A TECHNICAL BASIS FOR MEETING WASTE FORM STABILITY REQUIREMENTS OF 10 CFR 61*

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ABSTRACT

To assure that solidified low level waste forms meet the stability requirements of 10 CFR 61 regulations, the US Nuclear Regulatory Commission (NRC) has published Branch Technical Positions (BTPs) and draft Regulatory Guide on waste form stability. These guidance documents describe the test procedures and acceptance criteria for six stability parameters: leachability, compressive strength, immersion effect, radiation effect, thermal stability and biodegradability. The most recent set of recommended tests and acceptance criteria are presented in the November 1986 "Preliminary" Draft Regulatory Guide "Low Level Waste Form Stability." The objective of this study was to: (1) investigate the regulatory and technical bases for the required stability tests, (2) evaluate the relevance of these tests and acceptance criteria based on actual test results, and (3) recommend alternatives to the testing and acceptance criteria. The latter two objectives are discussed in this paper. Findings of this study include recommendation for modified test procedures and an alternative set of acceptance criteria. A cost impact analysis was also conducted to determine the potential savings from the implementation of the recommended alternatives.

INTRODUCTION

The 10 CFR 61 regulation contains specific requirements for stability of low level radioactive waste prior to disposal. The US Nuclear Regulatory Commission (NRC) has provided detailed test procedures and technical criteria for the determination of waste form stability. These test procedures and technical criteria were first published in the form of Branch Technical Position (BTP) May, 1983. In a more recent effort to refine and formalize the requirements of the BTP as regulatory compliance guidelines, the NRC has published these criteria in the form of draft Regulatory Guides. The first public draft Regulatory Guide was issued in February 1985. More recent "Preliminary" draft was prepared in November, 1986. When the regulatory guide (RG) is published in its final form, it will provide the basis for industry-wide compliance with the waste form stability requirements specified in 10 CFR 61.

In addition, the RG will become the technical foundation for the preparation of a waste form stability Process Control Procedure (PCP). This PCP will define the extent to which waste form stabilization processes have to be monitored, and periodically tested, for demonstrating consistency of results. Considering the overall impact of a finalized RG and its use by both the industry and the NRC for determining regulatory compliance, the RG must be both technically correct and practicable in addressing the regulatory and technical issues related to waste form stability.

The purpose of this NESP sponsored study was to: (1) investigate the technical and regulatory basis for the requirements in the RG; (2) evaluate objectively the relevance of the requirements based on waste form stability test data available from government and commercial sources; and (3) recommend alternatives to the testing and acceptance criteria. The November, 1986 draft version of the RG was used as the subject for this study.

TECHNICAL APPROACH

The study was organized into four tasks. The first task was to review the historical development of the 10 CFR 61 and the BTP to define the specific need, purpose and objective of the waste form stability requirements. The second task was to collect and systematically review the large body of vendor and government generated test data. The third task was to evaluate the technical and regulatory basis of the stability criteria in the RG using the collected test data. The

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last and fourth task was to provide recommendations for alternatives to the current criteria. A cost impact analysis comparing the effects of the RG requirements to the recommended alternatives was also performed.

METHOD FOR DATA COLLECTION AND EVALUATION

The data evaluation part of the study focused on the principal nuclear power plant generated waste streams. The collected data were stored and organized into a data base designated WASTFORM. This data base was composed of mostly vendor generated test results obtained in accordance to the BTP procedure.

Source of Data

The three sources identified for the collection of waste form stability test data were: NRC-sponsored research, DOE sponsored research and vendor tests. Although, all three sources were explored, the majority of the data entered into the data base was obtained from commercial vendors involved in waste stabilization. The vendors providing information for this study were:

- Advanced Technology, Inc.
- Chem-Nuclear Services, Inc.
- Dow Corporation, The
- General Electric Company
- London (LN) Nuclear Services, Inc.
- Stock Equipment Company
- US Gypsum Company
- WasteChem Corporation

Westinghouse Electric Company (formerly Westinghouse Hittman)

Data Base Framework

The data base was constructed on three major parameters: waste streams, RG stability criteria, and stabilization media. The technical reports reviewed for the preparation of the data base considered a variety of waste streams and waste to binder formulations. These waste streams were grouped in six categories of similar basic characteristics: mixed bed resins, mixed powdered resins, BWR filter/precoat media, PWR evaporator concentrates, BWR evaporator concentrates and decon solution.

To better characterize each of the waste stream categories, the data base also included information on the weight percent (w/o), concentration of the essential substances which make up each of the waste stream, waste to binder ratio, and vendor specified additives. The six BTP stability criteria considered in this study are leachability, compressive strength, immersion, radiation effect, thermal stability and biodegradability. The stabilization media consist of those currently commercially available, i.e., cement, gypsum, bitumen, and polymer. Other information stored in the data base included physical parameters of the test specimen such as shape and dimensions, volume, weight, surface area, and volume to surface area ratio.

