarding polyethylene and the HDPE HICs that were documented in his report. At the September meeting, NRC staff summarized the major technical issues regarding the structural capability of the HDPE HICs, and presented the information submitted in the vendor and South Carolina submittals regarding the Silling Report. As a result of the September meeting, the ACNW stated in a September 16, 1988 letter (Ref. 42) to Chairman Zech that it appeared that the present designs of HDPE HICs will have difficulty meeting the NRC criteria for containers for disposal of Class B and C wastes. The ACNW said that the NRC staff had obtained expert technical opinion during the review of the HDPE HIC Topical Reports and had made effective use of dialogue among the parties involved. The ACNW recommended that the NRC staff bring the study of the HDPE HIC Topical Reports to closure.

2.0 REGULATORY EVALUATION

2.1 Major Technical Issues

During the review of the three Topical Reports on HDPE HIC designs, several major technical issues arose regarding the capability of the polyethylene HICs

to meet certain criteria for HICs in the Waste Form TP and the basic requirement of 300-year structural stability for Class B and C wastes. These major issues arose from the NRC staff review, work by NRC contractors and consultants, and work by other engineering firms under contract to low-level radioactive waste management service vendors that were discussed in the previous sections of this TER. These major technical issues can be grouped under the following general terms, and will be discussed fully in the succeeding sections of this TER:

(1) Buckling

(2) Creep

(3) Ductile/Brittle Transition

(4) Irradiation Effects

2.2 Buckling

As part of the guidance for demonstrating the 300-year structural stability requirement of 10 CFR Part 61 will be met, the 1983 Waste Form TP (Ref. 2) includes a criterion that says HICs, "should be designed to have sufficient mechanical strength to withstand horizontal and vertical loads on the container equivalent to the depth of proposed burial.." To demonstrate that this TP criterion will be met, the HDPE HIC Topical Reports contain analyses and results of tests showing what the HIC mechanical loadings and responses will be under the expected disposal conditions. The buckling analysis presented in the Topical Reports and the consideration of buckling in the design of the HDPE HICs, as well as the results of some of the tests presented in the Reports is a major technical issue of concern to the NRC staff.

2.2.1 NRC Concerns with Buckling

NRC staff concerns with HDPE HIC buckling began with BNL's first review of the Topical Reports that is documented in the BNL technical reports submitted to the NRC (Refs. 15,16,17). As discussed earlier, BNL had two comments that generally applied to all three HDPE HIC Topical Reports; that analyses were not presented on all HIC designs and that the non-linearity of the material properties was not taken into account in the analyses presented. Further concerns regarding buckling came about following the BNL structural analysis methodology study (Ref. 18), when BNL determined through their own analyses that some large HDPE HIC designs had potential problems with buckling. Additional concerns surfaced with the results of the Silling Report (Ref. 32), which reports that design against buckling due to creep appears hopeless and presents analysis and supporting information to substantiate this conclusion. The meetings with and the submittals from the HDPE HIC vendors following the distribution of the Silling Report have concentrated most of the attention regarding buckling to two areas. These two areas are discussed further below.

2.2.2 Use of the Secant Modulus

The Silling Report includes independent buckling analyses offered by the author to demonstrate one methodology to analyze buckling that includes the effects of creep. The Silling Report performs a simple buckling analysis on a "generic" HDPE HIC using the Secant Modulus method (Ref. 32). In this methodology, linear elastic buckling analysis is used, but the Young's Modulus is replaced with the Secant Modulus. The Young's Modulus, normally used in linear elastic buckling analysis, is the stress over the elastic strain in a simple

compression test, while the Secant Modulus is the total stress over the total strain in a creep test. Substitution of the Secant Modulus into the analysis, thus, takes creep into account in the calculations. Using data submitted by the HDPE HIC vendors on creep of Marlex CL-100, the Silling Report estimates a Secant Modulus of 10,000 psi at 300 years, a considerably different value than the Young's Modulus of 100,000 psi generally used by the HDPE HIC vendors in their buckling analyses. When this lower value is used in analyses, results show the HICs would buckle at much lower stresses than vendor's analyses using the elastic Young's Modulus.

2.2.3 Support from Waste and Surrounding Soil

The simple buckling analysis that is included in the Silling Report uses the methods of Timoshenko and Gere (Ref. 43), adjusted to include the Secant Modulus described above. It also accounts for both axial compression loads and lateral loads, which is different from the HDPE HIC vendors' analyses, which only account for axial compression loads imparted by burial overburden. The Silling Report included results from a computer analysis of the generic HDPE HIC, reproduced here as Figure 1. Any combination of vertical and lateral loads above and to the right of the line indicates an unstable buckling condition. As can be seen, the lateral loads cause the most problem in making the HDPE HIC unstable. The Silling Report explains that buckling of the HIC could to an extent be inhibited by the soil surrounding the HIC. The Report details experiments conducted to quantify this support, and using one of the models in the literature, concludes that even under the most favorable conditions of support from surrounding soil, buckling would still occur.

