CALCULATIONAL APPROACH FOR SUBSTANTIALLY COMPLETE CONTAINMENT EXAMPLE PROBLEM

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PREVIOUS REPORTS IN SERIES

Number	Name	Date Issued
CNWRA 90-007	"Substantially Complete Containment" Feasibility Assessment and Alternatives Report	September 1990
NUREG/CR-5638	Technical Considerations for Evaluating Substantially Complete Containment of High-Level Waste Within the Waste Package	December 1990
NUREG/CR-5639	Uncertainty Evaluation Methods for Waste Package Performance Assessment	January 1991
Letter Report	Selection and Evaluation of Models for Substantially Complete Containment Example Problem	September 1992

ABSTRACT

The approach for calculation of waste package lifetime in regard to the "Substantially Complete Containment" requirement in 10 CFR 60.113 is explained. Estimation of container corrosion and container lifetime requires knowledge or prediction of the amount and composition of water contacting the container (i.e., waste package environment). The analysis is based on the prediction that most water contacting the container evaporates, leaving a scale deposit and brine solution behind. The vapor pressure lowering caused by the brine solution maintains a water film on the canister and waste even in the presence of a dry environment with thermal gradients. Presence or absence of localized corrosion is determined by estimating the corrosion potential of the container relative to a critical potential for localized corrosion. Mechanical failure of the container by buckling, cracking, and yielding is also considered. The mechanical failures are assumed to be initiated primarily by seismic loading. The various models are integrated in a structure that will facilitate the conduct of a probability-based analysis. The probability analysis will be carried out by using the algorithms being developed under the Iterative Performance Assessment (IPA) project.

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1 INTRODUCTION

The ambiguity in the interpretation of the words "substantially complete containment" (SCC) in 10 CFR 60.113 has led the U.S. Nuclear Regulatory Commission (NRC) to contract with the Center for Nuclear Waste Regulatory Analyses (CNWRA) to study the feasibility of a quantitative rule or guidance that could assist in clarifying NRC intent regarding the words in the regulation. Toward that goal, the CNWRA prepared three reports. The first of these reports identified the technical considerations necessary for evaluating any degree of containment for the waste package (Manaktala and Interrante, 1990). The second report presented, on a generic basis, different quantitative methods that can be used to describe and evaluate the various technical uncertainties associated with the waste package environment, materials and fabrication, and degradation processes (Wu et al., 1991). The technical uncertainties could be combined in an overall probability-based approach to present both probability of failure of any waste package, and the number of waste packages failing at a given time. The report presented the framework for establishing the probability-based criteria for expressing the degree of containment. It was concluded in this report that a quantitative approach was feasible. The third report provided alternate ways in which the probability based criteria could be implemented in a regulatory arena (Nair and Tschoepe, 1990). Four alternatives were explored. Two of the alternatives suggested the incorporation of a numerical criterion directly into the performance requirements of 10 CFR 60.113 or into the design requirements in 10 CFR 60.135. The other two alternatives considered providing qualitative guidance in the rule and/or in a separate technical document.

Following the completion of the feasibility study, the NRC determined that a two-pronged approach should be adopted for the resolution of the SCC issue. First, develop and execute an example problem consistent with the earlier studies (CNWRA, 1993). The example problem would exercise several process and mechanical models that would be applicable for an unsaturated repository site. Second, the NRC staff would develop a staff position paper that would provide a descriptive guidance on SCC with supporting documentation with the example problem providing the technical basis for evaluating waste package containment. The CNWRA was tasked to develop and prepare an example problem for the first phase of this two-pronged approach.

In preparing the example problem, the CNWRA identified three milestones. The first milestone, Selection and Evaluation of Models for Example Problem, was completed and a report issued in September 1992 (Sridhar, 1992). The second milestone, the subject of this report, describes the calculational approach adopted to conduct the example problem. The third and final report will present the results of the predictions of waste package lifetimes for several parametric variations and in a probability-based framework.

In March 1992, the CNWRA recognized the need to integrate the various performance assessment related calculations and decided to structure and execute the engineered barrier system performance analyses employing the same driver and Monte Carlo schemes as that are being developed for the Iterative Performance Assessment (IPA). As a result, the SCC example problem, as presented here, has developed the deterministic component of the analyses and parameterized the input and output to be compatible with the IPA schemes when available. For conducting the detailed probability analysis, consistent with the IPA structure, additional time will be needed to complete the problem. It is recommended that the current May 17, 1993, completion date be changed to September 15, 1993.

The lifetime of a container material is a function of the material properties and the physical and chemical environment surrounding the container. In the case of the proposed Yucca Mountain repository, the environment is a hydrothermally altered, partially water saturated system with tuff host rock. The container material and waste package design for the proposed repository have not been published by the Department of Energy (DOE) although a number of design concepts and materials are being considered (Short et al., 1991). In the absence of specific design information, computer codes developed for analysis of waste package lifetime must be made sufficiently general to encompass a spectrum of designs and materials. However, for the analyses, the waste package design presented in the Site Characterization Plan (SCP) (DOE, 1988) for a borehole emplacement condition will be the major focus. In the SCP design, the container is the major barrier for determining SCC. Thus, for the purposes of this report, the terms container and waste package are essentially the same.

In determining lifetimes for waste packages, there are basically two aspects that have to be considered. These aspects are: (i) the failure of waste packages in the presence of overload conditions due to seismicity or fault movements at any given time in the repository life, and (ii) the continuous degradation of the container barrier material exposed to the geochemical, thermal, and radiational environments.

