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MECHANICAL FAILURE MODE DATA REQUIREMENTS FOR TiCode-12 HIGH LEVEL WASTE CONTAINER SYSTEM

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P. Soo and C. Brewster

Manuscript Completed August 1982

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ABSTRACT

In this report, mechanical failure has been examined for high level waste container systems incorporating TiCode-12. Failure modes are shown to be highly dependent on waste package design and on the type of stress within the container system. Using conceptual Westinghouse defense and commercial waste package designs for salt and basalt repositories, it is clear that the failure of the TiCode-12 overpack is significantly influenced by the presence of the underlying cast steel reinforcement structure. This structure minimizes local deformation of the TiCode-12 caused by the hydrostatic/lithostatic stress components and greatly reduces the possibility of failure. The major potential for mechanical failure in the overpack will be connected with the presence of aggressive corrosion conditions. With respect to seismic activity, ground movement may result in large episodic stresses which potentially could shear containers situated along faults in hard rock media. However, such mechanical failure probably can be avoided by estimating the maximum anticipated stress condition for a repository site and designing a sufficiently strong waste package to withstand it.

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1. INTRODUCTION

In the NRC Proposed Rule 10 CFR 60 for the disposal of high level waste, an approximately 1000-year radionuclide containment requirement is placed on the performance of the waste package. Although the waste form and the discrete backfill have containment capabilities, it is the container system which provides the best potential for this purpose. The license applicant may demonstrate compliance with the containment criterion by providing a satisfactory data base to show that the container system will remain unbreached, for approximately 1000 years, by anticipated mechanical and chemical (corrosion) failure modes. Other work in this program addresses chemical failure mechanisms and will not be discussed here, even though many are closely associated with mechanical loading. These include, for example, stress-corrosion cracking and delayed failure of stressed containers due to the uptake of hydrogen and subsequent hydride formation.

In this report, potential failure modes for TiCode-12 container systems from stress alone will be addressed. Licensing data requirements to demonstrate that the container system will not be breached by mechanical means will be specified.

2. ANTICIPATED CONDITIONS FOR THE CONTAINER SYSTEM

Below will be described designs and expected loads and temperatures for candidate container systems.

2.1 Container System Designs

Table 1 outlines conceptual container system designs which have been proposed by Westinghouse Electric Corporation (W). Both defense and commercial high level waste packages are given with options for non-shielded and self-shielded designs. Shielded designs are specified to avoid complications from groundwater radiolysis and host rock irradiation. In the Westinghouse shielded packages, thick cast iron or cast steel containers (overpacks) are specified. For non-shielded designs, the cast iron or steel components are much thinner and serve as a reinforcement structure for the TiCode-12 overpack. It is the TiCode-12 overpack which will serve as the corrosion-resistant member of the container system.

The Westinghouse non-shielded waste packages are designed for vertical emplacement in boreholes, whereas the self-shielded designs are laid horizontally within the repository tunnel. The latter, less costly, emplacement scheme is possible because of the lower levels of radiation exposure for repository workers. Figures 1 through 4 show waste packages with container systems incorporating TiCode-12. These will be addressed in this report.

2.2 Temperatures for Container Systems

Owing to the longer storage time for defense high level waste (DHLW) compared to that expected for their commercial conterpart (CHLW) the former waste

Table 1

Container Designs for Borosilicate Glass Waste Forms

Waste Package Type	Host Rock	Container/Overpack Design	Max. TiCode-12 Temp. (°C)	Ref.
W DHLW (Non-Shielded)	Salt	9.5-14.0 cm cast steel overpack reinforcement, 0.25 cm TiCode-12 overpack.	82	1
W DHLW (Shielded)	Salt	30.5 cm cast steel.	85	1
W CHLW (Non-Shielded)	Salt	5.7 cm steel overpack reinforcement, 0.25 cm TiCode-12 overpack.	250	1
W CHLW (Shielded)	Salt	40.5 cm cast steel.	250	1
W DHLW (Non-Shielded)	Basalt	8.25-17.8 cm cast steel overpack reinforcement, 0.25 cm TiCode-12 overpack.	173	2
W DHLW (Shielded)	Basalt	30.5 cm cast steel.	147	2
W CHLW (Non-Shielded)	Basalt	4.45 cm cast steel overpack reinforcement, 0.25 cm TiCode-12 overpack.	250	2
W CHLW (Shielded)	Basalt	34.0 cm cast steel.	250	2

Note: Current DOE designs specify that borosilicate glass will be cast into a Type 304 stainlss steel mold. For the purpose of this study, this mold will be defined as being an integral part of the waste form rather than a part of the container system.

