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# Packaging Radioactive Wastes for Geologic Disposal

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## ABSTRACT

The M&O Contractor for the DOE Office of Civilian Radioactive Waste Management is developing designs of waste packages that will contain the spent nuclear fuel assemblies from commercial and Navy reactor plants and various civilian and government research programs, as well as high-level wastes vitrified in glass. The safe and cost-effective disposal of the large and growing stockpile of nuclear waste is of national concern and has generated political and technical debate.

This paper addresses the technical aspects of disposing of these wastes in large and robust waste packages. The paper discusses the evolution of waste package design and describes the current concepts. In addition, the engineering and regulatory issues that have governed the development are summarized and the expected performance in meeting the requirements are discussed.

## INTRODUCTION

TRW Environmental Safety Systems, Inc. (TESS) and its teammate companies function as the Management and Operating Contractor (M&O) for the Department of Energy's Office of Civilian Radioactive Waste Management. The team has been active for more than five years in the program to manage commercial and defense nuclear waste, including its ultimate disposal in a geologic repository. One of the major activities involves designing metallic containers to hold the various waste forms and developing materials to absorb and diffuse radionuclides that escape the containers. The waste forms to be disposed of include spent fuel from commercial nuclear power plants; high-level waste from the defense weapons programs;and a wide range of government-owned nuclear waste material such as foreign and domestic research reactor spent fuel and reactor cores from Navy nuclear power plants. The variety of waste characteristics requires a number of container types.

## DESIGN EVOLUTION

During the past five years, the disposal containers have been developed through the conceptual design phase and into preliminary design. Designs for commercial spent fuel have evolved from small, thin-walled, stainless steel containers intended for vertical emplacement in boreholes to large, robust, bi-metallic waste packages holding about six times as much waste with the containers emplaced horizontally in the repository drifts. Capacities of other disposal containers have progressed from single canisters of vitrified high-level waste to four or five such canisters plus a center canister for highly enriched uranium or other sensitive waste forms.

The much greater corrosion resistance of the new designs will improve waste package performance, lengthening the period of secure waste containment from a thousand to several thousands of years. Emplacing the containers in the drifts instead of in confining boreholes provides better heat dissipation and keep the temperatures of the spent fuel assemblies below 350 degrees C to protect the fuel cladding from degradation due to prolonged periods at high temperatures. Also, increasing the capacity of each waste package will lower the overall disposal cost.

Current designs of waste packages for commercial spent nuclear fuel hold 21 pressurized water reactor assemblies or 44 boiling water reactor assemblies (see Figure 1). The limiting factors on capacity are primarily the thermal output of the design-basis fuel and the capability of the handling equipment to load, close, transport, and emplace the waste containers. Four defense high-level waste canisters can be placed in one container of approximately the same diameter as a container for commercial spent fuel (see Figure 2). The relatively small quantities of DOE-owned spent fuel can be placed in specially designed individual containers or incorporated in defense high-level waste containers. For example, canisters holding varying quantities of DOE-owned fuel can be placed in the center of an array of five defense high-level waste canisters (see Figure 3). The diameter of the high-level waste container would be larger than that of the commercial spent fuel containers, but its weight would be less and population small.