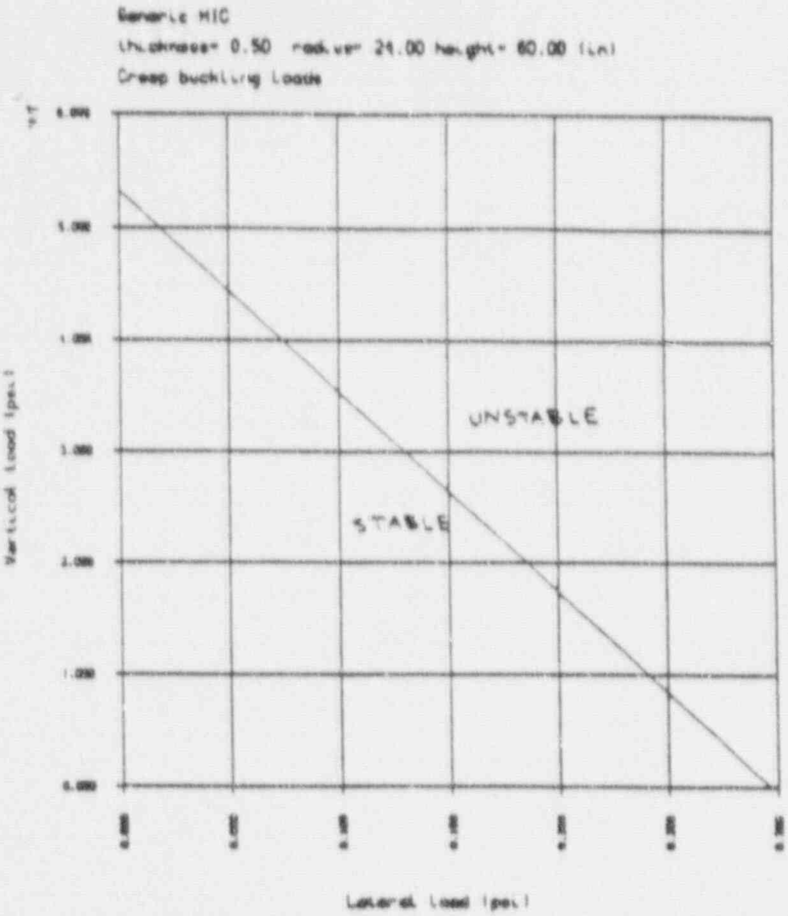

Figure 1. Critical vertical and lateral loads for creep buckling
(Figure taken from Silling Report (Ref. 32))

The Silling Report also explains that buckling would be resisted to some extent by the waste inside the HDPE HIC. The Report, however, notes that none of the vendors has characterized the mechanical properties of the waste, and that, even if the waste were properly characterized, operational procedures would be necessary to ensure that all HICs were filled with waste that had the identical properties that were analyzed. The Silling Report points out that if the waste acts like a fluid or a low-friction granular solid, the waste would provide very little, if any, structural support.

2.2.4 Vendor Responses on Secant Modulus

CNSI and Hittman both submitted information to the NRC regarding the use of the Secant Modulus in buckling analysis in the Silling Report.

In their submittal of August 8, 1988 (Ref. 37), CNSI argues that the use of the Secant Modulus in buckling analysis of HDPE HICs is inappropriate for several reasons. These include: (1) the analysis in the Silling Report assumes the response of the material depends explicitly on the present state of the material, when a more appropriate analysis that includes creep would incorporate past events in the analysis, (2) the analysis incorrectly assumes the dependence on the material properties and geometric properties can be separated, (3) the analysis incorrectly employs a critical effective strain approach where there is no stress redistribution, and (4) the analysis incorrectly assumes that compression and tensile properties for HDPE are identical.

In their submittal of August 25, 1988 (Ref. 38), Hittman argues against the use of the methodology employed in the Silling Report on the grounds that the equations are not correctly employed because the container will deform until the wall meets resistance from the container contents, whereupon the stresses will be relieved. Hittman says that it doesn't matter whether the Young's or Secant Modulus is employed because they argue that deformation analysis without container contents being considered is meaningless. Hittman points out that this conclusion is consistent with the BNL structural analysis methodology report (Ref. 18).

2.2.5 Vendor Responses on Waste/Soil Support

Hittman and CNSI have both submitted information to the NRC regarding the contribution of soil surrounding and waste contained in HDPE HICs towards the structural stability of the HDPE HIC.

One of the bases of Hittman's HDPE HIC structural stability analyses in their Topical Report (Ref. 10) is the assumption that the walls of the HIC will deform because of lateral loads from surrounding soil and will cease to deform when the wall meets the resistant waste contained in the HIC. Hittman's analyses concludes that a container must be 60% or more full of waste in order to provide sufficient column strength in its deformed condition and remain static in the burial environment. Hittman points out that this assumption is a bases for their stability analysis in their submittal to the NRC dated August 25, 1988 (Ref. 38) and emphasizes that a deformed container that is supported by the contents and the surrounding soil is predicted and shown to be true with testing and burial experience.

In their submittal to the NRC dated August 8, 1988 (Ref. 37) CNSI includes a discussion of how waste inside and soil surrounding the HDPE HIC could be included in analysis in more appropriate methods than in the Silling Report. Part of this would include testing certain wastes that go into CNSI HDPE HICs to determine certain material properties necessary to include them in a structural analysis. However CNSI argues that a physical test of some duration (500 hours or 21 days) would serve to answer many questions regarding the behavior of HDPE HICs in the burial environment.

2.2.6 NRC Evaluation of Buckling

The NRC staff has evaluated the information submitted on buckling of HDPE HICs. As discussed, the NRC staff concerns regarding buckling began with the BNL review of the structural analysis in the subject Topical Reports and has continued through the results reported in the Silling Report. One major technical area of concern to the NRC staff and consultants regarding buckling has been that buckling creates a stress/strain condition in the buckled area that is extremely difficult, if not impossible, to treat analytically. Another major concern throughout the review has been that creep of HDPE was not adequately considered by the vendors in buckling analyses presented in the Topical Reports and other supporting information. The Silling Report presents a buckling analysis that includes creep by using the Secant Modulus, and this analysis shows that HDPE HICs are more likely to buckle than the vendor analysis shows. The vendors present arguments attempting to show that the Secant Modulus method is not an appropriate method to use for HDPE HIC buckling analysis. The NRC staff recognizes that the Secant Modulus is only one way to conservatively incorporate creep into buckling analysis, but that it is an acceptable method. The NRC staff recognizes that other analytical methods that incorporate creep may be used instead of the Secant Modulus method. Another major technical area of concern to the NRC staff and consultants regarding buckling was that the structural analysis presented by the vendors did not properly consider the loads from the soil surrounding the buried HIC nor the support from the waste inside the HICs. The NRC staff recognizes that there is great uncertainty regarding the proper way to analyze for the lateral loads from the surrounding soil. The Silling Report concedes this, but presents results from the theory that provides the most favorable conditions for the HDPE HICs and concludes that there is still a problem with buckling. The NRC staff recognizes also that there can be a contribution from the waste in

supporting the loads upon burial. The Silling Report also concludes that such support is likely. However, the contribution of the waste in analysis must be supported by characterization of the waste, especially in terms of the change in material properties (e.g. the breakdown of organic resins) of the waste with time considering the long time (300 years) that the support must be present. The Silling Report also argues that it would be unlikely that a system could be implemented that would result in assurances that waste with the necessary properties would go into the HDPE HICs every time one is filled. The vendors have not submitted evidence that quantifies the contribution of the waste in analysis for buckling. The NRC staff concludes that the data and information presented indicates that vertical and lateral loads from the soil contribute to buckling of HDPE HICs. The NRC staff also concludes that it is difficult to include creep in buckling analysis of HDPE HICs and that there are large uncertainties about the contribution of waste materials in supporting the burial loads experienced by HDPE HICs. The NRC staff concludes that buckled HICs are virtually impossible to analyze using accepted structural mechanics methods; Buckling, thus, presents a major unresolved concern regarding the HDPE HICs ability to meet the 300-year structural stability requirement of 10 CFR Part 61.