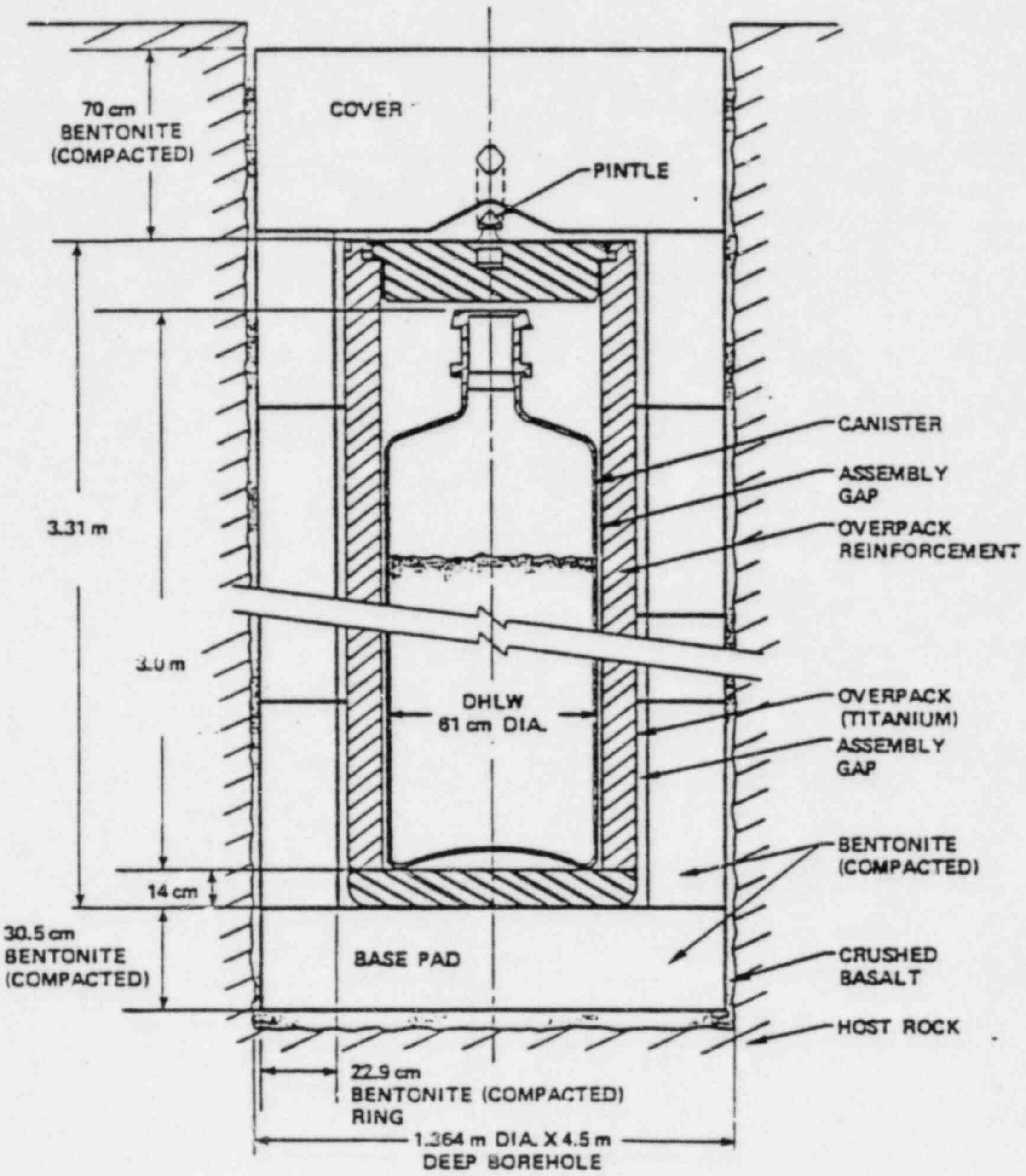

Figure 1. Reference DHLW package for borehole emplacement in basalt.

