WORK PLAN FOR THE DEVELOPMENT OF AN EXAMPLE OF WASTE PACKAGE CONTAINER PERFORMANCE CALCULATIONS

1. INTRODUCTION

The ambiguity in the regulatory requirement in 10 CFR 60.113 for "substantially complete containment" (SCC) has resulted in the exploration of ways to quantify the requirement. Three reports were produced by the Center that dealt with the feasibility of a quantitative demonstration of SCC. The first of these reports listed the technical considerations necessary for evaluating SCC, but did not address approaches to quantitative prediction. The second report detailed the uncertainty evaluation methods for waste package performance assessment, but did not address any specific information to which these uncertainty analysis methods will be applied. The third report delineated the various alternatives for quantitatively clarifying the concept of SCC in the current regulation. The work proposed in this plan is aimed at combining the various technical considerations presented in the first report with the methodologies for analyzing the performance of waste package materials used in the total system performance assessment code. This work plan is part of Task 2.1.1 activities of the EBS Operations Plan, FY92-93.

2. TECHNICAL APPROACH

The main objective of this task is to demonstrate the feasibility of a quantitative assessment of substantially complete containment through an example analysis. A secondary objective is to review field studies of buried structures to identify long-term corrosion modes and rates of alloys representative of candidate container alloys.

Quantitative assessment of substantially complete containment involves two activities: (1) the selection of failure modes and the development/modification of models that will be used in the example analysis, and (2) the development of a failure path logic for coding and performing the example analysis. For the purposes of the example analysis, the loss of containment is defined as the through-wall penetration of a container by a defect. It is also assumed that the waste package boundary is the container boundary. It is anticipated that the result of the example analysis will yield both a set of deterministic data and a family of Complementary Cumulative Distribution Functions (CCDF) in the form of the probability of having N or more breached containers in t years.

The secondary objective of this program is to evaluate the state of knowledge of the degradation of buried, metallic objects. Such an evaluation is not anticipated to provide any direct input to the quantitative assessment of substantially complete containment. However, awareness of the types of corrosion modes and maximum rates of corrosion processes may be valuable in establishing the reasonableness of long-term predictions made on waste package components. The work plan contains a subtask to review the information in the literature on the experience with buried structural components.

The plan presented here consists of three activities:

- Evaluate existing models for selected failure modes;

- Develop a failure path logic for a target container material considering the selected failure modes above, and code and perform a sample analysis;
- Survey the performance of various materials in underground environments.

3. TASK DESCRIPTION

3.1 Evaluation of Failure Models

Objective

To evaluate and select models for the example analysis.

Justification

The proposed methodology for prediction of the container material performance involves using various models to predict initiation time, growth rate, or cessation of various failure modes which then will be combined using a failure path logic. For this purpose, it is necessary to review the models available in the literature for the various failure modes and make modifications where necessary for use in the example analysis.

Subtask Description

For the purposes of the example analysis, the failure modes and type of models that will be included are given in Table 1. The inputs required and the outputs envisaged for these models are also identified.

Activities

- Review and select failure models for inclusion in the example analysis.

Milestones

MILESTONE TYPE	MILESTONE NUMBER	DESCRIPTION	DATE
Intermediate	20-3702-012-248-100	Selection and Evaluation of Models	9/25/92

3.2 Developing Failure Path Logic, Coding, and Performing Sample Calculation

Objective

The objective of this task is to develop a failure path logic diagram for the example analysis and to conduct a test case performance analysis. Although the eventual goal is to develop a generalized logic diagram that can be used for a variety of materials, the focus in this task will be on the reference container design presented in DOE's SCP for Yucca Mountain. The container material will be type 304L stainless steel.

