

**TOPICAL REPORT ADDENDUM**

**ENCAP™ ENCAPSULATION UTILIZING  
THE VERI™ SOLIDIFICATION PROCESS**

**T.R. No. DT-VERI-100-NP/P-A  
(Docket Number WM-105R1)  
Addendum 1**

**N. R. C.  
APPROVED**

**NON-PROPRIETARY VOLUME**

**CRCRD E-5  
March 31, 2000  
APPROVED**

**Submitted by:**

**Diversified Technologies Services, Inc.  
2680 Westcott Boulevard Knoxville, TN 37931-3111**

**PHN 865-539-9000  
FAX 865-539-9001  
E-MAIL [info@dts9000.com](mailto:info@dts9000.com)**



UNITED STATES  
**NUCLEAR REGULATORY COMMISSION**

WASHINGTON, D.C. 20555-0001

December 30, 1999

Mr. Charles E. Jensen  
President  
Diversified Technologies Services, Inc.  
2680 Westcott Boulevard  
Knoxville, TN 37931-3111

Dear Mr. Jensen:

The U.S. Nuclear Regulatory Commission has completed its review of the Topical Report (TR) Addendum, DT-VERI-100-NP/P-A, Revision 1, Addendum 1, "ENCAP™ Encapsulation Utilizing the VERI™ Solidification Process." The technical review included information that was contained in the TR Addendum, and further information that was submitted as a result of the review. The Technical Evaluation Report (TER) for this review is enclosed.

Staff has concluded that the TR Addendum, supplemented by additional information that was provided in response to staff comments and questions adequately describes low-level radioactive waste forms produced through use of the ENCAP™ process. This process applies to encapsulation of spent filter cartridges using the previously approved VERI™ [vinyl ester resin in-situ] process for solidification of spent ion exchange resins.

Staff also concludes that the solidified encapsulation waste forms described meet the structural stability requirements of 10 CFR 61 for the disposal of Class B and Class C wastes. These conclusions are based on satisfactory completion of a final revised TR Addendum, which should include all applicable information developed during the technical review and a copy of the enclosed TER Addendum. The following conditions shall also be met:

1. The ENCAP™ encapsulation process shall be used in accordance with the limitations called out in Section 3.1 of the enclosed TER Addendum, and all additional restrictions and requirements specified by the disposal facility operators and governing state agencies.
2. Diversified Technologies must notify users of the ENCAP™ encapsulation process that they shall certify that all restrictions and required procedures have been adhered to, and that the waste forms do not contain proscribed chemicals or waste materials.
3. Diversified Technologies must resolve the outstanding issues specified in Section 3.2 of the enclosed TER Addendum.

Note that final approval is contingent on completion of a revised TR Addendum which includes satisfactory resolution of the outstanding issues in item 3 above. The revised TR Addendum should be submitted to NRC within 90 days of this letter.

It should be noted that notwithstanding NRC's decisions on the adequacy of the ENCAP™ encapsulated wastes, the sited States have regulatory authority concerning the conditions of acceptance of waste forms at their disposal facilities. It is therefore the licensee's responsibility

C. Jensen

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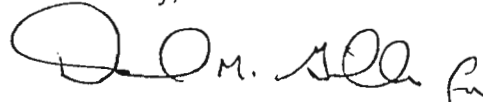
to contact the State regulatory authorities to determine the acceptability of the polymer encapsulated wastes at their State's facilities.

Copies of the enclosed TER Addendum, and this letter are being forwarded to the States of South Carolina, and Washington for their information and use.

Note that the low-level waste (LLW) TR review process at the NRC has been discontinued. The enclosed TER Addendum was written for the Diversified Technologies TR Addendum review that was in progress at the time of the review process termination. No other LLW TR reviews will be performed by NRC.

If you have any questions on this matter, please contact Jennifer Davis at (301) 415-5874, or [bjd1@nrc.gov](mailto:bjd1@nrc.gov).

Sincerely,

A handwritten signature in black ink, appearing to read "T. H. Essig". The signature is fluid and cursive, with a large initial "T" and "H".

Thomas H. Essig, Chief  
Uranium Recovery and  
Low-Level Waste Branch  
Division of Waste Management  
Office of Nuclear Material Safety  
and Safeguards

Enclosure: as stated.

United States Nuclear Regulatory Commission  
Office of Nuclear Material Safety and Safeguards  
Washington, DC 20555

TECHNICAL EVALUATION REPORT - ADDENDUM

related to

Topical Report Addendum DT-VERI-100-NP/P-A  
Revision 1, Addendum 1  
ENCAP™ Encapsulation Utilizing  
The VERI™ Solidification Process

Diversified Technologies  
Docket No. WM-105

Prepared by: Uranium Recovery and Low-Level Waste Branch  
Division of Waste Management  
December 1999

## ABSTRACT

This Technical Evaluation Report (TER) Addendum has been prepared by the Office of Nuclear Material Safety and Safeguards of the U.S. Nuclear Regulatory Commission for Diversified Technologies Services Inc. (DTS) Topical Report (TR) Addendum, DT-VERI-100-NP/P-A, "ENCAP™ Encapsulation Utilizing the VERI™ Solidification Process," Revision 1, Addendum 1, (Docket Number WM-105). The TR Addendum presents information and data to support a process for spent filter cartridge encapsulation in a polymer matrix. The polymer matrix consists of the VERI™ (Vinyl Ester Resin in Situ) waste form, previously described in DTS's TR, "VERI™ Solidification Process for Low-Level Radioactive Waste," and the associated NRC TER, dated December 1992.

The TER Addendum presented here addresses only those aspects of the TR Addendum which differ from the previously approved process. That is, the filter encapsulation will be addressed, but specifics on the VERI™ waste form will not be revisited. For information on the VERI™ waste form, please see the VERI™ TR and associated TER.

From the information presented, the staff concludes that the VERI™ waste form (as previously approved), when used for spent filter cartridge encapsulation, as described in the TR Addendum, should result in waste forms that meet the structural stability requirements of 10 CFR Part 61, the guidance provided in the Branch Technical Position on Waste Form, Revision 1, January 1991, and the guidance provided in the Branch Technical Position on Concentration Averaging and Encapsulation, January 1995. Limiting conditions for use of these waste forms may be specified by the regulating authority for a particular disposal site.

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TECHNICAL EVALUATION REPORT - ADDENDUM  
FOR SPENT FILTER CARTRIDGES ENCAPSULATED  
USING THE DTS VERI™ WASTE FORM (WM-105)

## 1.0 BACKGROUND

This report provides the evaluation results of the technical review of information and data submitted by Diversified Technologies (DTS) in the Topical Report (TR) Addendum entitled, "ENCAP™ Encapsulation Utilizing the VERI™ Solidification Process," Revision 1, Addendum 1, DT-VERI-100-NP/P-A, May 1, 1994 [1]. This Technical Evaluation Report (TER) Addendum is an evaluation of the waste form qualification test data provided by DTS to confirm that this spent filter cartridge encapsulation process will produce a waste form that meets the regulatory requirements of 10 CFR Part 61 with respect to structural stability. This TER Addendum addresses only those aspects of the DTS TR Addendum which differ from the previously approved process. That is, the filter encapsulation will be addressed, but specifics on the VERI™ waste form will not be revisited. For information on the VERI™ waste form, please see the VERI™ TR [2] and associated TER [3].

Once a topical report review has been completed and the associated product(s) has been approved, the TR process allows a user to reference the report to demonstrate that the subject area the report addresses has been through the regulatory review process and is acceptable to the staff. Thus, the TR process allows the use of a repeated process, action, etc., at several facilities after a single successful review has been completed. However, for waste form TRs, waste generators must take additional actions (e.g., plant-specific process control procedures) to demonstrate that all portions of Part 61 have been met. Note that the low-level waste (LLW) TR review process at the NRC has been discontinued [4]. This TER Addendum has been written for an LLW TR review that was in progress at the time of the review process termination. No further LLW TR reviews will be performed by the U.S. Nuclear Regulatory Commission (NRC).

### 1.1 Regulations

By Federal Register Notice dated December 27, 1982 (47 FR 57446), NRC amended its regulations to provide specific requirements for licensing of facilities for the land disposal of LLW. Most 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" [5]. These regulations are the culmination of a set of prescribed procedures for LLW disposal proposed in the Federal Register on July 24, 1981.

The effective date for the implementation of 10 CFR 20.311/20.2006, "Standard for Protection Against Radiation," which requires waste generators to meet the waste classification and waste form requirements in 10 CFR Part 61, was December 27, 1983. As set forth in 10 CFR 61.55, Class B and Class C waste must meet structural stability requirements established under 10 CFR 61.56(b). As noted in 10 CFR 61.56(b)(1), structural stability could be provided by (a) processing (i.e., solidification of) the waste form, (b) by the waste itself (as with large activated steel components), or (c) by placing the waste in a container or structure which would then provide the required stability (i.e., a high integrity container (HIC)). To the extent practical, Class B and C waste forms or containers should, according to Section 61.7 of Part 61, maintain structural stability for 300 years. In May 1983, NRC provided additional guidance

by means of a Branch Technical Position (BTP) on Waste Form [6] that describes test procedures and criteria that can be used to demonstrate the required long-term, 300 year, structural stability. The most recent guidance on waste form is provided in Revision 1 to the Branch Technical Position on Waste Form, which was issued in January 1991 [7].

The waste classification requirements of 10 CFR 61.55 are based on the concentration of specific radionuclides contained in the waste. The regulation, at 10 CFR 61.55(a)(8) states that "the concentration of a radionuclide [in waste] may be averaged over the volume of the waste, or weight of the waste if the units [on the values tabulated in the concentration tables] are expressed as nanocuries per gram." Guidance, as the "Branch Technical Position on Concentration Averaging and Encapsulation," of January 17, 1995 [8], defines a subset of concentration averaging and encapsulation practices that NRC staff would find acceptable in determining the concentrations of the 10 CFR 61.55 tabulated radionuclides in low-level waste. This BTP was being developed while the DTS TR was being developed.

The purpose of this TER Addendum is to summarize the technical review of the information submitted by DTS (also referred to as the vendor), and to demonstrate that the spent filter cartridge encapsulation process described in the TR Addendum, "ENCAP™ Encapsulation Utilizing the VERI™ Solidification Process," and in associated documents, will meet the long-term (300-year) structural stability requirements of 10 CFR 61.56 and the relevant portions of the January 1991, NRC Branch Technical Position on Waste Form, and the concentration limits of 10 CFR 61.55, with the relevant portions of the January 1995, NRC Branch Technical Position on Concentration Averaging and Encapsulation [8].

## 1.2 Topical Report Addendum Submittal

NRC staff concluded in December 1992, that the TR for the "VERI™ (Vinyl Ester Resin In Situ) Solidification Process for Low-Level Radioactive Waste," [2] subject to certain conditions, provides reasonable assurance that identified waste forms produced through use of this process meet the structural stability requirements of 10 CFR Part 61 for the disposal of Class B and C wastes. This process applies to the solidification of two waste streams, mixed bed bead resins, and LOMI [low oxidation state transition metal ion] resins. The TR Addendum, "ENCAP™ Encapsulation Utilizing the VERI™ Solidification Process," [1] was submitted on May 1, 1994. The TR Addendum presents a process (ENCAP™), which utilizes the NRC-approved waste forms generated using the VERI™ process referenced in the VERI™ TR to encapsulate spent filter cartridges in the solidified free-standing monolith. Additional information was requested by NRC staff [9], and was provided by DTS in three subsequent submittals [10], [11], [12].

