DESIGN OF A NUCLEAR WASTE PACKAGE
FOR EMPLACEMENT IN TUFF*

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ABSTRACT

Design, modeling and testing activities are under way at LLNL in the development of high level nuclear waste package designs. In this paper we discuss the geological characteristics affecting design, the 10CFR60 design requirements, conceptual designs, metals for containment barriers, economic analysis, thermal modeling and performance modeling.

INTRODUCTION

The National Waste Terminal Storage Program for disposal of high level nuclear waste is utilizing the multiple barrier approach to isolate nuclear waste. The geological formation provides the outer barrier. In addition, the engineered barrier system contains several barriers such as the waste form, the overpack, backfill and near field host rock. LLNL has undertaken the development of the waste package subsystem for the DOE NNWSI (Nevada Nuclear Waste Storage Investigations Project). This Project is examining the feasibility of siting a repository at Yucca Mountain at the Nevada Test Site. The LLNL work includes design, modeling and experimental activities such as testing of waste forms and candidate metals and backfills. This paper primarily addresses the waste package design and modeling aspects of our effort.

During 1982, conceptual designs were developed for disposal below the water table in tuff at Yucca Mountain, Nevada Test Site. In the spring of 1982, the primary target horizon for disposal was changed to a location above the water table (the unsaturated zone). Work was then re-focused on designs for this zone.

CHARACTERISTICS OF THE UNSATURATED HORIZON

The NTS site in general, and the Yucca Mountain site in particular, is unique among the proposed high level waste repository sites in offering the possibility of locating a deep repository above the water table. The static water table is deep (about 700 m below the surface)[1], there is a rock horizon ample in thickness and extent above the water table having properties suitable for a repository. The site is located in an extremely arid zone (about 15 cm/yr annual precipitation), the evaporation-transpiration rates are very high and so the net water percolating down from the surface is of the order of a few millimeters per year.[2] Specifically, the primary choice for a repository is a stratum in the Topopah Spring Member of the Paintbrush Tuff, consisting of welded, devitrified tuff of low porosity (about 10%).

The characteristics of this unsaturated zone are: (1) extremely low anticipated water flow anticipated; (2) partial saturation of the rock medium (80%)[3]; and (3) oxidizing conditions due to presence of air in rock pores and cracks.

In general, compared to the saturated zone, (1) and (2) create a benign environment from the viewpoint of waste package design. Since corrosion is effected primarily by water[4] and since all non-volatile radionuclides are transported by water, the low water flow is highly advantageous on both counts. Furthermore, hydrostatic head is negligible and lithostatic pressure is not experienced by the packages. Thus packages need not be designed to withstand external pressures, resulting in potential cost reductions.

An oxidizing condition, which would tend to exclude cheaper, more corrodible metals (e.g., carbon steel), must be considered in the light of the extremely low water flow anticipated. Also many actinides and technetium are more soluble in oxidizing than in reducing water. However, if the water movement near the waste packages is sufficiently low, both of these apparent disadvantages are no longer significant. Even for somewhat higher water flows, the rate at which the oxidant, air, is replenished at the waste package from the surrounding rock may be low enough to reduce corrosion rates and solubilities to acceptable values without more expensive materials or additional barriers.

The movement of both air and water are not adequately known at the repository depth, and are being studied. Furthermore, modeling of two-phase flow as modified by the thermal conditions in the vicinity of the waste package and its surroundings is still under development. Knowledge gained from more definitive work in the above areas will permit us to test materials under more realistic (i.e., less conservative) repository conditions and make more cost-effective waste package designs. In the current absence of this information, our initial materials testing is done under conservative

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conditions, viz., in the presence of air-saturated water, and in the air/steam/water system to determine the probable worst-case conditions.

DESIGN REQUIREMENTS AND CONSTRAINTS

We are designing waste packages to meet the latest NRC draft 10CFR60 and derivative requirements and constraints (NWTS 20, NWTS 33, N/DFT-35). To comply with 10CFR60 and additional system constraints we have developed the list of design requirements given in Table I. These requirements pertain to the disposal of defense high level waste (DHLW), commercial high level waste (CHLW) and spent fuel (SF). Requirements for transuranic waste (TRU) are being developed this year.

