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Conceptual Waste Package Interim Product Specifications and Data Requirements for Disposal of Borosilicate Glass Defense High-Level Waste Forms in Salt Geologic Repositories

Technical Report

June 1983

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**Office of Nuclear Waste Isolation
Battelle Memorial Institute
Columbus, OH 43201**

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**Office of Nuclear Waste Isolation
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ABSTRACT

The conceptual waste package interim product specifications and data requirements presented are applicable specifically to the normal borosilicate glass product of the Defense Waste Processing Facility (DWPF). They provide preliminary numerical values for the defense high-level waste form parameters and properties identified in the waste form performance specification for geologic isolation in salt repositories. Subject areas treated include containment and isolation, operational period safety, criticality control, waste form/production canister identification, and waste package performance testing requirements. This document was generated for use in the development of conceptual waste package designs in salt. It will be revised as additional data, analyses, and regulatory requirements become available.

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1 INTRODUCTION

The principal objective of the National Waste Terminal Storage (NWTs) program is to provide the technology and facilities for the disposal of radioactive wastes. Disposal in deep-mined repositories is the most advanced of the various disposal methods considered in this program and, thus, is being emphasized for near-term development.

Technical direction for the NWTs program is provided through the DOE/NWTs-33 series of documents. DOE/NWTs-33(1)¹ discusses program objectives, functional requirements, and performance criteria. Compliance with the functional requirements will establish the capabilities that the mined geologic disposal system must provide to achieve the program objectives. Performance criteria define the performance of the disposal system and its components to ensure that the functional requirements are met.

Three other documents respond to DOE/NWTs-33(1). DOE/NWTs-33(2)² presents the site performance criteria, DOE/NWTs-33(3)³, the repository performance criteria, and DOE/NWTs-33(4a)⁴ discusses the functional requirements and performance criteria that the U.S. Department of Energy (DOE) is using as a basis to develop waste packages for the disposal of radioactive wastes.

Performance specifications which are responsive to DOE/NWTs-33(4a) have been developed for the waste package (ONWI-463)⁵ and the waste form* (ONWI-462)⁶ in salt repositories. The next step in the definition of the waste package is the development of detailed specifications for individual package designs and waste forms. Figure 1 provides an overview of the hierarchy of program objectives, functional requirements, criteria, and specifications.

The U.S. Nuclear Regulatory Commission (NRC), in conjunction with the U.S. Environmental Protection Agency (EPA), will ultimately determine what constitutes an acceptable disposal system. Because the technical criteria of the regulatory agencies have not been established, the DOE has formulated these interim performance criteria and specifications to guide the ONWI Program.

*Because of the significance of the waste form as a component of the waste package, separate specifications have been developed for the waste form. The production canister is also treated in the waste form specifications.

FIGURE 1. HIERARCHY OF OBJECTIVES, REQUIREMENTS, CRITERIA, AND SPECIFICATIONS

This document presents interim product specifications and data requirements for the defense high-level waste (DHLW) form for conceptual waste package designs for geologic disposal in salt repositories. Currently, the waste package system is still in the conceptual design stage. In addition, the Defense Waste Processing Facility (DWPF) is in the preconstruction phase. Consequently, these product specifications are subject to change as additional data and analyses are completed.

The waste form performance specifications and data requirements respond to the Waste Package Performance Criteria. Each of these criteria was analyzed to identify the waste form parameters or characteristics which must be controlled to meet the criteria. These parameters and characteristics form the basis for the waste form performance specifications. Product or acceptance specifications for each different waste form are being developed to establish the numerical values for these parameters or characteristics for which control is required to meet the waste package performance criteria. The product specifications are intended to describe the characteristics of the waste form in sufficient detail to enable the waste form producer to develop a canistered waste form. The data requirements will provide the base of evidence to verify that the waste form meets the product specification. Meeting the specifications will thereby assure compliance with the NWTs criteria.

In general, except for product specifications dealing with gross weight, dimensions, and surface contamination, the product specifications do not require individual measurements to be made on each canister of DHLW. Some of the specifications may be met using data obtained as average values from a sample of each melter feed batch; other specifications may be met using data from generic studies on the waste form. Data requirements usually will be met with data from generic studies.

Unlike the waste form performance specification document, which is primarily qualitative in form and provides a numerical value for only one waste form parameter (waste form release rate), this document provides numerical limits, to the extent possible at this time, for the waste form parameters and characteristics requiring control.

The following discussion of the mined geologic disposal system is provided to help place in perspective the product specifications for the waste form.

The mined geologic disposal system is composed of three subsystems: the site, the repository, and the waste package which includes the waste form.

In evaluating the disposal system's performance, three time periods are of interest:

1. Operational period - the time when the repository is open, and waste can be emplaced, monitored, or retrieved. During this period, radioactivity levels and heat production are dominated by fission product decay. The operational period is expected to be 50 to 80 years.
2. Containment period - the time after the decommissioning of the repository when the radioactive waste must be contained within the waste package. For commercial and defense HLW, and spent fuel, this period coincides with the time period when radioactivity levels and heat production within the waste are dominated by fission product decay, and host rock temperatures around the waste packages are elevated. The containment period is expected to be no longer than 1,000 years.
3. Isolation period - the time following the containment period during which the radiological hazard is dominated by the decay of actinides and their daughters. The isolation period is expected to be about 10,000 years after emplacement.

The waste form is an integral part of the disposal system and will play a major role in the operational period and in the long-term isolation of radioactive wastes during the containment and isolation periods.

