QUAL REPORT

ATTACHMENT A

WASTE FORM QUALIFICATION REPORT

WVDP STABILIZED SLUDGE WASH CEMENT-WASTE
WITH
TYPE I PORTLAND CEMENT

WASTE FORM QUALIFICATION REPORT WVDP STABILIZED SLUDGE WASH CEMENT-WASTE WITH TYPE I PORTLAND CEMENT

Revision 1

Prepared By

W. J. Dalton

April 1993

Waste Form Qualification Report
WVDP Stabilized Sludge Wash Cement-Waste
With Type I Portland Cement

Table of Contents

LIST OF TABLES

LIST OF FIGURES

APPENDIX

LIST OF ABBREVIATIONS AND ACRONYMS

CFR	Code of Federal Regulations
CSS	Cement Solidification System
DOE	United States Department of Energy
EIS	Environmental Impact Statement
EPA	United States Environmental Protection Agency
HLW	High Level Waste
IRTS	Integrated Radwaste Treatment System
LDR	Land Disposal Restriction
LLW	Low Level Waste
LWTS	Liquid Waste Treatment System
NRC	United States Nuclear Regulatory Commission
PCP	Process Control Plan
TCLP	Toxicity Characteristic Leach Procedure
TDS	Total Dissolved Solids
TP	NRC Technical Position on Waste Form
W/C	Water-to-Cement weight ratio
WDV	Waste Dispensing Vessel
wt.%TDS	Weight Percentage of the Total Dissolved Solids
WVDP	West Valley Demonstration Project
WVNS	West Valley Nuclear Services
WVNS-TP	West Valley Nuclear Services Test Procedure
WVNS-TRQ	West Valley Nuclear Services Test Request
WVNS-TSR	West Valley Nuclear Services Test Summary Report

1.0 INTRODUCTION

This document is presented by West Valley Nuclear Services Co., Inc. (WVNS) to provide technical information on a stabilized (Class A, B, or C) cement-waste form that has been produced at the West Valley Demonstration Project (WVDP). The information contained herein demonstrates compliance to the requirements for radioactive low-level waste (LLW) as set forth in 10 CFR 61, supplemented by the 1991 US NRC Technical Position on Waste Form (TP), Reference 1.

2.0 BACKGROUND

The West Valley Demonstration Project Act of October 1, 1980 (Public Law 96-368) directs the Department of Energy (DOE) to carry out a radioactive high-level waste (HLW) management demonstration project at the West Valley, New York site. The West Valley site was the location of the only operating commercial nuclear fuel reprocessing plant in the United States. West Valley Nuclear Services Co., Inc., a subsidiary of Westinghouse Electric Corporation, has been the prime contractor to DOE for site operations since 1982.

The demonstration project will remove HLW from underground storage tanks and solidify it into a borosilicate glass for long-term storage at a future federal repository. The major portion of the HLW amounted to about 2 million liters of fluid stored in an underground storage tank, designated Tank 8D-2. The tank also contained a sludge layer on the floor of the tank that had insoluble oxides, hydroxides, and carbonates of many species (principally iron). Also in the sludge layer was undissolved sodium sulfate crystals that precipitated from the supernatant liquid.

Prior to HLW stabilization in borosilicate glass, several pretreatment operations were defined that would minimize the final volume of HLW glass. Beginning in 1988, WVNS processed the liquid supernatant solution from Tank 8D-2 through an ion-exchange process to yield a LLW solution (Figure 1). The LLW stream was concentrated and made into a cementitious waste form. The resulting Class C cement-waste is described in a previous topical report "Cement Waste Form Qualification Report - WVDP PUREX Decontaminated Supernatant" (Reference 2). Cement-waste drums were made up through November, 1990.

The next pretreatment step is being implemented at the WVDP. The HLW in Tank 8D-2 has been mobilized by five pumps, which allowed the sodium sulfate crystals to dissolve into the sludge wash water. By adding caustic during the sludge washing operation, uranium, strontium, and plutonium will be maintained at trace levels in the sludge wash solution.

The resulting sludge wash solution will be treated in the ion-exchange process as was done with the previous supernatant solution. A new ion-exchange zeolite has been used to retain cesium, strontium, and plutonium from the sludge wash solution. The resulting LLW stream will be concentrated and made into a cementitious waste form similar to previous supernatant cement-waste in the Cement Solidification System (CSS).

Depending on the level of plutonium, strontium, and cesium after ion-exchange, the cement-waste may be classified as A, B or C waste forms. Class A can be achieved because of the reduced levels of strontium and plutonium resulting from the alkaline sludge wash process, the new ion-exchange zeolite which retains strontium and plutonium in addition to cesium, and the lower waste loading in the sludge wash cement-waste material (compared to decontaminated supernate).

It is WVNS' desire to qualify the sludge wash waste form as stabilized, regardless of the class of cement-waste that may be produced. In doing so, WVNS acquires additional flexibility for the final disposal of this new waste form. Drums containing the new cement-waste will be stored with and may be disposed in conjunction with the previous decontaminated supernatant Class C cement-waste material, pending the results of the Environmental Impact Statement (EIS) for WVDP completion and site closure.

Figure 2 is a flow diagram showing the WVDP cement-waste form qualification program, and a summary of qualification testing and results for WVDP Stabilized Sludge Wash Cement-Waste is provided in Table 1.

3.0 WASTE CHARACTERIZATION

The LLW stream for which data are presented to demonstrate qualification is decontaminated sludge wash solution with 20 wt% dissolved salts. The waste has the following characteristics:

Major Constituents:	Nominal 20 wt% salt solution composed primarily of nitrate, nitrite and sulfate salts of sodium (about 95% of the total salts).
Density:	Nominal 1.15 - 1.16 g/mL
Temperature:	Ambient - 90°F
Secondary Species:	Tank 8D-2 actual sludge wash solution compositions are shown in Table 2.
Radioisotopes:	Key radionuclides for the decontaminated sludge wash solution and resulting cement-waste are shown in Table 3.
	Other trace radionuclides that are in the sludge wash solution and the resulting cement-waste are shown in Table 4.

4.0 MINIMUM REQUIREMENTS OF 10 CFR 61.56(a)

Section 61.56(a) of 10 CFR Part 61 contains the minimum requirements for all classes of low-level radioactive waste. The following sections summarize the different criteria and how the proposed waste form will meet those criteria.

4.1 Packaging

Criterion: The waste form must not be packaged for disposal in cardboard or fiberboard boxes.

Waste Form: The waste form will be poured into plastic-lined 268-liter square 16-gage steel containers as shown in Figure 3.

4.2 Liquid Waste

Criterion: The liquid waste must be solidified or packaged in sufficient absorbent material to absorb twice the volume of the liquid.

Waste Form: The 20 wt% salt solution will be made into a cementitious material.

4.3 Free Liquid

Criterion: Free standing liquid in the solid waste shall not exceed 1% of the solid volume.

Waste Form: Cement-waste product made with actual sludge wash solution has demonstrated no free liquid within one hour after creation of the cementitious material.

4.4 Reactivity of Product

Criterion: The waste must not be readily capable of detonation or of explosive decomposition or reaction at normal pressure and temperatures, or of explosive reaction with water.

Waste Form: The waste form does not contain any substances capable of such reactions.

4.5 Gas Generation

Criterion: The waste must not contain or be capable of generating toxic gases, vapors, or fumes harmful to persons transporting, handling or disposing of the waste form.

Waste Form:	The waste form does not contain any substances capable of such gas releases.

4.6 Pyrophoricity

Criterion:	The waste must not be pyrophoric or contain material which are pyrophoric as defined in 20 CFR 61.4.
Waste Form:	The waste form does not contain any pyrophoric materials.

4.7 Gaseous Waste

This provision is not applicable to a solidified waste form.

4.8 Hazardous Waste

Criterion:	Waste containing hazardous, biological, pathogenic, or infectious material must be treated to reduce the potential hazard.
Waste Form:	Chromium in the LLW salt solution is at a level considered to be hazardous per applicable EPA guidelines.
Test:	Samples from actual decontaminated sludge wash cement-waste drum 84698, produced under Test Procedure WVNS-TP-051 [24 wt% TDS, 0.66 water-to-cement (W/C)], were subjected to TCLP testing for listed metals per 40 CFR 261.24.
Results:	Results from TCLP testing of actual decontaminated sludge wash cement-waste drum 84698, for listed metals illustrate that all the species considered hazardous per 40 CFR 261.24 are well below regulatory levels, and the chromium concentration is only 0.6 mg/L, 12% of the 5.0 mg/L limit. The result of the TCLP metals testing is provided in Table 5.
Conclusions:	TCLP tests show that the cement matrix retains the chromium and can be classified nonhazardous.

5.0 STABILITY REQUIREMENTS OF 10 CFR 61.56(b)

Section 61.56(b) of 10 CFR Part 61 contains the stability requirements for stabilized waste forms. Two of the criteria, structural stability and free liquids, are specifically addressed in the NRC Technical Position on Waste Form (TP). Section 7 covers the recommendations of the TP and the data supporting the stabilized cement-waste form.

The other criterion in this section of the regulations specifies that void spaces within the waste and between the waste and its package must be reduced to the extent practicable. The steel drums that will contain the cement-waste will be filled while the waste form is still fluid. As a result, the void space between the waste and the containers are minimized to the maximum extent possible. Also, specific directions are provided in the Process Control Plan to ensure at least an 85% fill of each drum.

6.0 TESTING WITH DECONTAMINATED SLUDGE WASH

The objective of the Sludge Wash Cement-Waste Cores Windows of Composition testing, Test Procedure WVNS-TP-051 (Reference 9), was to qualify and demonstrate the stability of the nominal waste form recipe at approximately 20 wt% total dissolved solids (TDS) using portland Type I cement and actual decontaminated sludge wash waste liquid. Recipes at 24% and 27% TDS were also specified to determine if the waste loading could be increased. To provide an operating margin for potential plant operating conditions, the sulfate concentration of the decontaminated sludge wash concentrate was increased by a nominal 25%, elevating the sulfate concentration from 9.1% to 11.3% on a dry salt basis. This was accomplished by adding a sodium sulfate solution to the actual decontaminated sludge wash liquid while in the waste dispensing vessel (WDV), which feeds the Cement Solidification System. Eleven drums of the cement-waste were produced in CSS using normal production equipment and Process Control Plan, WVNS-PCP-002. After the required minimum 28 days of cure, cores from actual solidified waste were obtained for qualification testing. These cores provided excellent compressive strengths, thermal cycling resistance, and TCLP metals retention.

The cores did not however pass the 90-day immersion test. After 30 days of immersion in synthetic seawater, an examination of the immersed cores was performed and photographs were obtained. Unexpectedly, the cores were noticeably deteriorated. Based on this finding, the decision was made to commence crushing selected cores prior to the completion of the required 90-day immersion. Cores were crushed after 42, 65, and 90 days of immersion. The post immersion compressive strength values obtained showed a significant decrease in compressive strength which continued to drop with immersion time period. The results from the post immersion compressive strength portion of the qualification tests are less than the 500 psi requirement.