## 1.3 Diversified Technologies Encapsulation Process

The ENCAP™ process uses VERI™ solidification to create an enveloping monolith around a caged region of spent filter cartridges. This process involves preparing an encapsulation liner and internal cage, filling the internal cage with spent filter cartridges, then filling the entire assembly with spent ion exchange resins (of the type approved in the VERI™ TER [3]), and solidifying the resulting waste filled liner with the VERI™ polymer solidification process described in the VERI™ TR [2]. The VERI™ solidification process involves forcing (by pumping or suction) a catalyzed and promoted modified vinyl ester styrene through a disposal liner. As

the binder flows through the resin bed, it fills the void spaces between the resin beads, as well as those inside and between the filter cartridges, and forces any free water in the liner into the bottom dewatering internals. After filling the void spaces, and displacing the excess water, the binder cures to form a liquid-free, hard, free-standing monolith inside the liner.

## 2.0 TECHNICAL EVALUATION

The information presented in the TR Addendum and DTS letter responses to NRC's Request for Additional Information (RAI) provides the basis for the technical evaluation presented in the following sections. The review and evaluation were conducted by NRC staff members. The determination of the acceptability of the submitted information is based upon a comparison with the applicable regulatory requirements of 10 CFR Part 61, the guidance on solidified waste forms in the BTP on Waste Form [7], and the guidance on encapsulation and concentration averaging in the BTP on Concentration Averaging [8].

Note that this is an addendum to the VERI™ TER [3], and is not a complete TER in itself. This addendum will therefore refer frequently to the VERI™ TER.

### 2.1 Waste Characteristics

The minimum set of characteristics that all LLW intended for near-surface land disposal must meet is defined in 10 CFR 61.56(a). These requirements are intended to provide for ease of waste-handling and to provide for the protection of the health and safety of the personnel at the disposal site. Class A wastes only need to meet the minimum requirements, as long as they are segregated, and are not solidified waste forms. Class A wastes solidified and disposed of with Class B and Class C wastes shall meet the stability guidance for these wastes, in addition to meeting the minimum set of characteristics.

Waste forms classified as Class B or Class C should exhibit characteristics to meet the stability requirements of 10 CFR 61.56(b), that will enable the waste form to maintain its stability and package integrity during waste-handling and emplacement, and after disposal. Stability is intended to ensure that the waste does not structurally degrade and affect the overall stability of the site through slumping, collapse, or other failure of the disposal unit, and thereby lead to water infiltration. Stability is also a factor in limiting exposure to an inadvertent intruder, since it provides a recognizable and nondispersible waste.

### 2.2 Waste Streams Considered

The ENCAP™ process is designed to encapsulate spent filter cartridges in the VERI™ matrix described in the VERI™ TR [2]. The spent filter cartridges are not controlled with respect to source, waste loading or chemical loading. The TR Addendum lists waste types that are prohibited for physical or regulatory reasons, but no chemical "bad actors" have been identified, and the wastes are not expected to contain materials identified or defined as hazardous, biological, pathogenic or infectious. There are two limitations on the spent filter cartridges. First, the size is limited so that the void space created by the entombed object must be less than the span or diameter discussed in Section 2.4.3. Note that the item can be loaded to minimize its cross-section (shadow) when viewed from above. Secondly, spent cartridge filters that would provide a dose equal to or greater than  $10^8$  rad to the polymer matrix

are prohibited. The VERI™ waste form has been shown to withstand doses of  $10^8$  rad in conjunction with testing to meet the BTP on Waste Form. See the VERI™ TR [2] and VERI™ TER [3] for more details. Larger doses could negatively impact the VERI™ matrix.

Spent ion exchange resin beads, qualified for use with the VERI™ system, are described in the VERI™ TR [2] and the associated TER [3], and will not be discussed here.

### 2.3 Minimum Requirements [10 CFR 61.56(a)]

Section 61.56(a)(1) of 10 CFR Part 61 contains the minimum requirements for all classes of waste. These requirements are intended to facilitate handling at the disposal site and provide for the protection of health and for the safety of personnel at the disposal site. The waste form resulting from the VERI™ process described in the VERI™ TR [2] was evaluated against each requirement contained in 10 CFR 61.56, and the guidance contained in the BTP on Waste Form [7]. This evaluation remains wholly applicable to the waste form resulting from the ENCAP™ process described in TR Addendum. Please see Section 2.3 of the VERI™ TER [3] for the complete discussion.

### 2.4 Stability Requirements [10 CFR 61.56(b)] and Recommendations of the Branch Technical Position on Waste Form

The requirements of 10 CFR 61.56(b) are intended to result in waste products that exhibit structural stability. Stability is intended to ensure that the waste does not structurally degrade and affect overall stability of the site through slumping, collapse, or other failure of the disposal unit, and thereby lead to water infiltration. Stability is also a factor in limiting exposure to an inadvertent intruder, since it provides a recognizable and nondispersible waste. The Branch Technical Position on Waste Form elaborates on the provisions of Section 61.56.

#### 2.4.1 Structural Stability

A structurally stable waste form will generally maintain its physical dimensions and its form under the expected disposal conditions such as weight of overburden and compaction equipment, the presence of moisture and microbial activity, and internal factors such as radiation effects and chemical changes. Structural stability can be provided by processing the waste to a stable form, as proposed by DTS for the ENCAP™ process. The proposed waste forms resulting from the DTS ENCAP™ process will be packaged, but the liners are given no credit for stability. The waste form has been evaluated for use in direct trench burial, but can also be used in improved disposal conditions, such as in a high-integrity container or an engineered barrier system that might use a concrete vault.

##### 2.4.1.1 Structural Stability of the VERI™ Encapsulation Media

Discussion of as-cured compressive strength, radiation resistance, biodegradation resistance, leachability, immersion resistance and thermal cycling, as applied to the VERI™ waste form has been provided in the VERI™ TR [2] and VERI™ TER [3]. The test results and analyses are considered fully applicable to the ENCAP™ waste form described in the TR Addendum [1], except for the as-cured compressive strength. No other characteristics measured with the tests described in the BTP on Waste Form [7] are expected to be affected by filter

encapsulation. Compressive strength tests, however have indicated that there could be issues associated with slumping or creep of the polymeric waste form. These issues and their resolution are discussed below.

#### 2.4.1.2 Tensile and Compressive Strength of the ENCAP™ Waste Form

A waste form must have sufficient compressive strength to generally maintain its physical dimensions and its form under the expected disposal conditions, such as weight of overburden and compaction equipment. The minimum allowable compressive strength for polymeric waste forms is 60 psi [7]. The VERI™ waste form compressive strength, as demonstrated in the VERI™ TR [2], is expected to be well above the minimum. Test results were on the order of 2000 psi. However, the waste form exhibits some plasticity during compressive strength testing. That is, the VERI™ waste form bulges circumferentially without failure when subjected to maximum yield compressive forces.

Tensile tests were performed to determine the maximum void space which could be tolerated as a result of spent filter cartridge loading, which would still permit the ENCAP™ monolith to withstand the theoretical 60 psi overburden. Tensile strength results are provided in the TR Addendum (Appendix B), however, no data were provided to address deformation under load in tension. Information was requested [9] to address how the material in flexural tension above a permitted void space will behave with respect to time. The concern is whether or not plastic tensile flow or tensile creep can occur over time until a void is filled from above. This would, in effect, create a condition over the waste form similar to vertical settlement and have a potential impact on stability. DTS therefore performed tensile creep testing on VERI™ samples cut from the monolith prepared for testing for the VERI™ TR [2]. The tensile creep testing was performed according to ASTM D2990, "Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics," [13]. The results [11, 12] show that tensile creep samples loaded to 50% of the average measured tensile strength can withstand more than 4000 hours of creep test conditions without rupture. (The test method requires only 1000 hours.) Therefore, the permitted void space from filter cartridge loading was recalculated using 50% of the average measured tensile strength. (See Section 2.4.3.)

#### 2.4.1.3 Correlation Testing

The BTP on Waste Form [7] indicates that if small, simulated laboratory-size specimens are used for the qualification testing program, test data from sections or cores of the anticipated full-scale products should be obtained to correlate the characteristics of actual size products with those of simulated laboratory size specimens. Full size specimens were manufactured and tested for both the VERI™ TR [2] and ENCAP™ TR Addendum [1], so correlation testing is not necessary.

#### 2.4.1.4 Homogeneity

In addition to correlation testing, it is necessary to show that the product is homogeneous to the extent that all regions in the product have compressive strengths analogous to those of the lab-scale specimens. Homogeneity for the VERI™ waste forms was addressed in the VERI™ TR and VERI™ TER. With respect to the ENCAP™ process, the BTP on Concentration Averaging and Encapsulation [8] states that "the bounding volumes and weights [in Appendix

C] will ensure that the potential radiological impacts from encapsulated, single discrete source disposals are within the envelope of impacts that would be calculated if the radioactivity were homogeneously distributed throughout the encapsulating media." The ENCAP™ waste forms are expected to meet the criteria specified in Appendix C, and therefore are considered to act as though they were homogeneous. (See discussion in Section 2.5 for more information.)

#### 2.4.2 Free Liquid

Section 10 CFR 61.56(b)(2) requires that wastes processed to a stable form have a liquid content that does not exceed 0.5 percent of the volume of the waste. The BTP on Waste Form [7] addresses this requirement. Section C.2.g recommends that waste specimens have less than 0.5 percent by volume of the waste specimen of free liquids as measured using the method described in ANS 55.1 [14]. Free liquids should have a pH between 4 and 11.

During testing for the VERI™ TR [2], a small amount of water was discovered when the liner was cut open to retrieve test samples. There were approximately 1.5 gallons (less than 0.10% of the liner volume) located in the small circumferential void between the liner and the solidified VERI™ monolith. Inspection indicated that the water was probably driven off the monolith by the exotherm and volume shrinkage experienced during the binder curing process. This is supported by bench scale testing. When samples are removed from their molds, a small amount of moisture is evident on the surface. This surface moisture seems independent of the degree of pre-watering. Although there may be some free water present following solidification, the volume is well within the maximum, and the VERI™ waste forms therefore fulfill this criterion. The pH of the liquid was determined to be about 6.0 to 6.5, which is well within the permitted range.

The spent filter cartridges encapsulated by this process may contain small amounts of liquid which are not displaced by the binder. All excess liquid is removed during the dewatering process described in the VERI™ TR [2]. Any remaining liquid associated with the spent filter cartridges will be encapsulated. Due to the general imperviousness, and the immersion characteristics of the VERI™ waste form (as discussed in the VERI™ TR [2] and VERI™ TER [3]), such liquids will be effectively isolated within the monolithic waste form, and are not free to migrate to the environment. Therefore, water present inside encapsulated filters does not constitute free liquid as defined by 10 CFR 61.56(a)(3).

