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Waste Package and Material Testing for the Proposed Yucca Mountain High Level Waste Repository

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INTRODUCTION

Over the repository lifetime, the waste package containment barriers will perform various functions that will change with time. During the operational period, the barriers will function as vessels for handling, emplacement, and waste retrieval (if necessary). During the years following repository closure, the containment barriers will be relied upon to provide substantially complete containment, through 10,000 years and beyond. Following the substantially complete containment phase, the barriers and the waste package internal structures help minimize release of radionuclides by aqueous- and gaseous-phase transport. These requirements have lead to a 'defense-in-depth design philosophy. A multi-barrier design will result in a lower breach rate distributed over a longer period of time, thereby ensuring the regulatory requirements are met.

The design of the Engineered Barrier System (EBS) has evolved. The initial waste package design was a thin walled package, 3/8 inch of stainless steel 304, that had very limited capacity, (3 PWR and 4 BWR assemblies) and performance characteristics, 300 to 1,000 years. This design required over 35,000 waste packages compared to today's design of just over 10,000 waste packages. The waste package designs are now based on a defense-in-depth/multi-barrier philosophy and have a capacity similar to the standard storage and rail transported spent nuclear fuel casks.

Concurrent with the development of the design of the waste packages, a comprehensive waste package materials testing program has been undertaken to support the selection of containment barrier materials and to develop predictive models for the long-term behavior of these materials under expected repository conditions. The testing program includes both long-term and short-term tests and the results from these tests combination with the data published in the open literature are being used to develop models for predicting performance of the waste packages.

WASTE PACKAGE DESIGN

The design of a waste package is based on the waste forms that it will contain. Allocation of a waste form to a waste package of a particular design is based on the characteristics of the waste, not on its origin or current state of ownership. Additionally, the waste package has been developed to fulfill the following design requirements:

- Restrict the transport of radionuclides
- Provide criticality protection during and after the waste package is loaded with waste
- Manage the decay heat for the potential repository
- Provide unique identification of waste package and its contents.
- Enhance safety of personnel, equipment, and the environment
- Prevent adverse reactions involving the waste form
- Withstand loading, transportation, emplacement, and retrieval
- Withstand the emplacement drift environment
- Provide physical and chemical stability for the waste form
- Promote heat transfer between the waste form and the outside environment
- Facilitate decontamination of its outer surface

Due to the list of performance needs the design of the waste package has evolved into a multi-barrier component with specialty materials and with each component, in general, performing more than one function. As can be seen in Figure 1 and 2, the SNF basket provides structural support for the fuel assemblies. This support is maintained during the preclosure time period as well as the postclosure, (10,000 year and beyond), performance time period. The SNF basket must also provide thermal heat removal in a thermally stressing environment. The thermal characteristics of the repository rock act similar to a thermos bottle holding in the heat, and this has focused the designs to be thermally efficient in a wide range of thermal environments. In addition, the waste package, along with the surrounding engineered barrier system (EBS), must ensure postclosure nuclear criticality control over the regulatory time period.

In addition to the numerous performance based requirements, the fact that there is a large variability in the characteristics of spent nuclear fuel (SNF), several waste package (WP) designs have been developed to accommodate all of the SNF earmarked for disposal in the proposed repository. There are logical common design features that have been implemented in the family of basic waste package designs. There are four basic families of Waste Package designs, which are listed in Table 1. These are designs for commercial SNF, defense HLW, Navy waste and DOE SNF/waste glass co-disposed waste.

As is shown in Table 1 and the figures, the designs are all similar in that the outer and structural shell are made of the same material, the internal basket configuration uses a basket design style that accommodates the different waste forms, i.e., the BWR basket accommodates BWR size assemblies as does the PWR basket design.

A review of the projected waste streams provides a basis for the different waste package design concepts. The major determinants that were used to decide the number and size of waste package designs are: BWR assemblies; PWR assemblies; DOE waste forms; need for additional neutron absorbing material for criticality control; and the thermal output of the SNF assembly. Included in the determination of the size of the waste package was the proposed repository thermal loading

Engineering Evaluations

The waste package design philosophy is rooted in engineering evaluations of thermal performance, structural performance, criticality, and radiation shielding issues. To create an acceptable WP design, it is essential to identify the major parameters that influence the performance and to quantify the important design parameters. A number of significant engineering evaluations and methods that are important for defining the behavior of the waste packages in the repository environment have been developed. These include:

- Disposal Criticality: includes probabilistic analyses, burnup credit for 'Principal Isotopes', material performance, and repository environments.