TABLE I
DESIGN REQUIREMENTS AND CONSTRAINTS (PRELIMINARY).

Waste packages shall be designed to:

1. Contain the waste for 1000 years.
2. Maintain a release rate less than 10^{-5} of radionuclide inventory present at the end of the containment period (1000 years).
3. Be retrievable for 50 years after emplacement of the first waste package.
4. Not exceed a criticality coefficient of 0.95 (minus 3 std. dev.) for normal or accident conditions.
5. Not exceed temperature limits of the waste forms of 773 K (500C) for DHLW glass, 673 K (400C) for CHLW glass and 698 K (425C) spent fuel cladding.
6. Not leak radioactive material in excess of applicable federal and state standards after a drop test of two times waste package length onto an unyielding surface.
7. Not leak radioactive material in excess of applicable federal and state standards after sustaining an 1073 K (800C), 15 minute fire test.
8. Not leak radioactive material in excess of applicable federal and state standards after handling, emplacement, retrieval and expected seismic loads. Further, these loads must not compromise long-term performance.
9. Maintain legible externally labeled identification up to and including retrieval.
10. Meet requirements at optimum costs, including direct package costs and related repository system costs through emplacement.

CONCEPTUAL DESIGN

For reprocessed waste (CHLW and DHLW) melted into borosilicate glass, it is expected but not yet proven that the very long-term slow release-rate requirements can be satisfied by the waste forms themselves. In the case of spent fuel, a tailored backfill may be necessary to satisfy this requirement. To attain acceptable thermal conductivity the backfill will have to be compressed to high density. Possible alternatives to backfill are including the effect of Zircaloy cladding on release rates or an overpack which would provide containment for 5000-10,000 years.

Conceptual Designs Completed in September 1982

Westinghouse Advanced Energy Systems Division (AESD), Pittsburgh, PA, developed conceptual designs for nuclear waste packages during 1982.[4] The primary emphasis of the work was on concepts for below the water table in tuff, where significant hydrostatic pressure exists (3.0 MPa [435 PSI]). At this pressure, liquid water exists up to 505 K (232C), the boiling point. Some work was done to evaluate several concepts for emplacement in the unsaturated zone above the water table. The emplacement concepts evaluated were vertical boreholes below tunnel floors, horizontal boreholes in tunnel walls and emplacement directly on tunnel floors (self-shielded concept). Figure 1 shows the reference DHLW (Defense High Level Waste) canister overpacked in steel.

The horizontal borehole concept consists of nuclear waste packages emplaced end-to-end in 185 m (600 ft) long horizontal boreholes which are drilled laterally from mined tunnels. Each borehole could contain up to 55 waste packages. Compared to the 6 m (20 ft) deep vertical borehole concept, which contains only one package per borehole, there is considerably less mining and backfilling cost per package. This is because more packages per foot of drift can be emplaced in the horizontal configuration, which takes advantage of the horizontally bedded geology of Yucca Mountain. If, instead, many packages were emplaced on top of each other in a vertical borehole this would span too much vertical extent of the limited optimum geology. Also, the added load on the lower packages would require a stronger, more expensive design.

The tunnel floor concept incorporated a thick-walled overpack to provide a corrosion allowance and structural strength, plus some personnel shielding during handling and emplacement operations.

For each of the borehole emplacement concepts, Westinghouse evaluated alternative barrier metals consisting of carbon steel and grade 12 titanium. For the self-shielded concept, cast steel and cast iron were evaluated. For each of the different waste forms, designs for reference size and larger than reference size alternatives were evaluated. Multiple canister per package alternatives were evaluated for the self-shielded concept.

Each concept was analyzed for technical and cost performance. All designs met the containment and other requirements listed in the report. Table II lists the concepts considered in the Westinghouse report.

Cost Comparisons for the Unsaturated vs. Saturated Zones

Two concepts were evaluated for emplacement above the water table. These were designed for disposal of CHLW in both the self-shielded overpack and in the horizontal borehole scheme with corrosion barrier hole liner. Cost of the horizontal borehole concept for emplacement in the unsaturated zone was about 20% lower than for below the water table. There was no cost difference in the self-shielded design for above and below the water table. The horizontal borehole scheme was the least costly emplacement concept (Ref 4, p 44).