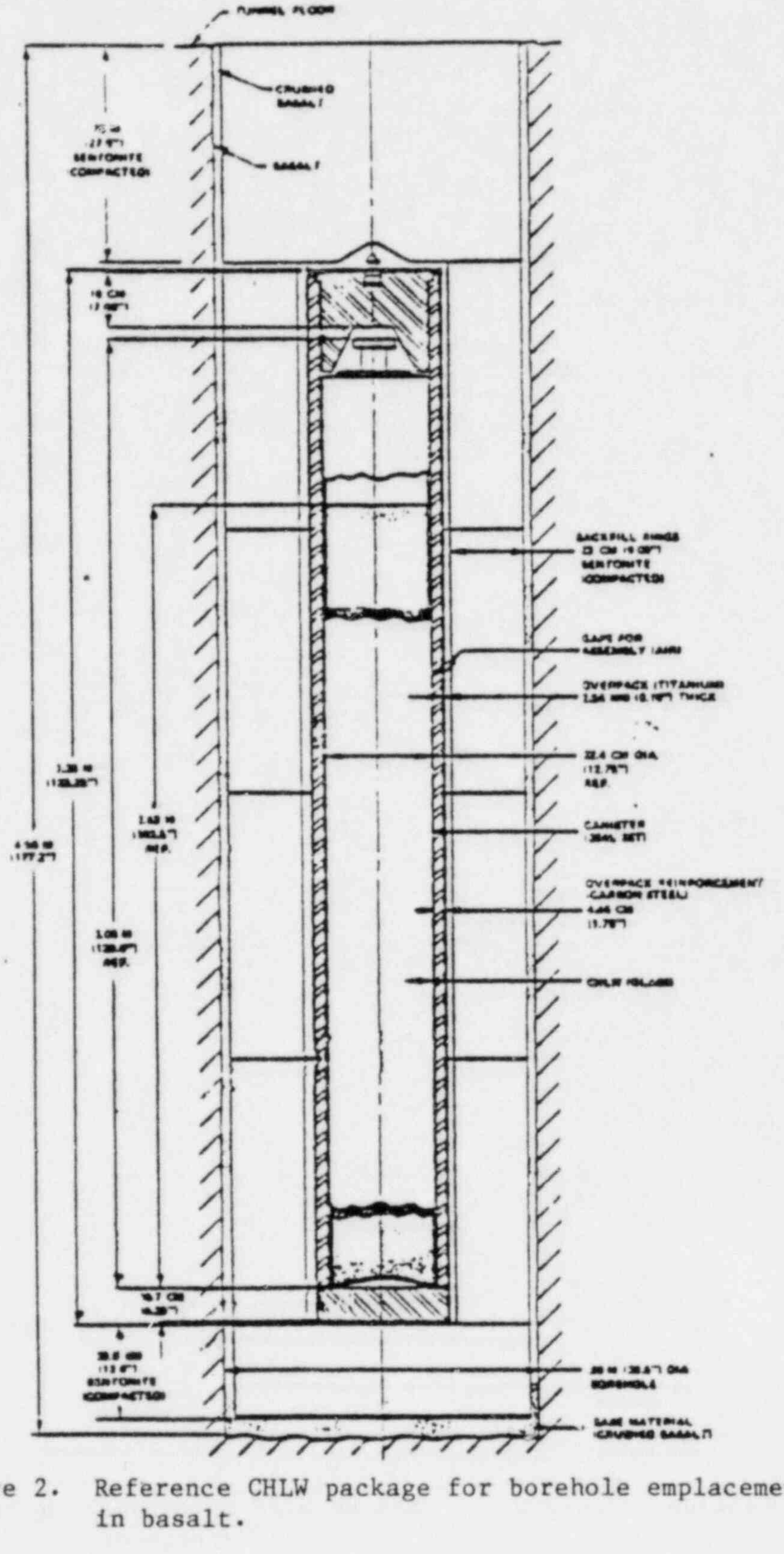

Figure 2. Reference CHLW package for borehole emplacement in basalt.