#### 2.4.3 Void Spaces

Section 61.56(b)(3) of 10 CFR Part 61 states that void spaces within the waste and between the waste and its package must be reduced to the extent practicable. The polymer binder is forced through the waste and around the spent filter cartridges, then the waste form solidifies in the liner. A circumferential void usually forms between the liner and the final solidified monolith when the curing binder undergoes shrinkage (approximately 2-5%). Otherwise, the solidification reactions are usual polymerization reactions and do not involve formation of gaseous byproducts which might create gas-filled voids within the solidified waste form. No voids were noted during visual inspections of the solidified monolith during testing for the VERI™ TR [2]. The process is effective in minimizing void spaces to the extent practicable, however, it is the responsibility of the user to ensure that liners are filled to reduce void spaces.

The void space in the waste cage (i.e., the central cage filled with spent filter cartridges) is expected to be minimal. The low viscosity of the VERI™ binder, and its natural wetting properties enable migration of the binder throughout the monolith, including the waste cage, while displacing both air and water. This causes the binder to flow into areas previously occupied by air or water. The air and water are swept toward the dewatering internals by the driving force of the vacuum being applied, and are pulled into the dewatering internals due to their lower viscosities. The more viscous binder meets more resistance in attempting to pass into the dewatering internals.

Although void spaces are expected to be filled during dewatering, binder addition, and binder solidification, DTS measured the tensile strength of VERI™-solidified resin, and calculated the maximum void space in the caged area that could be tolerated by the 4-inch VERI™ -solidified protective boundary surrounding the cage. (The cage is fully surrounded by at least 4 inches of VERI™ -solidified resin on every side, including the top and bottom.) These calculations indicated that the ENCAP™ monolith is structurally secure if underlying void spaces are less than 20.2 inches in diameter. Analysis of possible filter loading configurations showed that no single element could create a void large enough to endanger the integrity of the monolith. During loading, filters can be positioned to preclude creation of void spans or diameters greater than the permitted values. Loading specifications can be found in the "General Operating Procedure DT-VER-03, ENCAP™ Debris Loading" [15].

NRC raised questions [9] regarding creep; specifically, whether plastic tensile flow or tensile creep could occur over time until a void is filled from above. This would, in effect, create a condition over the waste form similar to vertical settlement and have a potential impact on stability. The maximum permissible void space was recalculated [11] using 50% of the observed VERI™ tensile strength. (Section 2.4.1.2 discusses how the 50% factor was selected.) The revised calculations [11], [16] indicated that a void space with a dimension not to exceed a diameter of 13.25 inches will maintain its integrity when subject to the overburden of the burial site. Appendix B to the TR Addendum [1], and the General Operating Procedure [15] should be revised to reflect the smaller void space permitted, and the associated limitations on filter loading and positioning.

## 2.5 Waste Loading, including Recommendations of the Branch Technical Position on Concentration Averaging and Encapsulation

The regulation, "Licensing Requirements for Land Disposal of Radioactive Waste," 10 CFR Part 61 [5], establishes a waste classification system based on the concentration of specific radionuclides contained in the waste. The regulation also states that, "the concentration of a radionuclide [in waste] may be averaged over the volume of the waste, or weight of the waste if the units [on the values tabulated in the concentration tables] are expressed as nanocuries per gram." The BTP on Concentration Averaging [8] defines a subset of concentration averaging and encapsulation practices that NRC staff would find acceptable in determining the concentrations of the 10 CFR 61.55 tabulated radionuclides in low-level waste. When the TR Addendum review began, the BTP on Concentration Averaging and Encapsulation was available only in draft form [17].

For filter encapsulation, concentration averaging may be over the volume or mass of the encapsulation providing that the volume and attributes of the waste comply with Appendix C of

the BTP [8]. Review of the TR Addendum [1] indicates that the ENCAP™ waste forms can meet the criteria specified in Appendix C, as follows:

- A minimum amount of encapsulation is necessary to increase the difficulty of an inadvertent intruder moving the waste by hand.

The waste form is approximately 200 ft<sup>3</sup> with the cartridge filters centrally encapsulated. The monolith is large enough to prevent an inadvertent intruder moving the waste by hand.

- The maximum amount of encapsulation is 0.2 m<sup>3</sup> unless a specific rationale is provided.

This limit is provided to ensure that extreme measures are not taken solely for the purposes of dilution. DTS has presented a rationale for encapsulating multiple cartridge filters in 200 ft<sup>3</sup> liners. In Appendix A to the TR Addendum [1], the dilution factor for one filter cartridge encapsulated in a 55-gallon drum (0.2 m<sup>3</sup>) is 7.35, which corresponds to a packing efficiency of 13.6%. The minimum packing efficiency for the ENCAP™ filter loading is expected to be 30% (by filter envelope volume), which is a lower "dilution" factor than that calculated from standard 55 gallon drum encapsulations.

- The maximum amount of gamma-emitting activity is that which, if credit is taken for a 500-year decay period would result in a dose rate less than 0.02 mrem/hr on the surface of the encapsulating media.

In normal low-level waste, the classification-controlling nuclide is Cs-137. Cartridge filters generally do not contain enough of this nuclide, and their classification is usually controlled by either of the beta-emitting nuclides, C-14 or Ni-63. Most of the waste to be encapsulated using the ENCAP™ process does not contain long-lived gamma emitters. Therefore, this is not expected to be an issue. However, if any of the cartridge filters to be encapsulated contain gamma emitters which control the waste classification (see below), the surface dose rate should be calculated and must be less than 0.02 mrem/hr on the surface of the encapsulating media (after a 500-year decay period).

- The classification of the encapsulated package does not exceed Class C.

Classification may be calculated as described below. Waste forms with radionuclide concentrations greater than Class C are not acceptable for disposal.

- The discrete activity source is reasonably centered in the encapsulation.

The monolith is designed with a filter encapsulation cage centered within the monolith with not less than 4 inches of VERI™ waste form on every side. This criterion is met through design of the waste form.

- The structural form meets the requirements of 10 CFR 61.56 for Class B and C waste.

See Section 2.4.

The determination of the waste classification of the disposal package containing the filters within the ENCAP™ liner may always be based on the highest classification associated with any filter, or alternatively, with any 0.2 cubic meter volume of the liner containing the encapsulated filters. Alternately, concentration averaging over the entire ENCAP™ liner containing the filters is permissible if: (a) the concentrations of the primary gamma emitters within individual filters within the ENCAP™ media are reasonably expected to be within a factor of 1.5 of the average concentration over all such filters<sup>1</sup> or (b) the concentration of the other 10 CFR 61.55, Table 1 or 2 nuclides within individual filters are within a factor of 10 of the average concentration over all encapsulated filters within that liner. In either case, the sum-of-the-fractions rule, described in 10 CFR 61.55(a)(7) would apply to the classification of the entire ENCAP™ volume or mass containing the filters.

The waste form also may contain spent ion exchange resin beads as part of the VERI™ matrix. In this case, "waste classification involving averaging the total activity over the total volume or mass of the waste in the [liner] would be accepted, if the classification of the mixture is not lower than the highest waste classification of any individual components [i.e., individual filter cartridges] of the mixture" [Reference 8, Section 3.8].

NRC staff recommends that the vendor or licensee classifying the mixture of filter cartridges [and spent ion exchange resin beads, if applicable] have in place a quality control program to ensure compliance with the waste classification provisions of 10 CFR 61.55.

## 2.6 Process Control Program

The introduction to the BTP on Waste Form [7] recommends that waste generators using an approved topical report process develop plant-specific process control procedures to demonstrate that a stabilized plant-specific waste stream satisfies Part 61 waste form requirements. DTS provided a set of operating procedures as part of the VERI™ TR. The operating procedures consist of PCP-03, "Process Control Procedure, Vinyl Ester Resin in Situ (VERI™) Solidification," and GOP-08, "General Operating Procedure, VERI™ Solidification." The Process Control Procedure (PCP) describes the method for developing the quantities of catalyst and promoter that will achieve the desired optimal solidification formulation. Once the amounts of catalyst and promoter necessary to achieve the desired gel time and quality of the final product have been determined, the General Operating Procedure lists the steps for final waste form solidification. These procedures, with the comments outlined in the associated RAI, were determined to be generally acceptable [3]. Note that use of modifiers, as described in these documents, has not been approved by the NRC. See the VERI™ TER [3] for details.

A General Operating Procedure specific to the ENCAP™ process has also been provided [15]. This document, when used with PCP-03 and GOP-08, described above, has been determined to be generally acceptable. It should be revised to reflect the updated limits on void spaces through revised criteria for filter loading and positioning according to the discussion in Section 2.4.3 above, and should also be revised to limit waste to spent filter cartridges only.

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<sup>1</sup> Applies if these nuclides would dictate the classification of the waste.

## 2.7 Reporting of Mishaps

According to the BTP on Waste Form [7], vendors and processors are included in the group who are requested to report mishaps. For the DTS ENCAP™ process the following types of mishaps should be reported for solidified Class B or Class C waste forms:

- Greater than 0.5 percent volume of free liquid.
- Concentrations of radionuclides greater than the concentrations demonstrated to be stable in the waste form in qualification testing accepted by the regulatory agency.
- Greater or lesser amounts of solidification media than were used in qualification testing accepted by the regulatory agency.
- Presence of chemical ingredients not present or accounted for in qualification testing accepted by the regulatory agency.
- Instability evidenced by crumbling, cracking, spalling, voids, softening, disintegration, non-homogeneity, or change in dimensions.
- Evidence of processing phenomena that exceed the limiting processing conditions identified in the applicable TRs or operating procedures such as foaming, excessive temperature, premature or slow hardening, production of volatile material, etc.
- The calculated classification of the encapsulated waste form exceeds Class C.

Waste form mishaps should be reported to the NRC's Director of the Division of Waste Management and the designated State disposal site regulatory authority within 30 days of knowledge of the incident. For any such waste form mishap occurrences, the affected waste form should not be shipped off-site until approval is obtained from the disposal site regulatory authority. Low-level waste generators and processors are required by 10 CFR 20.311/20.2006 to certify that their waste forms meet all applicable requirements of 10 CFR Part 61, and waste forms that are subject to the types of mishaps listed above may not possess the required long-term structural stability. When mishaps of the nature described above occur, it is expected that, before the waste form is shipped to a disposal facility, either adequate mitigation of the potential effects on the waste form, or an acceptable justification concerning the lack of any potential significant effects of the affected waste form on the overall performance of the disposal facility would be provided.

## 3.0 CONCLUSIONS

The DTS Topical Report Addendum [1], with the DTS responses to NRC comments and questions [10, 11, 12] is acceptable as a reference document for licensing the waste form produced by the ENCAP™ process, subject to certain limitations and further actions by DTS. NRC staff recommendations are also listed.

### 3.1 Limitations

- a. The resins used to produce the encapsulating waste forms are limited to those specifically identified in the VERI™ TR and associated TER as those used to prepare the test specimens on which the data were obtained.
- b. The disposal unit containing the encapsulated mass must be segregated from disposal units containing Class A wastes that do not meet the structural stability requirements in 10 CFR 61.56(b).
- c. If any of the cartridge filters to be encapsulated contain gamma emitters which control the waste classification (see Section 2.5), the calculated dose rate must be less than 0.02 mrem/hr on the surface of the encapsulating media (after a 500-year decay period).