Continuing Conceptual Design for the Unsaturated Zone

Figure 1 shows one of the current leading candidate waste package designs for emplacement in either vertical or long horizontal boreholes. The design consists of a single, highly reliable metallic containment barrier which is used to enclose the canistered glass waste form or spent fuel rods. As discussed in the next section, many

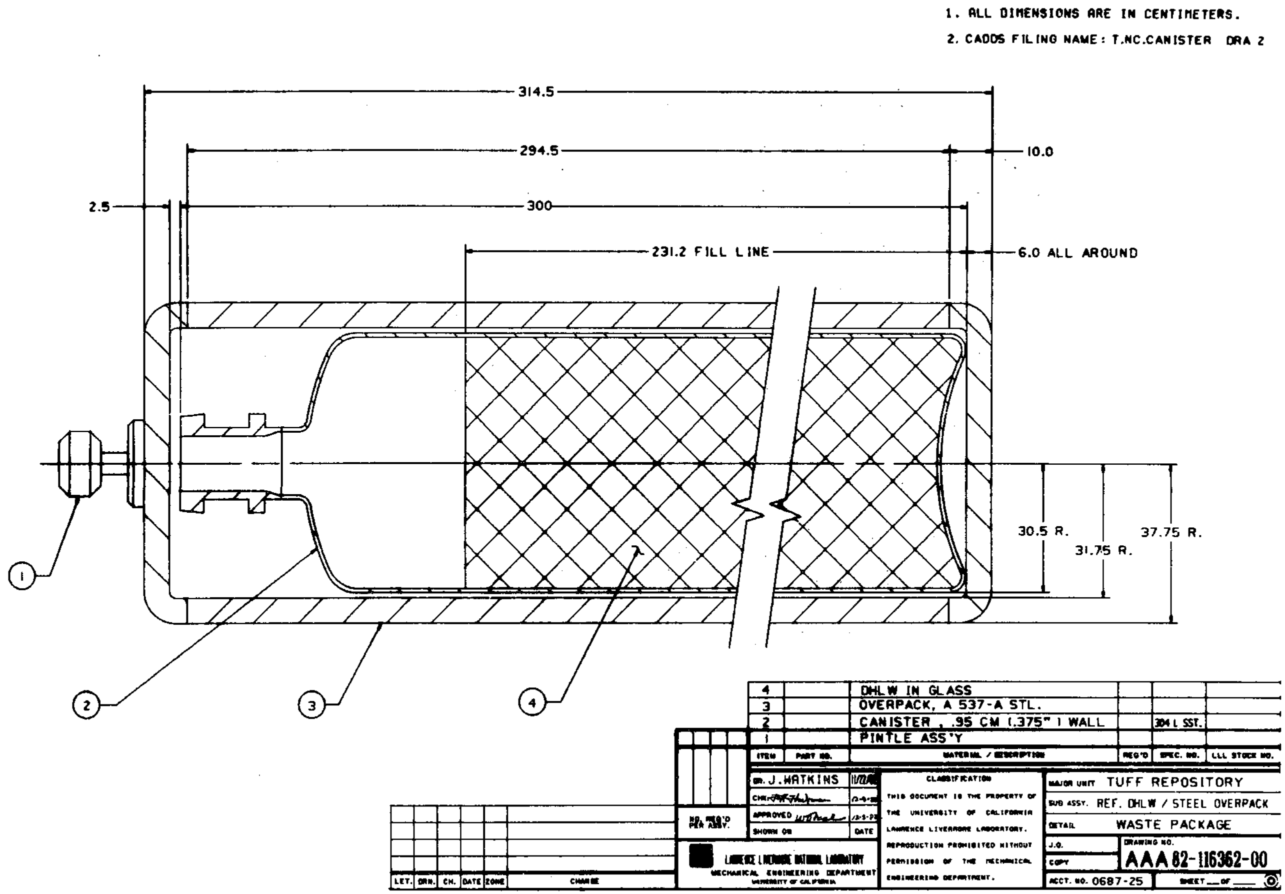

Fig. 1. DHLW in Carbon Steel Overpack.

metals are being evaluated as potential candidates for the containment barrier. These range from low carbon steels to alloys of titanium and zirconium.