The overload conditions are addressed by evaluating the container failure against buckling and fracture resulting from seismic loads. Three mechanical failure modes are considered in this analysis: (i) buckling failure, (ii) fracture failure, and (iii) yielding failure. To determine whether the mechanical failure occurs at any time, the external (seismic) loading condition is compared with the residual strength of the corroded container. Container properties as a function of time are provided by the corrosion calculations.

Meaningful estimates of corrosion rates require a knowledge of the physical and chemical environment surrounding the containers. Prediction of the environment surrounding the container is very difficult because the likely conditions at long time periods bear little resemblance to initial or starting conditions. The role of the environment is particularly important at the proposed Yucca Mountain repository because the fate of water surrounding the container is a central feature of waste package performance in the DOE strategy.

The approach presented here accounts for the effect of water composition on the waste package behavior through simulation of temperature changes over time, access of water to the container, water evaporation rates, and concentration of salts in solution on the container surface. Generation of brine solutions on the container, including influence on vapor pressure of water, thermodynamics of moisture migration, and the impact of dissolved electrolytes on localized corrosion, is considered as explained below. The concept that elevation of temperatures above the boiling point of water will protect the waste containers from corrosion is explored.

Corrosion of the container may be either localized or general. Of the two types, localized corrosion is expected to be the most problematic and difficult to predict. The occurrence of localized corrosion is considered using the corrosion potential of the container material as the master variable. The corrosion potential is estimated as a function of time, temperature, and chemical composition of the water film on the container. The occurrence of localized corrosion (pitting, crevice corrosion, and stress corrosion cracking) is determined by comparison of the corrosion potential with various critical potentials characterizing localized corrosion (i.e., repassivation potential for crevice corrosion). If the corrosion potential is greater than a given critical potential, the specific localized corrosion will occur. The approach assumes that the various critical potentials for localized corrosion have been determined from a combination of experimental studies and more detailed mathematical models of localized corrosion.

For the example analysis, the critical potentials derived from experimental studies will be used. More detailed models developed in the Engineered Barrier Systems Performance Assessment Code (EBSPAC) program will address the modeling of these potentials.

2 CONCEPTUAL APPROACH

The initial question to be addressed is how water reaches the container surface in the partially water saturated environment. In the absence of thermal effects, water can reach the container surface by fracture flow and dripping. Dripping from the ceiling in mine tunnels through fractured rock in the unsaturated zone is a commonly observed phenomenon even in arid climates. Dripping can be observed, for example, in the G-tunnel on the Nevada Test Site. In a repository with no thermal effects and at very long time periods in the proposed repository, dripping from the ceiling, generally related to fracture flow, is anticipated to wet some unknown but small fraction of the containers.

In the presence of thermal effects, the problem is more complex. Higher temperatures raise the vapor pressure of water in the region around containers and the repository as a whole, leading to migration of water vapor to cooler regions where condensation occurs. The water movement is a complex problem with flow in liquid and gas phases in a heterogeneous fractured porous medium. In general, most vapor migration will occur in fractures with liquid flow in both fractures and matrix. Migration of moisture along the temperature gradient leads to a dry-out zone around individual waste packages and, potentially, the entire repository (Pruess et al., 1990; Buscheck and Nitao, 1992) (Figure 1).

During the thermal period, several lines of evidence suggest that condensate flow and dripping may result in the wetting of a small fraction of the containers. The evidence is both theoretical and empirical. Empirical evidence comes from the Climax test and the "heater test". During the Climax test, 1 of 17 waste containers experienced saturated conditions related to fracture flow (Patrick, 1986). In heater tests in G-tunnel, Zimmerman and Blanford (1986) removed $\sim$0.5 liters of vapor condensate from a heater handling pipe in 1 of 2 tests with vertical waste emplacement and found evidence of condensate drainage near thermocouples in a horizontal heater test. The physical evidence also suggests condensate drainage may wet some waste containers. If water vapor cools and condenses near a fracture, the liquid may drain down the fracture. If the fracture is large, flow over large distances can occur prior to evaporation of the liquid. Another source of liquid water may be lateral drainage of condensate above the repository. As the repository cools, the drainage water may intersect with the outer fringes of the repository, leading to increased fracture flow and dripping around the periphery of the repository. Thus, the potential for the wetting of some containers is present throughout the repository lifetime.

A second question of interest is the fate and composition of water reaching the containers. Water on the containers may result from several phenomena and have several sources. The anticipated sources of water are (i) water initially present in the rock pores prior to repository operations, (ii) water spilled or modified during repository operations, (iii) infiltrating water from precipitation events, and (iv) condensate water resulting from vapor migration of water with cooling at distance. The water composition may be modified by hydrothermal reactions and evaporation. In the dry-out zone, water may flow out of matrix blocks to fractures and vaporize, leading to salt film formation. At greater distances, water trapped in the matrix evaporates.

Condensate initially represents distilled water; however, as soon as it condenses, the condensate begins to react with the rock and mix with other waters present. As water nears the waste package, it may contact salt films deposited during higher temperature periods. For these reasons, the composition of water contacting the containers is expected to be highly variable, ranging from distilled water to more concentrated salt solutions.