TABLE 1. LIST OF MATERIAL PERFORMANCE MODELS THAT WILL BE USED IN THE SAMPLE ANALYSIS

Phenomena of Interest	Type of Models		Sources of Input	Types of Inputs	Types of Output
	determ	probab			
Crevice corrosion	Y	N	a) Geochemical, thermal, and radiolysis codes b) Experiments	E_h, pH, anions, cations, temperature, heat output, E_{corr}, E_{rp}, i_p, crevice geometry, area ratio, hydrolysis equilibria	a) Initiation time b) Growth rate c) Crevice chemistry d) Repassivation potential
Pitting	Y	—	a) Geochemical, thermal, and radiolysis codes b) Experiments	Temperature, anions, cations, size scale, growth rate equation (empirical), E_h, pH, E_{corr}, E_p, E_{rp}	a) Growth rate b) Initiation time
Pitting	—	Y	Experiments	E_h, E_{corr}, pit generation and repassivation rates (empirical), pit growth rate (empirical), area, number of containers	a) Pit generation rate b) Pit growth rate c) Repassivation potential

TABLE 1. LIST OF MATERIAL PERFORMANCE MODELS THAT WILL BE USED IN THE SAMPLE ANALYSIS (cont'd.)

Phenomena of Interest	Type of Models		Sources of Input	Types of Inputs	Types of Output
	determ	probab			
Stress Corrosion Cracking	Y	—	a) Geochemical, thermal, mechanical, and radiolysis models b) Crevice corrosion model c) Experiments	E_{corr}, strain rate, stress intensity, empirical crack tip dissolution data, solution chemistry	a) Growth rate b) Threshold stress intensity c) Threshold potential/ protection potential
Stress Corrosion Cracking	—	Y	Prior failure experience in related applications	Time to failure distribution, number of containers failed	Failure rate, failure probability
Overload Failure	Y	Y	a) Mechanical and thermal models b) Experimental results	Temperature, K_{IC}, K_C, fracture strength, crack length, stress field, buckling load	Failure probability

Justification

In the following discussions, failure of a container material is defined as complete penetration of a container by a single or multiple defect of any size. A container material may experience a variety of failure modes. These failure modes are not all independent, but interact in complex ways depending on the material-environment combination. For example, stress corrosion cracking has been shown to occur under crevices after crevice corrosion has initiated or from pits after they have grown to a critical size. Similarly, microbial organisms may influence certain localized corrosion modes. On a micro-mechanistic level, dealloying has been considered to be the first step in stress corrosion cracking in one model, while hydrogen embrittlement has been considered to be a factor in another model of stress corrosion cracking.

The design will be based on a type 304L container in a vertical emplacement with an air gap. It is recognized that this alloy most probably will not be the eventual container material. However, much research has been published regarding this alloy; and, hence, the task of performing the example analysis may be easier. Failure path analysis provides a logical structure to represent the pathways towards final failure of the container.

Quantitative analysis of containment and release rate is part of the EBSPAC development program under Task 3 of the EBS element and is being performed as an integral part of the iterative performance assessment (IPA) program. While a complete development and maturation of this assessment is expected to take considerable time, it is desirable to conduct a test-case analysis utilizing the method developed at the end of the first year of the program. Such a test analysis will aid in identifying flaws in the method as well as provide future direction for the program. It will also aid in the future phases of IPA since more failure modes have been added in this example analysis than are found in the current phase of IPA.

Activities

The failure path logic diagram developed for the SCC example analysis is shown in Figures 1 and 2. It is intended to be a qualitative diagram to indicate the logical sequence of anticipated failure modes, although the symbolism follows that used in the development of fault trees. As mentioned before, for the purposes of the initial failure path diagram development, the SCP reference design of DOE will be used with the general environmental conditions postulated to prevail in the proposed Yucca Mountain repository site. It is assumed, for the purpose of this example analysis, that a through-wall penetration of a container will constitute loss of containment. However, the calculations and computer codes make no attempt at establishing criteria for containment. Instead, it is envisaged that the example analysis will provide both a spectrum of deterministic results and probabilistic estimates of performance which will constitute a framework within which informed decisions can be made.