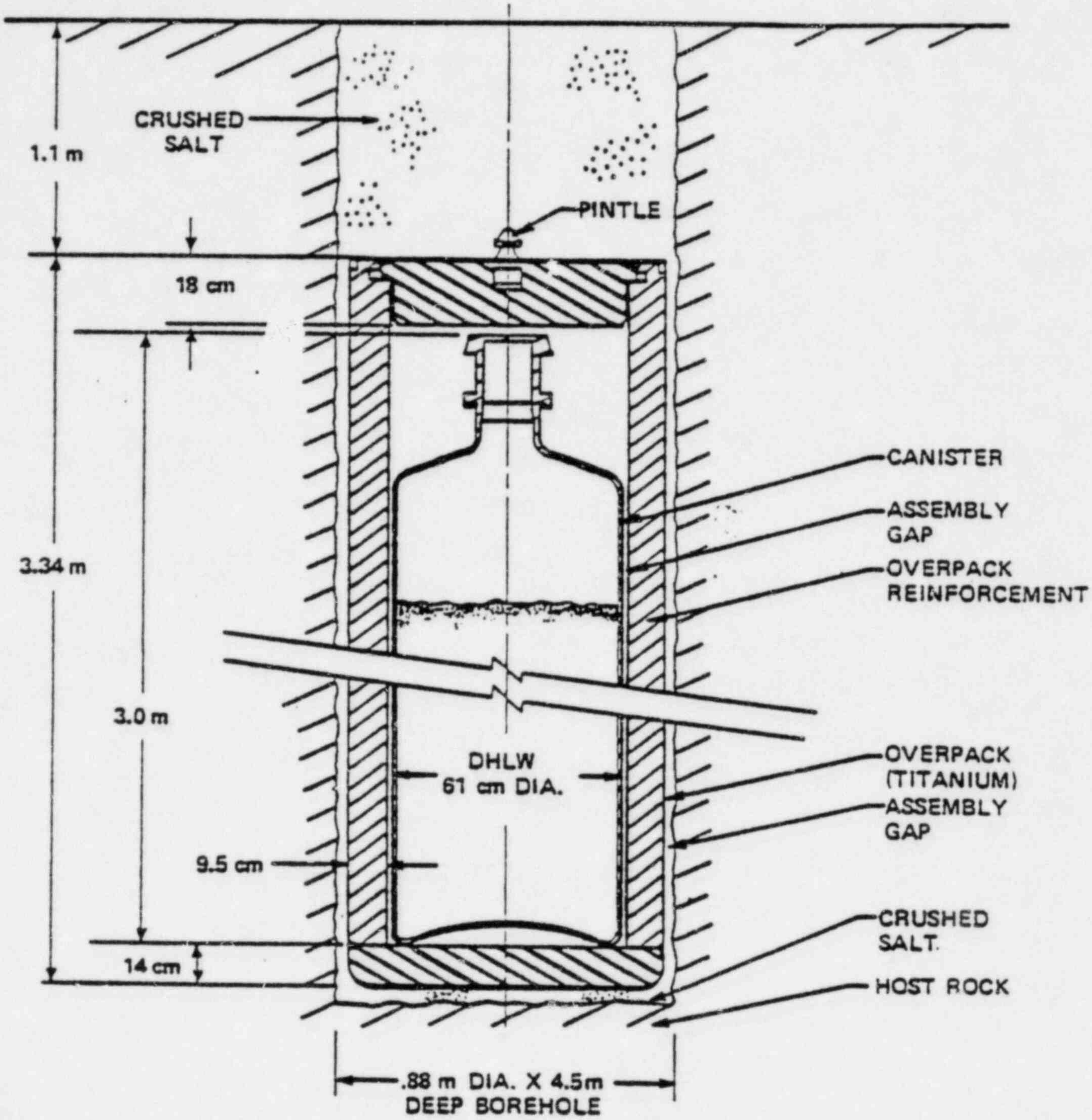

Figure 3. Reference DHLW package for borehole emplacement in salt.