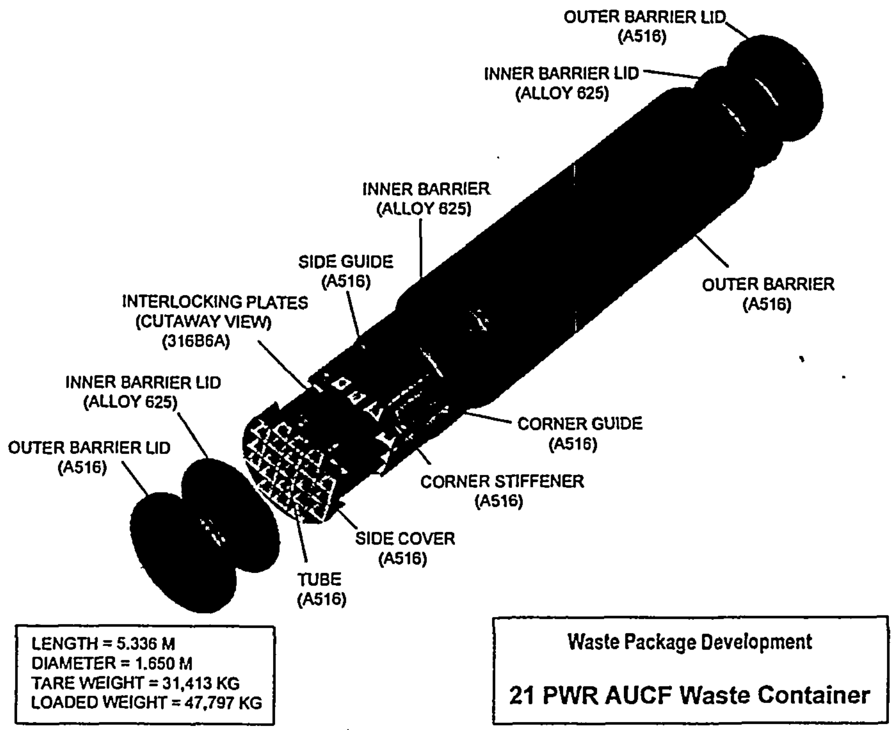


Figure 1

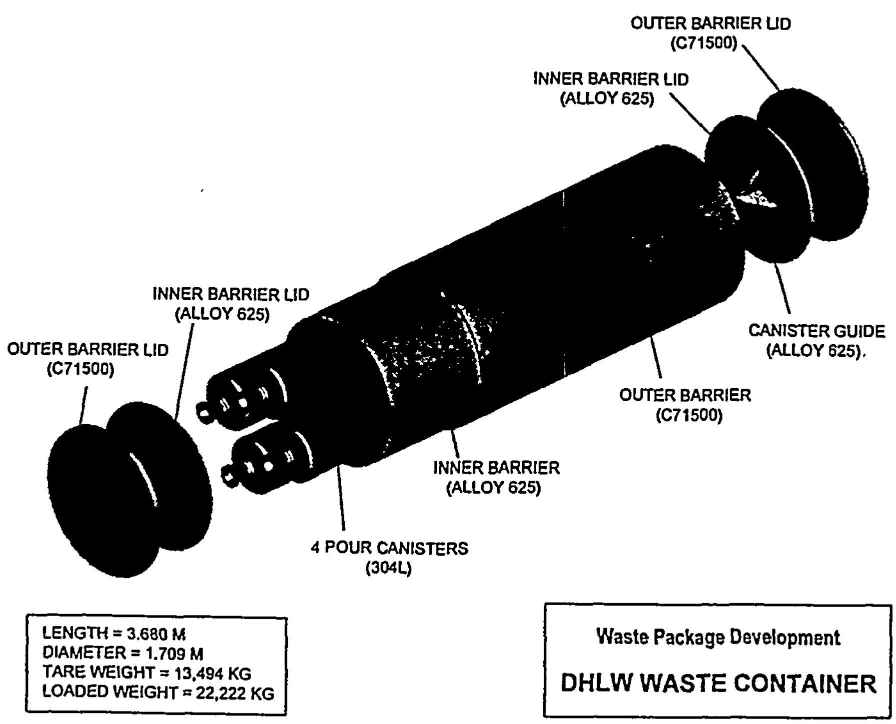


Figure 2

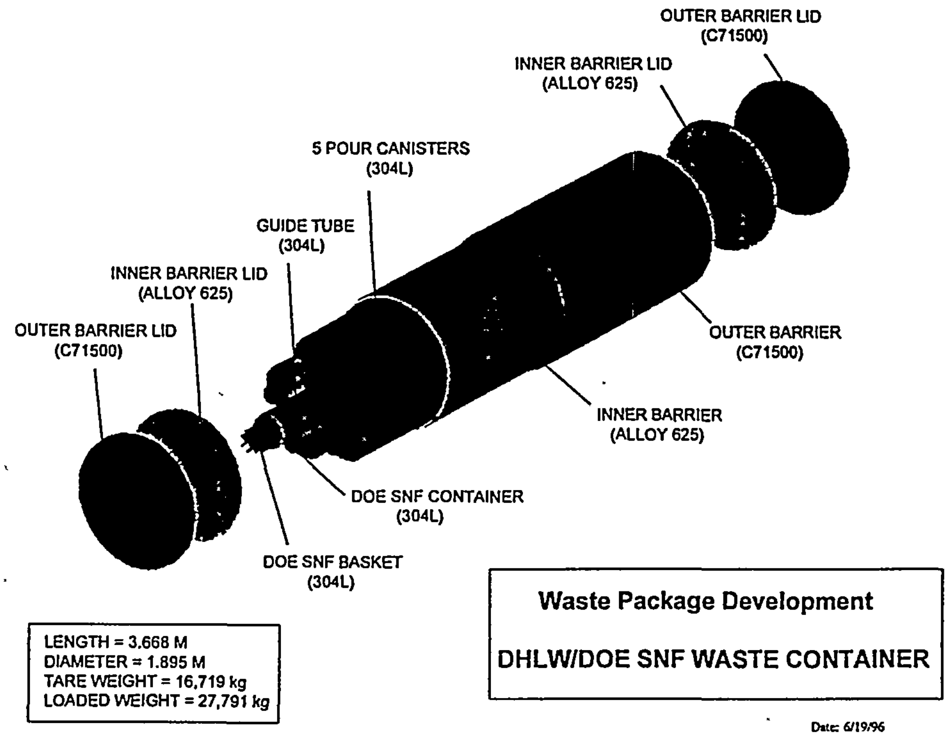


Figure 3

## MATERIALS

Selecting the appropriate materials for the major barriers preventing the release of radionuclides is of primary importance to the performance of the waste packages. Two different metals form the shell of the waste containers: a corrosion-resistant barrier (Alloy 625) inside a corrosion-allowance barrier (A516 carbon steel). The mechanisms by which the two barriers may eventually fail are different - the outer corrosion-allowance barrier would normally be subject to general corrosion processes including aqueous corrosion and oxidation, while the inner corrosion-resistant barrier would normally be subject to localized corrosion including pitting. Having a system that requires two separate failure mechanisms to cause a waste package breach tends to spread the total failures over a longer period of time thus reducing the number of failures and the potential release of waste package contents in any one period.

The current design uses 100 mm of carbon steel A516 for the outer barrier. The rate of corrosion of this material will depend on the environment, particularly the relative humidity, the likelihood of water dripping on the surfaces, the pH of any water contacting the waste packages, and the possible presence of microbiologically influenced corrosion processes. Under assumed environmental conditions, the corrosion rate will be predictable within reasonable limits and the average time-to-failure can be adjusted by varying the thickness of the metal barrier. The A516 also will provide galvanic protection for the more-noble corrosion-resistant barrier.

The material for the inner corrosion-resistant barrier is a high-nickel alloy, currently Alloy 625, and is 20 mm thick. The inner barrier provides the primary containment because of its strong resistance to corrosion in water and high humidity. Although the material is highly resistant to general corrosion and to the initiation of pits, the time to failure after a pit is initiated is currently unpredictable and assumed to be relatively short.

The corrosion processes and rates for these materials will be tested by immersion in test cells containing waters of various degrees of purity, pH, and temperature for periods of five or more years. Other materials are being similarly tested to assess their performance relative to the currently-selected materials.

The thickness of the inner and outer barriers together provide enough shielding to reduce radiolytic corrosion to acceptable levels. The waste packages will not, however, be shielded for personnel protection and the radiation doses two meters from the surface of the containers will generally exceed five rem/hour.