Data Evaluation

The WASTFORM data base contains 960 records of data entry. Nearly all of those records were created from vendor generated test results. Data reduction was accomplished by sorting the data file on important parameters.

Leachability data were sorted by the 5-day and 90-day leachability indices to determine if the 5-day result was an accurate predictor of the 90-day test result. The second set of sorts was performed by leachants, i.e. synthesized sea water or demineralized water. The purpose was to compare the leachability indices of the same specimen obtained from the two different leachants.

Compressive test data were sorted for two aspects of the RG criteria: (1) the post-test compressive strength value relative to the maximum value of 60 psi; and (2) the percentage change between the pre-test and post-test compressive strength. For each RG criterion, a safety factor relative to the 10 percent strength reduction requirement was determined.

TECHNICAL EVALUATION

The following presents an evaluation of the six RG criteria based on the vendor test data stored in the WASTFORM data base.

Leachability Testing

The WASTFORM data base contains 423 records of leach test data. Each record may contain up to four leachability indices for the same specimen the 5-day and 90-day indices in demineralized water and/or synthesized sea water.

A review of the data sets shows that a vast majority of the 5-day leachability indices are equal to or lower than the 90-day indices. This is true for 94 percent of the 163 sets of test data conducted in demineralized water and 85 percent of the 84 sets of test data conducted in synthesized sea water. Only a small percentage of the results (6 and 15 percent) show lower 90-day indices. The small differences between the 5-day and 90-day test results confirmed the theory that leachability index is a time-independent constant.

This evaluation was conducted further by comparing the 90-day test results obtained in demineralized water to those in synthesized sea water for the same specimen. A total of 195 data sets using three radioactive tracers, i.e., Co-60, Sr-85, and Cs-137, was identified for four binder media. Results of the evaluation showed that the leachability

indices were much lower for tests conducted in synthesized sea water for two stabilization media, polymer and bitumen. Results also showed that both leachants were equally severe for the cement and gypsum binders.

An acceptable technical basis to support the requirement for a leachability index greater than six could not be found. However, based on the performance records of the tested specimens and the demonstrated ability of the criterion to eliminate poor waste forms, it was concluded that the RG acceptance criterion of a leachability index greater than six is reasonable. This evaluation concluded that a 5-day leach test is conservative and adequate for the determination of the leachability of a waste form. The evaluation also showed that it is unnecessary to use two leachants to determine the leach characteristics of a waste form. The use of one leachant synthesized sea water, is sufficient for the test.

Compressive Strength Test

The NRC method for determining structural stability of a waste form is based on the compressive strength of the material. To demonstrate that a waste form continues to be structurally stable under disposal conditions indicated in 10 CFR 61.56(b), the NRC requires compressive strength tests to be conducted following each of the five tests in the RG except leachability.

The data base included a 127 sets of data with results ranging from 126 psi to 9530 psi. The lowest compressive strength has a safety factor of 2.1 compared to the minimum strength of 60 psi. A review of the test data indicates that the test procedure prescribed in ASTM C39 is an adequate means for determining the structural stability of waste form. However, the variability in the test procedure should be considered in determining the acceptable range of strength loss following a test. The 60 psi acceptance criterion is reasonable and attainable by most material which possess some structural strength. The ASTM D621 procedure recommended for bituminous (viscoelastic) material is not an appropriate procedure and should be replaced by a more applicable procedure. Other than the fact that this procedure will soon be removed by ASTM, the test procedure is also not practicable for testing waste form materials.

Immersion Test

The immersion test is by far the most severe tests required by the RG. It is also an important test for determining the compatibility of the stabilization medium to waste streams and for determining the maximum possible waste loading percent. A review of the test data in the WASTFORM data base indicated that, except for two bitumen samples, all other test specimens passed the NRC required minimum compressive strength of 60 psi for acceptance. However, the 37 percent (38 of 103) of the test samples failed the less than 20 percent reduction in strength criterion. Many of those "failed" samples have post-test strength in the range of several hundred to several thousand psi far exceeding the 60 psi minimum required strength. Judging from the test data reviewed, it was concluded that a 90-day test duration specified in the RG is adequate to determine the acceptability of a waste form specimen. This test should remain in the RG criteria. However, some of the acceptance criteria should be reassessed, in particular regarding the strength reduction criterion.

Radiation Stability Test

A review of the test data indicates that there is considerable variability in the reported values for pre- and post-irradiation compressive strength, and it is not apparent that compressive strength is a true indicator of radiation degradation effects on the waste form. However, the following observations and conclusions were drawn: (1) The 100 megarad dosage is reasonable, although it bears no relevance to waste forms which do not contain organic ion exchange resins. (2) The RG recommended criterion for post-testing compressive strength needs to be re-assessed. (3) Irradiation of polymer type binder material is not necessary, since irradiation consistently increases their compressive strength. (4) Irradiation testing of waste streams stabilized with cement is not required unless the waste stream contains organic ion exchange media.