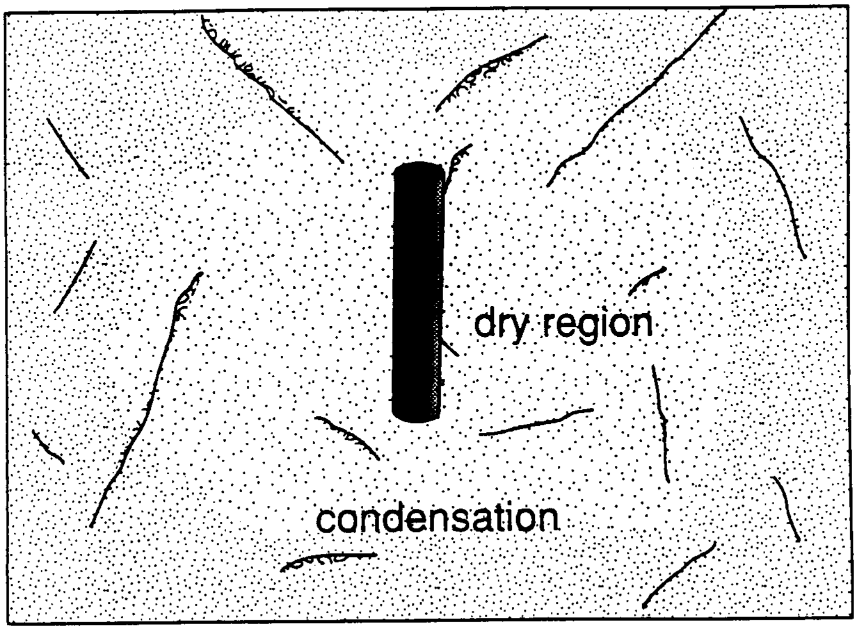


Figure 1. Schematic of dry-out region surrounding waste package

The fate of most liquid water contacting the container during the first several hundred years is simple–it evaporates. At all time periods, the waste container has a higher temperature than the rock a few meters away. Figure 2 presents an example calculation of the temperature drop between the container surface and the rock a few meters away. The higher temperature leads to an increase in vapor pressure of the water on the container relative to water in the rock at the edge of the dry-out zone. The change in vapor pressure drives migration of water away from the waste package. The likelihood that the water will remain on the container for a significant time period is determined by the rate of evaporation relative to the rate of dripping.

Scoping calculations of diffusion of water vapor away from the canister suggest that anticipated evaporation rates will exceed probable drip rates for time periods of 10,000 years or more. This would suggest that condensate drainage and other dripping mechanisms are unimportant in keeping the container wet. However, there are other complicating factors. As the water evaporates, the dissolved solids remain on the canister. The less soluble components such as calcium carbonate and silica will rapidly precipitate from the water film leaving the most soluble salts remaining in a solution on the container surface. As the concentration of salts increases during evaporation, the increased salt concentration leads to a lowering of vapor pressure in the water film on the container surface. The vapor pressure lowering or osmotic effect sequentially lowers the evaporation rate as the solution becomes more concentrated. The final amount of vapor pressure lowering is dependent upon the "endpoint" of the evaporation process (i.e., the solubility of the most soluble salt in the final solution formed). Depending upon the salt solution formed, the change in temperature between the container and the rock a few meters away, and the temperature of the container, the osmotic effect can overcome the thermal effect that drives the water away, leading to maintenance of a water film on the container for indefinite periods. This water film could be present even at temperatures significantly above the boiling point of pure water.

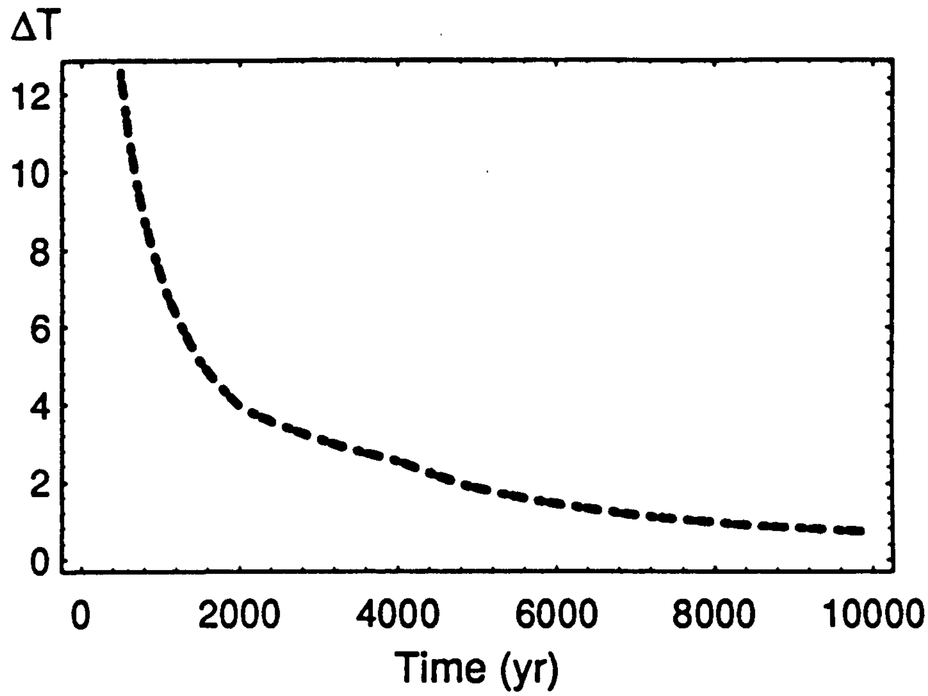


Figure 2. Temperature difference between waste container surface and surrounding rock