For a repository located above the water table structural design criteria are based on transportation and handling loads instead of hydrostatic or lithostatic loads. Material thickness will be based on the maximum required for corrosion resistance or structural loads. The thickness currently estimated for structural loads is about one cm. The thickness required for corrosion will be determined after the barrier material is chosen, considerably more corrosion data are available, and the anticipated environment is more certain. For some candidate metals, our best estimate is that the 1 cm structural thickness will provide sufficient allowance for the 1000 year containment period.

Several alternate package designs are being considered. One of the most cost effective designs is for long horizontal boreholes. These may be lined with concrete or steel pipe to prevent rocks from falling into the borehole and interfering with emplacement and retrieval.

For the unsaturated zone, a possible cost-effective approach to package design is to use the waste form canister as the long-term containment barrier. If the canister wall consisted of a one cm thickness of an appropriate metal which would not be degraded during the glass pouring process, no overpack would be necessary. We are continuing to develop modified conceptual designs for the unsaturated zone.

Selection of the Best Concepts

In order to select the best conceptual design for a non-saturated horizon in the tuff repository, we are performing comparative analyses of the candidate conceptual designs. To provide information for selection, each viable concept is first designed to meet 10CFR60 requirements using appropriate computer models with data for the unsaturated zone. The concept is then cost analyzed for present worth using an economic analysis code, which includes waste package, mining, packaging and shipping costs. Finally, comparisons of performance and cost are used to determine the best conceptual design. Cost/benefit analyses will be performed to determine incremental costs for additional performance.

There are alternate concepts for each component of the Waste Package subsystem. For example, the waste forms may be glass, spent fuel, or transuranic (TRU) waste. The long-term containment overpack may be titanium, carbon steel, stainless steel or other alloy. There are different backfill materials under consideration, and different materials are being evaluated for lining the boreholes. The self-shielded concept has been eliminated from current considerations due to apparent cost and handling disadvantages, leaving a choice between horizontal and vertical borehole concepts.

Selecting Candidate Metals for Overpacks and Canisters

We are selecting a few candidate materials for design of overpacks/canisters and for corrosion

Table II NNWSI WASTE PACKAGE DESIGN CONCEPTS

No.	Description	WF Dia cm	No. Pkgs
1.00	VERT BOREHOLE, DHLW, Ti-12 OP, SAT ZN*	61	7000
1.02	VERT BOREHOLE, DHLW, STEEL OP, SAT ZN	61	7000
1.04	VERT BOREHOLE, DHLW, Ti-12 OP, SAT ZN	81	3970
1.40	VERT BOREHOLE, CHLW, Ti-12 OP, SAT ZN	32	16,000
1.42	VERT BOREHOLE, CHLW, STEEL OP, SAT ZN	32	16,000
1.44	VERT BOREHOLE, CHLW, Ti-12 CAN, SAT ZN	32	16,000
1.46	VERT BOREHOLE, CHLW, Ti-12 OP, SAT ZN	41	7270
1.80	VERT BOREHOLE, SF-6PWR, Ti-12 CAN, SAT ZN	53	8700
1.81	VERT BOREHOLE, SF-18BWR, Ti-12 CAN, SAT ZN	65	3730
1.82	VERT BOREHOLE, SF-6PWR, STEEL CAN, SAT ZN	72	8700
1.84	VERT BOREHOLE, SF-6PWR, Ti-12 CAN, SAT ZN	83	8700
1.85	VERT BOREHOLE, SF-18BWR, Ti-12 CAN, SAT ZN	72	3730
1.90	VERT BOREHOLE, SF-4BWR, INT. BENT., Ti-12 CAN, SAT ZN.	38	15,500
2.40	HORIZ BOREHOLE, CHLW, Ti-12 OP, SAT ZN	32	16,000
2.42	HORIZ BOREHOLE, CHLW, STEEL LINER OP, UNSAT ZN	32	16,000
2.43	HORIZ HOREHOLE, CHLW, STEEL LINER OP, SAT ZN	32	16,000
2.41	HORIZ BOREHOLE, CHLW, Ti-12 CAN., UNSAT ZN	32	16,000
2.42	HORIZ BOREHOLE, CHLW, STAINLESS ST. CAN., UNSAT ZN	32	16,000
2.80	HORIZ BOREHOLE, SF-PWR, STEEL CAN., UNSAT ZN	TBD	TBD
2.81	HORIZ BOREHOLE, SF-BWR, STEEL CAN., UNSAT ZN	TBD	TBD
3.00	SELF SH, DHLW, STEEL OP, TUFF BKF, SAT ZN	61	7000
3.01	SELF SH, DHLW, IRON OP, TUFF BKF, SAT ZN	61	7000
3.02	SELF SH, DHLW, STEEL OP, TUFF BKF, SAT ZN	2 @ 61	3500
3.03	SELF SH, DHLW, IRON OP, TUFF BKF, SAT ZN	2 @ 61	3500
3.40	SELF SH, CHLW, TRI STEEL OP, TUFF BKF, SAT ZN	3 @ 32	5333
3.41	SELF SH, CHLW, TRI, IRON OP, TUFF BKF, SAT ZN	3 @ 32	5333
3.42	SELF SH, CHLW, SQ, STEEL OP, TUFF BKF, SAT ZN	46	5774
3.44	SELF SH, CHLW, SQ, IRON OP, TUFF BKF, SAT ZN	46	5774
3.45	SELF SH, CHLW, TRI IRON OP, TUFF BKF, UNSAT ZN	3 @ 32	5333
3.80	SELF SH, SF-8PWR, SQ, STEEL OP, TUFF BKF, SAT ZN	45 sq	6520
3.81	SELF SH, SF-8PWR, SQ, IRON OP, TUFF BKF, SAT ZN	45 sq	6520
3.82	SELF SH, SF-18BWR, SQ, STEEL OP, TUFF BKF, SAT ZN	45 sq	3730
3.83	SELF SH, SF-18BWR, SQ, IRON OP, TUFF BKF, SAT ZN	45 sq	3730