2.3 Creep

As part of the guidance for demonstrating the 300-year structural stability requirement of 10 CFR Part 61 will be met, the TP (Ref. 2) includes a criterion that says, "For polymeric material, design mechanical strengths should be conservatively extrapolated from creep test data." To demonstrate that this criterion has been met, the HDPE HIC Topical Reports contain test results from

the manufacturer of Marlex CL-100, the Phillips Chemical Company, and information based on these test results that shows that the HDPE HIC designs include creep in the calculations of their mechanical strengths. Creep of HDPE and the incorporation of creep test results in stability calculations is a major technical issue of concern to the NRC staff.

2.3.1 NRC Concerns with Creep

NRC staff concerns with creep of HDPE HICs began with BNL's first review of the Topical Reports that is documented in the BNL technical reports submitted to the NRC (Refs. 15,16,17). In the report on the TFC HDPE HICs, BNL concludes that, although the basic polyethylene material was tested for creep, that no mention is made of how to relate the creep data to actual field conditions. Further concerns with creep emerged following BNL's work developing criteria for review of HDPE HIC Topical Reports, when BNL determined that HDPE HICs should not be allowed to undergo tertiary creep. Additional concerns developed following the conclusions of the Silling Report (Ref. 32), in which the author says that the long-term creep properties of HDPE are not well known, that design against buckling as a result of creep "appears hopeless," and that the designs of the HDPE HICs do not adequately consider creep. The Silling Report discusses the fact that creep occurs even at the low stresses expected in HDPE HICs under burial conditions, and shows that Marlex CL-100 creeps more than all but one other type of HDPE manufactured by Phillips Chemical Company. The Silling Report cites experiments and includes analysis to support these conclusions. The Silling Report uses the data on creep that is cited in all three of the HDPE HIC Topical Reports, and shows one method to properly account

for creep in design analysis (See Section 2.2.2 for further discussion of this topic).

2.3.2 Vendor Responses on Creep

CNSI and Hittman both submitted information to the NRC regarding creep in the designs of their HDPE HICs, both in their Topical Reports and in their submittals on the Silling Report. TFC included information on creep only in their Topical Report.

CNSI includes data from the Phillips Chemical Company in their Topical Report (Ref. 3) on creep of Marlex CL-100 and presents analysis that includes creep in the determination of design strengths for their HDPE HICs. Hittman also includes data from the Phillips Chemical on creep of Marlex CL-100 in their Topical Report (Ref. 10), and argues that since there is such significant stress relaxation due to the support provided by the internal contents of a HDPE HIC after the initial deformation, that creep is not a concern at the resultant low stress.

In their submittal to the NRC dated August 8, 1988 (Ref. 37), CNSI reiterates the assumptions in their Topical Report, and attempts to support their establishment of a threshold stress of 1400 psi for creep of Marlex CL-100, below which no significant creep would take place over the 300 year required time frame for HDPE HIC structural stability. CNSI cites results of experiments conducted at BNL under an NRC Office of Research contract that were discussed in the BNL structural analysis methodology report (Ref. 18) that

indicate a threshold stress for creep in Marlex CL-100 may exist at approximately 1100 psi.

Hittman presents additional discussions in support of their Topical Report in their submittal to the NRC dated August 25, 1988 (Ref. 38). They reiterate that their experience shows that the foremost creep related deformations occur over short time periods, on the order of seconds and minutes, not years. Because of this, Hittman strongly disagrees with the Silling Report conclusion that creep is not included in the design, and states that enough is known about the creep properties of HDPE to adequately address most questions regarding HDPE HICs' response to the burial environment.

2.3.3 NRC Evaluation of Creep

The NRC staff has evaluated the information submitted on creep of HDPE. As discussed, the NRC staff concerns regarding creep began with the initial review of the structural analyses in the subject Topical Reports performed by BNL and has continued through the results reported in the Silling Report. The NRC staff recognizes that the long-term creep properties of HDPE are not well understood and that there are difficulties in factoring creep into structural analysis of HDPE HICs. The Silling Report emphasizes this, but still presents buckling analysis that includes creep (as discussed in the previous section) and concludes that design against buckling as a result of creep appears hopeless. CNSI argues that creep has been included in their design and has presented evidence that is intended to show that there is a threshold value of creep below which creep-rupture is not a concern. The results of BNL studies are used to support this contention. The NRC staff acknowledges that a

threshold value for creep-rupture of HDPE may exist. However, the evidence presented by CNSI is not conclusive, and the results of the BNL study are not complete. It is possible that further research would show that a threshold value for creep-rupture in HDPE does, or does not exist, or if one does exist that it is well below or above the 1400 psi value supported by CNSI. Current estimates, however, are that a minimum of one to two more years of research would be needed before conclusive evidence might be obtained regarding a HDPE creep rupture threshold, and there is no assurance or guarantee that such a threshold exists or would be quantified even then. The staff does not believe it would be prudent to delay a decision on HDPE HICs on the basis of hope that data supporting the HICs might be generated at some time, perhaps years in the future. The NRC staff concludes that the data and information presented indicate that creep of HDPE could lead to the initiation of buckling in HDPE HICs and that creep presents a major unresolved concern regarding the HDPE HICs ability to meet the 300-year structural stability requirement of 10 CFR Part 61.