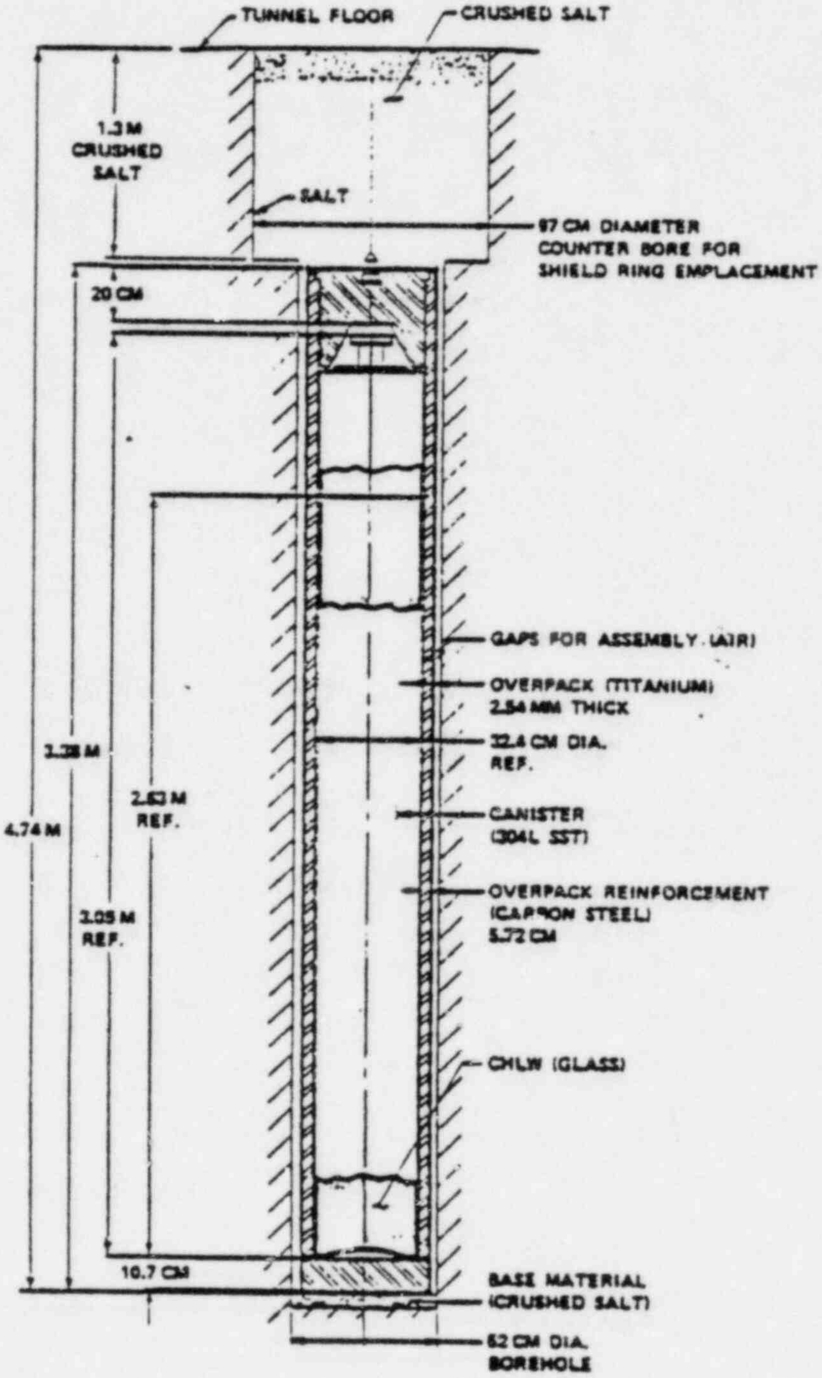

Figure 4. Reference CHLW package conceptual design for borehole emplacement in salt.

will be significantly cooler. Currently, defense waste will give maximum in situ container temperatures of approximately 85 and 173°C in salt and basalt repositories, respectively. For commercial waste, the maximum container temperature will be about 250°C for both host rocks. Based on data summarized in a study performed in this program[3] these maximum temperatures will be reached within the first 40-50 years following emplacement, after which significant cooling will occur. Temperatures of the container system will approach ambient host rock values after several hundred years.[3]

2.3 Stresses on Container Systems

Stresses on the container system during the containment period may originate from several sources, including:

- Waste form swelling from self irradiation
- Seismic events
- Residual stresses such as those due to welding
- Hydrostatic and lithostatic pressures.

These will be discussed below within the context of the Westinghouse conceptual waste package designs. The possible type(s) of failure mode resulting from each of the above stress conditions will be addressed.