*Abbreviations:

VERT - vertical
OP - overpack
SAT - saturated
ZN - zone
CAN - canister
UNSAT - unsaturated
WF - waste form
BKF - backfill
HORIZ - horizontal
SQ - square
TRI - triangular
TBD - to be determined
SH - shielded
SF - spent fuel

tests under repository conditions. A materials properties matrix reflecting engineering design criteria for 16 potential candidate materials was developed. The metals that were considered are presented in Table III. These are all commercially available alloys. The methodology of the systems engineering approach simplifies a potentially complicated problem by allowing optimization and comparison of the parameters on a broad level.

Our first step in this approach involved specifying and evaluating the properties considered to be important. These fall under four general categories:

1 General and Local Corrosion Resistance.
2 Fabrication Costs and Commercial Availability
3 Required Mechanical Properties
4 Weldability

1. Corrosion

General and local corrosion data was obtained from the available literature and limited LLNL corrosion tests. All high-rate corrosion mechanisms that a particular material will be subjected to in the Yucca Mountain repository environment were investigated.

2. Fabrication Costs

Rolled and welded pipe manufacturing processes are representative of the kind of fabrication involved in manufacturing overpacks. A diameter of 0.91 m (36 in) represents the largest overpack we contemplate in our designs, so we used the cost of 0.91 m (36 in) by 12.7 mm (1/2 in) wall welded pipe as a measure. These costs were obtained by telephone contact with commercial fabricators. The

TABLE III POTENTIAL CANDIDATE METALS FOR OVERPACKS

ASTM Unified Numbering System	Commercial Material Designation	Typical Chemical Constituents
UNS G10200	AISI 1020 steel	.2 C, .5 Mn, bal. Fe
----	ASTM A537A steel	.2 C, 1 Mn, bal. Fe
UNS S40900	AISI 409 st. steel	11 Cr, 1 Mn, 1 Si, bal. Fe
UNS S44626	26 Cr - 1 Mo steel	26 Cr, 1 Mo, bal. Fe
UNS S30400	AISI 304L st. steel	18 Cr, 8 Ni, 2 Mn, 1 Si, bal Fe
UNS S32100	AISI 321 st. steel	18 Cr, 10 Ni, 2 Mn, 1 Si, bal. Fe
UNS S31603	AISI 316L st. steel	17 Cr, 12 Ni, 2 Mo, 2 Mn, 1 Si, bal. Fe
UNS S30403	AISI 304ELC st. steel	18 Cr, 2 Mn, 9 Ni, 1 Si, bal. Fe
UNS S31703	AISI 317L st. steel	19 Cr, 2 Mn, 3 Mo, 13 Ni, 1 Si, bal. Fe
UNS S32550	Ferralium 255	25 Cr, 5 ni, 3 Mo, 2 Cu, bal. Fe
UNS N08825	Incoloy 825	42 Ni, 30 Fe, 21 Cr, 2 Cu, 1 Mn, 3 Mo, 1 Ti
UNS N06625	Inconel 625	61 Ni, 21 Cr, 5 Fe, 3 Cb, 9 Mo
-----	Ti Code 2	99 Ti
-----	Ti Code 12	98 Ti, 1 Ni
UNS R60702	Zr 702	98 Zr, 1 Hf
UNS C70600	Cupronickel 90/10	90 Cu, 10 Ni