### 3.2 Further Actions

- a) Information to be added to the revised Topical Report Addendum:
  1. Appendix B to the TR Addendum [1] should be revised to reflect the smaller void space permitted considering tensile creep test results.
  2. The General Operating Procedure [15] should be revised to reflect the smaller void space permitted considering tensile creep test results, and the associated limitations on filter loading and positioning.
  3. The General Operating Procedure [15] should be revised to limit waste to be encapsulated to spent filter cartridges, and other items such as tools, instruments or valves that do not exceed the specified size, and will not chemically or mechanically attack, or otherwise impugn, the integrity of the monolith.
  4. Additions/alterations as discussed in the responses [10, 11, 12] to the NRC RAI [9].

### 3.3 Recommendations

- a) NRC staff recommends that the vendor or licensee classifying the mixture of filter cartridges [and spent ion exchange resin beads, if applicable] have in place a quality control program to ensure compliance with the waste classification provisions of 10 CFR 61.55.

## REFERENCES

1. "ENCAP™ Encapsulation Utilizing the VERI™ Solidifications Process," Revision 1, Addendum 1, DT-VERI-100-NP/P-A, May 1, 1994. (Docket Number WM-105).
2. "VERI™ (Vinyl Ester Resin In Situ) Solidification Process for Low Level Radioactive Waste," DT-VERI-100-NP/P-A, April 5, 1993.
3. "Technical Evaluation Report related to Topical Report DT-VERI-100-NP/P, VERI™ (Vinyl Ester Resin In Situ) Solidification Process for Low-Level Radioactive Waste," U.S. Nuclear Regulatory Commission, December 1992.
4. "Elimination of Low-Level Radioactive Waste Topical Report Review Program," Federal Register Notice dated May 17, 1995 (60 FR 26466).
5. Code of Federal Regulations, Title 10, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," U.S. Nuclear Regulatory Commission, Washington, D.C., January 1, 1991.
6. U.S. Nuclear Regulatory Commission, "Technical Position on Waste Form," Rev. 0, May 1983.
7. U.S. Nuclear Regulatory Commission, "Technical Position on Waste Form," Rev. 1, January 1991.
8. U.S. Nuclear Regulatory Commission, "Issuance of Final Branch Technical Position on Concentration Averaging and Encapsulation," January 17, 1995.
9. Request for Additional Information from J. Thoma/NRC to C. Jensen/DTS, dated September 14, 1994.
10. Letter enclosing "Response to RAI #1," from C. Jensen/DTS to J. Thoma/NRC dated October 21, 1994.
11. Letter enclosing "Supplemental Submittal" from C. Jensen/DTS to J. Thoma/NRC, dated December 18, 1997.
12. Letter enclosing "ASTM Test Report, Supplement #2 to ENCAP™ RAI #1," from C. Jensen/DTS to J. Davis/NRC, dated March 23, 1998.
13. "Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics," ASTM D2990-90, American Society for Testing and Materials.
14. ANS 55.1, "American National Standard for Solid Radioactive Waste Processing System for Light Water Cooled Reactor Plants," American Nuclear Society, 1979.
15. "General Operating Procedure DT-VER-03, ENCAP™ Debris Loading," Rev. 0, Diversified Technologies, Inc.; December 4, 1994. Submitted via letter from C. Jensen/DTS to J. Thoma/NRC, December 6, 1994.

16. "VERI Liner Protective Cage Calculations," fax transmittal from C. Jensen/DTS to J. Davis/NRC dated 29 December, 1999.
17. Memorandum from M.R. Knapp/NRC to Distribution, "Final Branch Technical Position on Concentration Averaging and Encapsulation," dated April 21, 1994.

**TOPICAL REPORT ADDENDUM**

**ENCAP™ ENCAPSULATION UTILIZING  
THE VERI™ SOLIDIFICATION PROCESS**

T.R. No. DT-VERI-100-NP/P-A  
(Docket Number WM-105R1)  
Addendum 1

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## ABSTRACT

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This Addendum to Topical Report DT-VERI-100-NP/P-A, VERI™ (Vinyl Ester Resin In Situ) Solidification Process for Low-Level Radioactive Waste (Docket Number WM-105R1) presents information and data in support of a process of heterogenous waste encapsulation in a polymer matrix.

This process, hereinafter referred to as ENCAP™, utilizes the NRC-approved waste forms generated using the VERI™ process referenced in the parent Topical Report (TR) to encapsulate or entomb waste in the solidified free-standing monolith. The incorporation of non-uniform waste products in the monolith generates a heterogenous waste form.

While spent filter cartridges are envisioned as the primary object(s) to be encapsulated, other objects may include such items as tools, instruments, or valves that do not exceed a specified size and will not chemically or mechanically attack, or otherwise impugn, the integrity of the monolith.

This TR revision describes the process for encapsulating these heterogenous wastes in an entombing monolithic polymer matrix, including the steps taken to protect the integrity of the monolith, the design basis to preclude environmental exposure of the entombed waste, and the limitations on the applicability of the process.

Results of full-scale filter cartridge encapsulation efforts undertaken in 1993 are discussed and cited as qualitative evidence of the efficacy of the encapsulation process.

## 1.0 INTRODUCTION

The ENCAP™ process is needed by the nuclear industry to minimize the environmental impacts and costs of shallow land burial (at low level waste disposal facilities) of waste filter cartridges from nuclear power plants.

For purposes of this Addendum, the waste to be encapsulated will be generally referred to as "filter cartridges," though this is intended to be inclusive of the general type or category of waste to be encapsulated. While spent filter cartridges are envisioned as the primary object(s) to be encapsulated, other objects may include such items as tools, instruments, or valves that do not exceed the specified size and will not chemically or mechanically attack, or otherwise impugn, the integrity of the monolith.

The reduction in environmental impact and in waste disposal costs would be achieved through reduced handling of waste packages at the reactor site, during transport, and at the disposal facility. The use of the ENCAP™ process would also reduce transportation and burial space requirements for disposal of waste filter cartridges because of the packaging efficiency of large waste containers, compared to smaller waste packages currently in use.

The traditional methods of waste filter cartridge disposal have been: 1) to encapsulate a single filter cartridge in grout inside a 55-gallon drum, or 2) to place several filters inside a high integrity container (HIC).

The ENCAP™ Process would result in encapsulation of numerous filter cartridges in a matrix of vinyl ester styrene and spent ion exchange bead resins. The spent bead resins may or may not be contaminated with radionuclides. A 200 ft<sup>3</sup> ENCAP™ monolith could encapsulate from 20 to approximately 100 filter cartridges. The number of cartridges to be loaded in a given ENCAP™ liner would depend upon a number of variables, including the size of the filter cage, size and shape of the cartridges, and the concentration of radionuclides on the filters and in the resin matrix.

## 2.0 PROCESS DESCRIPTION

The ENCAP™ process uses VERI™ solidification to create an enveloping monolith around a caged region of heterogenous wastes (i.e., spent filter cartridges). The ENCAP™ process involves preparation of an encapsulation liner and internal cage (as described in this document) and solidification of the resulting resin-filled liner with the VERI™ polymer solidification process described in the parent TR.

An encapsulation liner is set up with dewatering internals in the same manner as that described in the parent TR for preparation of a solidification liner. A cage that complies with the design criteria discussed in this document is placed in the liner in preparation for receiving waste.

A protective layer of ion exchange resin is introduced to the liner. This resin layer must be a minimum of 4" deep, and may consist of either contaminated or non-contaminated resins. The resin may be sluiced with water or manually poured into the liner. Permitted resins are described in the parent TR.

This resin layer serves the dual function of physically protecting the dewatering internals from damage during introduction of filter cartridges and establishing the bottom exclusionary zone that consists entirely of VERI™-solidified resins.

When the cage has been loaded with filter cartridges or other wastes to be entombed, the cage lid is closed and the liner is filled with ion exchange resin to a level covering the caged waste a minimum of 4". The fill resin may be contaminated or non-contaminated, as long as it is of the type identified in the parent TR as being accepted for VERI™ solidification.

The resin may be sluiced in a slurry form or manually poured from containers in a dry or damp state. Dry resin, like slurried resin, tends to flow well into the crevices and channels of the waste cage. Damp resin, if manually introduced to the liner, tends to clump, resulting in uneven distribution. The liner may be filled with water to permit the damp resin to become buoyant in the aqueous solution and to migrate readily throughout the encapsulation liner.

When the ENCAP™ liner has been filled with resin, VERI™ solidification equipment is positioned as described in the parent TR, and the VERI™ process proceeds in the same manner. Upon completion of introduction of the catalyzed and promoted binder to the encapsulation liner, the exotherm is monitored, verification of compliance with acceptance criteria is confirmed, and the ENCAP™ liner is capped and prepared for shipment.

### **3.0 ENCAPSULATION LINER**

The encapsulation liner is a right cylinder of carbon steel or polyethylene plastic with maximum bounding dimensions of 78" in diameter and 72" in height, yielding a maximum volume of approximately 200 ft<sup>3</sup>. The configuration, dewatering internals and maximum liner size are described in TR DT-VERI-100-NP/P-A. No credit is taken for the structural strength of the disposal liner in the encapsulation process for waste form qualification.

The structural integrity of the ENCAP™ carbon steel or polymeric liner does apply for compliance with DOT regulations as well as integrity requirements for handling the monolith at the burial site.

The key feature of the encapsulating liner is a cage positioned inside the liner for receipt of the material to be encapsulated. This cage is designed to create an exclusionary zone between the entombed waste and the side wall of the encapsulation liner. Several generic features must be incorporated in the cage to ensure maintenance of the exclusionary zone, including the following design characteristics:

- maintenance of a minimum 4" free space between the cage and the bottom and outside wall of the liner;
- construction of perforated carbon steel, heavy wire mesh, fiberglass sheet, or other material of sufficient strength to maintain its physical shape and the minimum boundary region when filled with filter elements;
- a minimum of 10% of the cage's surface area must consist of holes or slots that result in areas of contiguous solidified media connecting the entombed waste to the boundary exclusionary region;

- a closure device to prevent buoyant filters or other objects from surfacing when submerged in the polymer matrix prior to gelation;
- stand-offs or other material used for physically positioning or supporting the cage shall be of material and a design (emphasis added) that precludes corrosion (which is prohibited and which may result in a pathway between the entombed waste and the environment) during storage/burial.
- when possible, stand-offs and other supports should be fabricated of material that will fuse to the curing polymer (e.g., fiberglass material cured with either polyester or vinyl ester resin).

A general configuration drawing of the ENCAP™ liner is shown in Fig. 1 of the Graphics section of this report. Details of a typical ENCAP™ protective cage appear in Fig. 2. Fig. 5 and 6 are photographs of a VERI™ solidified mass fused to the FRP side wall of a liner. The chemical fusion between the VERI™ mass and the FRP material resists delamination, even when challenged with mechanical separation (e.g., penetration with a screwdriver).