The endpoint of the evaporation process may be dependent upon many phenomena including (i) temperature, (ii) gas (e.g., CO_2) partial pressures, (iii) evaporation rate, (iv) drip rate, (v) presence or absence of rock material contacting the water film, (vi) corrosion rates and corrosion products, and (vii) initial composition of the water contacting the container. Of the parameters listed, only temperature can be determined with a high degree of certainty. The magnitude of the likely osmotic effect can be estimated by examining measured vapor pressure depressions from several salt solutions representing plausible endpoints of the evaporation process. Figure 3 gives the vapor pressure of four saturated salt solutions as a function of temperature compared with the vapor pressure of pure water using data from the International Critical Tables (National Research Council, 1928): (i) sodium chloride solution, (ii) sodium nitrate solution, (iii) sodium carbonate solution, and (iv) calcium chloride solution. Sodium is the dominant cation in the groundwaters below Yucca Mountain, while chloride, carbonate, and nitrate represent major anions. Nitrate may also be generated by radiolysis (Reed, 1991). Other potential endpoints of the evaporation process include sodium hydroxide, which can be formed by chemical decomposition of sodium carbonate and various potassium salts. Relatively little work has been performed on evaporation of Yucca Mountain waters. Figure 3 illustrates that water can be held at temperatures significantly above the boiling point of pure water.

A simple method for putting the osmotic effects in perspective is to compare the vapor pressure of pure water with the vapor pressure of the salt solution at a higher temperature. The change in temperature required to equalize the vapor pressures can be compared to the calculated temperature drop in moving from the container to the rock a few meters away. If the osmotic ΔT is equal to or greater than the actual ΔT, then liquid water will remain on the container (i.e., we can compare driving forces for moisture migration on a thermodynamic basis). Figure 4 gives the calculated osmotic ΔT as a function

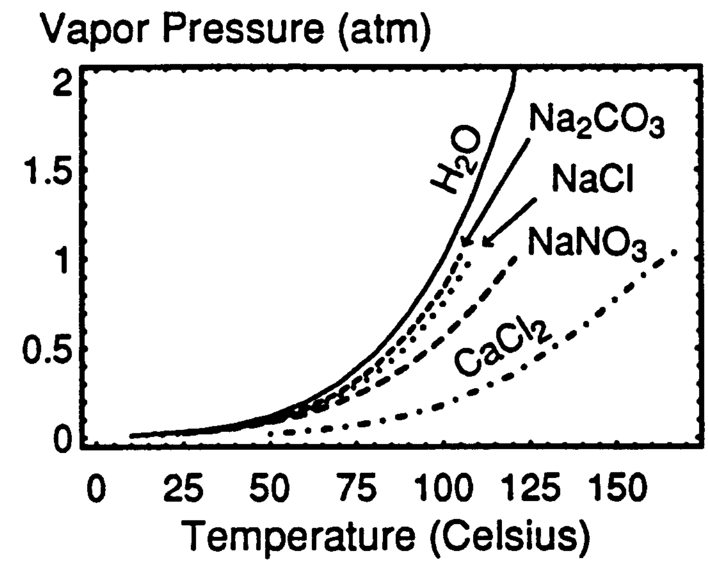


Figure 3. Vapor pressure of saturated salt solutions as a function of temperature

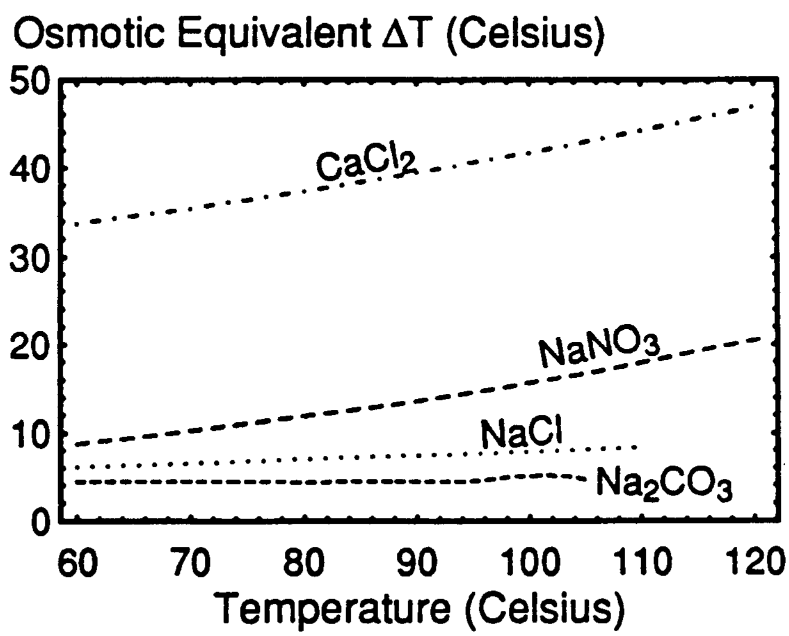


Figure 4. Equivalent temperature drop from osmotic lowering of vapor pressure

of container temperature. Figure 2 represents an estimate of the anticipated ΔT for the Yucca Mountain repository. Note that, after about 500 years, the osmotic effect at any temperature exceeds the actual temperature difference. This means that the osmotic effect is likely to be a major factor in keeping water on the container surface. Although the endpoint of the evaporation process is unknown, work on evaporation of similar waters (Garrels and Mackenzie, 1966) suggests that an alkaline brine may form.