During the operational period, handling at the repository and the protection of the health and safety of the repository operating personnel and the public must be considered in establishing the performance of the waste form. For the long term, the waste form must function to limit any radionuclide release to a gradual process that results in release rates that are a very small fraction of the total waste inventory.

The waste form is a part of the waste package. The complete waste package is defined as the waste form and the enclosing envelope that separates the waste from the host rock. In addition to the waste form, the package, depending on its final design, may include the following components: stabilizer, canister, overpack, emplacement hole backfill, and protective sleeves

or coatings as appropriate. Waste package designs are still evolving and the makeup of components may vary. An important consideration is the treatment of the waste form as a part of a system. Clearly, the performance of the waste form must be considered in relation with the other components of the package and the host rock. For purposes of these product specifications, the canister is included with the waste form. Each product specification will clearly identify whether it applies to the DHLW form, canister, or both components.

The objective of these product specifications is to guide the designer or producer of the waste form to meet the NWTs criteria. For a detailed discussion and application of the overall NWTs objectives, requirements, and criteria, the reader is referred to References 1 through 4.

2 INTERIM PRODUCT SPECIFICATIONS AND DATA REQUIREMENTS

The product specifications presented here are applicable specifically to defense high-level waste borosilicate glass for geologic disposal in salt repositories. These specifications were developed from the more general waste form performance specification document, ONWI-462.

The product specifications presented in this document apply to the normal product of the Defense Waste Processing Facility. It is recognized that occasional variations in product quality will occur, and that some deviations from these specifications are inevitable. These variations and deviations will be considered individually as special cases.

Since the waste form is one component in a larger system made up of the waste package, the repository, and the site, it cannot be fully specified without input from these other parts of the overall isolation system. It is necessary to define waste package and repository design and performance limits before the performance limits for the waste form can be fully quantified. Since designs for these elements of the isolation system are currently under development, and are subject to change, interim product specifications are being developed for the various waste forms to provide preliminary numerical values for the waste form parameters and properties identified in the waste form performance specification. The numerical values given in this product specification document will be verified in a future reconfirmation of this document.

The waste form performance specifications (ONWI-462)⁶ were derived from the Waste Package Functional Requirements and Performance Criteria [NWTs-33(4a)]⁴ which are undergoing public review and thus are subject to change. Therefore the performance specifications themselves are interim and will require reconfirmation following the public issuance of the waste package criteria.

In this section, each of the performance specifications from ONWI-462 is presented in the same order as in that document. Following each performance specification, the product specifications and data requirements derived from it are presented. A brief discussion and explanation of the product specification and data requirement follows. Throughout this section, **PRODUCT SPECIFICATIONS** will be capitalized and *DATA REQUIREMENTS* will be italicized to distinguish between the two types of information.

2.1 CONTAINMENT AND ISOLATION

2.1.1 Containment

Performance Specification 1

The heat generation rate of the waste form shall be limited to ensure that the temperatures reached in the waste form during the containment period do not significantly deteriorate its capabilities to act as an isolation barrier during the isolation period. In addition, the heat generation rate shall be limited as necessary to ensure that the temperatures reached in other package components or the host rock do not significantly reduce their performance capabilities.

PRODUCT SPECIFICATION 1-1

THE DHLW FORM HEAT GENERATION RATE SHALL NOT EXCEED 1,500 WATTS PER PRODUCTION CANISTER. THE DOCUMENTED HEAT GENERATION RATE SHALL BE ACCURATE TO + 100 WATTS OF THE ACTUAL THERMAL OUTPUT.

Discussion: The maximum heat generation rate is based on heat transfer analyses assuming a DHLW canister 24 in. in diameter by 10 ft long. A maximum value is needed in order to proceed with package and repository design, material selection, analysis, etc. Thermal analyses in References 7 and 8 indicate that for credible spacings of DHLW form packages (waste form, canister, overpack, and backfill), thermal heat generation rates less than 1,500 W are well within repository local areal thermal limits. The heat generation rate values required by this specification shall apply at the time of receipt of the DHLW form and canister at the repository. For program purposes, this time is scheduled as 1998.

PRODUCT SPECIFICATION 1-2

IN ORDER TO ENSURE COMPLIANCE WITH PERFORMANCE SPECIFICATION 3, THE DHLW FORM SHALL RETAIN ITS PERFORMANCE CHARACTERISTICS AT OR BELOW A CENTER-LINE TEMPERATURE OF 500 C DURING THE CONTAINMENT PERIOD.

Discussion: The DHLW form producer must demonstrate that, during the containment period, the DHLW form retains those performance characteristics necessary to ensure that it will have adequate performance during the isolation period, assuming complete loss of containment at any time after the defined containment period (up to 1,000 years). The specification of the 500 C limit is based on two considerations. First, for credible emplacement configurations of DHLW forms, the maximum centerline temperature is not expected to exceed 500 C, based on expected repository environments. Calculations performed by ONWI indicate that a maximum centerline temperature of 275 C results from a DHLW form heat generation rate of 1,500 W at a canister spacing in salt identical to that in Reference 7. Second, it is understood that no significant degradation of the DHLW form occurs at temperatures below 500 C. This product specification requires that the DHLW form producer demonstrate this performance capability. Compliance with this product specification and PRODUCT SPECIFICATION 1-1 eliminates the need for a temperature specification on the DHLW form.

DATA REQUIREMENT 1-3

The waste form producer shall specify the maximum waste form centerline temperature at which any of the PRODUCT SPECIFICATIONS would be violated.