2.4 Ductile/Brittle Transition

2.4.1 NRC Concerns with Ductile/Brittle Transition

The Silling Report (Ref. 32) describes problems with the degradation of the mechanical properties of high-density polyethylene that were reported in the literature. Silling describes published results of tests performed by Graube on pressurized pipes manufactured by the extrusion process with Hostalen GM 5010, which is a linear HDPE of moderately high molecular weight. Figure 2 shows the data of Graube, as reported in the Silling Report. The horizontal axis is time and the vertical axis is stress. The curves are drawn at stresses

where failures occurred in the pressurized pipes for the given temperatures. The distinct bends in the curves indicate a transition from ductile failure to brittle failure (ductile failure means that extensive deformation of the material will occur prior to rupture, while a brittle material fails without extensive deformation). At room temperature (20°C), the Graube data indicate that this ductile/brittle transition would take place at approximately 11 years. From the graph, it can be seen that failure will occur at much lower stresses as time goes on after this ductile/brittle transition takes place. The Silling Report points out that the material in the Graube tests was different than Marlex CL-100, and points out that there is evidence that a controlled amount of cross-linking tends to reduce the susceptibility of HDPE to brittle failure. However, the Silling Report goes on to say that this reduction in susceptibility is evident mostly at high temperatures, and that,

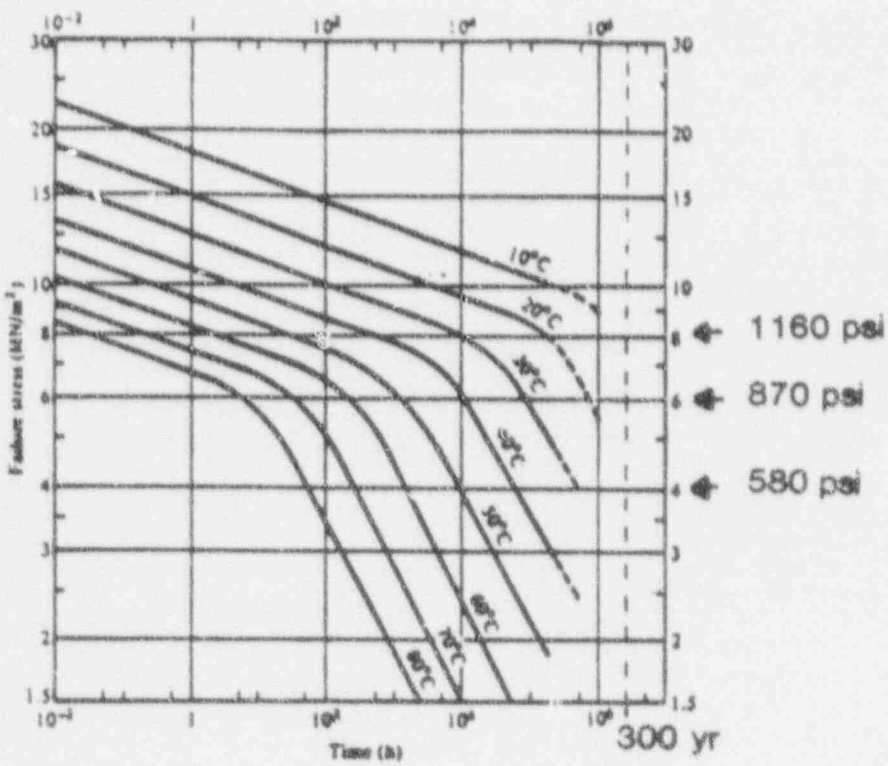

Figure 2. Time to failure of unirradiated HDPE (data of Graube)

(Figure taken from Silling Report (Ref. 32))

while the ductile/brittle transition may take place at a later time, the failure is much less sensitive to the stress level once the transition occurs, and thus, failures may occur at very low stress levels.

2.4.2 Vendor responses on Ductile/Brittle Transition

CNSI and Hittman both submitted information to the NRC regarding the ductile/brittle transition for HDPE reported in the Silling Report.

CNSI argues two points about the information in the Silling Report in their August 8, 1988 (Ref. 37) submittal to the NRC. CNSI first cites information they obtained from the Phillips Chemical Company, manufacturers of Marlex CL-100, that indicates that CL-100 has improved ductile properties. Figure 3 is a graph submitted to the NRC by CNSI to support their claim. The graph is the Graube data graph redrawn to show just 20°C and 60°C results from Graube, with graphical interpretations of the new Phillips data on Marlex CL-100 drawn on the graph by CNSI. The CNSI graphical interpretations are extrapolations of on-going 20°C and 60°C pipe tests being conducted at certain stress levels by Phillips during which no failures have taken place. The CNSI extrapolated data indicates that the ductile/brittle transition "knee" is at a later time for Marlex CL-100 than the Graube curves, and therefore, this material has better performance regarding this property. The second point that CNSI argues is that the Graube data are not applicable since the uniform axial and circumferential stresses imposed on the pipes during the tests described are both tensile, while burial loads are mostly compressive. CNSI also argues that the data is inapplicable because the Graube tests are uniform loading tasts, while the loading in a real burial environment will not be uniform due to stress relaxation.

GRAUBE CURVES REPLOTTED FOR 20°C AND 60°C

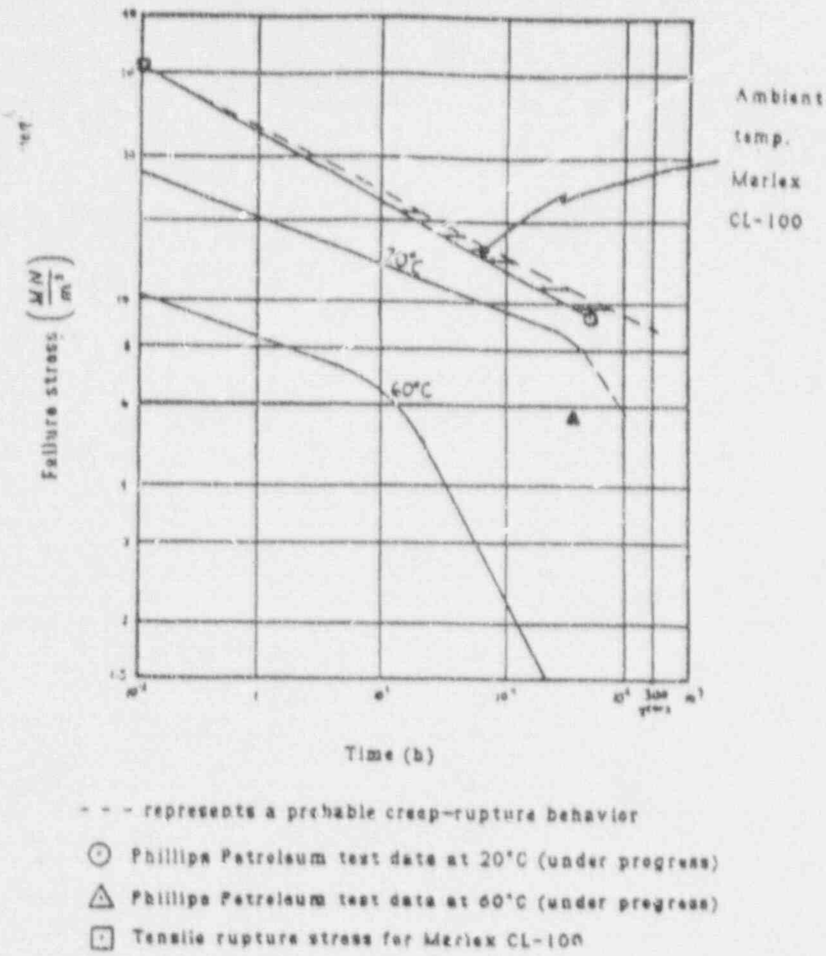

Figure 3. Stress to rupture data of Marlex CL-100 drawn by CNSI

(Figure taken from Ref. 37)