economics of other competing fabrication processes such as extrusion and centrifugal casting were also considered.

3. Required Mechanical Properties

Required Mechanical Properties deals with the following subjects: fracture toughness at 255 K (-18C), tensile strength, yield strength at 1073 K (800C), elongation at an intermediate strain-rate, and the nil-ductility temperature. Fracture toughness at 255 K (-18C) is a property of a material that defines its resistance to brittle fracture. Tensile strength is a standard mechanical property used for overpack stress analysis during handling. The yield strength at 1073 K (800C) is related to the requirement of surviving a 1073 K (800C), 15 minute fire test without leaking. The ductility (elongation) at intermediate strain-rates also is dictated by a requirement for the overpack to survive a drop test from up to a nine meter height without leaking. The fracture toughness of certain alloys exhibits significant variations with changes in temperature. The nil-ductility temperature is that temperature where normally ductile materials behave in a brittle fashion. Candidate metals meet all of the minimum requirements.

4. Weldability

The next category covered, weldability, which must be adapted to remote operations, was evaluated based on four criteria: required operator skills, process cost, process technical sophistication, and weld quality. Weld quality includes all dimensional and mechanical property requirements of the weld and heat affected zone.

Candidates with less desirable values for all properties will be eliminated from the matrix. The next step is to explicitly define the trade-off values. This requires a conversion to a constant measure, usually dollars. We are using a microcomputer to perform sensitivity analyses which allow an efficient calculation of the effects of changing property and trade-off values. The selection of materials for waste package components rather than for testing will involve an additional step of quantifying and incorporating uncertainty into the decision process.

THERMAL ANALYSIS OF THE WASTE PACKAGE AND HOST ROCK

We have begun thermal analyses of candidate conceptual designs to determine temperature-limited waste package dimensions and spacings. The initial analysis was done on DHLW (Defense High Level Waste) packages in horizontal boreholes. TACO2D[5], a two dimensional implicit finite element code, is being used for the analysis. The input to TACO2D consists of the temperature dependent material properties, a mesh representing the physical geometry and the time dependent thermal loading of the waste form. Code output consists of temperature histories of all nodes of the mesh.

A high value of areal loading of 215 kW/acre was used in this calculation to determine the sensitivity of waste centerline temperature to package spacing. Repository areal loading will probably be less than 100 kW/acre.

Description of the Model

The thermal design of the waste package is closely coupled to the design of the Yucca Mountain tuff repository in which it will be emplaced. With this in mind we elected to use a 2D-model oriented perpendicular to a horizontal borehole of infinite length. The model, utilizing symmetry when appropriate, allows for variable spacing between horizontal boreholes and the presence of the ground surface 350 m above the repository. Similar models have been used by others.[4,6] Figure 2 shows the finite element mesh used in the calculations and includes a description of the various barriers modeled.