#### **4.0 WASTE FORM**

The encapsulating waste form is spent ion exchange resin solidified in a VES polymer matrix, as described in TR DT-VERI-100-NP/P-A. The waste to be encapsulated does not affect the structural stability of solidified monolith when the potential void spaces are limited, as shown in the structural analysis and discussion presented in Appendix B. Such waste form characteristics as compressive strength, water immersions, biodegradation, irradiation tolerance, and leachability are not influenced by the entombed waste.

##### Minimum Requirements [10 CFR 61.56(a)]

##### Packaging [10 CFR 61.56(a)(1)]

The waste form will be contained in steel drums or liners, thus satisfying the requirement that waste must not be packaged in cardboard or fiberboard boxes.

#### Liquid Waste [10 CFR 61.56(a)(2)]

This section specifies that liquid waste must be solidified or packaged in sufficient absorbent material to absorb twice the volume of the liquid. The liquid portion of the waste will be solidified in the VES binder, and thus fulfill this requirement.

#### Free Liquid [10 CFR 61.56(a)(3)]

This section specifies that free-standing liquid in the solid waste shall not exceed 1% of the volume of the solid waste. The objects encapsulated by this process may contain small amounts of liquid that are not displaced by the binder. Examples of such liquids are water held in inside-loading filter cartridges and water held in the irregular shapes of otherwise-solid objects.

All excess liquid is removed during the dewatering process described in the parent TR. Any remaining liquid associated with the objects to be entombed will be entombed/encapsulated with the object. Due to the general impervious and water immersion characteristics of the VERI™-solidified resin (as demonstrated in the waste form testing for the parent TR), such liquids will be effectively isolated within the monolith and are not free to migrate to the environment, even when the liner corrodes away in the burial environment. Therefore, any water present in the entombed waste does not constitute free standing water or free liquid as defined by 10 CFR 61.56(a)(3).

Empirical testing performed in support of the parent TR demonstrates that a liner containing spent ion exchange resin (or other process media as defined in the TR) and solidified with the VERI™ process results in a final waste form that complies with the maximum permissible volume of free standing water of <1% by volume of waste.

#### Reactivity of Product [10 CFR 61.56(a)(4)]

This section specifies that the waste must not be readily capable of detonation, explosive decomposition, reaction at normal pressures and temperatures, or explosive reaction with water. The solidified binder and contained waste meet all these requirements.

#### Toxic Gas Generation [10 CFR 61.56(a)(5)]

This section specifies that the waste must not be capable of generating toxic gases, vapors, or fumes harmful to persons transporting, handling, or disposing of the waste form. The solidified VES emits none of the above that would be harmful to personnel.

#### Pyrophoricity [10 CFR 61.56(a)(6)]

This section specifies that a waste must not be pyrophoric, as defined in 10 CFR 61.2 of the regulations. The solidified waste forms are not pyrophoric, nor do they contain any materials that are pyrophoric. Therefore, the encapsulated/solidified wastes satisfy this requirement.

#### Gaseous Wastes [10 CFR 61.56(a)(7)]

This encapsulation/solidification process is not proposed for use on gaseous wastes, so this section of the regulation is not applicable to the Diversified Technologies Services, Inc. waste forms.

#### Hazardous Waste [10 CFR 61.56(a)(8)]

This section requires that waste containing hazardous, biological, pathogenic, or infectious material must be treated to reduce to the maximum extent practicable the potential hazard from the non-radiological materials.

Neither the VERI™-polymerized binder material nor the waste stream materials identified will contain materials defined as hazardous, biological, pathogenic, or infectious. Numerous TCLP tests of the binder, catalyst, promoter, and additives have consistently shown the polymerized form to be non-hazardous both with and without the presence of wastes.

#### Stability Requirements [10 CFR 61.56(b)]

This section requires that the solidification process result in a waste form with structural stability. Stability is intended to ensure that the waste does not structurally degrade and affect the overall stability of the burial site subsidence through slumping, collapse, or other failure of the disposal unit, leading to water infiltration. Stability is also a factor in

limiting exposure to an inadvertent intruder, since it provides a recognizable and non-dispersible waste form.

### Structural Stability

The ENCAP™ entombing of waste within the VERI™-solidified monolith does not physically impair dimensional stability under the expected disposal conditions such as weight of overburden and compaction equipment. Previous testing has shown that the presence of liquid, microbial activity, and radiation (when limited to  $<1 \times 10^8$  Rad) has no negative effect on the structural integrity of the binder matrix and, hence, the integrity of the monolith.

It has been shown, as reported in the parent TR, that the compressive strength (typically  $>2000$  psi) of the VERI™ waste form is several factors greater than the minimum required for stability. Qualitatively, the plasticity of the VERI™ waste form is well suited for encapsulation. This plasticity is evident during compressive strength testing, as shown in Fig. 3 and 4 in Graphics section of this report.

Unlike cementitious waste samples (which tend to experience acute failure by shearing or spalling during testing), the VERI™ waste form tends to bulge circumferentially without failure when subjected to maximum yield compressive forces. It is postulated that this plasticity may tend to protect the integrity of the monolith when subject to compressive forces in the burial environment. It should be noted that no credit is taken for the favorable plasticity of the waste form in establishing the ability of the waste form to maintain integrity of the monoliths. The information is presented simply for its anecdotal value.

Likewise, no credit for stability is taken for the liners in which the VERI™ process is used. In those instances when the entombed waste may be stored on an interim basis before final disposal, consideration should be given to performing the ENCAP™ process in corrosion-resistant liners. Such corrosion resistance, while not an issue from a waste form perspective, may be important to ensure the viability of the waste package a number of years from now, when the waste is moved from its storage site to the transport cask for disposal. No aspect of the ENCAP™ process is affected by, or prohibits use in, such liners.

Appendix B of this report presents a discussion and mathematical analysis of the impact of potential void spaces created by the entombed waste on the integrity of the monolith.

The waste forms produced by the ENCAP™ process meet the structural stability requirements of land burial or burial in an engineered barrier system. The minimum separation of the waste-containing cage from the side wall of the liner is intended to ensure sufficient strength to prevent environmental intrusion into the caged waste area, or escape of waste from the area. The filling of interstitial space within the caged waste provides additional strength and stability to the monolith.

## 5.0 WASTE LOADINGS

Waste loadings (or packaging efficiencies) for ENCAP™ entombing of spent filter cartridges were ascertained from full-scale encapsulations. Filter media loading values for the 80 ft<sup>3</sup> ENCAP™ liners referenced in the table below are based on the volume of entombed filters calculated by two different methods.

Loading values for filter media were determined by subtracting internal void volume from the outside envelope volume, divided by the disposal volume of the liner. Filter envelope volumes are based on the volume of entombed filters (as determined by the outside filter envelope volume) divided by the volume of the solidified monolith. Based on this data, typical filter loadings for the ENCAP™ process can be expected to be a minimum of 15% by filter media volume and 30% by filter envelope volume. The following table shows the actual data from three 80 ft<sup>3</sup> ENCAP™ liners.

			FILTER WASTE LOADING CALCULATIONS	
Container I.D.	Filters #	Filter Env. Vol - C.F.	Filter Media Volume	Filter Envelope Volume
93-F-001	64	22.6	$\frac{13.86}{88.00} = 16\%$	$\frac{22.60}{76.46} = 30\%$
93-F-002	67	26.5	$\frac{14.79}{88.00} = 17\%$	$\frac{26.50}{76.46} = 35\%$
93-F-003	91	29.5	$\frac{18.00}{88.00} = 20\%$	$\frac{29.50}{76.46} = 38\%$

The proposed Branch Technical Position (BTP) on encapsulation permits the radionuclides of an encapsulated source to be averaged over the volume of a 0.2 m<sup>3</sup> (55-gallon drum) liner. The practice of encapsulating a single filter element (e.g., ≈ 1 ft<sup>3</sup>) per drum equates to a waste loading of 13% (1 ft<sup>3</sup> filter vol ÷ 7.5 ft<sup>3</sup> liner volume).

Present industry practice varies among licensees, but the standard method is to average curie content over the filter envelope. In some instances, when filters are shredded, or when a more conservative approach is desired, curie concentration is averaged over the filter media volume, which is less dilutive.

The waste loading in each of the ENCAP™ liners shown above is greater than the 13% cited for cement encapsulation of a filter in a 55-gallon drum (discussed in Appendix A). As a result, the averaging of radioisotopic activity over the volume of the ENCAP™ solidification liner is less dilutive than that of a filter or source encapsulated in a 55-gallon drum.

## 6.0 VOIDS

A number of qualitative postulations provide grounds for belief that the fraction of void space in the waste cage is minimal. Void spaces or pockets inside (or contiguous to) irregularly-shaped objects introduced in a random manner to the solidification liner cage are minimized by the inherent characteristics of the encapsulation binder and process. The vacuum drawn on the liner during the filling of the liner in the VERI™ solidification process tends to expand the air present in void spaces in and around the waste objects, resulting in a net reduction of air volume in the voids.

Upon cessation of the vacuum and return of the liner to atmospheric pressure plus the column depth of the binder, any remaining air pockets will collapse to one-half to one-quarter their size under the vacuum. This collapse effectively pulls binder into these pockets, thus reducing the net volume of the void space present.

The low viscosity of the VERI™ binder (100-200 cps) and its natural wetting properties due to its low surface tension enable migration of the binder throughout the monolith while displacing both air and water. The water and air are swept toward the dewatering internals by the driving force of the vacuum being applied. The water and air are preferentially pulled into the dewatering internals due to their much lower viscosity. The more viscous binder meets resistance in passing into the internals through the restrictive openings.

Thus, even though the binder front may not reach all sections of the dewatering internals at the same time, the water and air preferentially enter, causing the binder to flow into areas previously occupied by water/air. For this reason, the period of time during which a mixture of binder and air/water is seen in the sight glass exiting from the liner is relatively short.

Any voids that may be present in the caged waste will be totally encapsulated, and have no means of transport of material to the environment.

## **7.0 PROSCRIBED WASTES**

Certain wastes and waste forms are not physically compatible with the polymer encapsulation process, or are prohibited for regulatory reasons.

### Physical Incompatibility

Included in incompatible waste forms are those materials that interfere with the proper migration of the encapsulating binder throughout the monolith, or that may react chemically with the solidified monolith, negatively impacting its strength and durability.

The variety of physical sizes and characteristics of waste to be encapsulated cannot be precisely defined or quantified. Nonetheless, prudent judgment can be exercised regarding introduction of many objects, to ensure maximum monolith integrity.

An example of an inappropriate physical waste form is plastic bags of dry active waste (DAW). Plastic bags or other objects with a large horizontal cross-section may result in excessive void space, as well as create a shadow (that may have deficit binder impregnation) directly below the object. In addition, the void space created by the entombed object must be less than the span or diameter discussed in Appendix B.

In the case of large flat objects, the shadowing problem can be mitigated or eliminated by positioning the object in a vertical orientation to minimize the cross-section of the object when viewed from above. Likewise, a large sheet of plastic draped in the cage may unnecessarily obstruct the normal binder pathway. The same plastic, when formed into a tight roll, would permit adequate polymer impregnation past and under the roll.