Hittman also argues two points in response to the ductile/brittle transition issue in their submittal to the NRC dated August 25, 1988 (Ref. 38). First, they argue that since reliance is placed on the waste inside the HDPE HIC for support and it, therefore, does not support the entire load, then constant stress testing like the Graube tests are inappropriate because of support provided after the initial deformation and the subsequent reduction in the stress on the container. Hittman also cites new data they received from the Phillips Chemical Company reporting failures of Marlex CL-100 pipes at 20°C and 60°C for two stress levels, and on-going tests that have not failed yet at several lower stress levels. Hittman has not presented a graph of these

results, but merely states that the new Phillips data indicate the G-aube results are not quantitatively applicable to CL-100, and may not be qualitatively applicable.

2.4.3 Fu ner NRC Work on Ductile/Brittle Transition

NRC staff placed two telephone calls to Mr. Robert Rees of the Plastics Division of the Phillips Chemical Company on August 26, 1988 (Ref. 44) and September 12, 1988 (Ref. 45) to discuss the information on Marlex CL-100 pipe tests that were submitted to the NRC by CNSI and Hittman. During these phone calls, several points were clarified and discussed regarding the pipe tests cited by the vendors, including the following:

1) The tests were run on sample Marlex CL-100 p es in order to establish a standard with the Plastics Piping Institute.

2) Failures have taken place, as reported in the Hittman submittal.

3) After further investigation, Mr. Rees determined that the stresses the pipe tests had been conducted at, which he reported to CNSI and Hittman (who then reported to the NRC) were in error, and that the correct stresses are approximately 200 psi less than had previously been reported.

4) The tensile rupture stress value for Marlex CL-100 is between 3000 - 4000 psi, and that the value of 4600 psi used by CNSI in their graph (Figure 3) is high.

This clarification of the test information allowed the NRC staff to draw its

own interpretation of the Marlex CL-100 pipe test results using the same graph that was submitted by CNSI. Figure 4 is this graph, including the NRC staff interpretation of the Marlex CL-100 test results. The 20°C curve for Marlex CL-100 drawn by NRC staff is nearly the same as the Graube linear HDPE data, indicating that the behavior of the Marlex CL-100 is likely to be very similar to that of the HDPE tested by Graube.

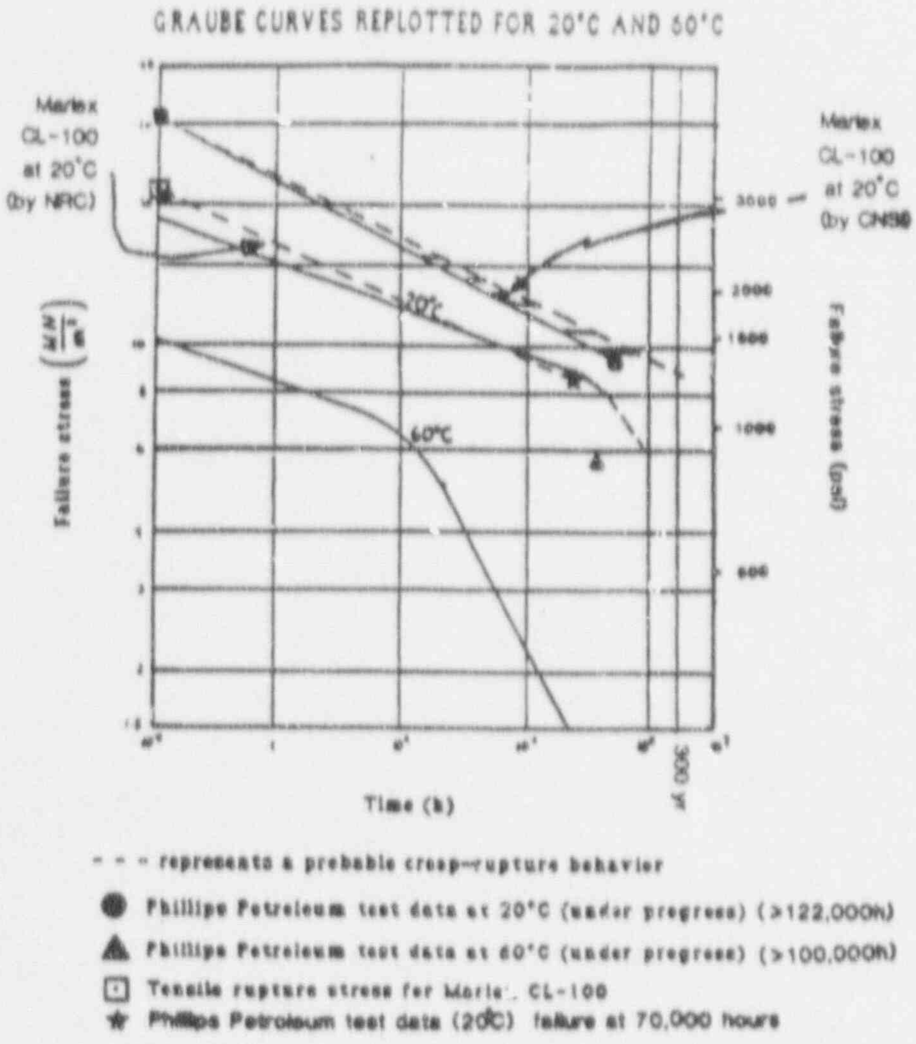

Figure 4. Marlex CL-100 curve drawn by NRC staff

2.4 4 NRC Evaluation of Ductile/Brittle Transition

The NRC staff has evaluated the information regarding the phenomenon of a

ductile/brittle transition in HDPE. The NRC staff recognizes that there is great uncertainty regarding whether the embrittlement of the linear HDPE pipes tested by Graube and reported in the Silling Report is indicative of a problem with embrittlement of the cross-linked HDPE that is used to make the HICs. The Silling Report points out this uncertainty and also points out the differences between the two types of HDPE and that it is unknown whether these differences play a part in the performance of the HDPE in regards to a ductile/brittle transition. The Silling Report, however, points out that other data similar to the Graube test results are also available from other studies. The information submitted by CNSI and Hittman that they obtained from the Phillips Chemical Company presents evidence that is intended to show that the ductile/brittle transition behavior of Marlex CL-100 is much different than the linear HDPE of the Graube tests, but further investigations into the limited Phillips information by the NRC staff indicate that the behavior of the Marlex CL-100 HDPE is not dissimilar to the linear HDPE of the Graube tests at extended time periods. The NRC staff concludes that the data presented indicate that embrittlement of Marlex CL-100 HDPE at low stress levels can be a problem and that embrittlement presents a major and unresolved concern regarding the HDPE HICs ability to meet the 300-year structural stability requirement of 10 CFR Part 61.