In summary, water dripping on the container will evaporate, leading to scale formation and a salt film. As temperatures decline, the osmotic vapor pressure lowering caused by the salt film counterbalances the temperature-induced vapor pressure changes, and a water film remains on the container surface. If dripping continues, the size of the surface water film grows with time as the total salt content increases. Larger amounts of salts can hold more water at a given vapor pressure. At very long time periods, evaporation rates will slow and the salt film may be diluted. This will lead to strong gradients in ionic strength on the container surface followed by solutions of low ionic strength as the soluble salts are removed.

Subsequent to container breach, the same scenario may be replayed inside the waste package. The change in temperature in moving from the inside (centerline) of the container to the outside surface may lead to brine formation, including strong gradients in ionic strength of the water film within the waste package. Many perturbations on the basic scenario described are possible.

- The salt solution may first form away from and above the container in the backfill material. As the system cools, the salt film slowly migrates downward through the backfill material onto the container surface.

- Drip rates are unlikely to be constant. Water may impinge upon the container early in time when temperatures are too hot to keep water on the container surface but not drip during later time periods. However, the salt film will remain and lead to diffusion of water vapor towards the container and a water film in later time periods.

3 DESCRIPTION OF CALCULATIONS IN CODE, SIMPLIFYING ASSUMPTIONS

3.1 INTRODUCTION

Prediction of container corrosion is based upon the use of the corrosion potential as the master variable controlling the type of corrosion expected. The approach was explained in a prior report (Sridhar, 1992). This section explains the numerical implementation of the waste package environment, corrosion, and mechanical failure calculations in the computer code SCCEX (Substantially Complete Containment Example Problem). As with any implementation of a conceptual model, simplifying assumptions and approximations are required by limitations of data and available manpower for code development and analysis. The initial calculations represent a deterministic analysis for a single waste package for various parameters of interest. The calculations are then expanded to study the probability of failure of multiple waste packages when combined with the schemes in the IPA code.

3.2 FLOW CHART

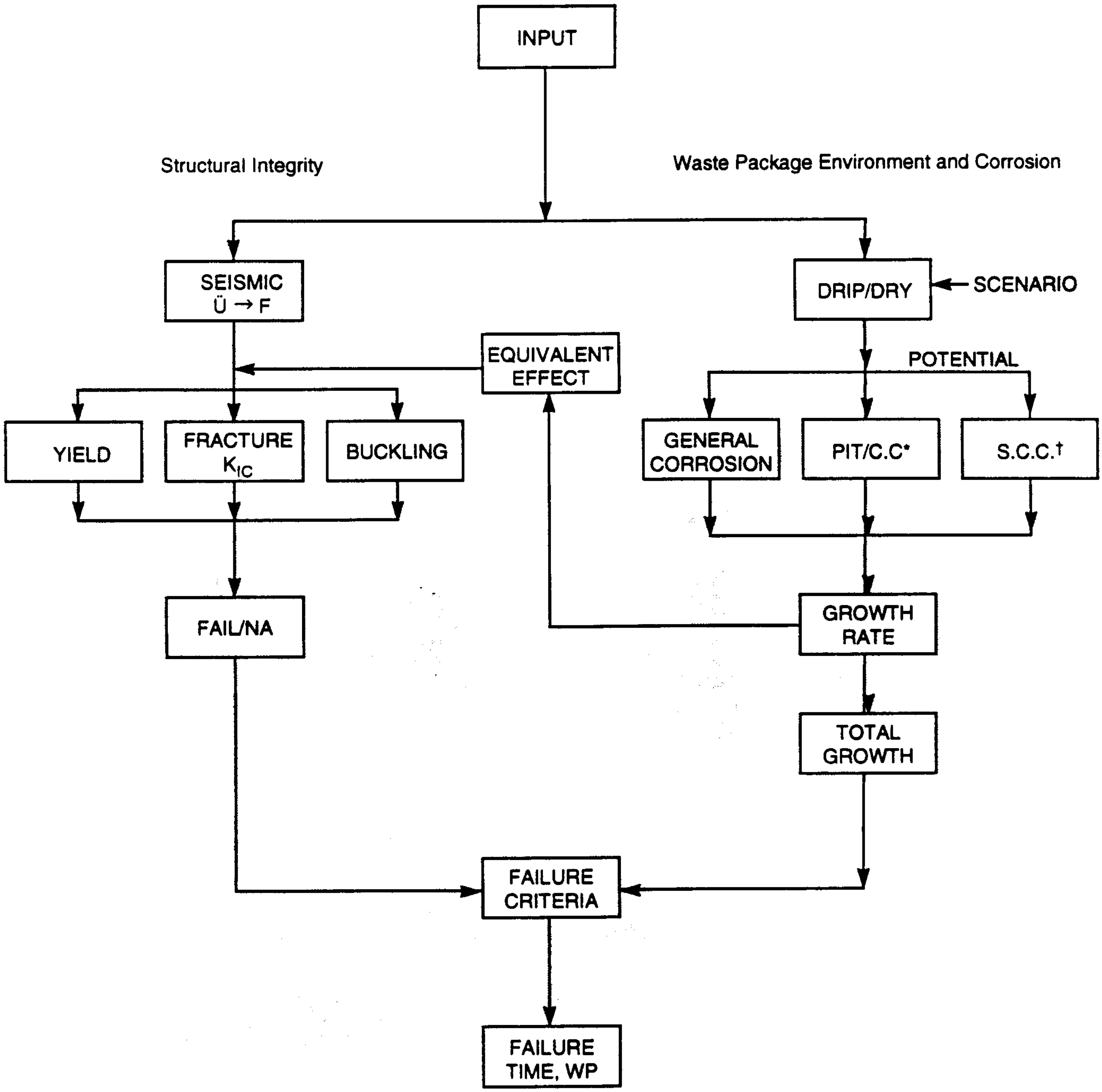
Figure 5 presents the logic in the calculations for an individual waste container. The temperature, waste package environment, and corrosion portions represent one computer code. Mechanical and failure calculations are performed in a separate code that reads the output from the environmental code. The calculation begins with estimates of thermal loading and resulting temperature effects. The average repository temperature, the container surface temperature, and the container internal temperature are calculated as a function of time and stored in arrays. In a later section of the code, the thermal calculations are combined with water drip rates to estimate the amount of water on the container surface and its composition. Based on water composition and temperature, the corrosion rate is estimated. The container temperature, corrosion penetration, and area penetrated by corrosion are output to a disk file read by the mechanical code. The information is translated into simplified equivalent mechanical effects and used to estimate the timing of mechanical failure. The time of full penetration of the container is determined in the mechanical code.