Discussion: In conjunction with this data requirement, and as a requirement of the Data Base Performance Specification 28, the safety margin of the production DHLW form and canister performance characteristics shall be verified.

Performance Specification 2

The radionuclide content of the waste form shall be controlled as necessary to avoid unacceptable deterioration of the waste form leach resistance from radiation.

PRODUCT SPECIFICATION 2-1

THE RADIOACTIVITY OF THE DHLW FORM SHALL NOT EXCEED 100,000 CURIES/LITER OF GLASS FOR FISSION PRODUCTS, AND 1,000 CURIES/LITER OF GLASS FOR ACTINIDES. THE WASTE FORM PRODUCER SHALL SPECIFY THE RADIONUCLIDE CONTENT (I.E., FISSION PRODUCTS AND ACTINIDES) ON AN AVERAGE PER CANISTER BASIS, ALONG WITH AN ASSOCIATED UNCERTAINTY. THE INVENTORY SHALL INCLUDE RADIONUCLIDES IN AMOUNTS GREATER THAN 0.1 PERCENT OF THE TOTAL CURIE CONTENT. THE REMAINDER MAY BE GROUPED AS A SINGLE QUANTITY. THE INVENTORY SHALL BE SPECIFIED AS OF THE TIME OF PRODUCTION OF THE WASTE FORM. THE INVENTORY MAY BE MEASURED ON A BATCH OF GLASS FEED, AND REPORTED ON AN AVERAGE-PER-CANISTER BASIS.

Discussion: The limits on the fission product and actinide quantities included in the canistered waste form are intended to reduce the effects of radiation on DHLW form and canister performance to a negligible level. No specific limits on radionuclide content due to radiation damage of other package components or the host rock are defined at this time. This PRODUCT SPECIFICATION provides the radionuclide inventory information needed to evaluate the consequences of potential radionuclide releases under expected repository environments and events.

2.1.2 Long-Term Isolation

Performance Specification 3

After waste package containment failure, the annual release rate from the waste form due to leaching and dissolution at the expected ground-water conditions shall be limited.

PRODUCT SPECIFICATION 3-1

THE SOURCE TERM FOR THE RELEASE OF RADIOACTIVITY FROM THE DHLW FORM SHALL BE LESS THAN ONE PART IN 10,000 PER YEAR OF THE TOTAL ACTIVITY IN THE WASTE FORM AT THE END OF THE CONTAINMENT PERIOD UNDER EXPECTED REPOSITORY CONDITIONS AS DEFINED BY THE REPOSITORY DESIGNER. THIS SPECIFICATION DOES NOT

APPLY TO RADIONUCLIDES WHOSE CONTRIBUTION IS LESS THAN 0.1 PERCENT OF THE TOTAL ANNUAL ACTIVITY RELEASE.

Discussion: ONWI-462 presents the basis for the DHLW form release rate source term specification. Analyses specific to DHLW are under way which may result in a change in the numerical limit specified here.

DATA REQUIREMENT 3-2

The waste form producer shall provide data and analyses to show that the source term for the release of radioactivity from the DHLW form meets PRODUCT SPECIFICATION 3-1. The uncertainties associated with the accuracy and precision of data used to determine the source term release rate limit of PRODUCT SPECIFICATION 3-1 shall be taken into account in showing that the DHLW form is in compliance with the product specification.

Discussion: The purpose of this data requirement is to assure that the waste form producer provides the waste form release rate data which support its compliance with PRODUCT SPECIFICATION 3-1. Data analyses and methods developed to calculate the release rate source term should also be provided by the waste form producer.

PRODUCT SPECIFICATION 3-3

THE WASTE FORM PROPERTIES USED IN DETERMINING AND VALIDATING THE RADIONUCLIDE SOURCE TERM FOR THE DHLW FORM SHALL BE CONTROLLED IN PRODUCTION. DATA SHALL BE PROVIDED SHOWING THE EFFECTS OF VARIATIONS ON THE SOURCE TERM.

Discussion: The waste form producer shall assure that the waste form properties controlling the waste form release rate source term are maintained in the waste form production process such that the waste form release rate limit of PRODUCT SPECIFICATION 3-1 is met throughout the waste form production run. Variations in the waste form product must be supported by data showing the effects of the product variations on the waste form release rate source term.

Performance Specification 4

The waste form shall be capable of withstanding the expected repository hydrostatic or lithostatic pressure such that it will meet the release requirements of Performance Specification 3 in the isolation period.

PRODUCT SPECIFICATION 4-1

THE DHLW FORM SHALL BE CAPABLE OF WITHSTANDING A LOADING OF 18 MPa APPLIED IN TRIAXIAL COMPRESSION, AT TEMPERATURES EXPECTED AT THE END OF THE CONTAINMENT PERIOD, WITHOUT VIOLATING THE RELEASE LIMITS OF PRODUCT SPECIFICATION 3-1.

Discussion: The presence of an external pressure acting on the DHLW form following loss of containment shall not cause an increase in the source term for radionuclide release such that the release rates of PRODUCT SPECIFICATION 3-1 are exceeded.

The maximum projected pressure in a salt repository is less than 18 MPa (Reference 5). Until site-specific loading conditions are identified, the external pressure loading will be assumed to be triaxial.

2.1.3 Waste Package Interactions

Performance Specification 5

The waste form shall not contain material which has been shown to substantially increase the mobility of radionuclides through the package or host rock or which jeopardizes the containment features of the package.