2.5 Irradiation Effects

As part of the guidance for demonstrating the 300-year structural stability requirement of 10 CFR Part 61 will be met, the TP (Ref. 2) includes a criterion that says a HIC "design should consider the radiation stability of the proposed container materials as well as the radiation degradation effects of the wastes." To demonstrate that this TP criteria will be met, the TP goes on and

states that the HIC materials should be exposed to a total accumulated dose of 1E+08 rads and that no significant changes in the material design properties should result. The HDPE HIC Topical Reports contain results of testing and analysis of the test results and discussions that intend to show that radiation will not be a detriment to the HDPE's long-term performance. The effects of radiation and the results of testing by the HDPE HIC vendors and other work that illustrate the effects of radiation on HDPE is a major technical issue of concern to the NRC staff.

2.5.1 NRC Concerns with Irradiation Effects

NRC staff concerns with irradiation effects on HDPE first surfaced with the recognition that polyethylene electrical insulation being used at nuclear power plants was deteriorating more rapidly than expected, and it was suspected that radiation was one cause. NRC's Office of Research initiated work with Brookhaven to determine the effects of radiation on samples of Marlex CL-100. The results of this work are published in a December 1984 document (Ref. 46) that shows, generally, polyethylene loses ductility following irradiation and is less tolerant to deformation before breaking. Studies by BNL continued in a follow-on research project, and preliminary results of this further research are contained in a March 1986 document (Ref. 47). This work confirmed that irradiation causes a loss of ductility in HDPE. The Silling Report (Ref. 32) increased NRC staff concern with irradiation effects on HDPE because the result of irradiation and the loss of ductility would tend to make brittle failures more likely. Irradiation effects, therefore, may exacerbate the ductile/brittle transition concern brought out by the Silling Report and discussed in the previous section. The Silling Report cites results of the

second BNL research study mentioned above showing crack growth in strips of Marlex CL-100 that have been bent in the shape of a U and have been irradiated. This crack growth is particularly significant because the specimens have bends at constant strains comparable to bends in a HDPE HIC under burial conditions.

2.5.2 Vendor Responses on Irradiation Effects

CNSI and Hittman both submitted information regarding the irradiation effects on HDPE, first in their Topical Report submittals, and secondly, in response to the Silling Report. TFC included information on irradiation effects only in their Topical Report.

In their Topical Report (Ref. 3), CNSI includes results of testing and analyses on HDPE samples, and concludes from this data that irradiation of HDPE leads to increases in density, tensile strength, hardness, degree of cross-linking, and resistance to stress cracking, and decreases in solubility and elongation. Hittman argues in their Topical Report (Ref. 10) that the worst case HIC would not receive a dose rate greater than 1.4E+08 rads, which they cite as the industry standard for when degradation of polyethylene from irradiation begins. They also state that irradiation leads to higher tensile strength and Shore hardness and a reduction in elongation properties

In their response to the Silling Report dated August 8, 1988 (Ref.), CNSI presents detailed analysis of waste streams that actually are disposed of in their HDPE HICs and calculated the hypothetical worst case radiation exposure dose to one of their HDPE HICs. Their calculations indicate that the worst

exposure dose to a HDPE HIC would be less than 4.0E+07 rads. From this, CNSI concludes that the effects of radiation on HDPE will be relatively small.

In their response to the Silling Report dated August 25, 1988 (Ref. 38), Hittman argues that it is difficult to draw any conclusions about the effect of radiation on HDPE based on data in the industry. To support this, Hittman presents several facts, including: (1) much of the work on irradiation effects on HDPE has been done by a non-HIC holder (BNL), (2) the HDPE samples tested by BNL had different properties, (3) actual dose rates experienced by HICs are much less than test dose rates, (4) the effects of irradiation are dependent upon dose rate and the indicated tendencies are not fully rationalized, some properties being improved while other properties degrade at various dose rates, and (5) the effects of irradiation in a dewatered resin environment appear to be substantially attenuated versus an ambient air environment.

2.5.3 NRC Evaluation of Irradiation Effects

The NRC staff has evaluated the information on irradiation effects of HDPE. As discussed, the NRC staff concerns with irradiation effects on polyethylene began with the initial review of the subject Topical Reports and has continued through the results of the investigations and studies by NRC staff consultants and the Office of Research studies. The Silling Report, however, resulted in increased concern with irradiation effects on HDPE because irradiation would tend to exacerbate the embrittlement of HDPE that may occur with time that was discussed in the previous section. The vendors present evidence that an actual HDPE HIC will not experience the 1.0E+08 rads exposure dose that is required by the TP and show that improvements to certain properties of the HDPE HICs will

result. However, there is no evidence in any submittal that radiation at the lower exposure dose calculated by the vendors does not cause embrittlement. In fact, results of the BNL research studies cited in the Silling Report indicate that embrittlement of HDPE is likely at much lower doses than the 1.0E+08 rads TP criteria. The NRC staff concludes that the data presented indicates that irradiation of HDPE causes embrittlement of HDPE, that irradiation exacerbates the embrittlement of HDPE that can occur at low stresses, and that irradiation effects present a major unresolved concern regarding the HDPE HICs ability to meet the 300-year structural stability requirement of 10 CFR Part 61.

2.6 Other Considerations

The Silling Report (Ref. 32) also reports two other concerns regarding HDPE HICs and their burial that could affect the performance of the HICs for the required 300 year life:

1) The Topical Reports did not report on any limits on deformation of the HICs under expected loads. Gross shape changes could lead to redistribution of stresses in the HIC shell that could cause the analysis and assumptions used in the analysis of the HICs structural capability to be incorrect.