With the apparent failure of WVNS-TP-051 cement-waste cores during the immersion test, a review of the entire test program, including production of the cement-waste and the decontaminated sludge wash solution, was conducted. Based on the factors described below, it was then decided to obtain cores from actual CSS production drums and commence waste-form qualification testing on these cores. It was expected that WVNS IRTS Campaign 22-1S drums would provide a better representation of the solidified sludge wash waste recipe than the previously tested WVNS-TP-051 cement-waste for the following reasons:

- Unlike the earlier liquid waste solution used in the production of cement-waste for WVNS-TP-051, the decontaminated sludge wash waste concentrate had reached a pH of between 12.0 and 12.6, a level at which all future cement-waste production will take place. The simulant solution used in original recipe development, WVNS-TP-044, had a pH of 12.0 and the cement-waste cores passed the 90-day immersion test with a wide margin.

- IRTS had resumed operation for 3 cycles, processing over 26,000 gallons of sludge wash liquid from Tank 8D-2. This additional volume would have mitigated the effects on the cement-waste form of any residual heels of decontaminated supernatant and LWTS evaporator acid flush residual remaining in the system.

- Salt concentrations of the liquid waste stream had transitioned from previous supernatant levels to sludge wash expected levels, based on the analyses of the sludge wash solution in Tank 8D-2.

- No additional sulfate was added to the waste concentrate in the WDV feeding the CSS, as was required for WVNS-TP-051 testing. When this addition was done previously, there were difficulties in dissolving the sodium sulfate which led to variations in sulfate concentrations that may have actually contributed to the failure of the 90-day immersion test.

Representative CSS production drums, processed with decontaminated sludge wash solution at the nominal salt loading of 20 wt% TDS from IRTS Campaign 22-1S, were then identified and sampled (cored). Cores from these production drums yielded a cured cement-waste form with excellent compressive strengths, leach indices and acceptable immersion resistance performance.

With the unacceptable immersion test results of WVNS-TP-051 cores and the successful immersion testing with actual CSS production cement-waste, the difference in immersion test conditions between WVNS-TP-051 and the previous WVNS recipe development work were evaluated to explain the results obtained. The results of this assessment are presented below.

6.1 LOW pH OF SLUDGE WASH LIQUID

WVNS-TP-051 was processed during the transition phase between supernatant processing and sludge wash processing. The low pH (pH 10.4), measured on the decontaminated sludge wash solution during WVNS-TP-051 drum processing, indicates that there was a residual heel of decontaminated supernatant and/or acid flush remaining in the system. During previous cement development work (WVNS-TP-044), used to arrive at the candidate recipe evaluated in this test, simulated sludge wash solutions at 20 wt.% TDS and a pH of 12.0 were solidified and successfully passed the 90-day immersion test. WVNS-TP-051 drums were ssed at pH 10.4 which is at least 97% lower on a hydroxyl [OH sis than the early Campaign 22-1S production drums produced at i of 12.0.

The r cause of post-immersion failure of the WVNS-TP-051 cement-wast ores is attributed to the decontaminated sludge wash high sulfate concentration and corresponding low pH. These conditions contributed to significant sulfate attack and expansion of the cement cores during the immersion period.

6.2 CHANGE IN IMMERSION TEST CONDITIONS

Due to the EPA Land Disposal Restrictions (LDR) covering conditions during this test, and the possibility of generating a mixed-waste, i.e., hazardous and radioactive, the immersion tests conditions were modified for WVNS-TP-051 testing from those employed during the successful 90-day immersion as part of WVNS-TP-044. Each core was immersed singly in a 5-gallon bucket filled with 14 liters of immersion fluid. This provided an immersion liquid volume-to-specimen surface area ratio of 30 cm compared to a nominal ratio of 10 cm used in all previous cement-waste qualification immersion and leach tests. These immersion buckets were stored in the Upper Warm Aisle of the Main Plant for the initial portion of the immersion period. The ambient temperature in this section of the plant during the test period was nominally 35°C. This contrasts with previous immersion tests during recipe development of supernatant and sludge wash cement-waste qualification testing that were conducted with three cores per immersion bucket and stored in the laboratory under controlled temperature for the immersion period duration. Direct observation of single and multiple cores per immersion bucket performed during subsequent testing with CSS Campaign 22-1S sludge wash drum cores has confirmed suspicions:

- The increased quantity of synthetic seawater used in the immersion test has a marked impact on cement core degradation and resulting reduction in post immersion compressive strength, and
- Immersion testing conducted at temperatures above ambient result in significant core degradation and a decrease in resulting post immersion compressive strength.

6.3 SULFATE ATTACK ON IMMERSED CORES

The low pH of the waste solution during processing of the WVNS-TP-051 full-scale cement drums, the change in immersion test conditions, and the resulting rate of core deterioration and the physical condition of the immersed cores indicate that the sulfate present in the waste solution probably reacted with the tricalcium-aluminate components of the portland Type I cement to form ettringite. Ettringite is a crystal formation or solid phase that contributes to cement expansion and failure under the immersion conditions. The formation of ettringite may be suppressed at pH levels above 12. The suppression of ettringite formation was demonstrated by the earlier cement recipe development testing (WVNS-TP-044) that used higher sulfate concentrations (14% vs. 11% dry basis) and higher pH (pH 12.0 vs pH 10.4) waste solutions. Cores from this cement-waste passed the 90-day immersion test by a wide margin (Reference 12).

6.4 INITIAL 20 Wt% TDS SLUDGE WASH PRODUCTION DRUMS

After the failure of WVNS-TP-051 cement-waste cores during immersion testing, a decision was made to commence waste form qualification testing on CSS drums for reasons mentioned in Section 6.0. The CSS drums were selected from two different sludge wash concentrate lots; the first lot was processed during the earlier portion of sludge wash Campaign 22-1S and the second lot was processed during the later period of sludge wash processing.

It was suspected that if the earlier or transition phase between supernatant processing and sludge wash processing contributed to the failure of WVNS-TP-051 cores, then CSS cement-waste drums processed around the same time period might also be suspect.

The two production drums selected from <u>early</u> sludge wash processing were made from the decontaminated sludge wash concentrate batch just following the production of the WVNS-TP-051 cement-waste drums. The liquid had a pH of 12.0, which is similar to the surrogate sludge wash solution used during earlier recipe development, WVNS-TP-044 (Reference 7). The cores obtained from these drums after 65 days of cure were noticeably damp during removal from the drums indicating the cement may have not fully cured. The average compressive strength value at this time was 1140 psi. Additional cores taken later from the same drum after 82 days of cure were dry and exhibited a significantly higher average compressive strength of 1620 psi. Cores for the immersion portion of the qualification testing were obtained during the 62-day cure core drilling operation. Therefore, these cores were not fully cured prior to commencing the 90-day immersion test and this fact may have led to these cores not passing the immersion test requirements.

Two production drums selected from the later portion of the sludge wash processing were produced from a decontaminated sludge wash concentrate batch whose pH was 12.6. Cores from these drums had an average compressive strength of nearly 1500 psi after 50 days of cure and did not exhibit the dampness observed during coring the earlier production drums. Cores from these drums successfully passed the 90-day immersion test. It is important to note that following the initial 200 to 300 transition drums at the start of sludge wash processing, all subsequent decontaminated sludge wash concentrate batches which have been solidified, producing nearly 3,000 drums as of April 14, 1993, exhibit consistent pH's of 12.4 to 12.6.

7.0 REQUIREMENTS OF 1991 TECHNICAL POSITION ON WASTE FORM

The TP contains recommendations on the stability requirements for all classes of stabilized waste. The following sections summarize key criteria from the TP, including Appendix A. Results of testing are presented to show that actual decontaminated sludge wash solutions at 20 wt% TDS, and portland Type I cement at the proposed cement-waste-form recipes, meet the criteria. These test results are also summarized in Table 1.

All of the test results presented are from drums made with actual decontaminated sludge wash solution at a nominal 20 wt% TDS. Test results from the WVNS-TP-051, "Sludge Wash Cement-Waste Cores Windows of Composition," drums are presented for thermal cycling and TCLP metal requirements. WVNS Cement Solidification System production drum cores from Campaign 22-1S were used to determine compressive strengths, post immersion compressive strengths, and leach indices. As mentioned in Section 6.0, all of the testing on cement cores obtained from WVNS-TP-051 passed all stability requirements except post-immersion compressive strength, and this failure is attributed to the abnormally low waste solution pH.

7.1 Compressive Strength

Criteria:	Sufficient specimens (at least 10) shall be compression tested after a minimum cure time of 28 days. Average compression strength greater than 500 psi is required. Testing shall also be performed to determine the compressive strength increase with time to ensure that the specimens have attained near-maximum compressive strength.
Waste Form:	Cores (2-5/8" diameter x 5-1/4" length) were removed from three full-scale cement-waste Campaign 22-1S production drums prepared with decontaminated sludge wash solution at 20% TDS and 0.66 W/C ratio following the 28-day minimum cure time.

Tests: A total of 12 cores obtained from the top, middle and bottom of the three drums were crushed per ASTM-C39 to determine the compressive strength.

Results: The average compressive strength of all 12 cores is 1438 psi, well in excess of the 500 psi minimum. Results are shown in Table 6 and Figure 4.

Lines representing the 95% confidence interval of the regression line through all the data are provided. Unlike the other cores obtained that were dry in appearance, the first three cores obtained from production drum 82112 (one of the three full-scale cement-waste production drums) after 65 days of cure were noticeably damp during removal from the drum. This would indicate that the cement in the drum was not fully cured at this time. However the resulting compressive strength values were within 74% of the average compressive strength of the nine other cores obtained.

Conclusion: The average compressive strength is well in excess of the 500 psi requirement and the results demonstrate that the near-maximum strength has been obtained for this waste form; the 49-day compressive strengths are within 75% of the 82-day values.

7.2 Radiation Resistance

Criterion: Waste forms containing ion-exchange resins or other organic materials shall be tested for radiation stability.

Conclusion: The proposed WVNS waste form does not contain any ion-exchange resin and only trace quantities of organic materials, thus this test is not required.

7.3 Biodegradation Resistance

Criterion: Waste forms containing carbonaceous materials shall be tested for biodegradation resistance.

Conclusion: The proposed WVNS waste form does not contain appreciable carbonaceous materials, thus this test is not required.