The computer code for substantially complete containment will execute under the umbrella of the total system performance assessment computer code executive module (developed under IPA Phase 2). The codes for total system performance assessment, engineered barriers system performance assessment, and substantially complete containment example analysis will all execute under the same executive program. The executive program will handle basic input/output, uncertainty/sensitivity

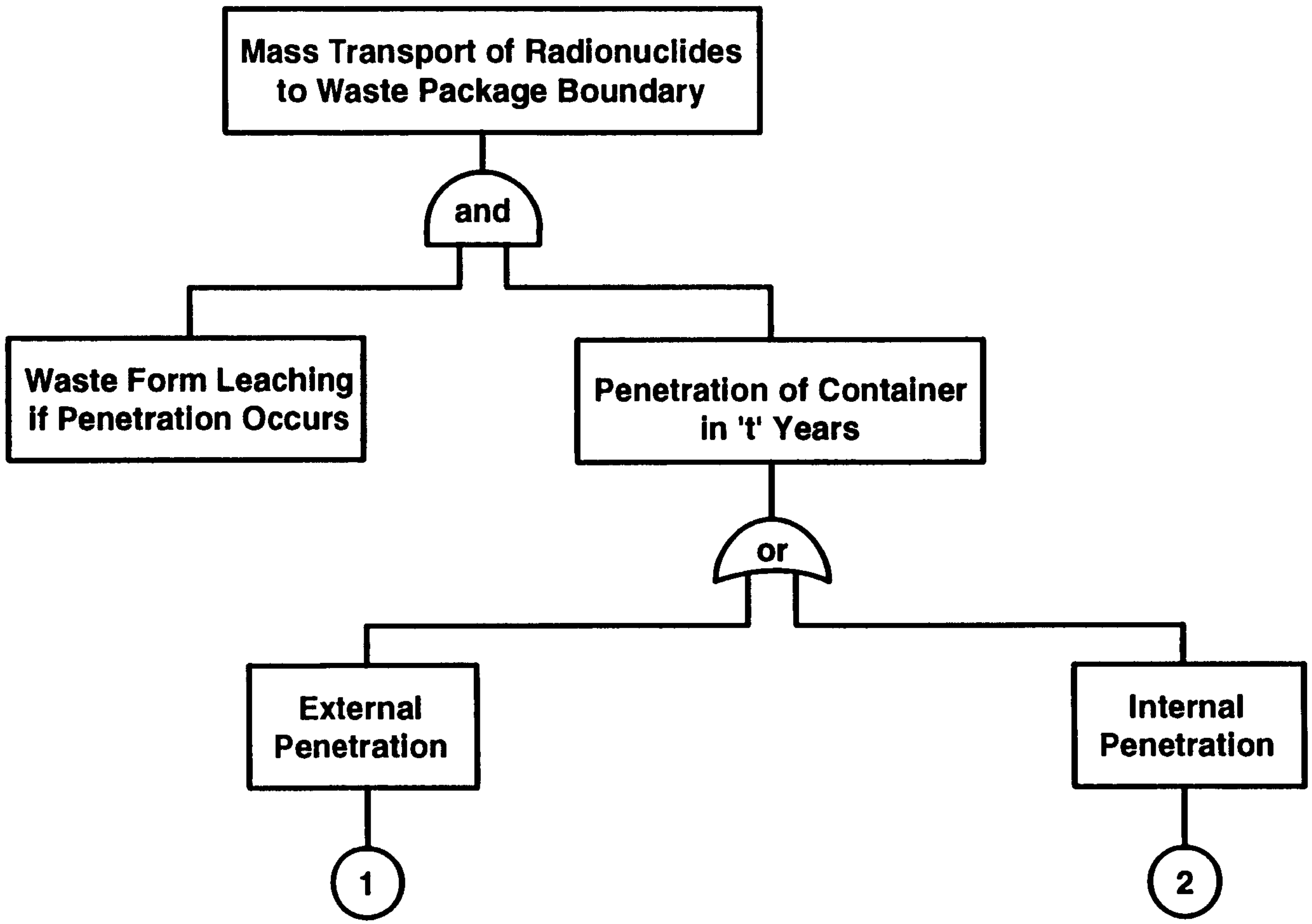

Figure 1. Failure path diagram, including eventual radionuclide release

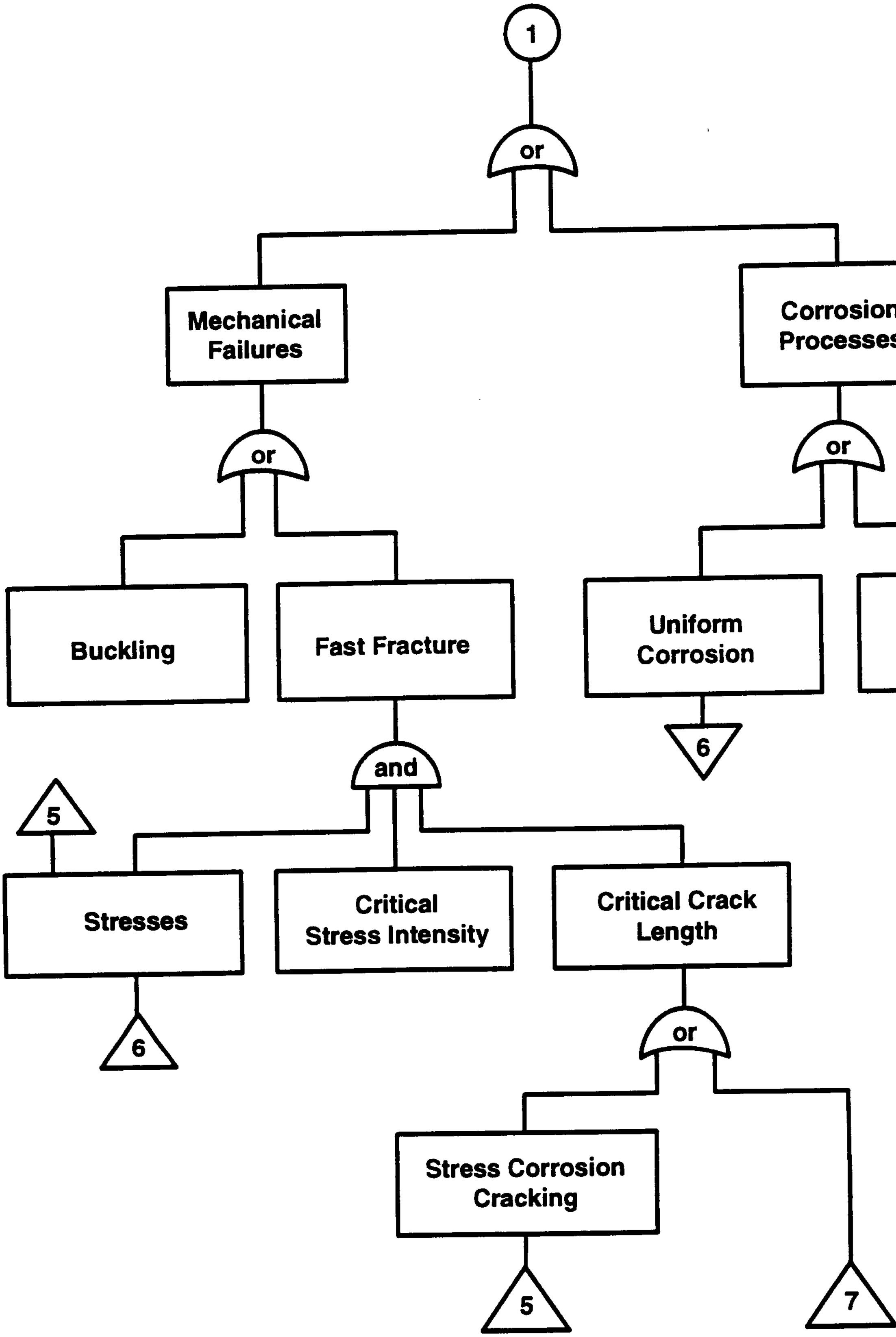

Figure 2. Failure path diagram for penetration of container

calculations, and graphical post processing of the results. This common structure among the three different codes will ensure consistency among the three codes and shorten development times by avoiding unnecessary duplication. Initially, the three codes will differ primarily in terms of how far the calculations will be taken. Eventually, if a clear need develops, separate modules may be developed for each regulatory performance measure. For this example, the calculations for SCC will be initially treated as a subset of the calculations required for total system performance assessment. More detailed analysis may require modification to the calculation schemes currently planned.

Because the total system performance assessment computer code executive module will handle uncertainty analysis, the format of the individual failure models in the SCC module will be treated as deterministic. For purposes of temperature and moisture calculations, the repository will be broken down into a