3. MECHANICAL FAILURE SCENARIOS FOR TiCode-12 CONTAINER SYSTEMS

3.1 Failure from Waste Form Swelling

Certain borosilicate glasses have been shown to swell approximately one percent by volume after irradiation doses expected over 1000 years.[4] This will introduce tensile stresses in the Type 304 stainless steel mold containing the glass. However, this stress is unlikely to be transmitted to the TiCode-12 overpack in the Westinghouse waste packages since there is an annular clearance of 1.27 cm (0.5 in) between the stainless steel mold and the carbon steel overpack reinforcement structure. Radiation-induced swelling of the waste form could, therefore, only become a problem if there was limited clearance between adjacent container components and if they were sufficiently thin to cause deformation of the TiCode-12. For this situation, stress-enhanced failure modes such as hydrogen embrittlement and stress-corrosion cracking are possible. These two failure modes are discussed elsewhere in this program.

3.2 Failure from Seismic Loading

One of the many considerations for selecting a repository site is that it be located in a region of low seismic or volcanic activity. However, it is conceivable that even in a carefully chosen site, earth movement will occur from natural processes such as rupture at new or undetected faults, tectonic forces and hydraulic fracturing, etc.[5] Such episodic events could cause mechanical loading of a waste container causing damage or failure. The difficulty in designing container systems against mechanical failure lies in predicting when such events will occur and the type and magnitude of the stresses on the container. Pusch[6] attempted to resolve this problem by estimating loading effects on waste containers in the following way:

1. First, he assumed a reasonable regional stress situation for a hard rock repository site.

2. Secondly, he superimposed on this regional stress a stress change which would lead to general failure of a large rock volume.

3. Finally, the deformation pattern for this failure condition was determined and its impact on the mechanical integrity of the container was estimated.

Using available data on Swedish sites, Pusch concluded that previously-estimated stresses for sudden general failure of a rock mass were inappropriate since weaker clayey or chloritic zones could deform at much lower stresses by creep. This would cause a relaxation of the stresses which could initiate rock mass failure. Pusch, therefore, concluded that the possibility of sudden large strains in any large rock mass in Sweden is almost nonexistent implying that container failure from this event is also improbable. He did, however, consider an incredible case in which movement along a fault plane could shear a horizontally emplaced container. For his particular assumptions he stated that high-quality steel containers can survive such shear loads, whereas copper containers could not.

It is clear that Pusch's work is highly dependent on loading conditions and waste package and repository geometries. However, his calculations are of value in designing a waste package to withstand stresses from seismic or volcanic activity in hard rock repositories. Similar studies in the DOE waste package program would help determine whether a container system is likely to fail mechanically during the approximately 1000-year containment period. It appears that if a conservative estimate can be made of the nature and magnitude of stresses anticipated from seismic events, then a waste package could readily be designed to prevent container failure from rock movement.

3.3 Failure from Lithostatic/Hydrostatic Stresses

In a sealed repository, the steady state pressure at repository depth would be determined by hydrostatic and lithostatic pressures. For basalt, Siskind and Hsieh[3] elsewhere in this program have carried out a literature review and have shown that at a repository depth of 1100 m the hydrostatic and lithostatic pressures would be 11 and 33 MPa, respectively. In the case of a waste package incorporating a swellable bentonite containing discrete backfill, it has been suggested that the swelling pressure and hydrostatic pressure are additive giving a total effective hydrostatic pressure of about 21 MPa.[2] Although the initial Westinghouse conceptual waste package design was for a maximum anticipated hydrostatic pressure of 11 MPa, it was stated[2] that the extra pressure from the swellable bentonite could be easily accommodated by increasing the thickness of the reinforcement structure beneath the

TiCode-12 overpack from 8.52 to 15.8 cm. It seems that Westinghouse is assuming that tunnel collapse after repository closure is not an anticipated event. Thus, they have not designed the waste packages to accommodate the 33 MPa lithostatic stress limit. Because of this, the Westinghouse waste package design is not likely to be conservative. This is especially so since recent work by Doe[7] shows that in Scripa granite rock masses, the horizontal stress levels at depth may be up to twice as large as the vertical stresses calculated from rock overburden loads. If a similar situation exists for basalt, then the maximum stress on a waste package could be as high as 2 x 33.0 MPa or 66.0 MPa.

In rock salt repositories, Siskind and Hsieh's review[3] shows that the uniform lithostatic stress could vary between 18 and 35 MPa depending on depth. For the Westinghouse reference defense waste package design, however, the design stress in only 16.2 MPa. In this design, the high lithostatic stresses cited by Siskind and Hsieh[3] could cause buckling and collapse of the container head.