7.4 Leachability

Criteria:	Leach testing in accordance with ANSI/ANS-16.1 shall be performed on the waste form. Five-day tests in both demineralized water and synthetic seawater shall be completed on the cement-stabilized waste form. Leach indices, as calculated per the ANSI/ANS method, shall be greater than 6.0.
Waste Form:	Mini-cores, 1" diameter x 3" length, were obtained from full-scale cement-waste production drum 82113 (20 wt% TDS), produced by the CSS during Campaign 22-1S.
Tests:	The mini-cores were subjected to leach testing in accordance with ANSI/ANS-16.1. Three mini-cores each were tested in demineralized water and synthetic seawater.
Results:	The results of the leachability testing are shown in Table 7 as well as Figures 5 and 6. The lowest leach index for any of the key radionuclides was 7.69 for Cs-137 in demineralized water leachant.
Conclusion:	The cement-waste passes the leach test criteria; all leach indices exceed the required minimum of 6.0.

7.5 Immersion Resistance

Criteria:	Waste specimens shall be immersed for 90 days in the synthetic seawater which was determined to be the more aggressive immersion liquid identified in earlier WVNS cement-waste form development testing (WVNS-TP-044, Reference 7). Visual examination of the immersed samples shall be performed to verify no significant degradation (e.g., cracking or spalling). The average compression strength after immersion shall be greater than 500 psi and more than 75% of the preimmersion baseline average obtained after the minimum 28-day curing cycle. For those waste forms that lose more than 25% of the compressive strength compared to the preimmersed average, additional immersion testing through 180 days shall be completed. Sufficient samples shall be tested to show a stabilization of the compression strength by 180 days of immersion. Visual examination of the immersed

samples shall be performed to verify no significant degradation (e.g., cracking or spalling). The average compression value after immersion shall be greater than 500 psi.

Waste Form: Cores (2-5/8" diameter x 5-1/4" length) were removed from two Campaign 22-1S full-scale cement-waste drums prepared with decontaminated sludge wash solution at 20 wt% TDS and a pH of 12.6.

Tests: The immersion test was conducted at the same conditions as required for the radioactive leach testing, i.e., laboratory ambient temperature and nominal immersion liquid volume-to-core surface area ratio of 10 cm. Three cores (one each from the upper, middle, and lower sections of the cement-waste drum) were placed in each 5-gallon bucket for the immersion test. Each immersion bucket had cores from the same drum and was filled with 14 liters of synthetic seawater.

Results: After 90 days of immersion, core specimens from production drum 82538 (produced later in IRTS Campaign 22-1S) showed only minor surface cracking around the circumference of the core end (photograph is attached in the Appendix). Compression testing results after synthetic seawater immersion were 1410, 1030, and 1250 psi for an average of 1230 psi.

Compared to the preimmersion baseline average of 1438 psi, these represent a decrease in compressive strength of 14%. Based on these results, the proposed waste form made with 20 wt% TDS actual decontaminated sludge wash solution meets the criteria.

As noted in 6.0, prior testing in WVNS-TP-051, with waste loadings up to 27 wt% TDS and spiked with additional sulfate (SO_4 dry basis, increased from 9.1% to 11.3% of the total salts) was performed. Cores of cement-waste drums made with this solution were immersed in synthetic seawater. After 42 days of immersion, compressive strength was less than 75% of the un-immersed average. By 90 days of immersion, the average strengths had fallen below 500 psi.

Failure of the cement-waste form in WVNS-TP-051 tests led to the investigation of reduced salt loading in the waste form processed after WVNS-TP-051 processing.

As noted in 6.4, prior testing with the same LLW stream taken from the earlier portion of the IRTS Campaign 22-1S was also performed. Cores of cement-waste drums made with this solution were immersed in synthetic seawater. After 90 days of immersion, production drum 82112 core specimens showed significant cracking and the resulting compression test values after immersion were 320 and 280 psi for an average of 300 psi. It is suspected that because the cores were not fully cured prior to the start of the immersion test, this contributed to sulfate attack during immersion. Other possible causes that contributed to the failure are the slightly low pH of the waste solution and LWTS evaporator acid wash residuals, discussed further in Section 6.4.

Conclusion: The cement-waste produced with decontaminated sludge wash solution concentrated to 20 wt% TDS and at a pH of 12.6 yielded excellent immersion resistance performance. The cement-waste passes the immersion test criteria.

7.6 Thermal Cycling

Criteria: Waste specimens shall be subjected to thirty thermal cycles between -40°C and 60°C in accord with ASTM B553. Visual examination of the cycled samples shall be performed to verify no significant degradation (e.g., cracking or spalling). The average compression value after cycling shall be greater than 500 psi.

Waste Form: Six cores (2-5/8" diameter x 5-1/4" length) were removed from a full-scale cement-waste drum 84699 prepared with decontaminated sludge wash solution at 24 wt% TDS under Test Procedure WVNS-TP-051.

Tests: After removal from the drum, the three cores along with a special thermocouple equipped cement cylinder were inserted into the environmental chamber. Thirty temperature cycles were completed from 60°C to 20°C to -40°C and back with one hour soak periods at each temperature, as measured by the thermocouple embedded in the cement-waste cylinder.

Results: After completion of the required thirty temperature cycles, the cores were removed from the chamber and inspected. No spalling or cracking was noted. Compression results for the cycled cores were 930, 1390, and 1180 psi for an average strength of 1167 psi. This compares to the 1097 psi average for three cores from the same drum that were used as test control and did not undergo thermal cycling. The cement cores pass the thermal cycling test requirements.

These very positive results at the higher salt loading (24 wt% TDS sludge wash solution) and similar results during WVNS-TP-026 using a 33 wt% TDS simulant waste solution bound the lower salt loading (20 wt% TDS sludge wash solution) of the candidate recipe. Therefore, WVNS does not plan to repeat thermal cycle testing of cores taken from cement-waste drums made with sludge wash solution at the lower 20 wt% TDS loading. The results are summarized in Table 8.

Conclusions: The cement-waste passes the thermal cycling test criteria.

7.7 Free Liquids

Criterion: Waste specimens shall have less than 0.5% (by volume) of the waste as free liquids as measured by the method in Appendix 2 of ANS 55.1.

Waste Form/ Tests/ Results: WVNS performed alternate testing to meet this criterion. A two-step approach is presented to show equivalence.

Step 1 was to prepare small-scale specimens (2" x 2" x 2" cubes) in the laboratory from each batch of decontaminated sludge wash concentrate solution prior to making full-scale cement drums. Triplicate cubes were made for each decontaminated sludge wash batch prior to full-scale drum production. All of the compressive strength results were above the Process Control Plan minimum of 383 psi and all of the cubes were free of bleed liquid prior to crushing (after 24-hour cure). A graph of the pre-solidification 2-inch cube results obtained during IRTS Campaign 22-1S is provided in Figure 7.

Step 2 of the approach was to produce full-scale drums after acceptable 2-inch cube compressive strengths had been verified on the same batch of decontaminated sludge wash solution. Bleed water on the surface of the cement-waste was absent on all the drums produced after 24 hours of curing.

and only superficial bleed water was present after a 1-hour cure. After curing, four of the full-scale production drums were extensively cored. About 5% of the drum contents were sampled from side-to-side and top-to-bottom. No free liquids were detected. The cores provided material for baseline compressive strength tests, homogeneity verification, and immersion tests.

Conclusion: The criterion for no free liquids has been demonstrated by the absence of bleedwater and free liquids.

7.8 Full-Scale Specimen Test Results

Criteria: If small, simulated laboratory-size specimens are used to support the above tests, test data from cores of the full-scale products also should be obtained. Correlations between the performance of the lab-size specimens and the core data shall be prepared.

Samples shall be taken from throughout the entire full-scale waste form to ensure that product is homogeneous and all regions of the product will have compressive strengths of at least 500 psi.

Waste Form: For every key supporting test, cores from the full-scale cement-waste drums have been the specimens utilized to demonstrate compliance with stability requirements. Verification specimens using cubes are discussed in Section 7.10.2.

To demonstrate homogeneity, two different waste tank concentrate lots, with two production drums from each lot, were selected for core sampling and testing purposes. The four CSS production drums from Campaign 22-1S were produced with decontaminated sludge wash solution at a nominal 20 wt% TDS and 0.66 W/C ratio.

Tests: The four CSS production drums were extensively cored, with more than 54 cores (2-5/8" diameter x 5-1/4" length) removed. The cores were taken from different heights and distances to the drum center. Twelve cores were crushed per ASTM-C39 to determine the average compressive strength.

Results: Compression results of the 12 cores tested (Table 6) were found to be statistically from the same population and showed no visible inhomogeneities.

Cores obtained from production drum 82112 after 65 days of cure were noticeably damp during removal from the drum. This would indicate that the cement in the drum was not fully cured at this time. However the resulting compressive strength values were within 74% of the average compressive strength obtained for the nine other cores. The remaining 42 cores underwent synthetic seawater immersion testing. The cores that were immersed also showed no inhomogeneities (see Section 7.5).

To determine the uniformity of curing conditions within the cement-waste, two production drums from Campaign 22-1S were instrumented with three thermocouples at the drum centerline: one near the bottom of the drum, one near the middle, and one at the top. These temperatures, shown in Figures 8 and 9, were monitored during the curing process and attained a maximum of 86°C approximately 16 to 18 hours following cement-waste production. The data obtained indicate that the bottom portion of the drum is always the coolest, achieving a maximum temperature of approximately 60°C. The middle and upper regions of the cement-waste in the drum are always significantly higher and usually within 5°C of each other. Sometimes the maximum drum temperature is reached in the upper portion of the cement-waste and other times the maximum occurs in the middle of the drum. The maximum temperature appears to peak between the middle and upper installed thermocouples, which would create a situation where one or the other of these thermocouples would indicate the highest temperature. This temperature distribution within the waste is attributed to conduction of heat from the bottom of the drum to the conveyor system; the insulating air space above the cement waste within the closed drum; and the chimney effect whereby the air surrounding the drum is heated, rises and maintains a higher convective heat loss at the bottom of the drum due to the lower film temperature of the air adjacent to the drum. Due to the slightly different curing conditions within the cement-waste product, all testing has utilized cores from all three regions of the cement-waste drum examined. There is not a discernable difference in test results between the three regions, which indicates a homogeneous waste form, and cores from each drum region meet all applicable stability test requirements.

Conclusion:	The proposed waste form is homogeneous and meets the 500 psi strength value for all regions.

7.9 Qualification Test Specimen Preparation

Criteria:	Appendix A of the TP recommends certain precautions be taken during the mixing, curing, and storage of qualification test specimens. The goal is to produce specimens in the laboratory that are representative of the actual waste form product.
Waste Form/ Tests/ Results:	For all of the qualification tests, WVNS utilized cores obtained from the full-scale drums prepared with actual decontaminated sludge wash solution. This ensured that the waste form samples are representative of the full-scale cement-waste form.
Conclusions:	These criteria have been met by using cores from actual full-scale drums of cement waste.