PRODUCT SPECIFICATION 5-1

THE DHLW FORM PRODUCER SHALL COMPLY WITH PRODUCT SPECIFICATION 3-1 UTILIZING A SOURCE TERM WHICH REPRESENTS THE CHEMICAL COMPOSITION AND CONSTITUTION OF THE WASTE FORM AND CANISTER FOLLOWING THE CONTAINMENT PERIOD.

Discussion: The waste form producer shall ensure that the contents of the waste form and canister do not increase the mobility of the radionuclides after the containment period. Changes in phase and composition of the waste form during the containment period shall be accommodated in the source term without increasing release rates above specified limits. The containment period is defined as up to 1000 years after emplacement.

2.2 OPERATIONAL PERIOD SAFETY

2.2.1 Accident Conditions

Performance Specification 6

The DHLW form and canister shall be capable of withstanding a drop from a specified height onto an unyielding surface without breaching.

PRODUCT SPECIFICATION 6-1

THE DHLW FORM AND CANISTER AT AMBIENT TEMPERATURE AND PRESSURE SHALL BE CAPABLE OF WITHSTANDING A DROP OF 9 M OR TWO TIMES THE CANISTER LENGTH (WHICHEVER IS GREATER) ONTO AN UNYIELDING SURFACE WITHOUT BREACHING. THE CANISTER SHALL BE ORIENTED TO PRODUCE THE MOST SEVERE LOADING. BREACH IS DEFINED AS A RELEASE RATE FROM THE CANISTER IN EXCESS OF 10^{-5} ATM-CC/SEC.* TEST RESULTS (LEAK TEST PROCEDURE, LEAK RATE, MEASURED DEFORMATIONS, ETC.) SHALL BE DOCUMENTED. IN ADDITION, THE DOSE LIMITS SPECIFIED IN PARAGRAPHS 103, 105, AND 106 OF 10 CFR 20 (REFERENCE 9) SHALL BE MET.

Discussion: The drop test specified is intended to be a compromise between a low probability, high consequence event and conditions expected to be encountered in normal handling operations. In addition, it is recognized that accidents occurring during the operational period are more likely to be detected and remedied than are events occurring after emplacement/isolation.

*Release rate is defined in terms of a leak rate based on dry air at 25 C, with a pressure differential of 1 atmosphere.

A nonradioactive form may be utilized for testing given that it has properties (physical and structural) which are representative of the actual waste form and will result in a valid test.

For transport packages, release rates are specified in terms of activity release rates for specific groups of radionuclides. Depending on the form and type of the package contents, temperature, and pressure, a corresponding leak rate can be quantified. Leak rates for various transport packages can range from 10^{-3} to 10^{-9} atm-cc/sec (dry air at 25 C). Techniques exist to measure leak rates as small as 10^{-8} atm-cc/sec (Reference 10). Currently, no basis exists to account for differences between transport and disposal package designs. These differences include: variations in waste content and form, transport environments versus repository environments, and package designs (transport versus repository). Further, the allowable leak rate for a canistered waste form would be higher during those times when it is within a larger package. Consequently, until further data are available, a leak rate limit of 10^{-5} atm-cc/sec will be applied to the DHLW canister.

DATA REQUIREMENT 6-2

An estimate shall be made of the canister drop height necessary in the test of PRODUCT SPECIFICATION 6-1 to breach the canister.

Discussion: This information shall permit an evaluation of the safety margin in the canister design.

Performance Specification 7

The fractions of the waste form being converted into particles having a geometric diameter of 200 microns or less for dispersion control and 10 microns or less for respiration control shall be limited in the event of a drop from a specified height of the waste form in its primary canister onto an unyielding surface.

DATA REQUIREMENT 7-1

The results of the drop tests in PRODUCT SPECIFICATION 6-1 shall include the fractions of the DHLW form that are converted into particles having aerodynamic equivalent diameters of 10 microns or less and 200 microns or less.

Discussion: The 10-micron size is applicable to respiratory effects and the 200-micron size is related to dispersion control. Fraction limits will be established based on an assessment of the effects of the size of particles released and their consequences. A PRODUCT SPECIFICATION which specifies these limits will be defined and included in the final publication of these specifications.

Performance Specification 8

The waste form canister shall have sufficient burst strength such that canister breach due to internal overpressure will not occur in the event of a fire of 800 C and 15 minutes duration.

PRODUCT SPECIFICATION 8-1

THE DHLW FORM CANISTER SHALL HAVE SUFFICIENT BURST STRENGTH TO PREVENT CANISTER BREACH IN THE EVENT OF AN 800 C FIRE LASTING 15 MINUTES.

Discussion: In the event of an accidental petroleum/electrical fire, canister breach allowing the release of possibly gaseous radionuclide materials must not occur. The waste form canister must have sufficient strength to avoid breach due to internal overpressure. The basis for the 800 C/15 min specification is the NRC transport regulations, wherein the basis for a shipping cask fire test (800 C/30 min) is justified as being a hypothetical event, not the maximum credible event. The choice of fire temperature and duration reflects the availability of potential sources of fuel to sustain a fire, and the availability of resources to terminate it. For transportation environments, this includes proximity to truck, rail, and ship fuel tankers. For a repository, such quantities of fuel are not as common, and fire-fighting

equipment is more available; hence, it is assumed that a corresponding fire specification for a canister in the repository should reflect the lower probability of a transport-type fire.