Objects with a potential to expand in size due to chemical or biological reactions that may impugn the integrity of the monolith are prohibited. No objects with this potential have been identified. Likewise, no solid wastes subject to encapsulation are chemically incompatible with the solidified polymer monolith.

#### Regulatory Incompatibility

10 CFR Part 61 and certain other regulations prohibit solidification or encapsulation of wastes that may physically impair the integrity of the final waste form, or result in a waste form that is not allowed under present regulations. Examples are:

- Reactivity of Product [10 CFR 61.56(a)(4)]: Prohibits wastes readily capable of detonation, explosive decomposition, or reaction, at normal pressures and temperatures, or of explosive reaction with water.
- Toxic Gas Generation [10 CFR 61.56(a)(5)]: Prohibits waste capable of generating toxic gases, vapors, or fumes harmful to persons transporting, handling, or disposing of the waste form.
- Pyrophoricity [10 CFR 61.56(a)(6)]: Prohibits wastes that are pyrophoric, as defined in 10 CFR 61.2 of the regulations.
- Gaseous Wastes [10 CFR 61.56(a)(7)]: Prohibits encapsulation/solidification of gaseous wastes.
- Hazardous Waste [10 CFR 61.56(a)(8)]: Prohibits waste containing hazardous, biological, pathogenic, or infectious material. When present, such materials must be treated to reduce to the maximum extent practicable the potential hazard from the non-radiological materials.
- EPA Regulations: Prohibits encapsulation or solidification of organic wastes as a means of disposal, if the process does not alter or destroy the organic waste in a manner that renders it non-hazardous. Since the VERI™ process is not intended to do so, encapsulation of hazardous organic wastes is prohibited.

Neither the VERI™-polymerized binder material nor the waste that is acceptable to be entombed contains materials identified or defined as hazardous, biological, pathogenic, or infectious. Numerous TCLP tests of the binder, catalyst, promoter, and additives have consistently shown the polymerized waste form to be non-hazardous both with and without the presence of wastes that were initially non-hazardous.

## 8.0 ACCEPTANCE FOR BURIAL

The VERI™ process described in TR DT-VERI-100-NP/P-A, "VERI™ (Vinyl Ester Resin In Situ) Solidification Process for Low-Level Radioactive Waste" (Docket No. WM-105), is qualified for stabilization of Class B and C wastes when spent ion exchange resin (and related media) is solidified in liners as large as 200 ft<sup>3</sup>. VERI™ solidification of spent ion exchange resin is utilized as the base process for the ENCAP™ process for encapsulation of heterogenous wastes.

Since the mechanical and chemical nature of the in situ solidification process (and the resulting waste forms), are unaffected by the presence of heterogenous wastes, it is presumed that the solidified homogenous spent resin remains an accepted stabilized waste form.

The State of South Carolina Department of Health and Environmental Control (DHEC) granted approval on June 28, 1993 for burial of resins solidified using the VERI™ process in the manner described in the parent TR. The ENCAP™ filter encapsulation process was reviewed, and approval was by DHEC was granted on July 8, 1993. A clarifying letter issued by CNSI on August 3, 1993 confirmed that burial of encapsulated filters was acceptable at Barnwell, South Carolina with the provision that they would be subject to the same burial restrictions and requirement as all other Class B and C wastes.

Subsequently, three 80 ft<sup>3</sup> liners were filled with filters and solidified with the VERI™ process described in this Addendum. The liners were transported to and buried at Barnwell during 1993. This encapsulation process has not been submitted to the Hanford, Washington facility for similar approval.

The solidified polymer material passes TCLP testing for absence of toxic or hazardous materials, including volatiles. The Department of Energy's Hanford, Washington facility has approved the VERI™ solidification agent as meeting its Waste Acceptance Criteria (WAC) for disposal in its land burial facility.

## 9.0 FULL-SCALE EXPERIENCE

In addition to the full-scale testing performed by Diversified Technologies Services, Inc. in support of the parent TR, commercial solidifications have been performed using this process. In 1992, a nuclear power plant solidified spent resin generated from cleanup of a LOMI-CANDEREM decontamination process. The resin liner was successfully solidified and buried at the Barnwell, South Carolina disposal site.

In 1993, a liner of spent mixed bed resin, primarily Reactor Cleanup System (RCS) resin, was solidified using the VERI™ process. The liner was also buried at Barnwell.

In 1993, three liners of spent filter cartridges were encapsulated using the ENCAP™ process. These cartridges were generated from the primary, spent fuel pool, and radwaste cleanup systems in a PWR plant. During these encapsulations, it was observed that 50% of the cage volume was displaced by filters, but this is not parametrically important.

The encapsulations proceeded in the manner typical of a VERI™ solidification, though three enhancements were incorporated into the ENCAP™ process as a result of this experience.

First, the vacuum pump drawing a suction on the liner was turned on before introduction of the binder. This initiated a suction on the liner immediately when the binder cap was established on the resin bed, and provided a downward pathway for air displaced by the binder.

Second, a closure was placed on the internal cage to preclude buoyant objects from breaching the surface prior to gelation of the binder. Upon gelation, all objects are effectively locked in place throughout the balance of the cure process.

Third, a low-volume sweep of the air from the freeboard of the liner was procedurally implemented using ports already available on the fillhead. This air was exhausted to a HEPA-protected exhaust point as a protective measure, though no airborne contamination was expected or found. This air sweep was designed to minimize the condensation that occurs on the cold steel liner during the exothermic cure. A small amount of moisture was present on top of the ENCAP™-solidified monolith. Though an on-site assessment of moisture deemed the volume to be insignificant, nil moisture was

desirable, and the described action was implemented. This procedural action was successful in preventing the formation of condensation in subsequent ENCAP™ solidifications.

ENCAP™ solidifications performed after implementation of each of these precess enhancements were performed successfully and without incident. Full-scale experience using the VERI™ process itself is discussed in the parent TR.

## 10.0 SUMMARY

The ENCAP™ process uses VERI™ solidification to encapsulate a caged region of waste cartridge filters in a 200 ft<sup>3</sup> monolith. The monolith is composed of a waste form (i.e., spent ion exchange resin beads stabilized in vinyl ester styrene) that has been demonstrated to comply with the structural stability requirements of 10 CFR 61 for Class B and C waste forms.

A 200 ft<sup>3</sup> ENCAP™ monolith could encapsulate a large quantity (from 50 to 100) waste filter cartridges, with the number of cartridges depending on their physical volume, radionuclide content of the cartridges, and radionuclide content of the spent ion exchange resin beads in the ENCAP™ monolith.

The caged resin is positioned within the liner so that it is at least 4" from any surface of the monolith. Thus, the cage region that contains the filters entombed in the VERI™ waste form is itself entombed in a 4" thick cylinder of VERI™ waste form. Diversified Technologies Services, Inc. is not aware of any credible mechanism for an acceptable entombed waste to impugn the integrity of the monolith when encapsulated with the ENCAP™ process.

A specific rationale would be required (by the September 16, 1993 Proposed BTP on Concentration Averaging and Encapsulation) before taking credit for volumes or masses larger than 0.2 m<sup>3</sup> when determining waste concentrations. Such a rationale is presented in Appendix A to justify consideration of the volume or mass of an ENCAP™ monolith when determining waste concentrations. The rationale is based on maintaining a minimum ratio of waste volume to encapsulated mass volume that would be consistent with the accepted 0.2 m<sup>3</sup> encapsulated mass.

## GRAPHICS

This section contains the following drawings and photos:

Fig. 1 - ENCAP™ Liner: Protective Cage (1 pg)

Fig. 2 - ENCAP™ Protective Cage (1 pg)

Fig. 3 - Compressive Strength Testing: Start &

Fig. 4 - Compressive Strength Testing: End (1 pg)

Fig. 5 - Monolith: Sectioned Monolith Showing VES Fusion to FRP &

Fig. 6 - Sample: Sample for Machining Showing VES Fusion to FRP (1 pg)