7.10 Process Control Program

A Process Control Program has been instituted to control the variables that influence the process and affect the final waste-form product. Previously, for the WVDP supernatant cement-waste, a Process Control Plan (WVNS-PCP-001) was issued. A new version of the Process Control Plan (WVNS-PCP-002) has been prepared and is provided as Reference 6. This section discusses the key criteria cited in the TP and the sections of the WVNS PCP that meet those criteria.

7.10.1 Process Parameters

Criteria:	The PCP shall identify and restrict within acceptable bounds variables that influence the process and affect the product.
Waste Form:	As discussed in the Waste Form Interim Qualification Report for WVNS Stabilized Sludge Wash Cement-Waste (Reference 12), screening tests were performed on a wide range of process variables. The only key variable for gel time and compressive strength was the W/C ratio.

WVNS has established four controls to regulate the process:

- W/C ratio
- TDS of sludge wash solution
- SO_4 level
- pH of sludge wash solution

WVNS proposes to produce the cement-waste form at a W/C ratio of 0.66 ± 0.02. Combined with this, the salt content of the LLW stream shall be controlled to 20 ± 1 wt% total solids. Along with a check on the level of sulfate to ensure that the sulfate concentration is below the maximum limit of 14% of total salts (dry basis: grams SO_4/grams total salts), these controls regulate the relative proportion of sulfate-to-cement in the product (maintains immersion performance). In addition, based on the waste solutions that have passed the qualification tests; earlier surrogate and actual sludge wash solutions, a minimum pH value for the LLW stream will be specified at 12.0 prior to solidification of the waste.

These controls are the main variables that influence the process and the cement-waste product. All other variables generate acceptable product as long as the parameters fall within the ranges specified by the Process Control Plan.

The order of addition is:

1) LLW solution
2) Antifoam
3) Cement blend
4) Sodium silicate solution

More specific information can be found in the Process Control Plan, WVNS-PCP-002.

7.10.2 <u>Verification and Surveillance Specimens</u>

Criteria: Prior to full-scale waste form solidification, verification specimens should be prepared for examination and compressive strength testing. The specimens should be free of significant visible defects (e.g., cracking or spalling) and should exhibit less than 0.5% by volume free liquid.

Compressive strengths should be measured within 24 hours after preparation. The values should be within two standard deviations of the mean value generated during waste qualification testing.

For certain waste streams (bead resins, chelates, filter sludges, and floor drain wastes) additional specimens are to be prepared for long-term performance testing.

Waste Form: Under Test Procedure WVNS-TP-053 (Reference 8), WVNS has completed a series of 30 verification (2"x 2"x 2") cement cubes in the laboratory using actual decontaminated sludge wash solution. The cubes were made to the same specification as the full-scale process centered around the operating window for 20 wt% TDS sludge wash:

- -water:cement ratio 0.66 ± 0.02
- -TDS of solution 20 ± 1 wt%

The cubes were cured and subjected to 24-hour compressive strength testing. All of the 30 cubes were free of bleed liquid.

Review of the compressive strength values showed them to be normally distributed with an average compressive strength of 792 psi and a standard deviation of 153 psi. Based on the 30 compressive strength values and the normal distribution, at a 95% confidence interval, the true standard deviation (sigma) could be as high as 204. For the Process Control Plan, the minimum compressive strength for a 2-sigma lower limit (average - 2*sigma) was calculated to be 383 psi. This established the minimum compressive strength for the pre-solidification cubes for 20 wt% TDS sludge wash at 383 psi. The results from this testing are provided in Reference 8.

All of the cube specimens are cured at 85°C in a laboratory oven. This temperature corresponds to the maximum centerline temperature measured on full-scale production drums during cement cure with decontaminated sludge wash at 20 wt% TDS and 0.66 W/C ratio (Figures 8 and 9).

As noted in the Process Control Plan, samples of the decontaminated sludge wash solution are sent to the laboratory for preparation of cube verification specimens. After curing for nearly 24 hours, the cube specimens are viewed for defects and any free water; then they are tested for compressive strength and must exceed the established minimum of 383 psi.

This verification step demonstrates that the waste stream can be prepared into a dry cement-waste form with good compressive strength.

WVNS will continue to restrict the process to a very tight W/C ratio and wt% solids in the decontaminated sludge wash solution. Full-scale specimens in this range have successfully passed the 90-day immersion test.

The sulfate in the LLW stream is measured and verified against an upper limit of 0.14 gram SO_4 per gram total salts. This limit corresponds to the level in the surrogate solution that passed immersion testing (Reference 7).

In addition, the pH of the LLW stream is measured and verified to be greater than 12.0. This corresponds to the level in the surrogate solution and actual sludge wash that have passed the immersion testing (Reference 7).

WVNS will implement long-term compressive strength testing on the 20 wt% sludge wash cement-waste and this test plan is provided in Reference 11.

8.0 CONCLUSIONS

This section summarizes the key qualification test results and presents future testing plans by WVNS.

8.1. Key Qualification Tests

Compressive strength of 12 cores taken from cured full-scale product drums made with 20 wt% TDS actual decontaminated sludge wash solution averaged 1438 psi. Immersion testing in synthetic seawater showed acceptable long-term physical stability. The average of three cores was 1230 psi, 86% of the preimmersion average compressive strength.

An alternate testing methodology is proposed to meet the specified free liquids limit. The recipe under full-scale testing has shown no free water after 24 hours, this has been demonstrated in the laboratory and full-scale drums prepared from actual decontaminated sludge wash solution. Pre-solidification cubes have been made prior to LLW drum solidification and all were free of bleed liquid after 24 hours.

Extensive coring of full-scale drums filled with the 20 wt% TDS decontaminated sludge wash cement-waste has shown no free liquid. Coring of the WVNS-TP-051 series of full-scale waste drums, made with decontaminated sludge wash solution ranging from 20 wt% TDS to 27 wt% TDS and from 0.62 to 0.70 W/C ratio, has shown no free liquid.

Tests with the decontaminated sludge wash solution at a higher salt content (24 wt% TDS vs. 20 wt% for the proposed waste form) have passed thermal cycling criteria. Radiation resistance and biodegradation tests of the waste form are not required.

8.2 Additional Qualification Testing

The proposed waste form meets and exceeds the various criteria set forth in the Technical Position on Waste Form.

WVNS is planning to evaluate higher salt loadings (25, 30, and 33 wt% TDS) in cement-waste forms using portland Type V cement. The portland Type V cement offers better sulfate resistance compared to the Type I cement due to the restricted tricalcium-aluminate content. WVNS will submit an additional Waste Form Qualification Report for WVDP stabilized sludge wash cement-waste with Type V portland cement.

8.3 PCP Information

Tests in the laboratory and confirmed in full-scale plant operations have shown that very few controls are needed to produce a qualified waste-form. Key control variables for production of full-scale drums are:

- W/C ratio: 0.66 ± 0.02
- salt in LLW stream: 20 ± 1 wt%
- sulfate in LLW stream: < 14 wt% of total salts
- pH of LLW stream: ≥ 12.0

During actual radioactive sludge wash processing, verification samples are taken from each of the two tanks alternately feeding the full-scale solidification system. After sample analyses confirm that the liquid meets PCP limits, a cement cube is prepared in the laboratory. Visual confirmation of no free water and no physical degradation is performed. A compressive strength measurement of the cube is made and must exceed the PCP minimum of 383 psi. All requirements must be within the PCP specifications prior to solidifying the batch of decontaminated sludge wash solution.

Through this process control, WVNS ensures that a quality cement-waste product is produced in full compliance with NRC stability criteria.

9.0 REFERENCES

1 "Technical Position on Waste Form," Revision 1, Technical Branch of the Low Level Waste Management and Decommissioning Division of the US Nuclear Regulatory Commission, dated January 1991.

2 McVay, C. W., J. R. Stimmel, and S. Marchetti, "Cement Waste Form Qualification Report - WVDP PUREX Decontaminated Supernatant," DOE/NE/44139-49 (DE89009019), August 1988.

3 Rykken, Larry E., "High-Level Waste Characterization at West Valley: Report of Work Performed 1982 - 1985," DOE/NE/44139-14 (DE87005887), June 2, 1986.

4 Mahoney, John L., "Sludge Wash Cement Waste Form Qualification Development of Process Control Parameters," WVNS-TSR-028, Revision 0, dated February 6, 1992.

5 Mahoney, John L., "Test Summary Results Report for Qualification Work for the Nominal Recipe for Cement Solidification of Sludge Wash Liquids," WVNS-TSR-026, Revision 0, dated February 6, 1992.

6 "Process Control Plan for Cement Solidification of Sludge Wash Liquid," WVNS-PCP-002, Revision 4, dated March 25, 1993.

7 Mahoney, John L., "Test Summary Results Report for Qualification Work for Waste Form Qualification Work for Sludge Wash Liquids," WVNS-TSR-044, Revision 0, dated June 30, 1992.

8 Dalton, William J., "Test Summary Results Report for Verification Cubes for 20 Percent Sludge Wash Cement Waste," WVNS-TSR-053, Revision 0, dated December 18, 1992.

9 Dalton, William J., "Test Summary Results Report for Sludge Wash Cement-Waste Windows of Composition," WVNS-TSR-051, Revision 0, dated January 27, 1993.

10 Letter CL:93:0025, J. J. Hollinden to A. J. Howell, "Sludge Wash Cement 10CFR61 Waste Classification," dated January 19, 1993.

11 "Long-Term Compressive Strength Testing of the Sludge Wash Liquid/Cement Waste Form," WVNS-TPL-70-13, Revision 0, (unpublished).

12 Mahoney, John L., "Waste Form Interim Qualification Report, WVDP Stabilized Sludge Wash Cement-Waste," Revision 1, May 1992.

Table 1

Summary of Qualification Testing for
WVDP Stabilized Sludge Wash Cement-Waste (a)

	Test Series		
	WVNS-TP-044	WVNS-TP-051	Campaign 22-1S (d)
Waste Liquid used in Cement-waste pH SO4(% total salts) % solids, TDS wt%	Surrogate Sludge Wash 12.0 14 20	Decontaminated Sludge Wash 10.4 11 20-27	Decontaminated Sludge Wash 12.0-12.6 9.5 20
Cement-waste water-to-cement ratio	0.64	0.62-0.70	0.66
TECHNICAL POSITION ON WASTE FORM REQUIREMENT			
Compressive strength > 500 psi	Average 1247 psi	Average 1496 psi	Average 1438 psi
Requirement Pass/Fail	Pass	Pass	Pass
Compressive strength following 90-day immersion > 500 psi and 75% of pre-immersion	Average 1189 psi 95% of preimmersion	all < 500 psi	Average 1230 psi 86% of preimmersion
Requirement Pass/Fail	Pass	Fail	Pass
Compressive strength following 30 thermal cycles > 500 psi	see note (b) 33 Wt% TDS, 0.66 W/C Average 1229 psi	24 Wt% TDS, 0.66 W/C Average 1167 psi	Not Scheduled
Requirement Pass/Fail	Pass	Pass	-------
Radionuclide Leach Indices >6.0	see note (c) Cs-137 > 7.8 Tc-99 > 7.7 Sr-90 > 9.9 α-Pu > 11.1	Not Scheduled	Cs-137 > 7.1 Tc-99 > 7.1 Sr-90 > 10.9 α-Pu > 13.7
Requirement Pass/Fail	Pass	-------	Pass

(a) All testing was performed on cores extracted from full-scale cement-waste drums produced in the Cement Solidification System, except where noted otherwise.
(b) WVNS-TP-026 Cylinders made with Surrogate Sludge Wash.
(c) WVNS-TP-026 Mini-cylinders made with Decontaminated Supernatant spiked with sodium sulfate and pH adjusted to 11.8, at 33 wt% TDS, to simulate sludge wash solution.
(d) Tests performed under work order 9203543.