Thermal Degradation Testing

The technical rationale for the inclusion of a thermal degradation test in the RG and the selection of the test parameters are discussed in NUREG/CR-4215. The NRC expressed its concern in that report regarding thermal degradation of the waste forms during transportation and interim storage. The discussion in the report also indicated the NRC rationale for selecting the number of test cycles, the temperature range and the test procedures.

Review of the ASTM B553 procedure and discussion with the Chairman of the responsible ASTM standards committee indicate that B553 is not applicable to thermal testing of waste forms. Furthermore, review of vendor test data indicates that results of thermal stability testings have shown no evidence of negative effects on polymeric or bituminous binder materials. However, freeze-thaw cycles of the thermal test have shown damaging effects on water containing binder materials such as cement and gypsum.

Biodegradation Test

Review of the G21 and G22 test procedures indicated that the two procedures are designed to determine the susceptibility of the material under most favorable conditions. The ASTM Section Committee Chairman responsible for the two test procedures confirmed that both the G21 and G22 are microbial growth tests and they are not biodegradation tests. These tests were not designed to evaluate the effects of microbial growth on materials. Therefore to follow

each of these tests with a compressive strength test is not the intent of the test and of no value.

Review of the biodegradation test data further supported the position that the G21 and G22 tests have no effect on waste form specimens. None of the test data reviewed indicated any bacterial or fungal growth. However, the post-testing compressive strength of approximately half of the data set decreased, while the other half increased.

RECOMMENDATION

These following recommendations address each of the specific test procedures and method required to satisfy each RG criterion. These recommendations are applicable only to the waste forms evaluated in this study. The RG test requirements and alternatives recommended by this study are summarized in Table 1.

Leachability. The ANS 16.1 Standard, in general, provides a reasonable method for determining the leachability of stabilized waste forms. The acceptance criterion of a leachability index greater than six is a reasonable indicator. However, two areas in the test procedure require modification: (1) the test duration of 90 days should be reduced to 5 days; and (2) the use of one leachant synthesized sea-water will be sufficient; or, the NRC can place the burden of demonstrating the most conservative leachant on the vendor if he chooses to use other leachants.

Compressive Strength Testing. For brittle materials, the RG recommended ASTM C39 test procedure and a minimum compressive strength of 60 psi. are reasonable. However, the current requirement concerning post-test strength reduction should be increased from 10 to 20 percent to account for test variability.

For viscoelastic materials, the RG recommended ASTM D621 test procedure is not applicable to waste form stability testing. The ASTM D1074 test procedure, previously recommended in the BTP, should be used as the procedure for determining the compressive strength of viscoelastic binder materials. The acceptance criteria for post-test strength reduction should be increased from 10 to 25 percent to account for test variability. Provisions for administrative controls as an alternative means of compliance should be retained.

Immersion Testing. The RG provision concerning compressive strength reduction of less than 20 percent should be revised to account for test result variability and the margin of safety between the post-test strength and the minimum strength requirement.

For brittle materials, the RG should be revised to provide for maximum reduction of 20 percent or a minimum post-test compressive strength of 90 psi. For viscoelastic materials, the RG should be revised to provide for a maximum reduction of 25 percent, or a minimum post-test compressive strength of 75 psi. These greater allowable *stresses* are to account for the relatively low pre-test compressive strength and the variability in the test results for using the ASTM D1074 procedure. The existing provision for using administrative controls as an alternative means of compliance should be retained.

Radiation Stability Testing. The use of 100 megarads as the test condition is reasonable and should be retained. However, the requirement for radiation effects testing should be exempted for :(1) polymer stabilized waste form; (2) cement based media containing no organic ion exchange resins; and (3) bitumen based waste form which the vendors have submitted evidence to indicate no or negligible amount of detectable irradiation degradation.

Thermal Degradation Testing. The existing thermal degradation test requirement should be eliminated. If the NRC determines that thermal cycling conditions during waste storage and transportation should be addressed in Part 61, then it is recommended that the currently adopted ASTM B553 procedure be replaced with a procedure which addresses specifically the effects of freeze-thaw cycles. And that, this procedure should be applied only to stabilization media which can contain water such as cement and gypsum. The acceptance criteria should accordingly be revised.

Biodegradation Testing. It is recommended that an alternate set of test procedure be developed. Meanwhile, the current biodegradation test requirements should be eliminated for all stabilization media except bitumen until a test procedure is developed.

REFERENCES

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6. American Society for Testing and Materials,"Thermal Cycling of Electroplated Plastics," ASTM B553, 1979.