- Thermal: Includes waste package, near field, and far field temperature evaluations to evaluate the thermal pulse that is caused by decay heat SNF. The design requirements are to accommodate a wide range of repository thermal designs. Therefore, a number of additional thermal enhancements have been considered over the past few years, these include convective cooling of the emplaced waste package and storing the fuel on the surface until the waste will meet the required lower thermal output.

- Structural: To investigate the loading conditions from the initial WP handling in the surface facility, loading of the WP, transportation of WP to the emplacement drift, and then emplacement and WP performance through time. Drift stability and rock fall have potential for adversely affecting the performance of the waste package during emplacement. Since Alloy 22 is on the outside of the waste package, damage from rock-fall drift collapse and may result in a reduction in performance of the barrier. However, with the addition of a drip shield, to preclude accumulation of water and minerals on the surface of the waste package and at the same time precluding rocks from damaging the barrier, the probability of loss of performance can be minimized. Figure 4 depicts a proposed drift emplacement configuration with the Drip Shield.

Table 1 shows that the basic commercial SNF waste package designs and the basic defense high level waste (DHLW) WP designs will accommodate all of the existing and projected SNF and DHLW. Table 1 also shows the thermal output that each WP design will accommodate, as well as when additional neutron absorber is needed, and an estimate of the percentage of waste package types.

Table 1: Waste Package Design Options

Commercial Waste Package Types	Thermal Capacity (Min) watts	Thermal Capacity (Max) watts	Criticality Range (Min)	Criticality Range (Max)	~ Percentage of Waste Packages	~ Percentage of MTHM by Waste Package
21 PWR - absorber plates	0	850	0**	1.13	~ 55 %	~ 38 %
21-PWR Control Rod	0	850	0	1.45	~ 1 %	~1 %
12 PWR - absorber plates base South Texas long WP	0	1500	0	1.13	~ 2 %	~ 2 %
44 BWR - absorber plates	0	400	0**	1.37	~3 2 %	~ 25 %
24 BWR - thick absorber plates	0	520	0	1.54	< 1 %	~ 1 %
Defense High Level Waste Short and Long	0	1200	0	1.0	~ 7 %	29 %
Navy Short and Long	TBD	TBD	TBD	TBD	< 2 %	3 %
2-MCO/2-DHLW Long	0	>1200	0	1.0	< 1%	~ 1 %

** k (infinity) is used as an indicator that additional neutron absorber is needed in addition to burnup credit. k (infinity) values bound k(effective). k(effective) is unique to the geometry of the storage, transportation, and disposal device and takes into consideration the specific geometry, burnup credit, and additional neutron absorber. The specific 'k (effective)' for each waste package design will be sufficiently below 1.0 that no criticality is probable.

Basic Waste Container Designs

Figure 1 and 2 shows the uncanistered fuel disposal container (UCF). The UCF container design is a right cylinder with two barriers and an internal basket to support the spent fuel. The waste package internals include a basket grid, structural supports, and thermal shunts. As is shown in Figure 3, the center region, inside the Defense High-Level Waste Package, is allocated to the canister that will hold the DOE waste forms.

WASTE PACKAGE MATERIALS TESTING

The waste package materials and waste form testing programs are intended to provide information in support of the materials selection process, engineered barrier system development, and total system performance assessment activities. In general the testing program consists of the following:

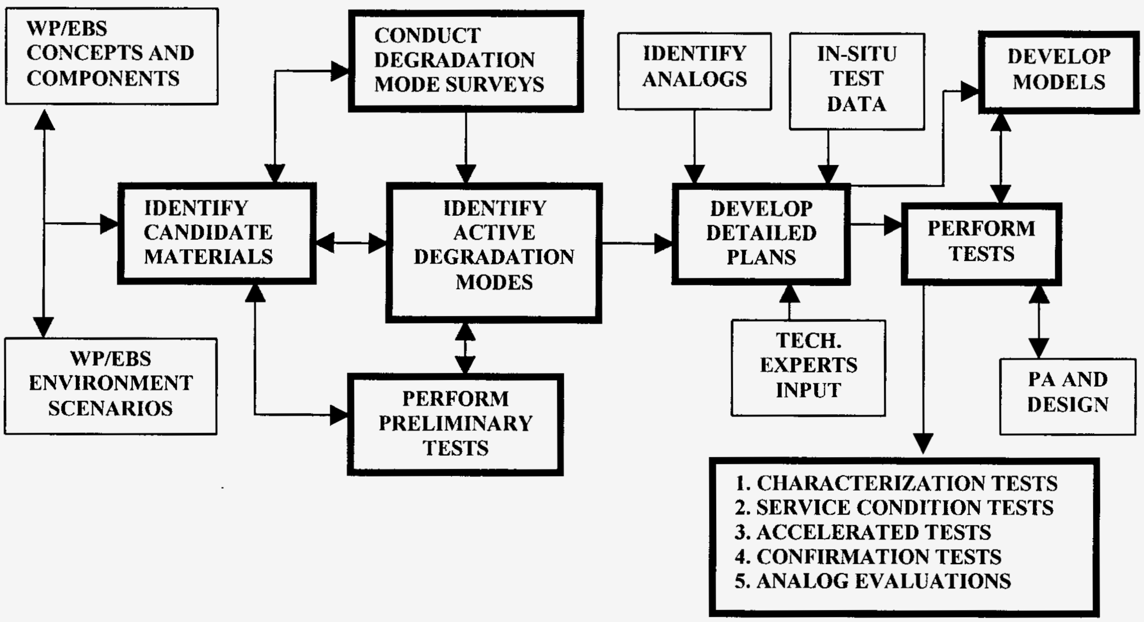
Container materials testing:
- Long-term corrosion
- Humid air corrosion
- Crack growth
- Electrochemical potential
- Microbiologically-influenced corrosion

Of these the long-term corrosion test program is the cornerstone of the overall material-testing program being conducted in support of the Yucca Mountain Project.

Comprehensive Corrosion Tests on waste Package Materials

Long- term corrosion tests are being conducted on waste package material specimens exposed to relevant repository environments. When completed, corrosion tests will have run for at least a period of five years, and some tests may continue for much longer periods of time beyond the license application period and into the repository construction period. The tests are comprehensive in the sense that many forms of corrosion can be tested. A planned interval test approach is being used, in which large numbers of specimens are initially exposed to the test environment and then periodic withdrawals of specimens are made and the specimens characterized. Thus, the time-dependence of the corrosion phenomena can be determined.

The strategy used for the waste package materials test program is shown below.



Test Environments

The test environments are construed to be of the "bounding" type and were selected so that there would be a large difference in behavior for the different materials. Formulas have been developed for formulating the test environments. The formulas were based on previous experience on making up simulated J-13 well water (well near the Yucca Mountain repository location) from various ionic salts. The characteristics of the four bounding water environments have been estimated as follows:

(1) The "base case" water with the low concentration of ions will have a pH of 8.5 and contain 1700 ppm total dissolved solids. For the purpose of comparison, this water is estimated to contain 67 mg/liter chloride ion.

(2) The base case water concentrated 100-fold. This water will have a high concentration of ions, a pH of 10, and contain 146,000 ppm total dissolved solids. This water is estimated to contain 6700 ppm chloride ion. This bounding environment represents what would happen with infiltrating ground water descending toward the repository, encountering the thermal zone, evaporating and concentrating dissolved salts.

(3) The concentrated water acidified with sulfuric acid to a target pH of around 2.7. This water is estimated to have a total dissolved solids content of 146,000 ppm and contain 24,250 mg/liter of chloride ion. This bounding case represents the condition where microbial activity from certain species have produced acidic metabolic products. It also represents a bulk test condition simulating the case of a localized, sequestered water chemistry, such as that produced in a creviced geometry.

(4) The concentrated water alkalized with calcium hydroxide to a target pH of 12. This water is estimated to have a total dissolved solids content of 132,000 ppm and contain 20,900 mg/liter of chloride ion. This bounding case represents water conditioned by prolonged contact with cementitous materials used to line the drift wall or used in the invert material underneath the waste package emplacement.

The four proposed bounding environments provide a range of pH (acid, neutral, and alkaline) and a range of ionic strength (dilute and concentrated).

Two test temperatures were selected for the long-term tests, 60 and 90°C. These temperatures are representative of the environmental conditions and cover the range where high corrosion rates and the effects of localized corrosion and stress corrosion cracking for the corrosion resistant alloys may occur.