number of user-selected subregions with different characteristics. For example, containers near the center of the repository will tend to have higher temperatures and resaturate more slowly than containers near the edge. This will affect the corrosion initiation and propagation times. Also, it will determine the times and rates for radionuclides to be released from a waste package. Calculation of a container breach will follow the failure path logic diagram.

The probability-based calculational results will be in the format of Complementary Cumulative Distribution Functions (CCDF) (i.e., probability of exceedance). If SCC is viewed in terms of container breach, then the probability of N or more breached containers in t years is computed.

Milestones

MILESTONE TYPE	MILESTONE NUMBER	DESCRIPTION	DATE
Intermediate	20-3702-012-248-295	Development of Code	12/20/92
Major	20-3702-012-249-300	Sample Analysis of a Reference Container	5/17/93

3.3 Survey of Underground Performance of Materials

Objective

The objective of this task is to critically review the literature on the long-term performance of various metallic waste package materials and materials of similar chemical composition in underground environments.

Justification

It is well known that there is little engineering experience in predicting performance of man-made materials for 300-1000 years. Hence, a question may be asked: "Is there a reasonable field experience over a shorter period of time to provide for an expectation of long-term performance of engineered structures?". As a corollary, we may want to know what engineering experience can be brought to bear on the design and evaluation of waste package materials for the repository program. The objective of this subtask is to survey the literature on underground performance of various materials, such as stainless steels and copper based alloys.