The basic code represents a calculation for an individual container. In order to estimate repository wide results in a probabilistic framework, additional calculations are required. The approach for probabilistic calculations is illustrated in Figure 6. The total systems code developed for the IPA program will be used to run SCCEX for multiple vectors of input parameters. The inner loop will represent spatial variability within the repository, and the outer loop will evaluate uncertainty in the predictions. Ideally, the inner loop would perform separate calculations for each waste container, however, this is not practicable because of limitations of current computers. Therefore, calculations will be performed for multiple groups of containers with all the containers in each group having identical properties.

The number of container groups will be determined by code run times. If the SCCEX code has excessive run times, it will be simplified for the probabilistic calculations.

The output files will be post-processed to provide the probability that the proportion Z of containers failing during the period $(0, T_o)$ does not exceed Z_o; is greater than R_o.

$$P\left[Z \leq Z_o\right] > R_o \qquad (1)$$



* C.C. = Crevice Corrosion
† S.C.C. = Stress Corrosion Cracking

Figure 5. Flow diagram of computer codes

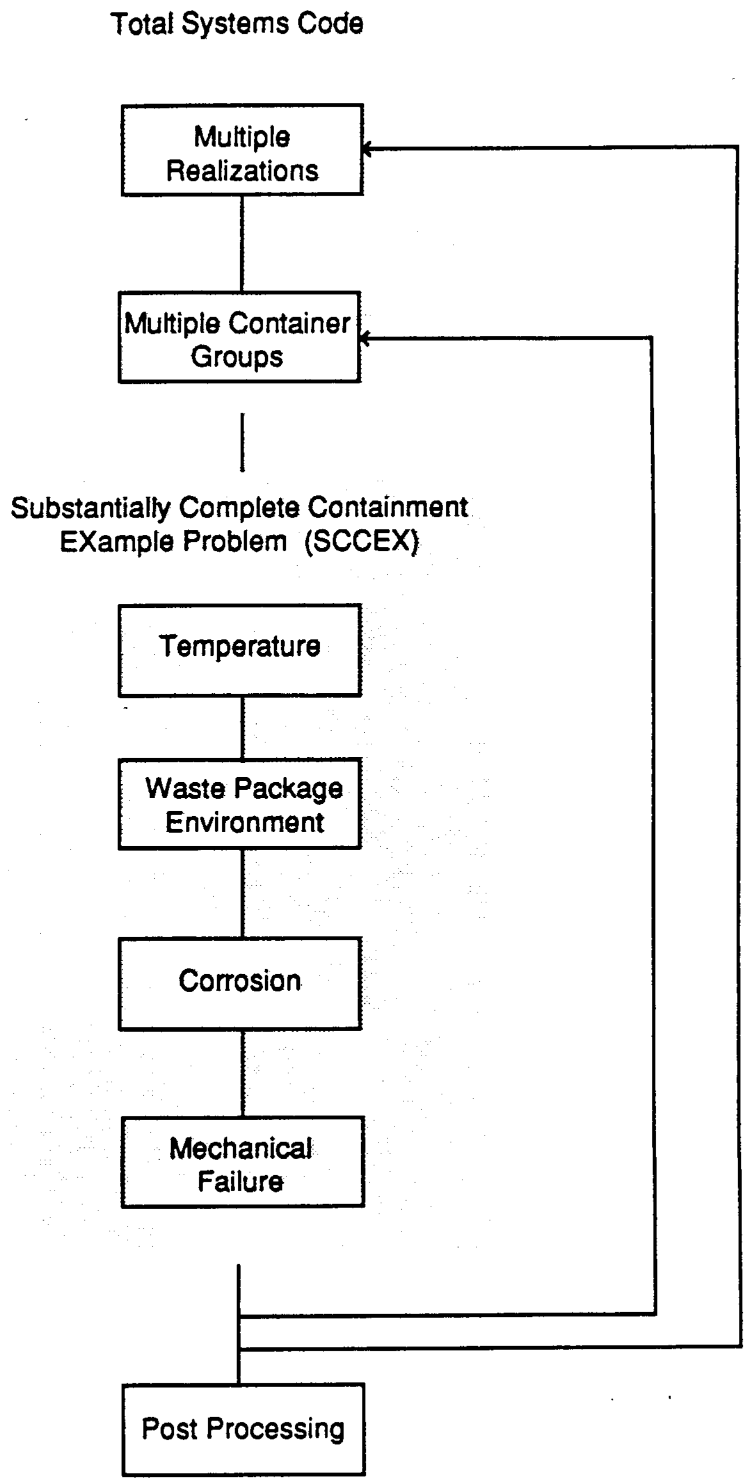


Figure 6. Schematic of probabilistic calculations

where

Z_0 is the maximum allowable proportion of waste packages failing in time T_0, to be determined by the Commission;
R_0 is the minimum acceptable probability that $Z \leq Z_0$, to be determined by the Commission;
and T_0 is the containment period, chosen by the Commission.