DATA REQUIREMENT 8-2

Results of tests or calculations to show that PRODUCT SPECIFICATION 8-1 is satisfied shall include the maximum internal pressure and temperature of the canister wall under the fire conditions of PRODUCT SPECIFICATION 8-1. If a test is conducted, the integrity of the canister shall be assured by a leak test, as referenced in PRODUCT SPECIFICATION 6-1. If a calculation is used to verify compliance with PRODUCT SPECIFICATION 8-1, the burst strength shall be assumed to be no greater than the canister material's yield strength at temperature.

Discussion: Data or analyses are required to show that the waste form canister is in compliance with PRODUCT SPECIFICATION 8-1.

DATA REQUIREMENT 8-3

Information shall be provided to develop a fire temperature versus fire duration curve at which the actual DHLW form canister burst strength is exceeded.

Discussion: The DHLW form canister would burst during a fire event if certain combinations of fire intensity (as measured by temperature) and duration existed. To evaluate the safety margin of the actual canister design, information is required that defines the fire temperature/duration curve at which the DHLW form canister burst strength is exceeded.

Performance Specification 9

The release of volatile materials in the waste form shall be limited in the event of a fire of 800 C and 15 minutes duration.

DATA REQUIREMENT 9-1

The DHLW form producer shall provide measurements or calculations of the quantity of materials volatilized inside the canister during the fire in PRODUCT SPECIFICATION 8-1 and DATA REQUIREMENT 8-2.

Discussion: The quantity of DHLW form materials volatilized during a fire shall be limited in the event of a canister breach. At the time of the final publication of these specifications, a numerical limit on the quantity of materials will be established.

Performance Specification 10

The waste form shall not be readily soluble in water.

PRODUCT SPECIFICATION 10-1

BASED ON COMPLIANCE WITH PRODUCT SPECIFICATION 3-2, NO ADDITIONAL SPECIFICATIONS ARE REQUIRED OF THE DHLW FORM TO MEET THIS PERFORMANCE SPECIFICATION.

Discussion: Since the DHLW form (borosilicate glass) is a relatively insoluble material, no limit is required during the operational period.

Performance Specification 11

The waste form shall be a solid capable of retaining its physical shape under expected repository handling and operating conditions.

DATA REQUIREMENT 11-1

The waste form producer shall provide physical/mechanical property data for the DHLW form to show that PERFORMANCE SPECIFICATION 11 is met. Specifically, thermal expansion coefficients, uniaxial compressive strengths, and bulk moduli shall be provided.

Discussion: The DHLW form should maintain a level of integrity during the operational period. This data requirement, in addition to the data required in Performance Specifications 27 and 28, will define this integrity.

Performance Specification 12

The waste form shall not contain free liquids to the extent that containment is jeopardized during the operational phase by internal corrosion/interaction, and no observable liquids shall flow/vaporize from the waste form as a result of conditions expected during handling or storage.

PRODUCT SPECIFICATION 12-1

THE DHLW FORM SHALL NOT CONTAIN FREE LIQUIDS TO THE EXTENT THAT INTERNAL CORROSION OF THE CANISTER COULD LEAD TO A LOSS OF CONTAINMENT DURING THE OPERATIONAL PERIOD. THE QUANTITY OF FREE LIQUIDS PRESENT AND THE AMOUNT OF CORROSION EXPECTED FROM THEIR PRESENCE OVER THE OPERATIONAL PERIOD (50 TO 80 YEARS) SHALL BE DOCUMENTED BY THE WASTE FORM PRODUCER.

Discussion: Free liquids within the DHLW canister shall be controlled to minimize canister degradation via corrosion and to minimize the release of radionuclides in the event the canister is breached during the operational period.

DATA REQUIREMENT 12-2

The DHLW form radionuclide source term (amount of radionuclides by isotope, form, quantity, etc. available for transport in the event of canister breach) during the operational period shall be specified.

Discussion: PRODUCT SPECIFICATION 6-1 requires that the radionuclide source term be specified for releases after the containment period. This *DATA REQUIREMENT* addresses the source term available during the operational period. The source-term transport mode is not defined here, and it is not implied that free liquids are available from the waste form or that an external source is

available. However, should a medium for source-term transport be available during an operational accident, the amount of radionuclides available for release must be quantified. For documentation purposes, the source term as existing in 1998 shall serve as the operational period source term.

2.2.2 Standardization

Performance Specification 13

The geometry, dimensions, and weight of the waste form shall be standardized for each waste type.

PRODUCT SPECIFICATION 13-1

THE FOLLOWING PARAMETERS OF THE LOADED DHLW FORM CANISTER SHALL BE BASELINED AND TOLERANCES MAINTAINED:

- UPPER WEIGHT LIMIT (5000 LB)
- WEIGHT (± 25 LB)
- LENGTH (± 0.12 IN.)
- DIAMETER (± 0.12 IN.)
- OVALITY (± 0.05 IN.)
- BOWING (± 0.31 IN.)
- LIFTING DEVICE GEOMETRY (± 0.020 IN.).

Discussion: By specifying and baselining the values and tolerances for the major dimensions of the DHLW form and canister, the goals of package standardization can be assured.

PRODUCT SPECIFICATION 13-2

THE LEVEL OF REMOVABLE RADIOACTIVE CONTAMINATION ON ALL EXTERNAL SURFACES OF EACH DHLW CANISTER SHALL BE AS LOW AS PRACTICAL, NOT TO EXCEED:

ALPHA -	220 DISINTEGRATIONS/MIN/100 CM ²
BETA + GAMMA -	2200 DISINTEGRATIONS/MIN/100 CM ²

Discussion: This specification is included under standardization to ensure that it is treated in a manner similar to other design parameters (weight, diameter, etc.). The limits in this specification are derived from Department of Transportation (DOT) regulations 49 CFR 173.397(11), Contamination Control.