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8. American Society for Testing and Materials,"Determining Resistance of Synthetic Polymeric Materials to Fungi," ASTM G21, 1980.

9. American Society for Testing and Materials,"Compressive Strength of Bituminous Mixtures," ASTM D1074, 1983.

10. American Society for Testing and Materials,"Compressive Strength of Cylindrical Concrete Specimens," ASTM C39, 1984.

11. US Nuclear Regulatory Commission, "Technical Factors Affecting Low-Level Waste Form Acceptance Criteria", NUREG/CR-4215, May, 1985.

TABLE I

Recommended Waste Form Testing Requirements.

Binder	RG Requirements (11/86)	Test Procedure	Recommended Alternatives	Test Procedure
		RADIATION STABILITY TEST		
Brittle Materials	o Expose to 10^8 Rads o Minimum compressive strength ≥60 psi	(ASTM C39)	o Expose to 10^8 Rads o Minimum strength 60 psi be <20% or post-test strength be >90 psi o Test not required for polymer and cement which does not contain organic ion ion exchange media.	(ASTM C39)
Viscoelastic Materials	o Expose to 10^8 Rads o Extrapolated deformation <10% over 300 yrs or o Administrative backfill plus leach index >6 or o Administrative backfill plus compressive strength ≥60 psi and no <10% reduction	(ASTM D621) (ASTM D1074)	o Expose to 10^8 Rads o Minimum strength 60 psi or o Minimum strength 60 psi o Strength reduction must be <25% or post-test strength >75 psi	 (ASTM D1074)
		BIODEGRADATION TEST		
Brittle Materials	o Resistance to Biodegradation o Minimum compressive strength ≥60 psi	(ASTM G21) (ASTM G22) (ASTM C39)	o It is recommended that with the exception of bitumen this test be eliminated for cement, gypsum and polymer binders until more appropriate test procedures are identified	
Viscoelastic Materials	o Resistance to Biodegradation o Extrapolated deformation <10% over 300 yrs or o Administrative backfill plus leach index >6 or o Administrative backfill plus compressive strength ≥60 psi and ≤10% reduction	(ASTM G21) (ASTM G22) (ASTM D621) (ANS 16.1) (ASTM D1074)		

TABLE I

Recommended Waste Form Testing Requirements.

TABLE I
Continued

Binder	RG Requirements (11/86)	Test Procedure	Recommended Alternatives	Test Procedure
		LEACH TEST		
Brittle Materials	o 90-day leach test o Leach index >6 o Use both demin. water & sea water as leachate	(ANS 16.1)	o 5-day leach test o Leach index >6 o Use only sea water as leachant	(ANS 16.1)
Viscoelastic Materials	o 90-day leach test o Leach index >6 o Use both demin. water & sea water as leachate	(ANS 16.1)	o 5-day leach test o Leach index >6 o Use only sea water as leachant	(ANS 16.1)
		COMPRESSIVE STRENGTH TEST		
Brittle Materials	o Compressive strength ≥60 psi	(ASTM C39)	o Comressive strength ≥60 psi	(ASTM C39)
Viscoelastic Materials	o Extrapolated deformation <10% over 300 yrs or o Documented site administrative control procedure	(ASTM D621)	o Compression strength ≥60 psi or o Documented Site administrative control procedure	(ASTM D1074)
		IMMERSION TEST		
Brittle Materials	o 90-day immersion o Minimum strength 60 psi, strength reduction must be <20% or provide technical justification o Test may be performed in conjunction with leach test o Cement cure time: 28 days	(ANS 16.1)	o 90-day immersion o Minimum strength 60 psi o Strength reduction must be <20% or post-test strength be ≥90 psi	(ASTM C39)
Viscoelastic Materials	o 90-day immersion o Extrapolated deformation <10% over 300 yrs or o Administrative procedure plus leach index >6 or o Administrative procedure plus compression test 60 psi and <20% decrease or provide technical justification o Test may be performed in conjunction with leach test	(ASTM D621) (ASTM D621) (ANS 16.1) (ASTM D1074)	o 90-day immersion o Minimum strength 60 psi o Strength reduction must be <25% or post-test strength ≥75 psi or o Administrative procedure plus leach index >6 o Test may be conducted in conjuction with leach test	(ANS 16.1) (ASTM D1074)
		THERMAL TEST		
Brittle Materials	o 30 cycles between 60/-40C o Minimum compressive strength ≥60 psi	(ASTM B553) (ASTM C39)	o It is recommended that this test be eliminated	
Viscoelastic Materials	o 30 cycles between 60/-40C o Extrapolated deformation <10% over 300 yrs leach index >6 or o Compression strength ≥60 psi and <10% reduction	(ASTM B553) (ASTM D621) (ANS 16.1) (ASTM D1074)		