The major assumptions and methods concerning the model are as follows. First, for these initial runs on DHLW waste packages, the effect of thermal radiation across air gaps was not included. This results in a somewhat higher calculated peak centerline temperature of the waste form. For DHLW, this is not a concern because the peak centerline temperature does not approach the 773 K (500C) design limit. Thermal radiation is a much more significant mode of heat transfer for higher heat loadings (and so, higher temperatures) than exist for DHLW (530 W, 836 W/m^3).[7] It is included in analyses of commercial and spent fuel waste packages which have much higher thermal loadings than DHLW, (2.2 kW for CHLW and 3.4 kW for spent fuel).[4]

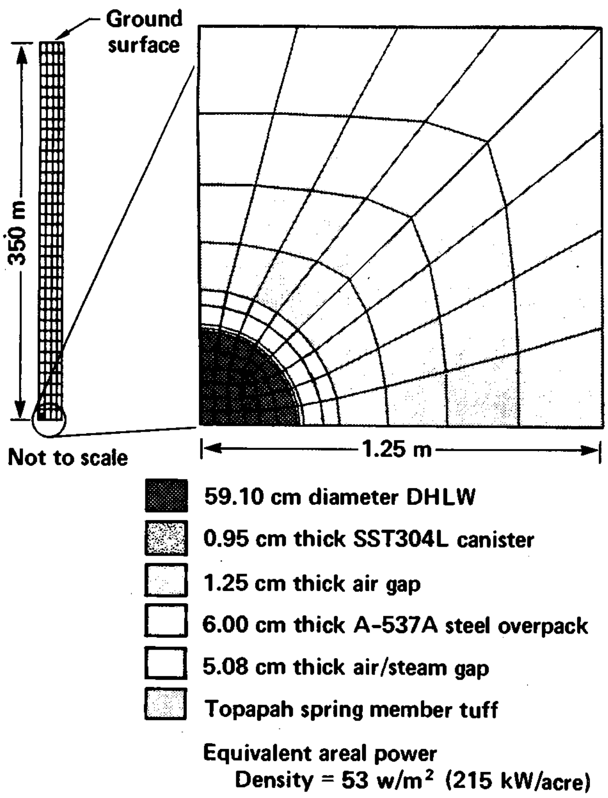

Fig. 2. Finite element mesh used in the defense high level waste thermal calculations including a description of the barriers.

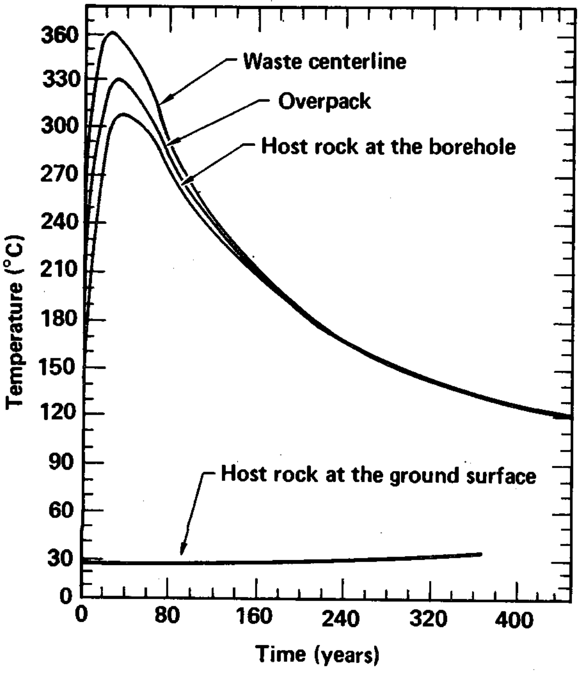

Fig. 3. Temperature histories of waste package components and host rock. The plots are time referenced to emplacement of five year old DHLW waste.

Dry air is assumed to exist between the canister and the overpack. One hundred percent humid air is assumed between the overpack and the surrounding tuff up to a temperature of 373 K (100C) at which time the atmosphere changes to 100% steam. Heats of vaporization and recondensation, and fluid transport were not included in the analysis. All materials are modeled as isotropic. Finally, no temperature gradient in the tuff from the repository to the ground surface was used. Instead, at emplacement a uniform initial temperature of 302 K (29C) was used throughout for these first analyses.

A combination of two computer runs was used to achieve the results shown in Fig. 3. This was a way of approaching 3D accuracy using the more economical 2D code. The first run assumed an infinite cylinder of reference power waste (836 W/m^3) with no allowance for gaps between packages and partially filled canisters. The second run allowed for gaps and an equivalent volumetric heat load (483 W/m^3) spread evenly over the volume bounded by the waste form diameter and waste package length in the borehole. The temperature history in the second run fairly accurately represents the overpack and rock temperature because the heat from the package is distributed evenly through the relatively high conductance overpack.