Subtask Description

Extensive compilation of underground corrosion of metallic materials buried at various sites of known soil characteristics exists (Romanoff, 1957; Gerhold, 1981). In these compilations, the time period of exposure of materials ranges from five to fourteen years. The underground corrosion data on stainless steels and copper-based alloys presented in these reports will be reviewed. Other literature on underground tanks and pipelines will be reviewed for information related to localized corrosion growth rate, statistical distribution of localized corrosion, and aspects of model verification pertinent to a material-environment combination. The relevance of the data from soil exposure to prediction of performance in a geologic repository will be examined.

Activities

- Review literature on underground corrosion with particular attention to the candidate container materials such as stainless steels and copper based alloys.

Milestones

MILESTONE TYPE	MILESTONE NUMBER	DESCRIPTION	DATE
Intermediate	20-3702-012-248-350	Report on Review of Underground Corrosion	2/12/93

4. REFERENCES

Gerhold, W. F., E. Escalante, and B. T. Sanderson, 1981, The Corrosion Behavior of Selected Stainless Steels in Soil Environments, NBSIR 81-2228, National Institute for Science and Technology, Washington, February, 1981.

Romanoff, M., 1957, Underground Corrosion, Originally issued on April 1, 1957, as National Bureau of Standards Circular 579, Now Reprinted by NACE, Houston, Texas, 1989.