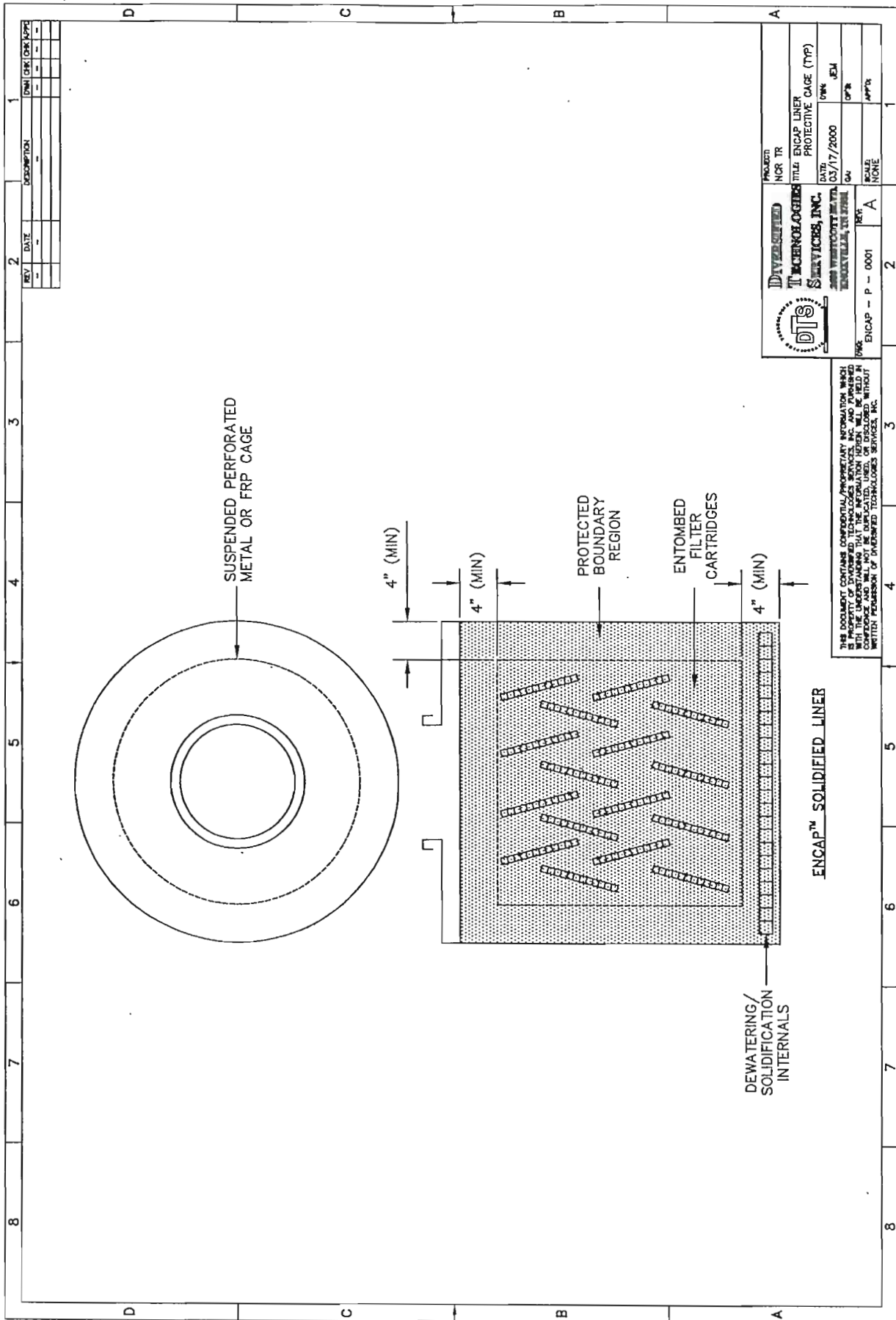


Fig. 1

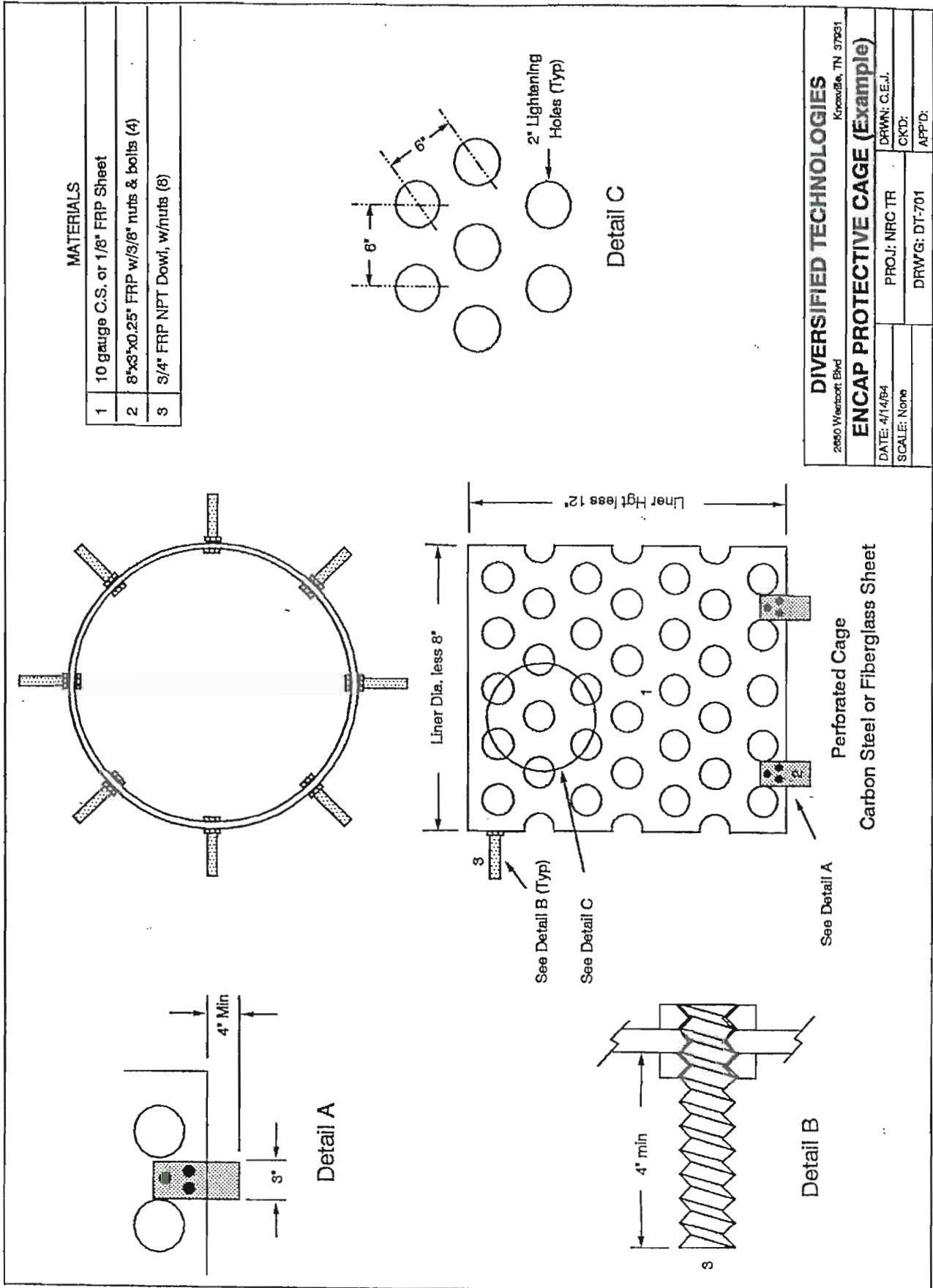
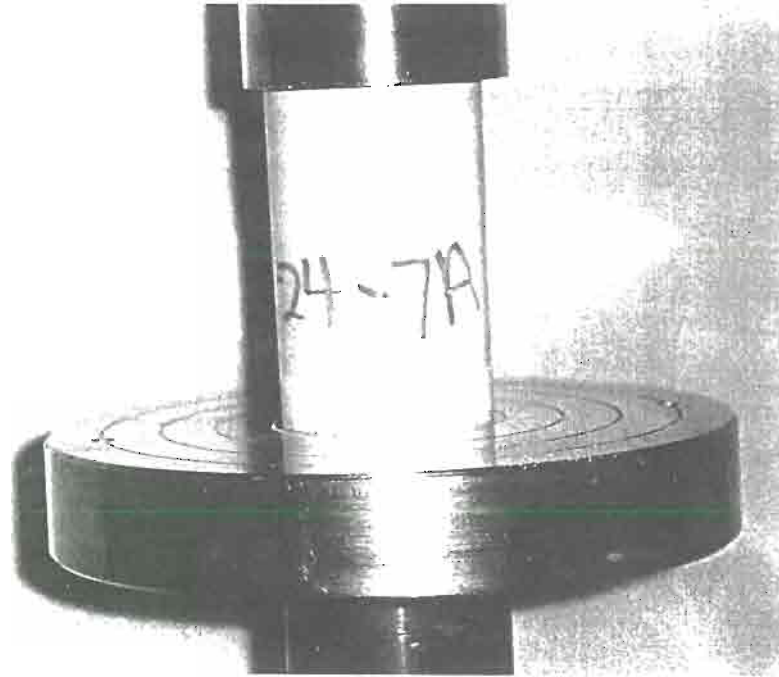
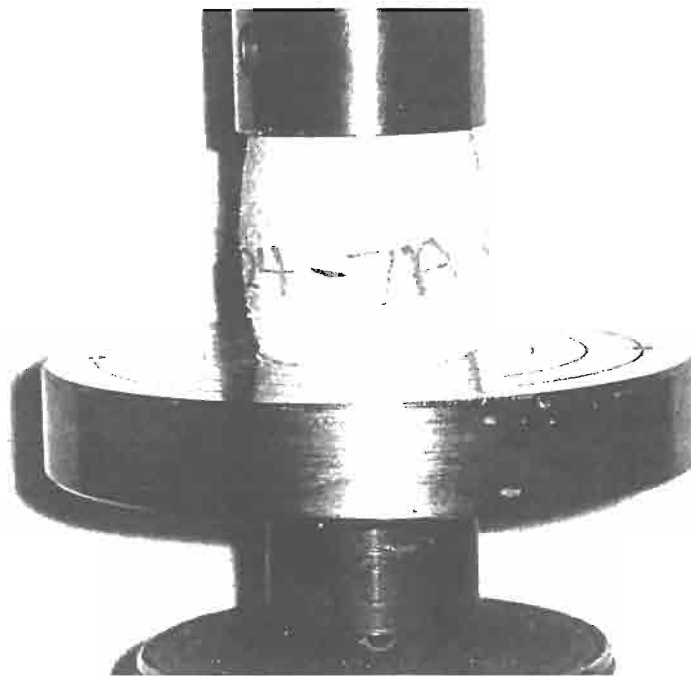


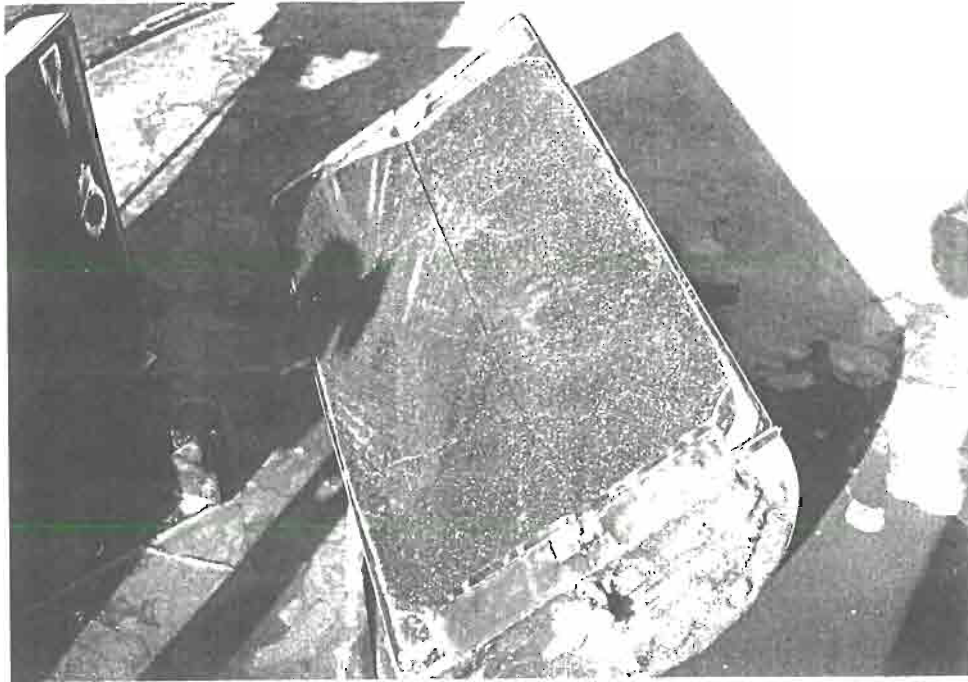
Fig 2.



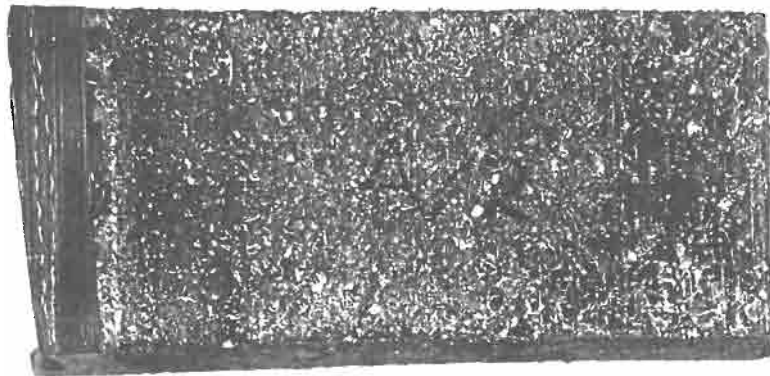
**Fig. 3** Compressive Strength Testing: Start  
Instron Tensile Tester : 0.05 in/min  
VES Solidified Resin



**Fig. 4** Compressive Strength Testing: End  
Plastic Deformation, Monolith Intact  
VES Solidified Resin



**Fig. 5** Sectioned VES Monolith  
Fused to FRP Container



A/2  
11-30-01

**Fig. 6** Sample for Machining  
Showing VES Fusion to FRP Sidewall

## APPENDIX A

This appendix contains the following document:

Rationale for Curie Concentration Averaging (2 pgs)

## RATIONALE FOR CURIE CONCENTRATION AVERAGING

The September 16, 1993 Proposed Branch Technical Position (BTP) on Concentration Averaging and Encapsulation would require that a specific rationale be provided before credit could be taken for the volume of the ENCAP™ liner that is greater than the 0.2 cubic meter encapsulation volume used when determining waste concentrations as referenced in the BTP. The following is a specific rationale that could be provided, and the regulatory background leading to the development of that rationale:

- Regulatory Background

The May, 1983 Technical Position on Radioactive Waste Classification (Section C.3, Concentration Volumes and Masses, last two paragraphs) states that "waste classification volumes of cartridge filters stabilized by emplacement within **high integrity containers** (emphasis added) should be determined as calculated over the volume of the cartridge filter itself rather than the gross volume of the container..."