Table 2

Chemical Composition of
Sludge Wash Solution from Tank 8D-2

	Dry Wt%	g/L
Major:		
Na	31	71
NO_3	28	64
NO_2	24	55
SO_4	11	26
Minor:		
Al	0.15	0.34
Cl	0.20	0.45
U	0.0020	0.0046
OH (est.)	0.78	1.8
pH	12.5	

Note: Tank 8D-2 analyses from sample # 56 (A&PC Log No. 9200901) dated April 27, 1992. Sample taken prior to IRTS resumption.

Table 3

Key Radionuclides in
Decontaminated Sludge Wash Solution

	Sludge Wash Measured Value at 20 wt% TDS μCi/g	Calculated for Cement-Waste with 20 wt% TDS, 0.66 W/C Ci/m^3
Tc-99	0.239	0.177
Sr-90	0.0036	0.0027
Cs-137	0.161	0.119
alpha-Pu	0.0046	1.986 nCi/gm

Measured on actual decontaminated sludge wash solution sample 5D-15A1#37 (A&PC Log. No. 9202038) dated September 4, 1992. Sample obtained from tank feeding full-scale solidification system.

Table 4

Trace Radionuclides of
Decontaminated Sludge Wash Solution at 20 wt% TDS

	Sludge Wash Measured Value µCi/g	Calculated for Cement-Waste @20 wt% TDS nCi/g
Pu-236	< 3.32E-11	< 1.45E-8
Pu-238	0.00278	1.2130
Pu-239,240	0.00125	0.5457
Pu-242	< 2.90E-8	< 1.27E-5
Pu-241	0.06784	13.1158
Am-241	0.00013	0.0576
Am-243	< 1.16E-5	< 0.0051
Cm-245,246	< 1.30E-5	< 0.0057
Cm-243,244	< 6.30E-6	< 0.0027
Cm-242	< 1.17E-5	< 0.0051
Np-237	4.78E-5	0.0208
	µCi/g	Ci/m3
C-14	0.0024	1.78E-3
I-129	4.36E-5	3.23E-5
Eu-152	< 4.71E-7	< 3.49E-7
Eu-154	< 1.71E-7	< 1.27E-7
Eu-155	< 1.25E-6	< 9.27E-7
Ce-144	< 2.49E-6	< 1.85E-6
Ni-59	< 1.08E-6	< 8.00E-7
Ni-63	8.00E-5	5.93E-5
H-3	0.00143	1.06E-3
Fe-55	3.27E-5	2.43E-5
Nb-94	< 6.51E-6	< 4.82E-6
Ru-106	< 3.86E-6	< 2.87E-6
Sb-125	0.000232	1.72E-4
Cs-134	6.90E-5	5.12E-5
Co-60	1.16E-6	8.60E-7
Pm-147	0.00022	1.63E-4

Measured on actual decontaminated sludge wash solution sample 5D-15A1#37 (A&PC Log. No. 9202038) dated September 4, 1992. Sample obtained from tank feeding full-scale solidification system (Reference 10).

Table 5

Results of TCLP Metals Analysis
WVNS-TP-051 Drum 84698, 24 wt% TDS, 0.66 W/C

Species	Results mg/L	Regulatory Limit mg/L
Arsenic	<0.190	5.0
Barium	0.762	100.0
Cadmium	<0.020	1.0
Chromium	0.612	5.0
Lead	<0.120	5.0
Mercury	<0.0002	0.2
Selenium	<0.240	1.0
Silver	<0.040	5.0

Table 6

Compressive Strength Testing Results
Cores from 20 wt% TDS Sludge Wash Cement-Waste Drums

Decontaminated Sludge Wash Batch	Drum Serial No.	Cured Time Days	Compressive Strength psi	Core Position in Drum
Mid-campaign	82538	49	1680	Top
22-1S	82538	49	1720	Middle
Tank 5D-15A1#27	82538	49	1410	Bottom
Mid-campaign	81849	50	1560	Top
22-1S	81849	50	1420	Middle
Tank 5D-15A1#27	81849	50	1190	Bottom
Early-campaign	82112	65*	990	Top
22-1S	82112	65*	1220	Middle
Tank 5D-15A1#17	82112	65*	1210	Bottom
Early-campaign	82112	82	1490	Top
22-1S	82112	82	1410	Middle
Tank 5D-15A1#17	82112	82	1960	Bottom
		1438	Average	

* See section 7.1, drum may not have been fully cured

Table 7

Leachability Testing Results
Full-Scale Cement-Waste Drum
20 wt% TDS, 1"x3" Core Sample

In Demineralized Water
Average Leachability Index

hrs	Tc-99	Sr-90	Cs-137	α-Pu
2	7.73	11.1	7.14	13.7
7	7.67	11.5	7.54	13.9
24	7.60	10.9	7.16	14.3
48	7.71	11.3	7.59	14.5
72	7.87	11.8	7.82	14.2
96	8.82	11.7	8.21	15.0
120	8.44	12.2	8.36	15.0
Averages =	7.84	11.5	7.69	14.4
Standard Deviation =	0.36	0.46	0.44	0.47

In Synthetic Sea Water
Average Leachability Index

hrs	Tc-99	Sr-90	Cs-137	α Pu
2	7.12	10.9	7.09	13.8
7	7.77	11.7	7.74	13.9
24	7.74	11.2	7.28	14.3
48	7.80	11.8	7.77	14.7
72	7.95	11.9	7.94	14.8
96	8.32	12.3	8.34	15.0
120	8.41	12.1	8.40	15.1
Averages =	7.87	11.7	7.79	14.5
Standard Deviation =	0.40	0.46	0.46	0.48

Comparison of Leachant Indices

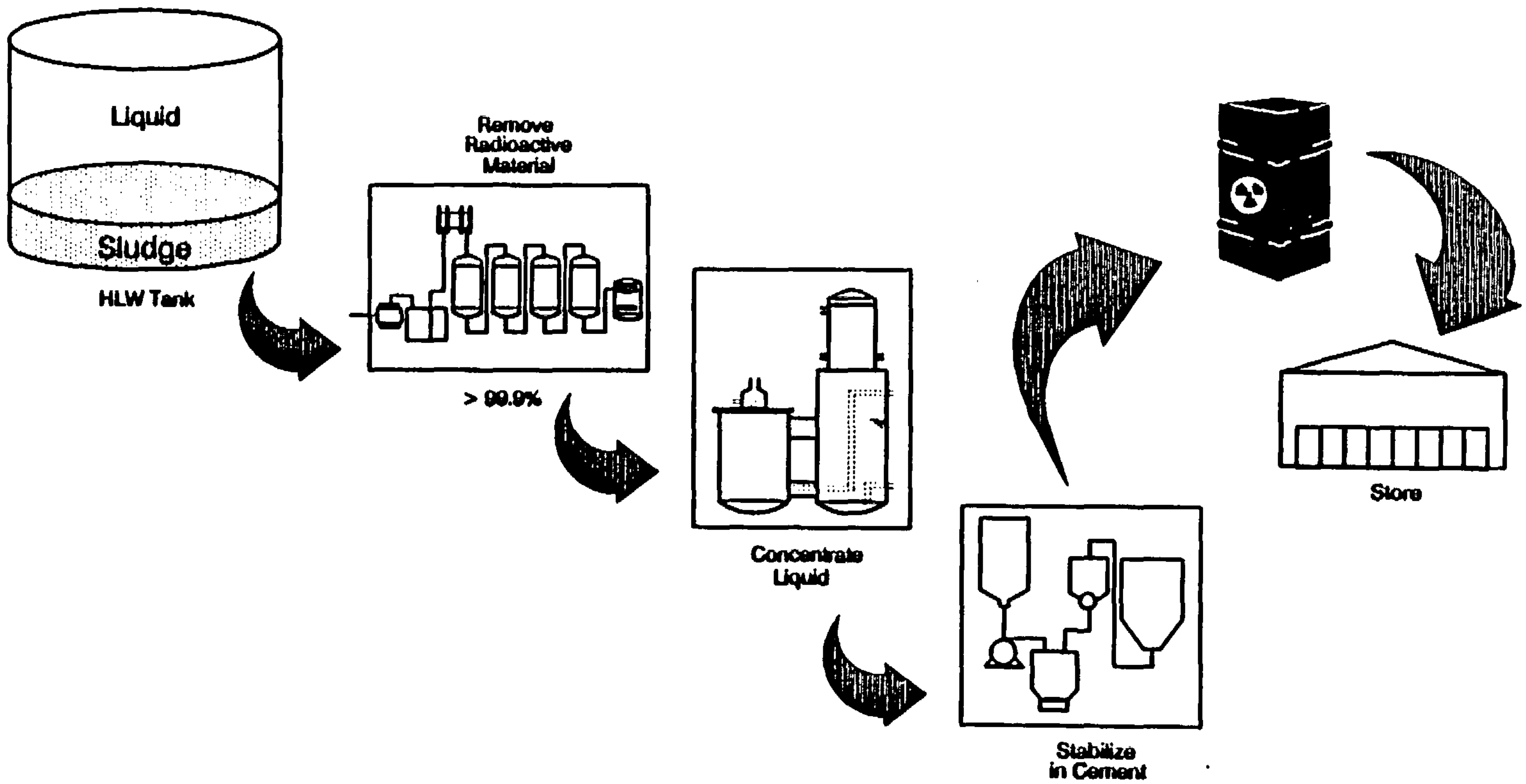
Species	Demineralized Water	Synthetic Sea Water	Significant Difference
Tc-99	7.84±0.36	7.87±0.40	NO
Sr-90	11.50±0.41	11.70±0.46	NO
Cs-137	7.69±0.44	7.79±0.46	NO
α-Pu	14.40±0.47	14.50±0.46	NO

Table 8

Thermal Cycle Compressive Strength Results
Sludge Wash Cement-Waste Drum Cores
WVNS-TP-051 Drum 84699, 24 wt% TDS, 0.66 W/C