Test Specimens

Some 13,000 specimens were procured in FY-96 in the three configurations. The materials are being tested in three categories:

Corrosion Allowance materials:

Wrought carbon steel (AISI 1018)	UNS K01800
Centrifugally cast carbon steel	UNS J02501
2.25 Cr - 1 Mo alloy steel	UNS K21590

Intermediate Corrosion Resistant Alloys:

Alloy 400 (Monel 400)	UNS N04400
70-30 Cu-Ni (CDA 715)	UNS C71500

Corrosion Resistant Alloys

Alloy C-22 (Hastelloy C-22, Inconel 622)	UNS N06022
Alloy 825 (Incoloy 825)	UNS N08825
Alloy G-3 (Hastelloy G-3)	UNS N06985
Alloy 625 (Inconel 625)	UNS N06625
Alloy C-4 (Hastelloy C-4)	UNS N06455
Titanium Grade 12	UNS R53400
Titanium Grade 16 (Ti-0.05 Pd)	none to date

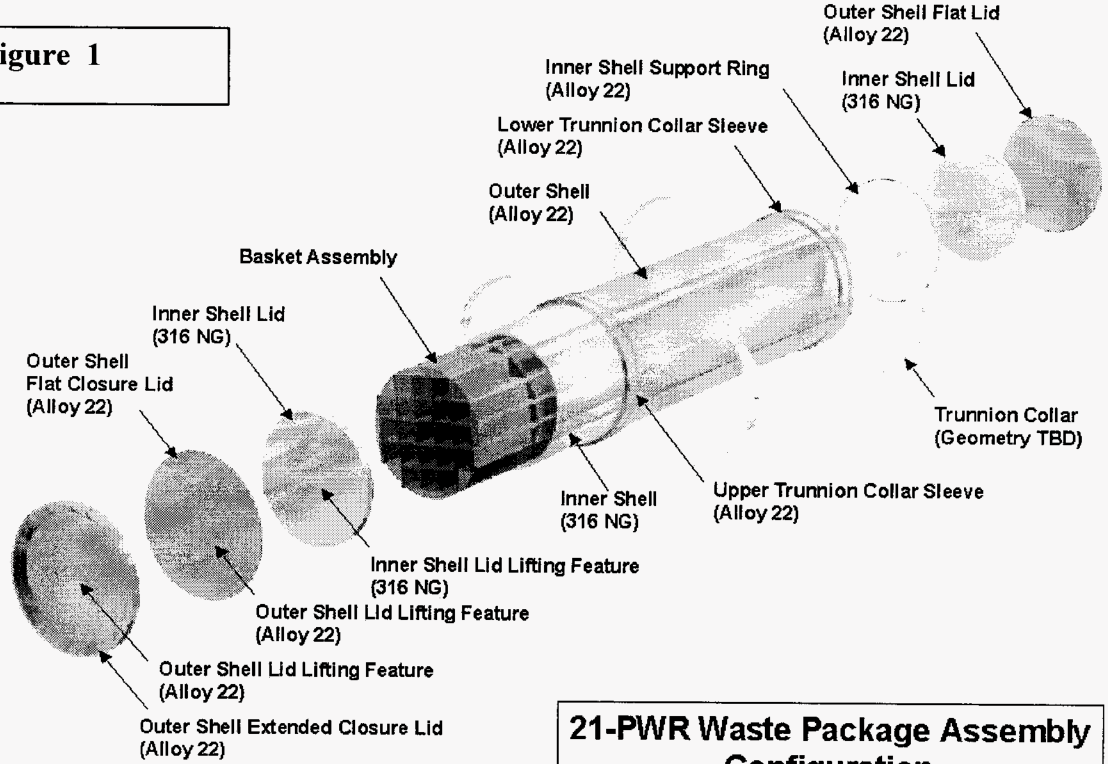
Other Testing Programs

The long-term comprehensive corrosion testing program is a cornerstone for much of the testing effort for waste package materials. Several other short-term activities interface with the long-term test. For example, the electrochemical tests predict the relative susceptibilities of the candidate materials to localized corrosion; the long-term corrosion test validates whether these predictions are true for the longer term. These tests are important for modeling efforts. Parts of the long-term comprehensive corrosion test have counterparts in the shorter-term stress corrosion-tests and galvanic corrosion tests. The saturated steam condition existing in the top half of the test vessels represents a condition approaching 100% relative humidity, and thus is an extension of data points obtained at lower humilities.