In order to more acurately analyze the mechanical behavior of a TiCode-12 overpack, detailed waste package designs must be available. The 0.25 cm thick overpack could be susceptible to buckling, and possible creep at repository temperatures if it ws not supported by the underlying cast steel reinforcement structure. Deformation of the overpack will still occur locally, however, in regions where there is a gap between it and the underlying structure. Since the overpack is only 0.25 cm in thickness, it will be collapsed by hydrostatic or lithostatic stresses onto the cast steel. Finite element structural analyses may be required to ensure that, for the design configurations and clearances used in the container system, the local strains present do not cause the overpack to be mechanically ruptured.

When collapse of the overpack has been completed, its subsequent deformation will be controlled by the underlying cast steel. If an accurate estimate of hydrostatic and lithostatic stresses can be made, it is probable that mechanical failure of the TiCode-12 overpack, during the containment period, can be avoided with reasonable assurance. However, in the presence of corrosive aqueous environments, there is a possibility that the overpack can be failed by stress-assisted mechanisms such as stress-corrosion cracking and delayed failure from hydrogen absorption. These are discussed elsewhere in this study.

3.4 Failure from Residual Stresses

Residual stresses are those present in a container due to normal fabrication and welding processes. They will also be introduced during plastic deformation of the overpack by hydrostatic/lithostatic stresses. In the Westinghouse waste package designs, closure welds for the TiCode-12 overpack do not appear to be scheduled for stress-relieving heat treatments so that it may be assumed that significant residual stresses exist in these regions. Since normal stress-relieving treatments for alpha-based titanium alloys are in the temperature range of 427 to 538°C,[8] significant in situ stress relief of the welds for the maximum container temperatures envisioned (about 250°C) is unlikely. Nevertheless, TiCode-12 welds appear to have significant ductility (10 to 16 percent tensile ductility at 316°C[9]), so that mechanical failure of the overpack is improbable. The main possibility for mechanically-assisted failure will result from the presence of corrosion processes, as discussed above in Section 3.3.

4. ADDITIONAL DATA REQUIREMENTS FOR CHARACTERIZING MECHANICAL FAILURE MODES IN TiCode-12 CONTAINERS

Based on discussions in Section 3, it is concluded that TiCode-12 container systems may be designed to withstand mechanical breaching from the action of internal stresses and hydrostatic/lithostatic stresses for approximately 1000 years. The added action of corrosive environments may accelerate failure but this is treated elsewhere in this program. In order to successfully specify a mechanically adequate container design, the following additional data are required:

- A conservative estimate of anticipated stress levels on the container system over the 1000-year containment period.
- A specification of the maximum compressive stresses (vertical and horizontal) and likely shear modes acting on a container system over the 1000-year containment period.
- Accurate estimates of temperature for the container system.
- A detailed description of waste package materials, geometry and dimensions. These would be needed to determine stress-strain behavior for the TiCode-12 overpack under the action of compressive and shear stresses.
- Detailed information on creep and tensile properties for TiCode-12 base and welded material for temperatures between approximately 80 and 250°C. These are required to calculate deformation during the containment period. At this time, an ASME Code Case for TiCode-12 is in preparation.[9]

5. SUMMARY AND CONCLUSIONS

A review of the types of stress on TiCode-12 high level waste container overpacks has been carried out to assess the potential for mechanical failure during the radionuclide containment period. Conceptual waste package designs from Westinghouse for basalt and salt repositories were considered during this work. Stresses from radiation-induced swelling of the borosilicate glass waste form were not important because of a clearance gap between the waste form and the cast steel structure below the TiCode-12. Residual stresses, such as those in welded regions of the overpack, are also unlikely to cause mechanical failure because of the low anticipated strains and high ductility of TiCode-12. Potential mechanical failure could occur in the long term from the presence of lithostatic stresses. These could be as high as 66 MPa for basalt and 35 MPa for salt. Also, movement along planar faults in hard rock repositories could potentially shear waste containers. Such mechanical failure, however, is likely to be avoidable provided that conservative estimates of the magnitudes of external stresses and types of loading (compressive, shear, etc.) are obtained and these are factored into the mechanical design of the waste package.

The major likelihood of mechanically-assisted failure will be connected with the presence of an aqueous corrosion environment which would promote stress-corrosion cracking or delayed failure of the TiCode-12 due to hydrogen uptake.

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