Core Location from Drum	Pre-Thermal Cycle Compressive Strength (psi)	Post-Thermal Cycle Compressive Strength (psi)
Top	810	930
Middle	1110	1390
Bottom	1370	1180
Average	1097	1167

High-Level Waste Pretreatment



PP-LLW-0645

Figure 1

WVDP CEMENT WASTE FORM QUALIFICATION TESTING OF SLUDGE WASH LIQUIDS

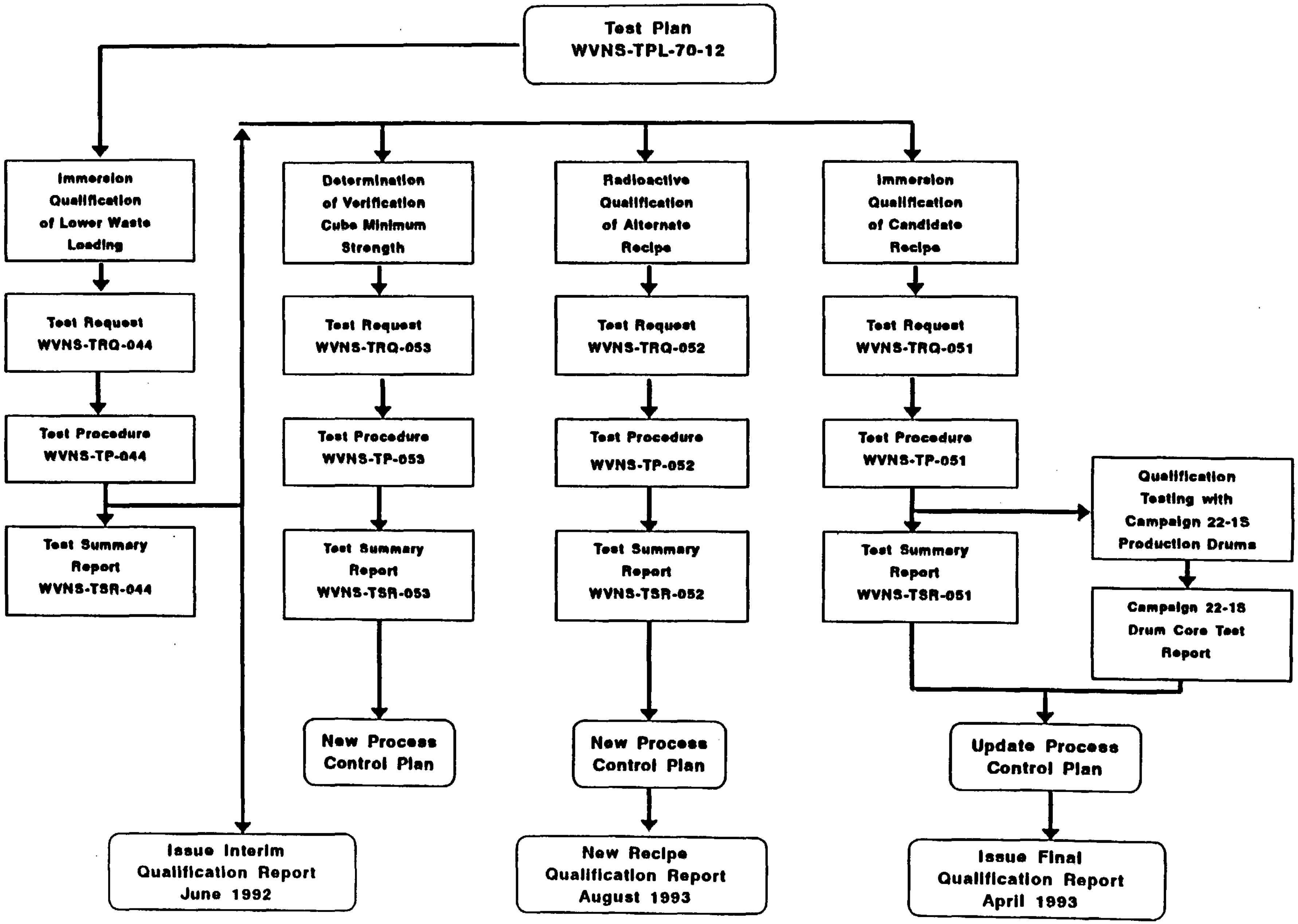
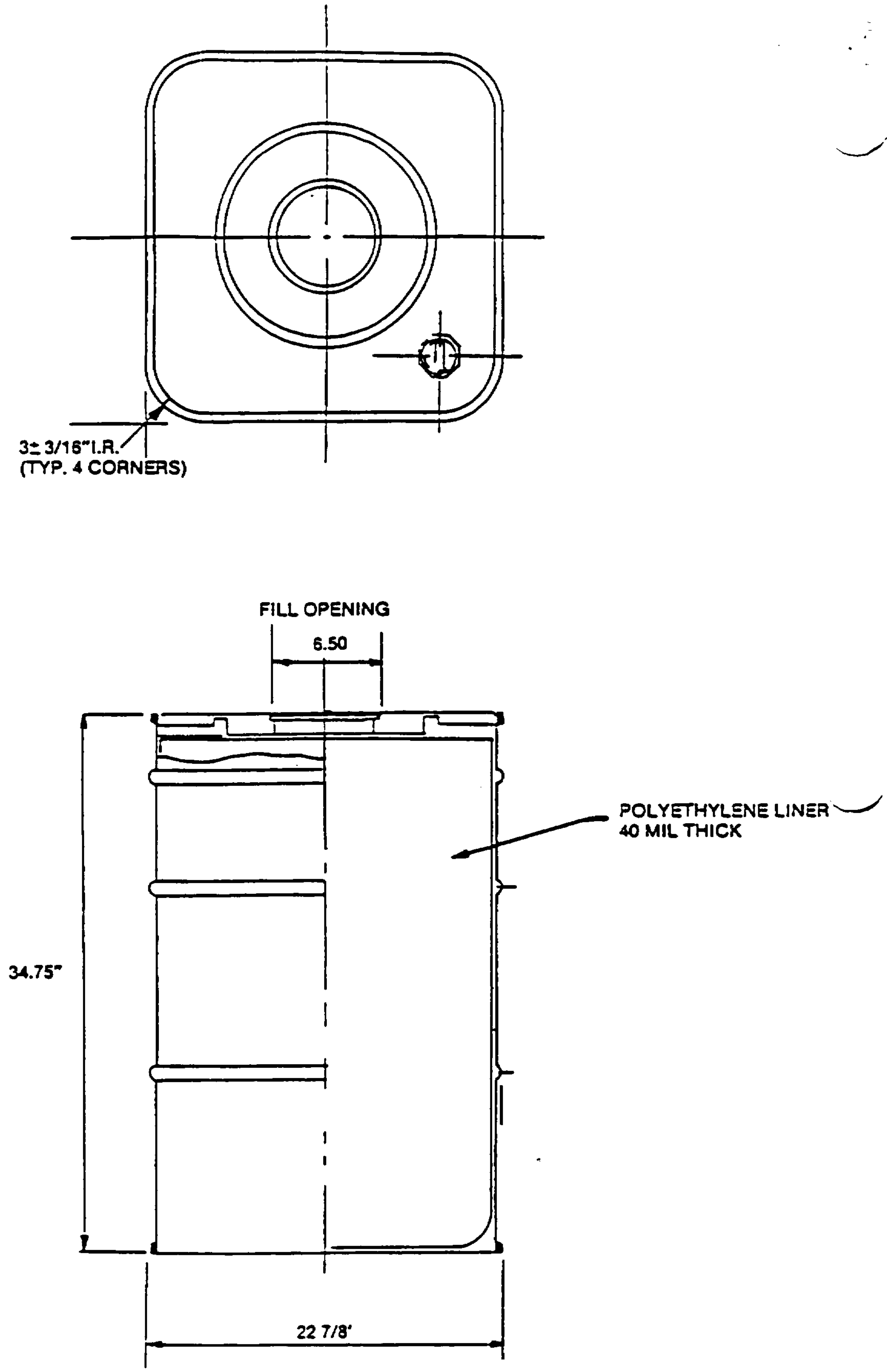