2) The phenomenon of soil arching and the subsequent change in the loads that the buried HIC may experience were not analyzed in any of the HDPE HIC Topical Reports. For soils that are stiffer than the HDPE HIC, soil arching would cause vertical loads to be transferred to the soil

surrounding the buried HIC, leading to more lateral loads, and more likelihood of a buckling condition.

NRC staff are also concerned over the interpretation of results of compression tests reported in the CNSI Topical Report. These compression tests were carried out in order to meet requirements of the South Carolina Department of Health and Environmental Control for the disposal of HICs. The tests involved placing loads on a filled HDPE HIC in a manner intended to replicate burial, and then measuring the deformation in the HIC over time. Ultimately, the determination of whether the test was passed or not was based on whether a rupture occurred in the container under any of the tested loads. The results of the tests published in the CNSI Topical Report show rather dramatic deformations in the HDPE HIC under the loads, from a 6.3% reduction in the height of the container at 15 psi after 6 hours, to a 39.8% reduction in height of the container at 62 psi after 2 hours. CNSI concludes in their Topical Report in describing these test results, "The side walls distorted, as expected buckling took place, causing container height to reduce.." CNSI further explains that the tests were successful because no rupture took place. In the opinion of the NRC staff, the tests merely show that the HDPE HICs can undergo extreme plastic deformation under vertical loading, and that rupture would not be likely under such conditions in the short term. The tests do not address the concerns about buckling, creep, ductile/brittle behavior, or the effects of irradiation that have been raised by the NRC staff and there is still an uncertainty about long-term effects that are not addressed by the short-term tests.

3.0 REGULATORY POSITION

The NRC Staff has completed its review of the Topical Reports on designs of high integrity containers manufactured with high-density polyethylene submitted by Chem-Nuclear Systems, Inc. (WM-18), TFC Nuclear Associates, Inc. (WM-76), and Westinghouse Hittman Nuclear, Inc. (WM-80). In its evaluation, the NRC staff was concerned with whether or not the HICs described meet the applicable requirements for stable waste forms that are codified in 10 CFR 61.56. The review of the Topical Reports was also guided by the applicable portions of the 1983 Technical Position on Waste Form. Based on evaluations of the information submitted by the three vendors in (a) their original Topical Reports (Refs. 3,6,10), (b) written correspondences between NRC and the vendors, and (c) meetings and telephone discussions between NRC, NRC consultants, vendor representatives, and others, the NRC staff concludes that the high integrity container designs presented in the three subject Topical Reports do not meet the applicable requirements for 300-year structural stability in 10 CFR Part 61.

The conclusion that the HDPE HIC designs presented in the subject Topical Reports do not meet the 10 CFR Part 61 structural stability requirements is based on concerns regarding the following material properties and associated physical behaviors of high-density polyethylene and HICs made of HDPE:

1) Buckling of HDPE HICs;

2) Creep of polyethylene that can lead to creep-rupture and contribute to the initiation of buckling;

3) Embrittlement of HDPE through time;

4) Embrittlement of HDPE from the effects of irradiation.

The conclusion that the HDPE HIC designs presented in the subject Topical Reports do not meet the structural stability requirements of 10 CFR Part 61 does not apply to other HIC designs that may utilize HDPE as a material for corrosion resistance or that are used for some other purpose where structural stability is provided by another material or system. In that regard, HDPE HICs might, for example, be acceptable for low-level waste disposal in cases where an engineered structure provides the structural stability. Other approaches, such as the use of concrete or steel caissons, may also prove feasible. Such alternative approaches should be reviewed carefully on a case-by-case basis to assure that the alternative structure design and material of construction provide the required 300-year structural stability without introducing other concerns.

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26. M. Tokar (USNRC), letter to J. J. Chando, Jr (TFC), October 15, 1987.

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NRC STAFF COMPLETES REVIEW OF HIGH INTEGRITY CONTAINER DESIGNS

The Nuclear Regulatory Commission's staff has completed its review of submittals by three companies on their high-density polyethylene high integrity container (HIC) designs. The staff concluded that these designs are not approved for disposal of Class B and C waste. The three companies that submitted HIC designs to NRC for approval were Chem-Nuclear Systems, Inc., of Columbia, SC; TFC Nuclear Associates, Inc., Moorestown, NJ; and Westinghouse Hittman Nuclear Inc., Moorestown, NJ. Copies of the NRC staff's Technical Evaluation Report are available for inspection and copying at the NRC Public Document Room, 2120 L Street, N.W., Washington, DC 20555.

Copies of the report were sent to the three companies that submitted their designs for approval and to the states of South Carolina, Washington, and Nevada, who have regulatory authority over the three operating low-level waste disposal facilities. The three states are taking steps to evaluate the impact of the new NRC position regarding high-density polyethylene HICs on site operations. NRC staff has discussed the continued use of high-density polyethylene HICs at the Barnwell, SC disposal facility with South Carolina state regulatory officials. Staff understands that South Carolina has directed their site operator to submit alternatives for the continued use of high-density polyethylene HICs for South Carolina's consideration in early 1989.

NRC Project Managers or Resident Inspectors who have questions about this review should contact Dr. Michael Tokar, Section Leader, Engineering Section at FTS 492-0590.