## FABRICATION

The inner and outer barriers must remain in electrical contact throughout the containment period if the outer barrier is to galvanically protect the inner barrier. Weld-cladding the inner barrier material to the outer barrier would be effective but is an expensive process. The current concept is to fabricate two separate containers by rolling plate and welding longitudinal seams to form cylinders. Because of equipment limitations, the length of the rolled cylinders will be less than the finished container, so two or more cylindrical sections will be welded together. The bottom will be closed with a circular plate welded in place. Then the outer container would be heated and the inner cylinder pressed into it. As the outer cylinder cools, tight mechanical contact over more than 90% of the surface is expected. After the container is loaded with the nuclear waste, the top would be closed with two separate lids of the same materials as each shell. The lids would be welded in place and individually inspected using non-destructive techniques.

## PERFORMANCE

The most challenging aspect of waste package design is predicting the expected and possible events that could occur over hundreds of thousands of years that would result in the degradation of the containers and the release of their contents. This scenario forecasting is very different from analyzing events during the forty-year life of a nuclear power plant. There are three key technical issues that must be addressed for all of the waste forms and their containers: susceptibility to degradation and release of radionuclides, potential for a criticality event, and the thermal output of the fuel. The first two of these issues require understanding how the containers and the various forms of nuclear waste will eventually collapse into a pile of rubble.

Regulations require that essentially all of the containers remain intact for a period not less than 300 years nor more than one thousand years. Current designs are expected to exceed the regulatory requirement and to contain the waste for several thousand years even in the presence of some water, either liquid or vapor, and much longer if the environment were to stay dry. The extended containment period will prevent radionuclide release until after the short-lived isotopes have decayed. It will also prevent water from entering the container and oxidizing the fuel until the temperatures are below the point where the oxidation rate is very low. This condition is important because fuel that has been oxidized becomes powdery and much more soluble, thus increasing the chances of radionuclides flowing out of the containers and eventually reaching inhabited areas.

Since commercial spent nuclear fuel assemblies continue to generate considerable heat for many years after they are removed from the reactor, emplacing the intended amount of waste in the repository will significantly alter the thermal conditions in the emplacement drifts and the immediately surrounding area. The current concept is to take advantage of that heat by emplacing the waste packages close enough to one another to keep the temperatures in the emplacement area above boiling for extended periods. In addition to eliminating most aqueous corrosion concerns for the required containment period, this arrangement also has the obvious advantage of reducing the total area required to dispose of any given volume and mass of waste. Thermal projections show that for average-aged commercial fuel spread throughout the repository at 20-25 kg of Uranium per square meter the temperature at the surface of the waste packages will remain above boiling for about 5000 years (see Figure 4).