SUMMARY

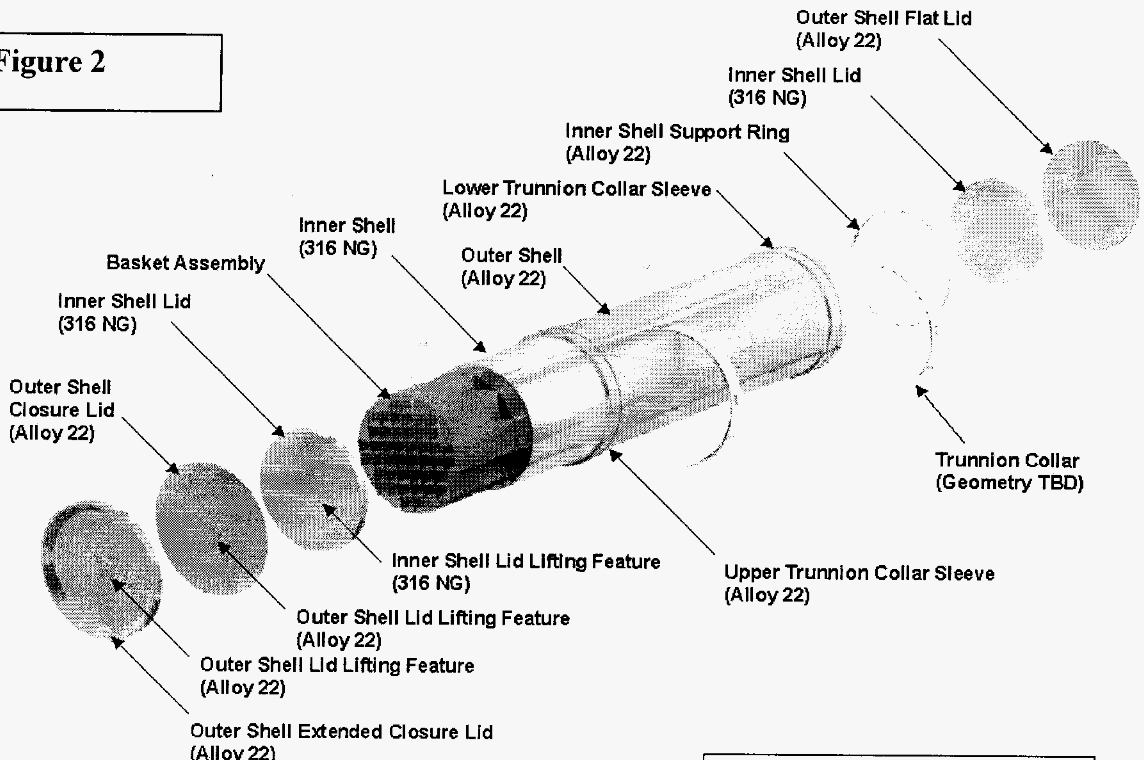
Through the application of scientific and engineering methods, the Engineered Barrier System continues to adapt to meet the performance requirements established by government regulatory agencies, and the Yucca Mountain Project. Continuing research and development of the waste package design will help reduce the environmental impact of the proposed geologic nuclear waste repository at Yucca Mountain, and ensure the success of the project for thousands of years.