Performance Specification 14

The thermal output of the waste form shall be less than the established limit for the waste package for each waste type.

PRODUCT SPECIFICATION 14-1

THE THERMAL OUTPUT OF THE DHLW FORM DURING THE OPERATIONAL PERIOD SHALL BE LESS THAN THE LIMIT ESTABLISHED FOR THE CONTAINMENT AND ISOLATION PERIODS.

Discussion: Compliance with PRODUCT SPECIFICATION 1-1 will assure compliance with this specification.

2.2.3 Waste Package Interactions

Performance Specification 15

Canistered waste forms shall not be capable of sustaining combustion reactions resulting from a fire of 800 C and 15 minutes duration that could compromise the effectiveness of other waste canisters, result in unacceptable radiation exposures to on-site personnel or the public, or adversely affect safety-related items.

PRODUCT SPECIFICATION 15-1

THE CANISTERED DHLW FORM SHALL NOT BE CAPABLE OF SUSTAINING COMBUSTION REACTIONS RESULTING FROM A FIRE OF 800 C AND 15 MINUTES DURATION APPLIED TO THE DHLW PACKAGE EXTERIOR SURFACE THAT COULD COMPROMISE THE EFFECTIVENESS OF OTHER WASTE PACKAGES (i.e., CANISTERS).

Discussion: DHLW form canisters should prevent the involvement of the DHLW contained within them in any postulated fire scenarios and should not act as a means for fire propagation. Combustible materials need not be eliminated from the DHLW form nor rendered incombustible if this specification can be otherwise demonstrated. This fire environment is to be applied to the DHLW canister exterior surface.

Performance Specification 16

Waste forms shall not contain pyrophoric materials, flammable inorganic solids and oxidizers, as defined in 49 CFR 173(11), Subpart E, and organic materials capable of combustion whose kindling temperature/flash point is less than expected repository temperatures or which will ignite if the exterior waste package surface is exposed to a fire of 800 C and 15 minutes duration, in concentrations which would cause Performance Specification 15 to be violated.

DATA REQUIREMENT 16-1

The waste form producer shall specify the type and quantity of any pyrophoric materials, flammable inorganic solids and oxidizers as defined in 49 CFR 173(11), Subpart E, and any organic materials capable of combustion which are included in the waste form or canister. Any reaction of the DHLW form during and after the 800 C/15 minute fire condition shall be described.

Discussion: While not prohibited, these materials shall be of limited concentration in the DHLW form and canister such that Performance Specification 15 is not compromised.

Performance Specification 17

Fire retardant chemicals or incombustible materials used to render combustible materials in the waste form noncombustible shall not increase waste form canister corrosion, gas generation, leach rate, or any other waste

form/canister interactions. The waste form producer must show that Performance Specification 15 is met if fire retardant chemicals are used.

DATA REQUIREMENT 17-1

The DHLW form producer shall specify the composition and quantity of all fire retardant chemicals or incombustible materials used in the DHLW form. The effect of such materials on the DHLW form and canister performance relative to other specifications applicable to the operational period shall be documented.

Discussion: Fire retardant chemicals or incombustible diluents added to render combustible materials within the waste form noncombustible shall not adversely affect important DHLW form properties.

Performance Specification 18

Waste forms shall not contain Class A and B explosive materials as defined in 49 CFR 173, Subpart C(11), in concentrations which pose a hazard to the repository work force or the public from detonations or the spread of radioactive contamination.

DATA REQUIREMENT 18-1

The DHLW form producer shall specify the type and quantity of all class A and B explosive materials as defined in 49 CFR 173, Subpart C(11), if any are included in the waste form, and document their effect on the capability of the DHLW form and canister to meet other specifications applicable to the operational period.

Discussion: The DHLW form producer shall verify that if explosive materials exist in the waste form, the concentrations are small enough to prevent a hazard to the repository work force or the public.

Performance Specification 19

Waste forms shall not contain toxic materials, defined as Poisons A and B in 49 CFR 173, Subpart H⁽¹¹⁾, except if the toxic material is an integral part of the waste form or is transformed into a nontoxic, chemically safe species.

DATA REQUIREMENT 19-1

The DHLW form producer shall specify the type and quantity of all toxic materials, defined as Poisons A and B in 49 CFR 173, Subpart H⁽¹¹⁾, present in the waste form, if any, and document their effect on the capability of the DHLW form and canister to meet other specifications applicable to the operational period.

Discussion: The DHLW form shall not contain chemically toxic materials in concentrations or forms that could compromise either the operation or performance of the disposal system or adversely affect operator safety under expected or accident operating conditions. In general, toxic materials must be excluded that are not already an integral component of the waste form or canister or that cannot be transformed into a chemically safe form.

2.3 CRITICALITY CONTROL

Performance Specification 20

Waste form geometry, in conjunction with overall waste package geometry, shall be considered in criticality control. Calculations shall show that the waste form geometry, as designed, and any credible changes in waste form geometry due to handling/emplacement/retrieval accidents (including moderation and reflection) will not cause $K_{eff}+3\sigma$ to exceed 0.95 for a single package or credible groupings of packages.