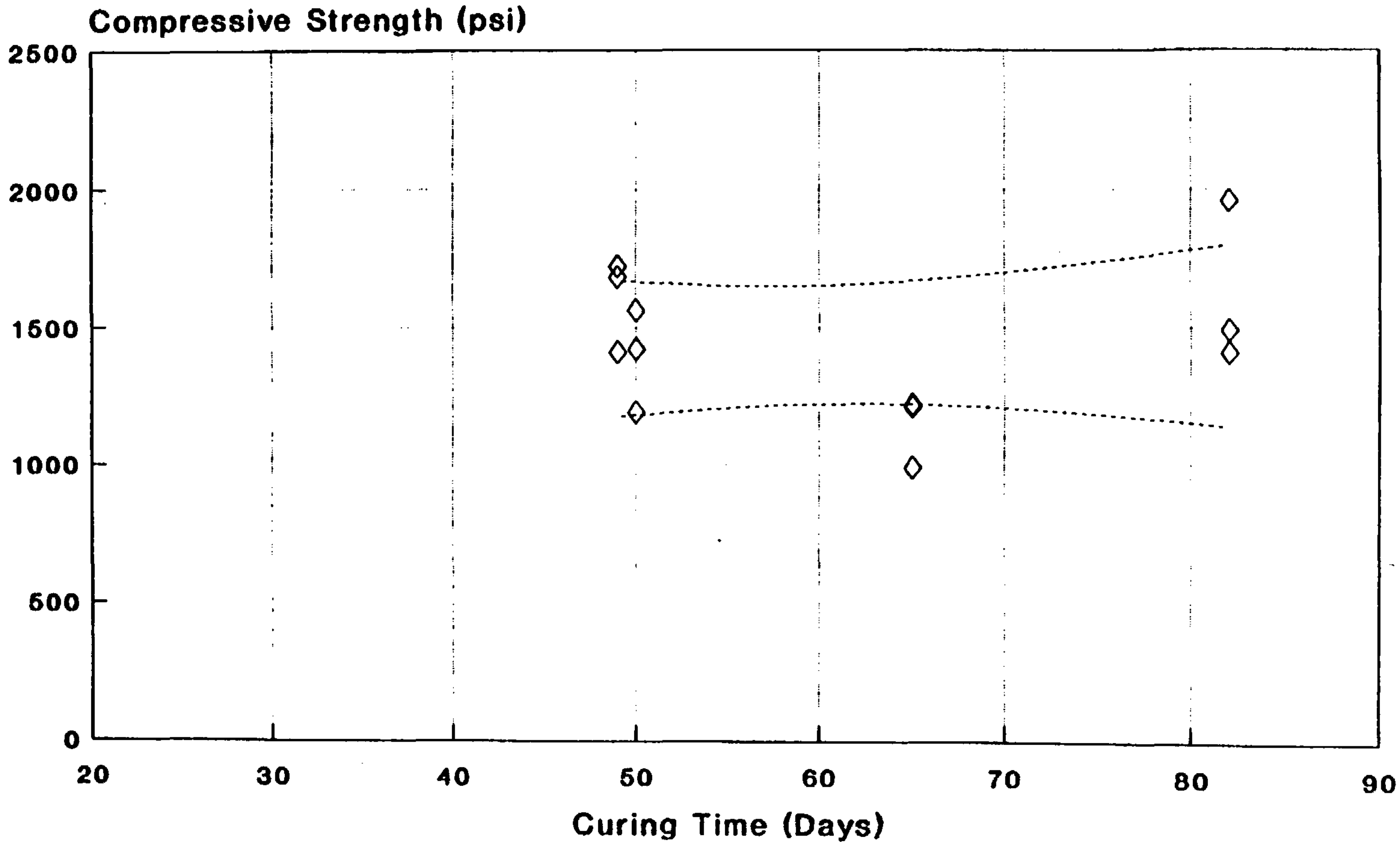
Figure 2



FULL-SCALE CSS DRUM DIMENSIONS

Figure 3

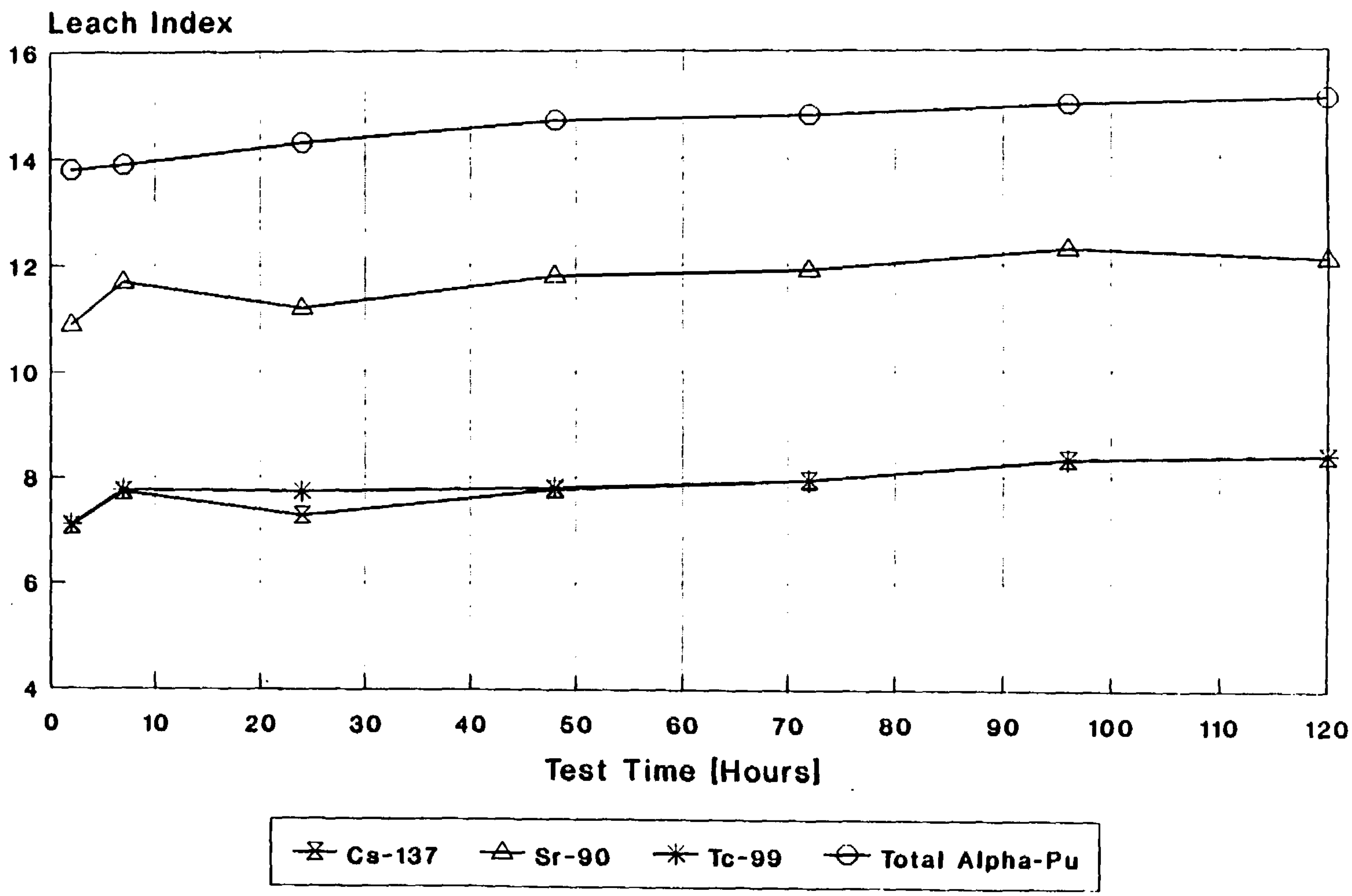
Cured Cement Strength vs Curing Days
Cores from Full-scale Drums made with
20% TDS Decontaminated Sludge Wash



Average = 1439 +/- 173 psi
(95% confidence of mean)

Figure 4

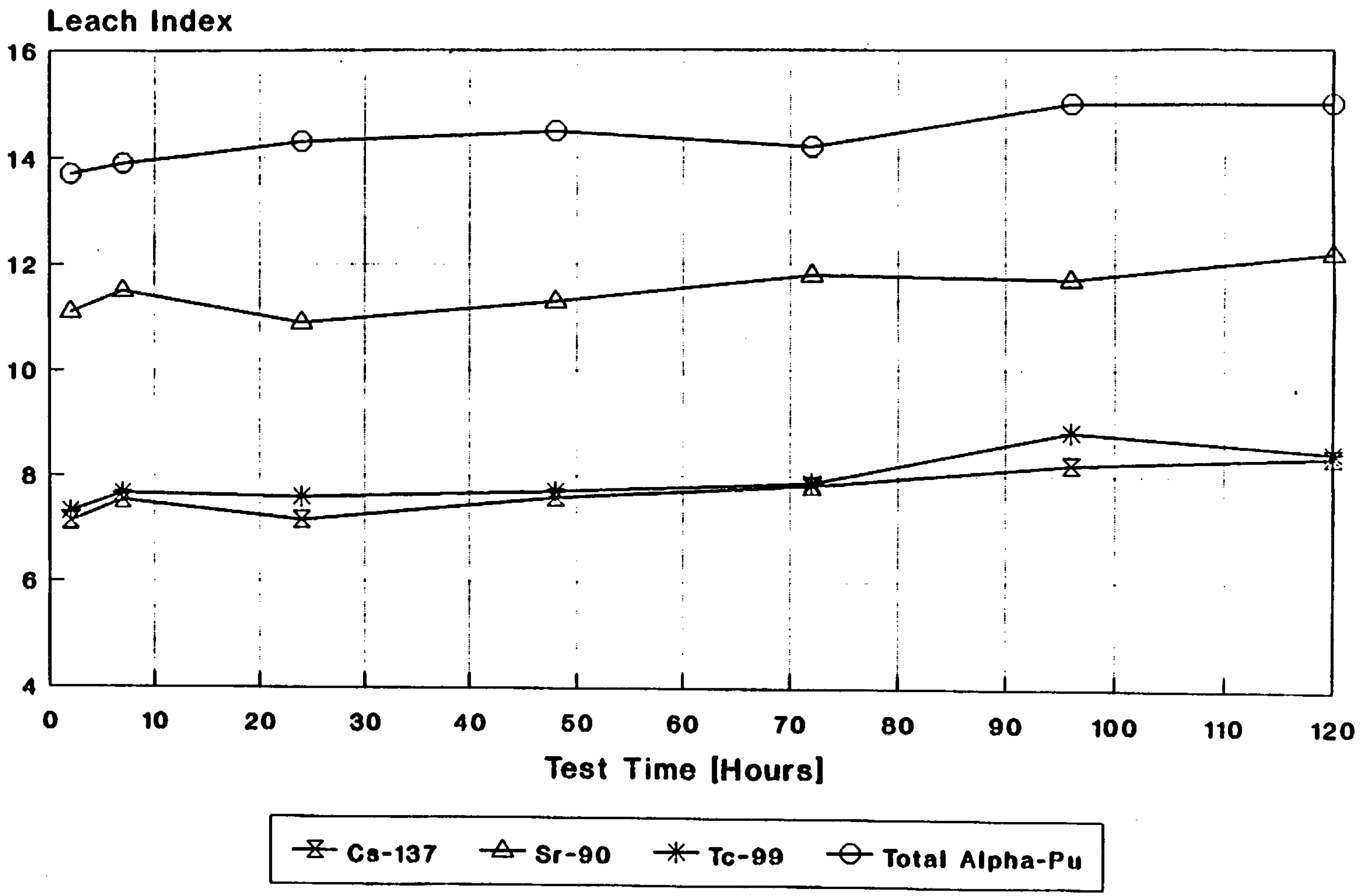
LEACHABILITY INDICES
Synthetic Sea Water