The performance of the loaded waste packages will be analyzed for all credible off-normal and accident events that could occur during the pre-closure period to ensure that the designs will not permit breaching of the containers and release of radioactive material. These credible events include the dropping of loaded containers from a height of two meters and tipping loaded containers over on their sides. In addition, the potential for rocks dropping on the emplaced waste packages, both during the period when the corrosion barriers are intact and after the corrosion processes have weakened them, is being analyzed to evaluate effects on safety and overall system performance.

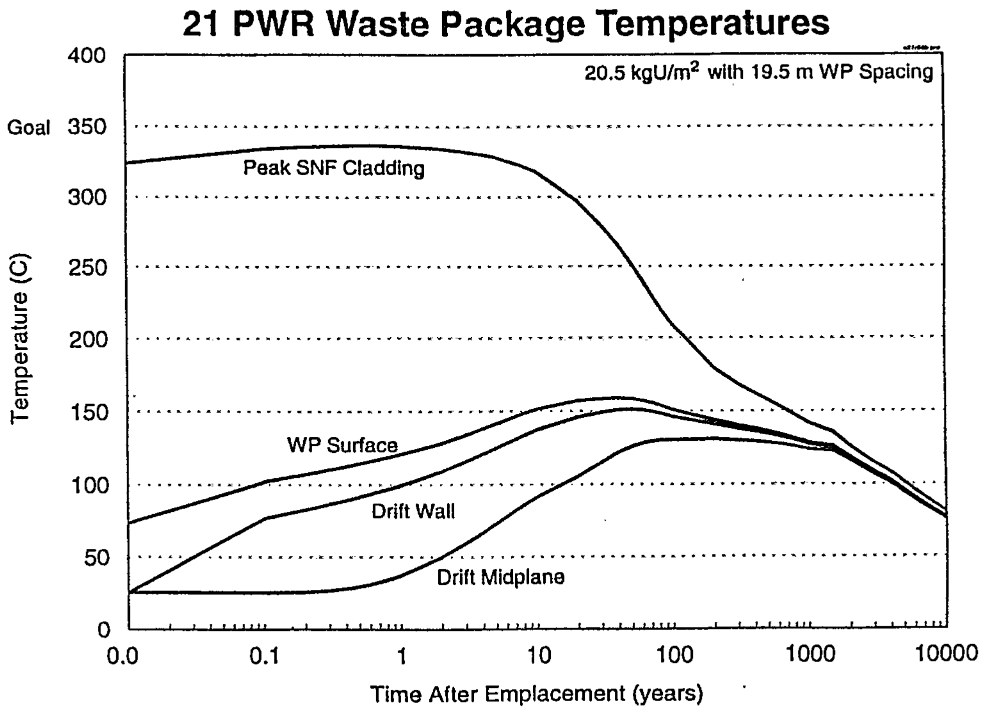


Figure 4

**CRITICALITY**

Although the effect of a criticality event sometime during a million years of entombment inside a mountain would be inconsequential, the current regulations do not permit criticalities unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Furthermore, although the expected repository site in southern Nevada is well above the water table in a desert with very little rainfall, the conservative assumption must be made that water will be present to act as moderator. The potential for criticality is controlled by designing a robust container, limiting the fissile content of the containers, adding supplemental neutron absorbers, and for some wastes using filler materials to displace water that otherwise might enter the container. The primary supplemental neutron absorber in the current designs is 316 stainless steel alloyed with boron. Other possibilities for special waste forms include gadolinium, hafnium, and silver-indium-cadmium. The use of depleted uranium as filler material to reduce the effective enrichment of the spent fuel is being considered for some of the highly enriched DOE-owned wastes.

Preventing criticality while the containers are intact is relatively straightforward. But ensuring that the criticality potential will not increase during waste package collapse, or that the waste will not migrate into a critical mass somewhere in the several square miles of the repository, is not. Models are being developed to analyze the potential for the degradation processes to increase the potential for criticality events within, and in the immediate vicinity of, the waste packages. Scenarios involving the possible transport of fissile material from one waste package to combine with the material from other waste packages are also being analyzed to ensure that the probability of such an event is acceptably small.

**SUMMARY**

The strategy for isolating the radioactive waste from potentially inhabited areas is relying on containment within the waste packages for periods of as much as several thousands of years. The M&O team is dedicated to meeting that goal and is making excellent progress in solving key technical issues of nuclear waste disposal in a cost-effective way. Although more work remains to be done, we are confident that the waste packages will meet the requirements of the regulations and those imposed by the rest of the geologic disposal system.