The temperature distribution of the waste form and the canister from the first run was then superimposed on the temperature history of the overpack from the second run to give the final centerline history. Figure 3 represents what we believe to be the most accurate representation of the thermal history within the constraints of the model discussed earlier.

The temperature time plot presented in Fig. 3 for a DHLW waste package with a borehole spacing of 2.5 m shows that the centerline temperature design limit of the waste form (773 K [500C]) was never reached.

ECONOMIC ANALYSIS

We are developing a simple economics code to assist in making waste package design decisions. It will help satisfy the requirement that the waste package technical performance requirements, discussed earlier in this paper, will be met in a cost effective manner. The code we are using is the commercially available SUPERCALC program, an "electronic spread sheet". It is a pre-programmed interactive code which permits the user to easily build a tailored program onto an existing backbone of formats and routines by adding his own subroutines, equations and data. We are using SUPERCALC on a NORTHSTAR Horizon 64K microcomputer.

The code is not intended to incorporate all aspects of the repository. It will be limited to the waste package and only those features of the repository design that will be strongly affected by changes in package design, such as consolidation, packaging, mining and emplacement. The inclusion of the "interface" costs between the package and the repository is essential for achieving a realistic cost optimized waste package design.

At present some parts of the code are operational, including most features of the waste package and some features of the repository which are affected by package design. We plan to add additional cost parameters as their relationship to package design is evaluated. However, at present our efforts are primarily directed towards establishing a cost data base for the features of the code that are already operational.

WASTE PACKAGE PERFORMANCE MODELING

In conjunction with the waste package design effort is a modeling and analysis task. Unlike design optimization studies, the primary goal of this task is a calculated prediction of the release initiation time and release rates from the waste package subsystem. Activities in support of this task include:

1) Development of a waste package subsystem model,
2) Definition of a suitable test problem for model evaluation and verification,
3) Assembly of the data bases associated with each level (i.e., conceptual, preliminary and final) of waste package design, and
4) Analysis of waste package designs to calculate performance measures, to identify the sensitivity of system response to variations in input parameters and to determine the impact of input uncertainty on the distribution of performance measures about their median values.

Input to this analysis combines the results of site geotechnical investigations, material characterization and interaction studies as well as design specifications, to predict the long-term performance of the waste package subsystem and provide a source term for repository scale and far field performance assessments.

Waste package subsystem performance assessment codes i.e., BARIER[8] and WAPPA[9] have been developed by others to predict the state of waste package components as a function of time by integrating the various barrier degradation mechanisms. The degradation process models included are: thermal, mechanical, radiation, corrosion, and leach. Process model algorithms rely on simple analytic equations and theory and an extensive, empirical data base. We are augmenting the data base to include repository and site conditions, material properties and design information, so that more realistic analyses can be conducted. These inputs draw extensively from the results of related detailed studies within the NNWSI Program.

These codes, however, were developed assuming emplacement below the water table and a critical evaluation of their limitations and applicability to the unsaturated (Topopah Springs) tuff horizon at Yucca Mountain is partially complete. Current effort is directed at evaluating the impact of two-phase, multi-component (air/steam/water) flow on thermal and fluid transport in the porous backfill. Similarly, corrosion process models which include the effects of steam corrosion on waste package components are being considered. The impact of these additional processes must be assessed in order to accurately predict or bound the long-term performance of the waste package subsystem.

It appears that with some modification and appropriate data, WAPPA and/or BARIER will provide useful information for initial design decisions and analysis. However further development and validation will probably be necessary to provide defensible input to the licensing procedures.

CONCLUSIONS

Results of our design and analysis to date indicate that technical and economic requirements for the waste package can be met in the unsaturated zone. Preliminary economic analysis shows a cost advantage in designs for this zone compared to a location below the water table because of the absence of hydrostatic pressure. We have almost completed development of a full range of general conceptual designs from which we can choose suitable designs specific to each waste form. When the candidate metals study is completed, a small number of metals (4-6) will be chosen for design and corrosion tests. Numerical design methods have been established. We are continuing to complete our initial data base and have begun analysis of some design concepts. Further waste package model development is under way to allow more realistic analysis of the waste package in the unsaturated zone.

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