If time permits, sensitivity studies may also be performed. The final output will include a simple parametric study of performance and a full probabilistic analysis.

3.3 DESCRIPTION OF MODELS

3.3.1 Waste Package Environment

All of the calculations require estimates of the temperature on the container surface and in the rock surrounding the container. In order to facilitate evaluation of the influence of thermal loading strategy and packing material on container lifetime, a simplified thermal model has been included in the code. The temperature of the repository horizon is estimated assuming that heat transfer occurs only by conduction in a homogeneous infinite medium. The temperature at any location and time is estimated from a convolution integral of the Green's function for three-dimensional heat conduction and the time variant heat generation rate (Carslaw and Jaeger, 1959). The temperature of the container surface is obtained by adding the steady state temperature rise around an individual container to the repository horizon initial temperature.

The convolution integral is written as an ordinary differential equation and solved by fifth order Runge-Kutta, the same numerical solver used in other portions of the code. Prediction of the waste package environment and container penetration by corrosion is estimated by solving a coupled set of ordinary differential equations. The integrated variables are:

- volume of water on the container surface
- mass of NaCl on container
- depth of corrosion penetration
- total volume of effluent water leaving container
- mass of scale on container.

The temperature history is calculated initially in the code and stored in arrays. Temperature at any point in time for later calculations is obtained by linear interpolation. The volume of water on the container surface represents a balance between evaporation and drip rate. Evaporation rate is estimated as diffusion of water vapor through stagnant air. The nonlinear diffusion equation is solved at steady state in a one-dimensional heterogeneous radial geometry. The assumption is made that water near 100 percent relative humidity is present in the rock a few meters away from the container.

The endpoint of the evaporation is assumed to be a sodium chloride brine (i.e., sodium chloride is the last salt to precipitate prior to complete evaporation of the aqueous solution). The osmotic effect expected from a sodium chloride brine is intermediate in strength (Figure 3), making it a good representative choice. Sodium chloride solutions also have the interesting property that the vapor pressure depression relative to water at the same temperature (i.e., relative humidity) is nearly independent of temperature at one atmosphere total pressure. The concentration of sodium chloride in the dripping water is an input variable and is assumed to be constant during a simulation. The buildup of "boiler scale" on the container is estimated based on an input concentration of scale formers in the dripping water.

3.3.2 Container Corrosion

The container corrosion is assumed to be a low value (approximately 0.1 μm/yr) while the container is dry. Once the presence of water is predicted by the calculations, aqueous corrosion processes are started. The depth of corrosion is determined by integrating the estimated corrosion rate. The corrosion rate is based upon temperature, solution composition, and the corrosion potential. The corrosion potential is defined as the potential where the rate of the anodic reaction of the metal is equal to the sum of the cathodic reaction rates. The cathodic reactions considered are oxygen reduction and hydrogen evolution. Initial calculations suggest that water will not stick to the container until after the period where gamma radiolysis is significant. Most gamma radiation comes from radionuclides with relatively short ~30 year half-lives. Additionally, the DOE is currently considering a set of thicker walled containers that effectively eliminate gamma radiolysis (Short et al., 1991). For these reasons, little emphasis is placed on radiolysis in the calculations. The most important cathodic reaction is oxygen reduction. Oxygen reduction is controlled by reaction kinetics and transport phenomena. Mass transport of oxygen from the air/water interface to the metal is influenced by vapor concentration, solubility, film thickness, and diffusion rates. Oxygen solubility is influenced strongly by temperature and the salting out effect from the brine solution. Transport of oxygen to the container surface occurs through a film of scale.

The type and rate of corrosion is determined from the corrosion potential as explained by Sridhar (1992). If the corrosion potential exceeds the critical potential for crevice or pitting corrosion, then corrosion is assumed to occur at the active rate (Figure 7). When the corrosion potential is below the critical potential, passive corrosion is assumed. The code produces a time dependent array of all integrated variables and the corrosion potential. The calculated corrosion depth is compared with the container thickness to estimate container lifetime.

3.3.3 Mechanical Models

In the current analysis, the only external load considered is the seismic load. This seismic load is assumed equal to a constant load caused by an earthquake with 0.4 g ground acceleration. Furthermore, this seismic load is assumed to be uniformly distributed on one-tenth of the container circumference. This uniformly distributed load will be used to compare with the buckling failure criterion. In the case of yield failure and fracture failure, the stresses are calculated on the basis of a uniformly distributed load acting along the length of the container. A simplification is made by assuming that an equivalent beam with the same stiffness as the container can be used to represent maximum stress development. Further, the beam is assumed to be pinned at both ends from horizontal movement. This results in treating the beam as a simply supported structure. Therefore, this maximum stress can be calculated by using the maximum bending moment at the center of the beam and the geometry of the beam. This maximum stress will be used to determine whether failure occurs or not by comparing with fracture and yielding failure criteria.

The residual strength for the buckling failure criterion, R_B, is determined based on a curved panel under uniform radial pressure condition (Roark and Young, 1975).