TOPICAL REPORT REVIEW STATUS/DISPOSITION LISTING
SOLIDIFIED WASTE FORMS AND HIGH INTEGRITY CONTAINERS (HICs)
JUNE 1991

VENDOR	TOPICAL REPORT	DOCKET NUMBER	STATUS/DISPOSITION	REVIEWER Past/Future	SUBMITTAL COMPLETION
1. VIKEN	Solidification (Oil/Cement)	WM-13	DISCONTINUED	T. Johnson ** (M. Adams)	12/13/82 09/30/86
2. Chem-Nuclear	HIC (HDPE)	WM-18	NOT APPROVED	K. McDaniel (J. Woodey)	12/23/83 12/27/88
3. Chem-Nuclear	Solidification (Cement)	WM-19	WITHDRAWN	L. Person	11/30/83 05/27/88
4. Scientific Ecology Group (LN Tech)	Solidification (Cement)	WM-20	LAST: Meeting between SEG and NRC regarding schedule and remaining issues. (08/17/89) NEXT: SEG to submit revised TR. Originally due: 12/90 Now expected: Mid-June '91	K. McDaniel M. Adams J. Woodey	08/85
5. Nuclear Packaging	HIC (Ferralium/FL-50)	WM-45	APPROVED	M. Tokar	02/13/84 11/07/85
6. Scientific Ecology Group (Westinghouse)	Solidification (Cement)	WM-46	LAST: Vendor submitted responses to RAI #2. (03/01/91 and 03/11/91) NEXT: NRC sends RAI #3 to SEG, due 06/21/91.	J. Kane J. Woodey	04/13/89
7. Chem-Nuclear	HIC (Fiberglass/Poly)	WM-47	WITHDRAWN	D. Tiktinsky (J. Woodey)	04/30/84 05/02/86
8. Pacific Nuclear Systems	Solidification (Envirostone)	WM-51	NOT APPROVED	J. Kane	05/29/84 03/03/88
9. LN Technologies	HIC (HDPE)	WM-57	WITHDRAWN	T. Jungling (J. Woodey)	06/21/84 05/13/85
10. Nuclear Packaging	Solid/Encap (Cement/Gypsum)	WM-71	WITHDRAWN	T. Johnson (J. Woodey)	10/22/84 11/21/85
11. TFC Nuclear	HIC (HDPE)	WM-76	NOT APPROVED	K. McDaniel (J. Woodey)	06/26/84 12/27/88
12. Westinghouse	Solidification (SG-95)	WM-79	WITHDRAWN	E. Wick	06/26/84 06/10/88

* For more information on any of these Topical Report Reviews, see attached summary sheets.
** Names in parentheses indicate custodian of TR archives if different from reviewer.

ENCLOSURE 3

VENDOR	TOPICAL REPORT	DOCKET NUMBER	STATUS/DISPOSITION	REVIEWER Past/Future	SUBMITTAL COMPLETION
13. Westinghouse	HIC (HDPE)	WM-80	NOT APPROVED	D. Widmeyer ** (J. Woodey)	06/28/84 12/27/88
14. Chichibu	HIC (Concrete/Poly)	WM-81 REV 2.1	APPROVED	K. McDaniel	06/29/84 06/25/86
15. DOW Chemical	Solidification (Polymer)	WM-82	APPROVED	E. Wick	06/29/84 06/01/88
16. Nuclear Packaging	HIC (Ferralium/ Enviralloy family)	WM-85	APPROVED	K. McDaniel (E. Wick)	06/29/84 04/20/88
17. Nuclear Packaging	HIC (Stainless/SDS)	WM-87	WITHDRAWN	E. Wick	08/84 10/25/88
18. General Electric	Solidification (Polymer/AZTECH)	WM-88	APPROVED	E. Wick	02/13/85 09/29/87
19. WasteChem	Solidification (Bitumen)	WM-90	APPROVED	K. Chang (M. Adams)	05/30/86 01/22/88
20. U.S. Ecology	Solidification (Bitumen)	WM-91	DISCONTINUED	M. Tokar	01/03/86 03/04/88
21. Stock	Solidification (Cement)	WM-92	DISCONTINUED	J. Kane	12/05/86 06/24/88
22. LN Technologies	HIC (Stainless/Poly)	WM-93	APPROVED	E. Wick	09/11/87 11/25/88
23. LN Technologies	HIC (Stainless/Poly)	WM-93 REV 1	APPROVED	E. Wick	03/23/89 04/89
24. Bondico	HIC (Fiberglass/Poly)	WM-94	LAST: Telecon from Bondico to NRC indicating that they intend to withdraw the TR. (06/11/91) NEXT: Formal withdrawal of TR from Bondico.	E. Wick	02/25/88
25. Avancer Technologies (Babcock & Wilcox)	HIC (Coated Carbon Steel)	WM-95	LAST: Vendor submitted responses to RAI #1 marked "Confidential". (04/15/91) NEXT: Vendor submits responses to RAI #1 marked "Proprietary".	R. Shewmaker J. Woodey	04/21/88
26. Chem-Nuclear	Solidification (Cement)	WM-96	WITHDRAWN	L. Person (J. Woodey)	03/01/88 05/27/88

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VENDOR	TOPICAL REPORT	DOCKET NUMBER	STATUS	REVIEWER Past/Future	SUBMITTAL COMPLETION
27. Chem-Nuclear	Solidification (Cement #2)	WM-97	LAST: NRC sent comments on draft TER to BNL on 06/04/91. NEXT: BNL revises draft TER in accordance with comments. Due 06/14/91.	M. Adams	06/03/88
28. Chem-Nuclear	Solidification (Cement #3)	WM-98	LAST: Vendor responded informally to RAI #4 on 04/15/91. NEXT: BNL revises draft TER in accordance with NRC comments on TER for WM-97. Due 06/14/91.	M. Adams	06/10/88
29. Scientific Ecology Group (LN Tech)	Solidification (Cement/Decon)	WM-99	LAST: Vendor submitted REV 1 to NRC on 04/10/89. NEXT: SEG to submit revised TR. Originally due: 09/01/89 Now expected: Mid-July '91	M. Adams J. Woodey	07/22/88
30. U.S. Ecology	Solidification (NS1 Bitumen)	WM-100	DISCONTINUED	". Jagganath ** (M. Adams)	07/15/88 09/13/90
31. Chem-Nuclear	Solidification (Cement #1)	WM-101	LAST: Vendor responded informally to RAI #4 on 04/15/91. NEXT: NRC revises draft TER in accordance with vendor responses. Due 06/21/91.	M. Adams	06/01/88
32. U.S. Ecology	Solidification (LLW Bitumen)	WM-102	LAST: Meeting (05/08/91) between NRC and USE resulted in decision to interim approve one waste form. NEXT: TER due to the Sited States on 06/20/91.	R. Shewmaker	07/13/89
33. Pacific Nuclear	HIC (Enviroglass)	WM-103	LAST: NRC sent RAI #1 to vendor on 06/29/90. NEXT: Vendor submits responses to RAI #1. Due: 06/15/91	R. Shewmaker	06/30/89
34. JGC Corp.	Solidification (Cement)	WM-104	LAST: TR submitted on 04/16/90. NEXT: NRC to send RAI #1 to vendor. Due: 06/28/91.	R. Shewmaker	04/16/90
35. Diversified Technologies	Solidification (VERI)	WM-105	LAST: NRC sent RAI #1 to vendor on 02/08/91. NEXT: DTI will submit a revised TR and test results on 09/01/91.	E. Wick	08/26/90

* For more information on any of these Topical Report Reviews, see attached summary sheets.
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