"An exception to the above would be a situation in which a particular waste type is stabilized within a waste container using a solidification media. For example, assume that a cartridge filter or large sealed source is solidified within a 55-gallon drum using a binder such as cement or bitumen. In this case, the waste and binder form a solid mass within the container and the waste classification volume may be considered to be the volume of the solidified mass..."

Thus, the 1983 Technical Position on Radioactive Waste Classification (TP) allowed curie averaging over the volume of the encapsulation mass (or cylinder). The example discussed in the TP involved a 55-gallon drum as the container. Accordingly, many waste generators (for purposes of concentration averaging over the volume of the encapsulated mass) adopted the 55-gallon drum as an informal standard for stabilizing cartridge filters within a waste container using a solidification binder. The 1983 TP, however, placed no limit on the volume of the encapsulated mass.

The Proposed Technical Position on Concentration Averaging and Encapsulation does limit "the amount of credit allowed for encapsulation so that extreme measures cannot be taken solely for the purposes of dilution," and states (in Appendix C, Bounding Conditions 2) that "a maximum solidified volume or mass for encapsulation (from which concentrations are determined) should be 0.2 cubic meters or 500 kilograms (typical of

55-gallon drums). Larger volumes and masses may be used for encapsulation but, in general, unless a specific rationale is provided, no credit beyond the volume or mass indicated should be considered when determining waste concentrations."

- Specific Rationale for Concentration Averaging over Large Encapsulation Volumes

Though the Proposed TP limits to 0.2 cubic meters the encapsulated volume that may be used for concentration averaging, a specific rationale can be presented for approving the use of larger encapsulation volumes (with the ENCAP™ process) in larger containers.

The informal standard for concentration averaging of encapsulated waste filter cartridges has been one filter cartridge encapsulated in 55-gallon drum (0.2 cubic meters or 7.35 cubic feet). The envelope volume of a typical filter (i.e., the envelope volume of a filter is based on the circumscribed exterior of the filter) is approximately one cubic foot. The packing efficiency (or reciprocal of the dilution ratio) may be calculated by dividing the envelope volume of the waste filter cartridge (1 cubic foot) by the encapsulated volume (7.35 cubic feet). Thus, the packing efficiency would be 13.6% and the dilution ratio would be the reciprocal of 13.6%, or 7.35. Therefore, if the packing efficiency of any encapsulated volume of cartridge filters does not fall below 13.6% (or the dilution factor does not exceed 7.35), "extreme measures taken solely for purposes of dilution" cannot occur.

As discussed above, the ENCAP™ process provides a higher waste loading than that authorized in Appendix C(2). Thus, the use of an encapsulation container larger than a 55-gallon drum and an encapsulation volume greater than 0.2 cubic meters is not indicative of dilution. On that basis, the larger encapsulation volume would be used to stabilize multiple waste filter cartridges, and dilution would not have occurred.

For containers larger than the 80 cubic foot example discussed here, the waste loadings become progressively higher, thus minimizing the dilution that would occur when curie averaging over the solidified mass.

Based on the specific rationale presented above, encapsulation volumes resulting from the ENCAP™ process are hereby submitted to be utilized for concentration averaging of encapsulated waste filter cartridges.

## **APPENDIX B**

This appendix contains the following document:

Discussion and Calculation of Structural Integrity (4 pgs)

## DISCUSSION AND CALCULATION OF STRUCTURAL INTEGRITY

The ability of the monolith to withstand the burial overburden is important to the integrity of the monolith. A structural analysis was performed to ascertain the maximum void space which could be tolerated and still permit the ENCAP™ monolith to withstand the presumed 60 psi overburden. The scope, assumptions, and calculations for the structural analysis follow this discussion.

The tensile strength of VERI™-solidified resin found in the boundary region was determined by testing a VERI™ sample prepared in accordance with the sample preparation described in the parent TR. The sample was machined to a bar shape 0.495" wide x 0.1905" thick and tested with an Instron Tensile Tester (also described in the parent TR) at room temperature with a head speed of 0.05" per minute. For calculational purposes, a tensile strength of 455 psi was used (approximately 90% of the observed tensile strength of 510 psi).

Calculations were performed to determine maximum void space in the caged area that could be tolerated by the 4" VERI™-solidified protective boundary surrounding the cage. The model shows that ENCAP™ monolith integrity is secure when underlying void spaces abutting the surface of the cage are less than 12.7" in span or 20.2" in diameter. Progressively larger spans and diameter voids can be tolerated as their position nears the center of the cage.

The filter geometry necessary to create a void in excess of the calculated span would have to be a flat-sided element with the flat side exceeding 12.7" width, or a right cylinder element with diameter greater than 20.2". The end of this filter element must also butt flush against the cage wall. Since no flat-sided filters are known to be in use, and the largest right cylinder filters are generally 6" or less in diameter, it is presumed that no single element could create a void large enough to endanger the integrity of the monolith.

Likewise, the right cylinder configuration of most filter elements in use today makes them physically unable to create a void of the necessary span or diameter, when introduced randomly to the protective cage. Filters loaded in an array or non-random manner can be positioned to preclude creation of void spans or diameters in excess of the values shown in the analysis. Even closely packed vertical elements allow sufficient pillar strength between the elements to support the cap with a safety margin of over 100 percent.

Based on the rationale presented above, the encapsulation of filter elements with the ENCAP™ process will not create void spaces of sufficient span or diameter to impugn the integrity of the monolith under pressures created by the overburden of the burial site.

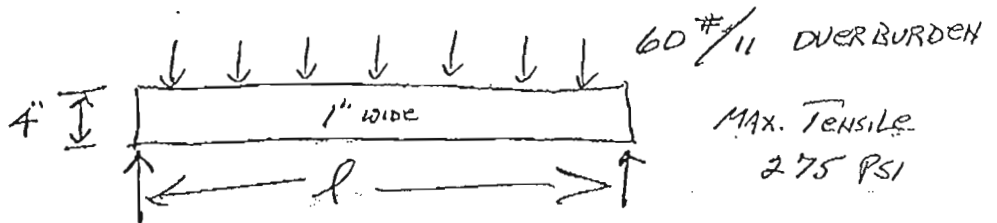


DIVERSIFIED Technologies  
 VERT LINER PROTECTIVE CASE CALCULATIONS

RE-CALCULATIONS BASED ON REDUCTION OF TENSILE STRENGTH OF MEDIA FROM 455 PSI TO 275 PSI

1. UNIFORM UNIT PRESSURE ALONG VERTICAL WALL OF LINER 4" WALL ACTING AS A BEAM HAVING A WIDTH OF 1" & SIMPLY SUPPORTED AT BOTH ENDS.

FIND LENGTH TO BRIDGE A VOID



$$S_{HEAR} = \frac{wl}{2} = \frac{60 \times l}{2} = 275 \quad \therefore l = 9.1"$$

$$BENDING\ MOMENT = \frac{wl^2}{8} = \frac{60 \times l^2}{8} = 7.5 l^2$$

$$I = \frac{bh^3}{12} = \frac{1 \times 4^3}{12} = 5.33$$

$$f = \frac{Mc}{I} = 275 = \frac{7.5 l^2 \times 2}{5.33} \quad \therefore l = 9.9"$$

LIMITING SPAN IS IN SHEAR = 9.1"

(SUSPECT THIS CALCULATION IS FAR TOO PESSIMISTIC FOR THIS APPLICATION. I BELIEVE THE THIRD CALCULATION IS MORE REASONABLE.)

Q. UNIFORM UNIT PRESSURE ACROSS A CIRCULAR VOID SECTION OF TOP COVER -

FROM "FORMULAS FOR STRESS & STRAIN" BY R.J. ROARK  
FOURTH EDITION - PAGE 216 - FORMULA #1

$$S = 275 \text{ psi} \quad S \times .707 = S_t + S_r$$

$$S_t = S_r = \frac{3 \times w \pi r^2}{8 \pi m t^2} (3m + 1)$$

$$.707 \times 275 = \frac{3 \times 60 \times r^2}{8 \times 6.67 \times 4^2} (3 \times 6.67 + 1)$$

$$r^2 = 43.9$$

$$r = 6.625'' \text{ OR } 13.25'' \text{ DIA. CIRCLE}$$

$$w = 60 \text{ PSI}$$

$$t = 4''$$

$$S_t = \frac{.707 \times 275}{.707} = 194 \text{ PSI}$$

$m = \text{Reciprocal of Poisson's Ratio}$   
 $= \frac{1}{.15} = 6.67 = m$

LIMITING CIRCULAR VOID UNDER COVER = 13.25" DIA.  
OR ENDS.

(3)

3. UNIFORM EXTERNAL UNIT PRESSURE ON OUTSIDE SURFACE OF LINER TO CAUSE BUCKLING FAILURE.

FROM R.S. ROARK, PAGE 298 - FORMULA #1

$$p' = \frac{t}{R} \left( \frac{S_y}{1 + 4 \left( \frac{S_y}{E} \right) \times \left( \frac{R}{t} \right)^2} \right)$$

$p'$  = COLLAPSE PRESSURE

$S_y$  = COMPRESSIVE STRENGTH -

DASH-GRADE FROM ORIGINAL 2600 PSI

$$2600 \times \frac{275}{455} = 1571 \text{ PSI} = S_y$$

$E$  = MOD. OF ELAS. =  $3.6 \times 10^6$

$R$  = RADIUS =  $27\frac{1}{2}$ "

$t$  = THICKNESS OF 4"

$$p' = \frac{t}{27.5} \left( \frac{1571}{1 + 4 \times \frac{1571}{3.6 \times 10^6} \times \left( \frac{27.5}{4} \right)^2} \right)$$

$$p' = \frac{4 \times 1571}{27.5 \times 1.08}$$

$$p' = \frac{6284}{29.8} \text{ psi}$$

APPLIES TO SIDE WALLS ONLY  
NOT TO ENDS

INDICATES AN OVERBURDEN OF 60 PSI WOULD NOT COLLAPSE VESSEL IF CENTER WAS ALL VOID SPACE.

VESSEL IS OK - SAFETY FACTOR FOR

$$\text{BUCKLING COLLAPSE} = \frac{211}{60} = 3.5 \text{ S.F.}$$

JAMES WARREN, TRI NUCLEAR CORP.

J. Warren 12/28/99