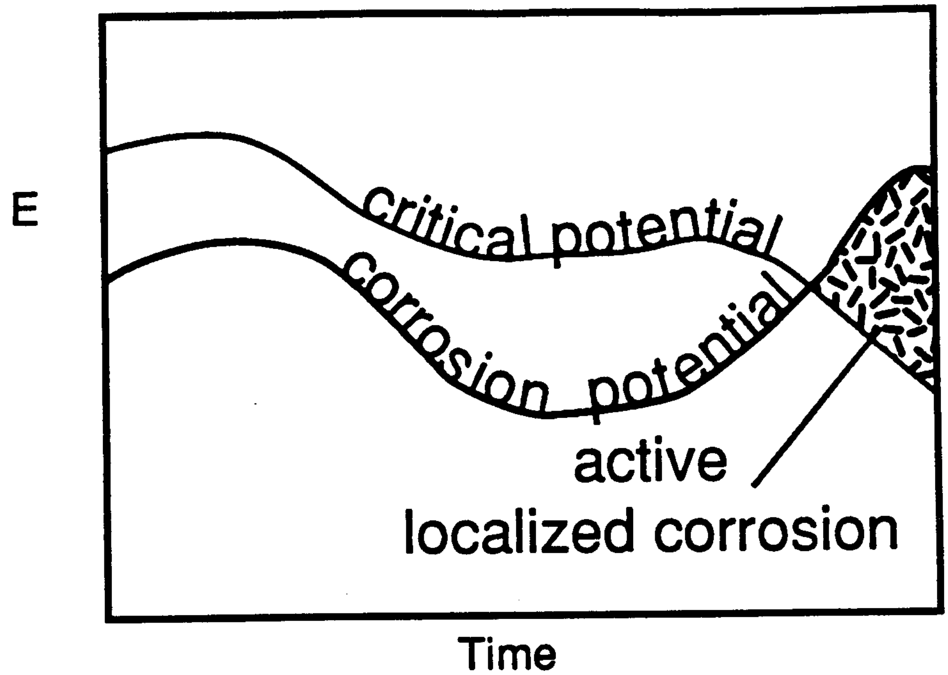


Figure 7. Corrosion potential concept

$$R_B = \frac{99 E t_R^3 \pi}{60 r^2 (1 - \nu^2)} \qquad (2)$$

where

E = Young's modulus

t_R = remaining container thickness

r = radius of the container

ν = Poisson's ratio.

To calculate this buckling residual strength, it is necessary to compute the remaining container thickness based on the information from the state of corroded condition of the container. Depending on the type of corrosion (i.e., general, crevice, or pitting), equivalent reduction in waste package thickness is calculated. The reduction in thickness can be localized over known surface areas. Equation (1) calculates the buckling .conditions of the reduced thickness area of the container. A factor of two is incorporated in the equation to provide for added conservatism.

The residual strength in the presence of cracks or flaws in the container is given by the criterion R_F (Rolfe and Barsom, 1977).

$$R_F = \frac{K_{1C}}{Y(\pi a)^{0.5}} \tag{3}$$

where

K_{1C} = fracture toughness

Y = geometry factor

a = $t - t_c$ for local corrosion

t = original container thickness

t_c = corroded container thickness.

Equation (2) describes the effect of a surface crack on a circular cylinder, subject to a normal tensile stress. A factor of two is also used in this equation to compensate for limitations to the assumptions made.

The residual strength in the case of yielding failure is represented by R_Y.

$$R_Y = R_{YO}\frac{A_R}{A} \approx R_{YO}\frac{t_R}{t} \tag{4}$$

where

R_{YO} = original yield strength

A_R = remaining area of container radius

A = original area of container radius

t_R = remaining thickness of container

t = original thickness of container.

Waste package failure due to yielding is also calculated on the reduced thickness of the corroded cylinder. Failure is assumed when the outer fiber of the cylinder reaches yield stress.

The container failure due to seismic loading is evaluated using the three mechanical models described above. At present, the seismic loading is represented by an acceleration. The value of the acceleration is treated as an input variable. For the initial set of calculations, it is assumed to be 0.4 g.

4 ANALYSES TO BE PERFORMED AND RELATIONSHIP TO OTHER CODES AND PROJECTS

The SCCEX code represents a significant effort toward definition of anticipated processes in the waste package and mechanistic prediction of container lifetime. This is a detailed effort containing many new concepts. Initial analyses will be in the form of simple parametric studies to obtain a better understanding of the importance of different processes on predicted corrosion rates. The parametric studies will examine the influence of thermal loading strategy, end point salt concentration, time variant drip rates, and kinetic parameters on the key outputs variables. The key output variables are the stability of the corrosion potential prediction, the time period when water first remains on the container surface, and the time required for leachate generation. The conceptual approach will provide an example of how the CNWRA personnel believe defensible estimates of container lifetime can be produced. In the hierarchy of codes from very detailed models to highly simplified performance assessment codes, this code is intermediate. Detailed models such as ones for localized corrosion are assumed to feed their (summarized) results to the SCC example problem. Similarly, in order to be useful in probabilistic performance assessment calculations, the calculations in the SCC example problem may require further simplification. A major purpose of the analysis will be to determine where simplifications can be justified and/or where greater complexity is needed. The SCCEX code may be extended to include radionuclide release rate calculations as part of the EBSPAC effort.

A version of the Total System Performance Assessment Computer Code (TPA) will be adapted to run the SCCEX code and develop the probability-based analyses. The results of the example problem analyses will be presented in terms of the probabilities of multiple waste package failures during the repository performance period. The methodology and the analysis of the results of the example problem will contribute to the technical basis needed to develop a NRC staff position on the "substantially complete containment" issue.

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