Decontaminated Sludge Wash Cement-Waste
20% TDS, 0.66 Water-to-cement ratio

Figure 5

LEACHABILITY INDICES
Demineralized Water

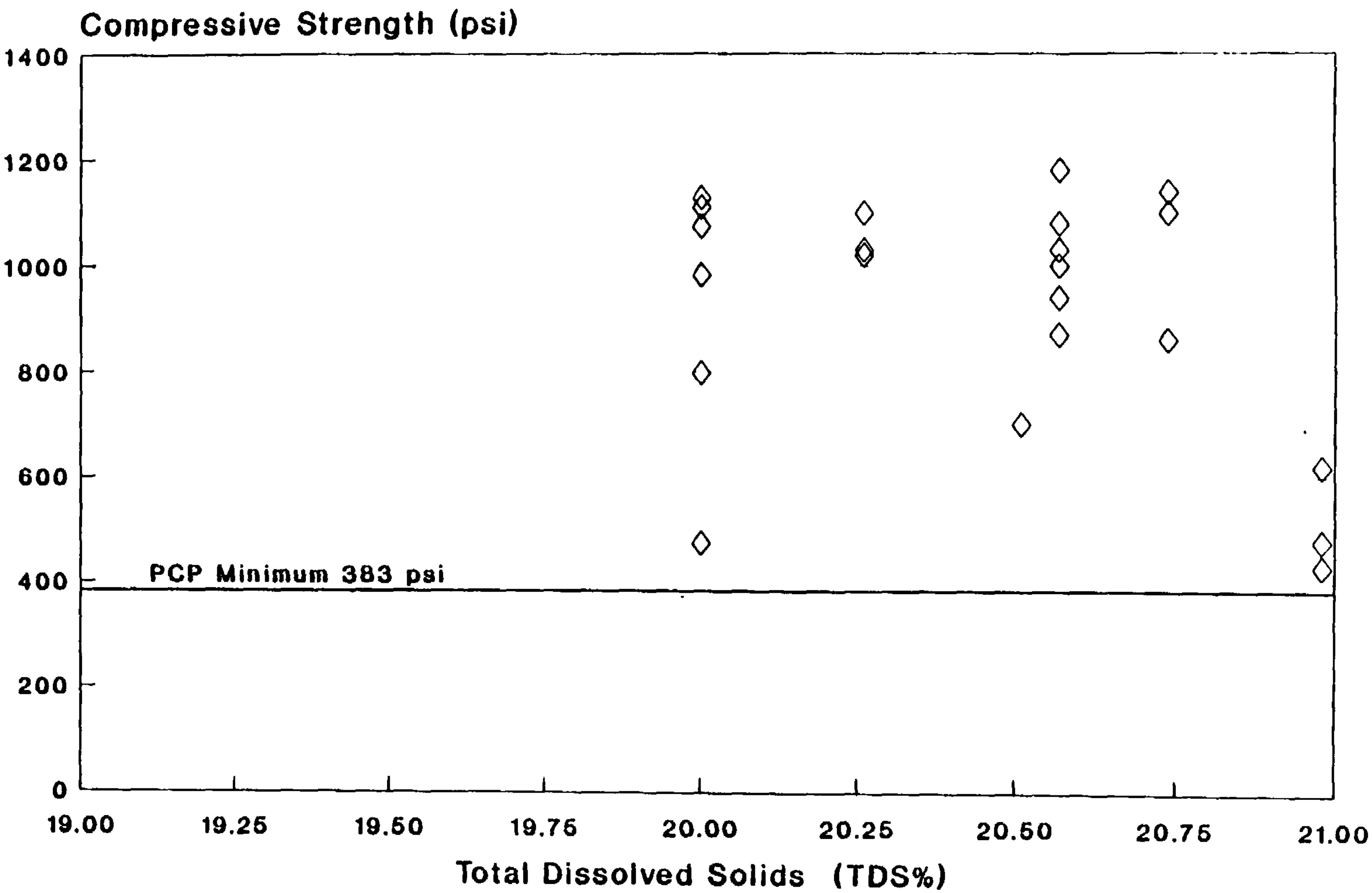


Decontaminated Sludge Wash Cement-Waste
20% TDS, 0.66 Water-to-cement ratio

Figure 6

Campaign 22-1S Cement Cube Data

Pre-Solidification Results



Compressive Strength for 2-Inch cubes
after 23-hour cure at 85 degrees Celsius

Figure 7

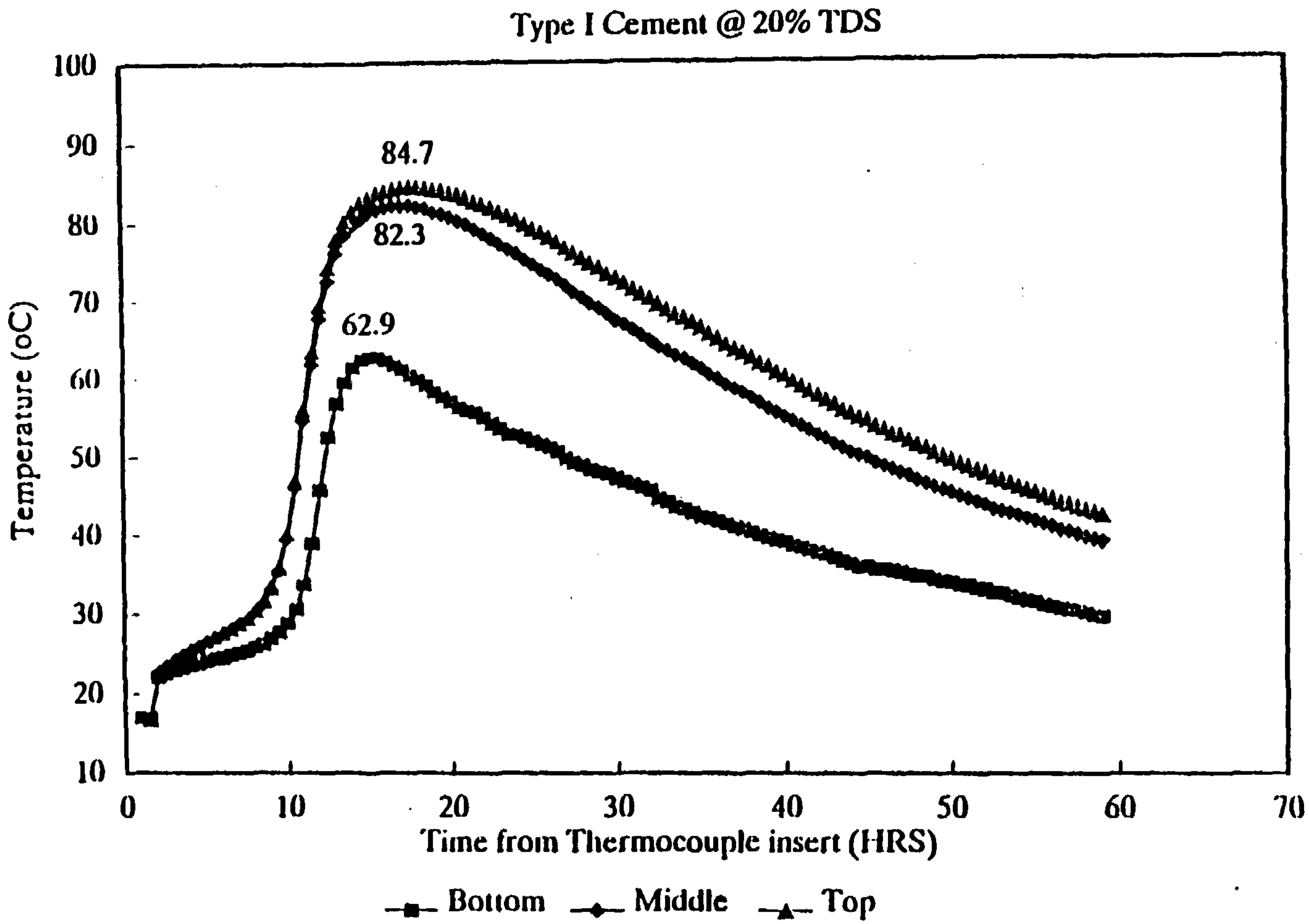


Figure 8 Campaign 23-1S Drum # 83550
Centerline Temperatures
During Curing

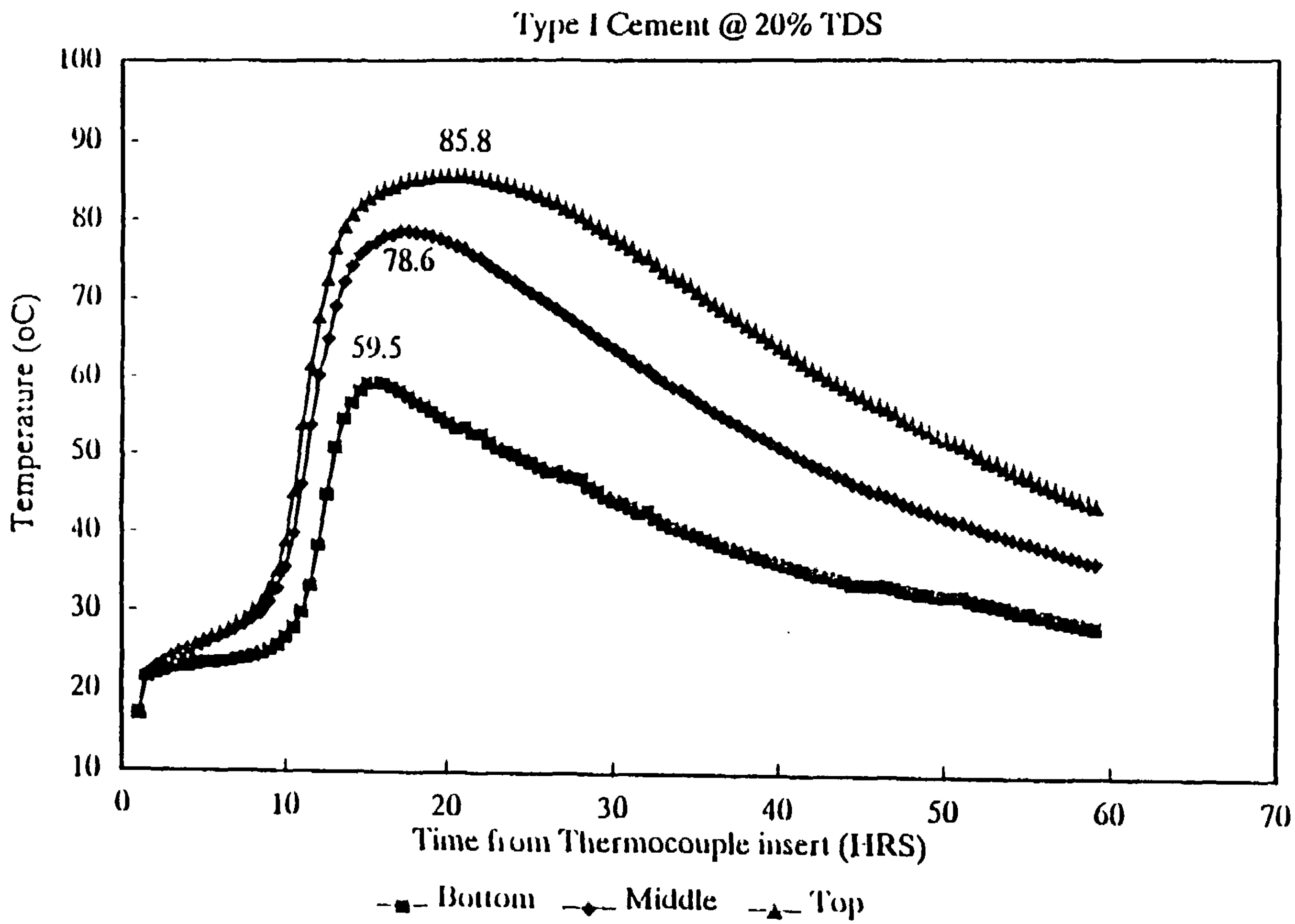


Figure 9 Campaign 23-1S Drum # 84162
Centerline Temperature
During Curing

APPENDIX

CEMENT CORES FOLLOWING 90-DAY IMMERSION TEST
IN SYNTHETIC SEAWATER

NOTE: CORES OBTAINED FROM DRUMS PRODUCED FULL-SCALE IN CSS WITH 20 WT% TDS DECONTAMINATED SLUDGE WASH SOLUTION