PRODUCT SPECIFICATION 20-1

CALCULATIONS SHALL SHOW THAT THE DHLW FORM AS DESIGNED SHALL REMAIN SUBCRITICAL ($K_{eff}+3\sigma$ NOT TO EXCEED 0.95) FOR A SINGLE PACKAGE.

Discussion: The value of $K_{eff}+3\sigma$ less than 0.95 is generally accepted by the NRC as adequate margin from criticality for packages containing fissile materials.

Performance Specification 21

The waste form shall incorporate fissile materials in such a way as to prevent their accumulation or redistribution into a more reactive configuration during normal handling or postulated operational phase accidents.

DATA REQUIREMENT 21-1

The DHLW form shall incorporate fissile materials in such a way as to prevent criticality during the operating period. This shall be demonstrated by calculations which show that the waste form geometry, including the effects of normal handling and accident conditions during the operating period, does not cause $K_{eff}+3\sigma$ to exceed 0.95 for a single package.

Discussion: Fissile materials which are an integral part of the waste form, shall not lead to a critical configuration (including a safety margin), since some waste forms and packages may contain in excess of a minimum critical mass.

Performance Specification 22

The fissile material in the waste form shall be structurally supported such that bulk relocation of the fissile material to a more reactive configuration upon package degradation is not credible.

DATA REQUIREMENT 22-1

The DHLW form geometry shall maintain a noncritical configuration after emplacement and throughout the containment and isolation period. Compliance with this specification shall include the effects of package degradation during this period. The waste form geometry shall not change in such a way that $K_{eff}+3\sigma$ exceeds 0.95 for a single package.

Discussion: This specification requires that the bulk fissile content of the waste form remain in a noncritical configuration (including a safety margin) upon degradation of the package after emplacement. This requirement adds assurance that criticality in the repository over the long term is not credible.

2.4 IDENTIFICATION

Performance Specification 23

The waste form producer shall provide the following information to the repository waste packaging facility:

- Name of waste producer
- Description of contents
- Type and number of fuel assemblies (spent fuel only)
- Date removed from reactor and name of reactor (spent fuel only)
- Fissile material content
- Production canister material and history
- Production and operation history, including product formation, post-formation treatment, and storage condition
- Thermal power measurement
- Dates of measurements, and
- Certification of compliance with all pertinent regulations and standards.

PRODUCT SPECIFICATION 23-1

THE DHLW FORM PRODUCER SHALL PROVIDE THE FOLLOWING INFORMATION AS A MINIMUM TO THE REPOSITORY WASTE PACKAGING FACILITY:

- NAME OF WASTE PRODUCER
- DESCRIPTION OF CONTENTS
- FISSILE MATERIAL CONTENT
- PRODUCTION CANISTER MATERIAL
- DEVIATIONS FROM NORMAL OPERATING CONDITIONS FOR PRODUCT FORMATION, POST-FORMATION TREATMENT, AND INTERIM STORAGE

- THERMAL POWER
- CERTIFICATION OF COMPLIANCE WITH PRODUCT SPECIFICATIONS.

Discussion: Waste package QA requirements can be met and certification can be achieved only when the waste form can be identified and traced. Thus, the aforementioned documentation is necessary to assure that the DHLW form is identifiable and traceable.

Performance Specification 24

The waste form producer shall label the production canister/primary container to uniquely identify the waste form and to relate it with the information defined in Performance Specification 23. The label must not adversely affect the performance of the package. If identification upon retrieval is dependent upon this label, it must function through the retrieval time period.

PRODUCT SPECIFICATION 24-1

THE DHLW FORM PRODUCER SHALL LABEL THE PRODUCTION CANISTER TO UNIQUELY IDENTIFY THE WASTE FORM AND TO RELATE IT TO THE INFORMATION DEFINED IN PRODUCT SPECIFICATION 23-1. THE LABEL SHALL NOT ADVERSELY AFFECT THE PERFORMANCE OF THE PACKAGE AND SHALL FUNCTION THROUGH THE OPERATIONAL PERIOD INCLUDING RETRIEVAL (50 TO 80 YEARS).

Discussion: The DHLW production canister shall identify the contents from the outset of the packaging operations to provide traceability of the DHLW form throughout subsequent operations.

2.5 WASTE PACKAGE PERFORMANCE TESTING REQUIREMENTS

2.5.1 Conditions

Performance Specification 25

The waste form producer shall conduct tests, or present documentation that the waste form has been tested under simulated repository conditions or design basis conditions.

DATA REQUIREMENT 25-1

The DHLW form producer shall conduct tests, or present documentation that the DHLW form and canister have been tested, under expected repository conditions that occur during operating, handling, retrieval, containment, and isolation time periods. The expected repository conditions will be defined by the NWTS salt project.

Discussion: These tests shall be standard tests, as available, recognized by the certifying agency (DOE) as applicable to the DHLW form.

2.5.2 Extrapolations

Performance Specification 26

The waste form producer shall use good engineering practice to establish the degree of conservatism which shall be applied to those models which project waste form performance. The established degree of conservatism shall be defined and documented.

DATA REQUIREMENT 26-1

The DHLW form producer shall specify the degree of conservatism that exists in the performance evaluation models (analytical and experimental).

Discussion: Certification depends upon projections that the PRODUCT SPECIFICATIONS of Sections 2.1, 2.2, and 2.3 will not be compromised. Thus, DHLW form performance refers to the behavior of those parameters and characteristics listed in *DATA REQUIREMENT 27-1* which must meet the PRODUCT SPECIFICATIONS of Sections 2.1, 2.2, and 2.3.