Figure 1



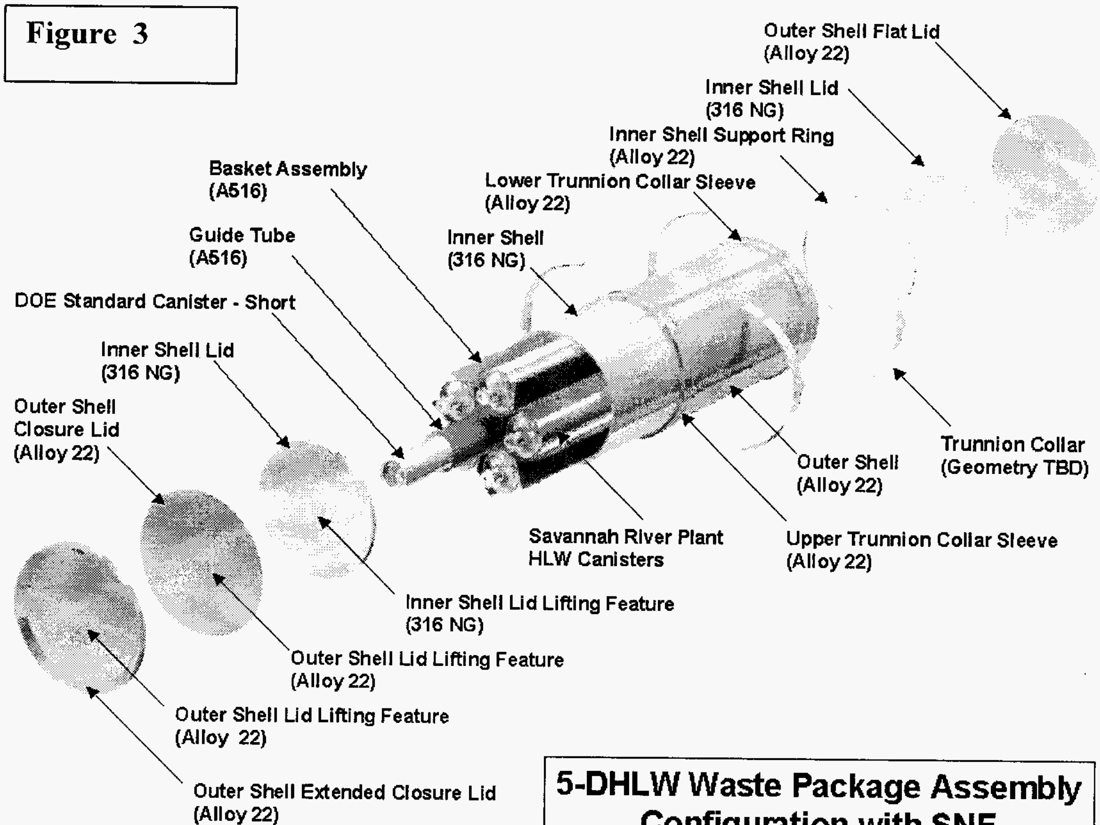
21-PWR Waste Package Assembly Configuration

Figure 2



44-BWR Waste Package Assembly Configuration

Figure 3



5-DHLW Waste Package Assembly Configuration with SNF

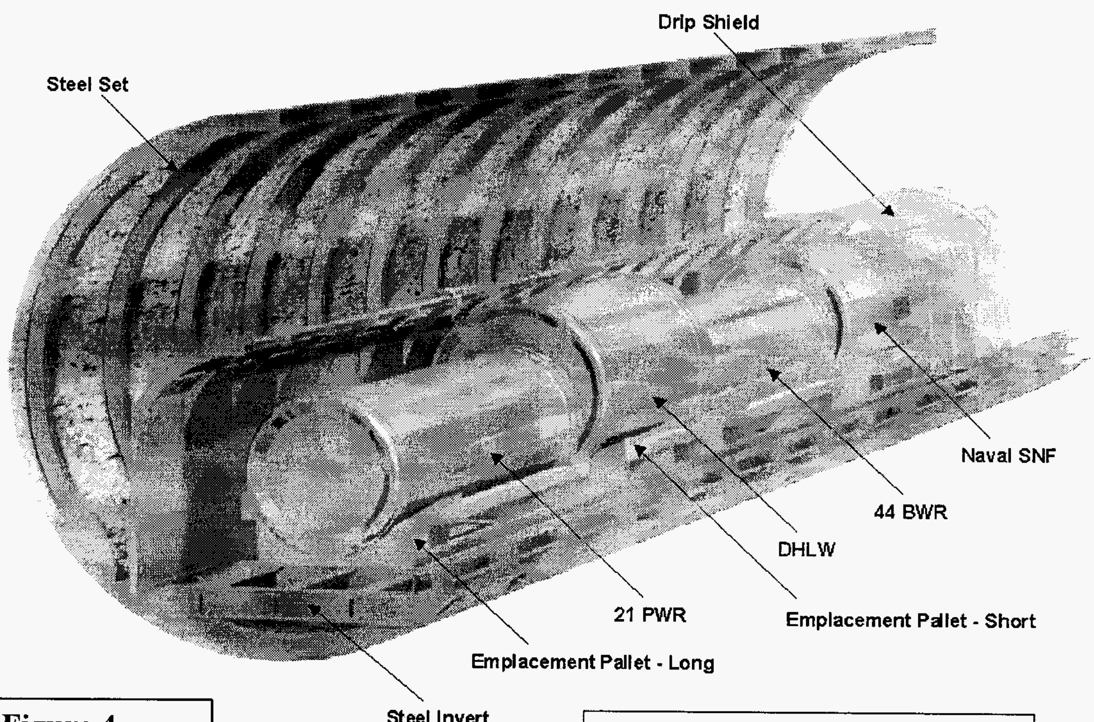


Figure 4

Emplacement Drift Segment for Site Recommendation

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