2.5.3 Nondestructive Testing

This performance specification provides for nondestructive testing (NDT) of a statistically significant number of waste packages prior to emplacement. These tests are not a requirement of the waste form producer.

2.5.4 In Situ Monitoring

This performance specification provides for monitoring of the in situ waste package environment as a means of determining whether the host rock environment is responding as predicted. Since this specification applies to emplacement and retrieval operations, it is not applicable to the waste form producer.

2.5.5 Waste Form and Waste Package Materials Properties and Performance Data Base

Performance Specification 27

The waste form producer shall produce test data to characterize the following properties and parameters of the waste form; the tests shall meet the full intent of Performance Specification 25.

- Isotopic content
- Chemical composition and form
- Characterization of phases containing radionuclides
- Amount of following:
 - Poisons A and B
 - Pyrophoric materials
 - Explosives
 - Flammable inorganic solids
 - Fire retardant materials
 - Free liquid
- Physical properties to include:
 - Dimensions, geometry, weight, density, structural support of fissile material, particle size distribution and particulate amount before and after drop test, and impact resistance
- Thermal decomposition rate
- Leach rate and total surface area available for leaching
- Volatility

- Flammability
- Flash point
- Behavior of fire retardant materials
- Thermal properties to include:
 - Thermal conductivity, specific heat, coefficient of thermal expansion, melting point*, and temperature limits
- Mechanical properties to include
 - Tensile strength
 - Compressive strength
 - Shear strength
 - Modulus of elasticity
 - Shear modulus
 - Bulk modulus
 - Elongation
 - Charpy impact
- Behavior of the production canister.

DATA REQUIREMENT 27-1

The DHLW form producer shall produce test data and information to characterize the following properties and parameters of the DHLW form and canister. The tests shall meet DATA REQUIREMENT 25-1. The uncertainty in property values shall also be defined as well as the dependence on fundamental parameters or ambient conditions (e.g., time, temperature, radiation level, density, etc.).

DHLW Form

- *Isotopic content*
- *Chemical composition and form*
- *Characterization of phases containing radionuclides*

*For purposes of DHLW (borosilicate glass), relevant properties are the glass transition point and the softening point.

- *Amount of following:*
 - Poisons A and B*
 - Pyrophoric materials*
 - Explosives*
 - Flammable inorganic solids*
 - Fire retardant materials*
 - Free liquids*
- *Physical properties to include:*
 - Dimensions, geometry, weight, and density*
 - Structural support of fissile material*
 - Particle size distribution and particulate amount before and after drop test*
 - Impact resistance*
- *Thermal decomposition rate*
- *Source term for radionuclide release*
- *Volatility*
- *Flammability*
- *Flash point*
- *Behavior of fire retardant materials*
- *Thermal properties to include:*
 - Thermal conductivity*
 - Specific heat*
 - Coefficient of thermal expansion*
 - Transition temperature*
 - Other temperature limits*
- *Mechanical properties to include*
 - Tensile strength*
 - Compressive strength*
 - Shear strength*
 - Young's Modulus*
 - Shear modulus*
 - Bulk modulus*
 - Elongation*

Canister

- *Chemical composition*
- *Physical properties:*
 - *Dimensions, geometry, weight, density*
 - *Buckling resistance*
 - *Impact resistance*
- *Flammability*
- *Thermal properties:*
 - Thermal conductivity*
 - Specific heat*
 - Coefficient of thermal expansion*
 - Melting point*
 - Other temperature limits*
- *Corrosion rate*
- *Mechanical properties (after processing in DWPF)*
 - Tensile strength*
 - Compressive strength*
 - Shear strength*
 - Young's modulus*
 - Shear modulus*
 - Bulk modulus*
 - Elongation*
 - Charpy impact*
 - Yield strength*
 - Poisson's ratio.*

Discussion: Each specification requires knowledge of various properties and parameters of the DHLW form. The availability of the specified data will enable more reliable performance assessments to be made.

Performance Specification 28

The waste form producer shall develop or have developed a data base which shall be the result of the tests on the waste form described in Performance Specifications 25 and 27.

DATA REQUIREMENT 28-1

The DHLW form producer shall develop or have developed a data base, as defined in DATA REQUIREMENT 27-1, which shall be the result of the tests on the DHLW form and canister as described in DATA REQUIREMENT 25-1.

Discussion: This data base shall be used in conjunction with DATA REQUIREMENT 26-1 to provide data for the certification of the DHLW form.

2.5.6 Quality Assurance

Performance Specification 29

The waste form producer shall provide an appropriate quality assurance program as defined by 10 CFR 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants"(12) for waste form fabrication, testing, and certification.

PRODUCT SPECIFICATION 29-1

THE DHLW FORM PRODUCER SHALL EXECUTE AN APPROPRIATE QUALITY ASSURANCE PROGRAM CONSISTENT WITH 10 CFR 50, APPENDIX B(12), FOR DHLW FORM FABRICATION, TESTING AND CERTIFICATION, AS DESCRIBED IN THIS DOCUMENT.

Discussion: An appropriate quality assurance program is necessary to provide a basic framework which will allow eventual certification of the DHLW form.

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- (12) U.S. Nuclear Regulatory Commission, 1980. "Domestic Licensing of Production and Utilization Facilities (10 CFR 50), Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants", Appendix B, Code of Federal Regulations, Federal Register, Washington, DC, January.

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