8900091 7

Mr. Ralph Stein, Associate Director
for Systems Integration and Regulations
Office of Civilian Radioactive Waste Management
U. S. Department of Energy, RW 30
Washington, D.C. 20545

NOV 0 9 1989

Dear Mr. Stein:

SUBJECT: INTERACTION RECORD FROM THE OCTOBER 26, 1989 TECHNICAL EXCHANGE ON WASTE PACKAGE CONTAINER MATERIAL

Enclosed is a copy of the interaction record from the October 26, 1989 technical exchange on waste package container material. At the exchange, staff from the U. S. Nuclear Regulatory Commission discussed with representatives from the U. S. Department of Energy strategies for waste package design development and selection of container material. Overall, all of the participants at the exchange found it to be productive because it was helpful in gaining detailed insight into the work that is being done by the different organizations.

If you have any questions, please feel free to contact Mr. Brian E. Thomas, who can be reached at (301) 492-0435 or FTS 492-0435.

Sincerely,

ORIGINAL SIGNED BY

John J. Linehan, Director
Repository Licensing and Quality
Assurance Project Directorate
Division of High-Level Waste Management

see enclosure on shelf

cc: R. Loux, State of Nevada
C. Gertz, DOE/NV
S. Bradhurst, Nye County
M. Baughman, Lincoln County
D. Bechtel, Clark County
K. Turner, GAO

DISTRIBUTION

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OFC :HLPD	:HLPD	:HLPD	:HLPD	:	:	:
NAME:BThomas	:JHolonich	:JLinehan	:JBunting	:	:	:
DATE:11/6/89	:11/ /89	:11/ /89	:11/7/89	:	:	:

OFFICIAL RECORD COPY

102.2
WM-11
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ENCLOSURE

Interaction Record for the
Technical Exchange on
Waste Package Container Material

On October 26, 1989 staff from the U. S. Nuclear Regulatory Commission held a technical exchange with representatives from the U. S. Department of Energy (DOE). Representatives from the State of Nevada were not present. The purpose of the exchange was to discuss issues surrounding the selection and testing of waste package container material. Attachment 1 is a list of attendees at the exchange.

A broad array of topics were extensively discussed. In particular, the major discussions were focused on: 1) strategy for the selection of container material; 2) the material selection process and criteria; and 3) testing and evaluation methods for selecting container materials. Attachments 2 through 5 provide copies of the DOE slides used during the exchange and Attachments 6 through 8 provide copies of the NRC staff's slides.

Overall, all of the participants found the exchange to be productive because it provided an opportunity to address some of the underlying fundamental and programmatic assumptions on which a container selection program should be based.

Brian E. Thomas 11/8/89
Brian E. Thomas, Project Manager
Repository Licensing and Quality Assurance Project Directorate
Division of High-Level Waste Management
U. S. Nuclear Regulatory Commission

Edward Regnier 11/8/89
Edward Regnier
Licensing Branch
Office of Civilian Radioactive Waste Management
U. S. Department of Energy

Attachment 1

List of Attendees

NRC/DOE Technical Exchange On Waste Package Container Material

Name	Organization
Brian Thomas	NRC/HLWM
John Beavers	Coretest
Mel Silberberg	NRC/RES
Prasad Nair	CNWRA
Michael Cloninger	DOE/NV-YMPO
Rick Weller	NRC/HLWM
Chuck Peterson	NRC/HLWM
Kien Chang	NRC/HLWM
Joe Bunting	NRC/HLWM
Jack Hale	DOE/OCRWM
Edward Regnier	DOE/OCRWM
Bill Clarke	LLNL
Joseph Farmer	LLNL
Bill Halsey	LLNL
Ed Beyr	Jacobs Eng/Weston
A. Berusch	DOE
C. Interrante	NIST
Patrick Watters	Jacobs Eng/Weston
Rosetta Virgilio	NRC/SLITP
James Kennedy	NRC/HLWM
Jim Conway	NRC/HLWM
John Gilray	NRC/HLWM
Janet Kotra	NRC/OCM
David Brooks	NRC/HLWM
Diane Harrison-Giesler	DOE/NV-YMPO
Philip Berger	DOE/EH/Energetics
Jerome Pearring	NRC/HLWM
Narasi Sridhar	Haynes International/CNWRA
Martha Mitchell	SAIC
George Birchard	NRC/RES
Claudia Abbate	NRC/HLWM
Phillip Reed	NRC/RES
Ken Kreider	NIST
Hersh Manaktala	CNWRA
Anna Fraker	NIST
David Stahl	SAIC

U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN

YUCCA MOUNTAIN PROJECT

OVERVIEW OF WASTE PACKAGE CONTAINER MATERIAL SELECTION, TESTING AND MODELING

PRESENTED TO THE

NRC - DOE

TECHNICAL EXCHANGE ON CONTAINER MATERIALS

PRESENTED BY

DR. DAVID STAHL

SENIOR METALLURGICAL ENGINEER

TECHNICAL & MANAGEMENT SUPPORT SERVICES

SCIENCE APPLICATIONS INTERNATIONAL CORP.

Attachment 2

OCTOBER 26, 1989

UNITED STATES DEPARTMENT OF ENERGY

NEVADA OPERATIONS OFFICE/YUCCA MOUNTAIN PROJECT OFFICE

102.2

GOAL OF THE WASTE PACKAGE EFFORT:

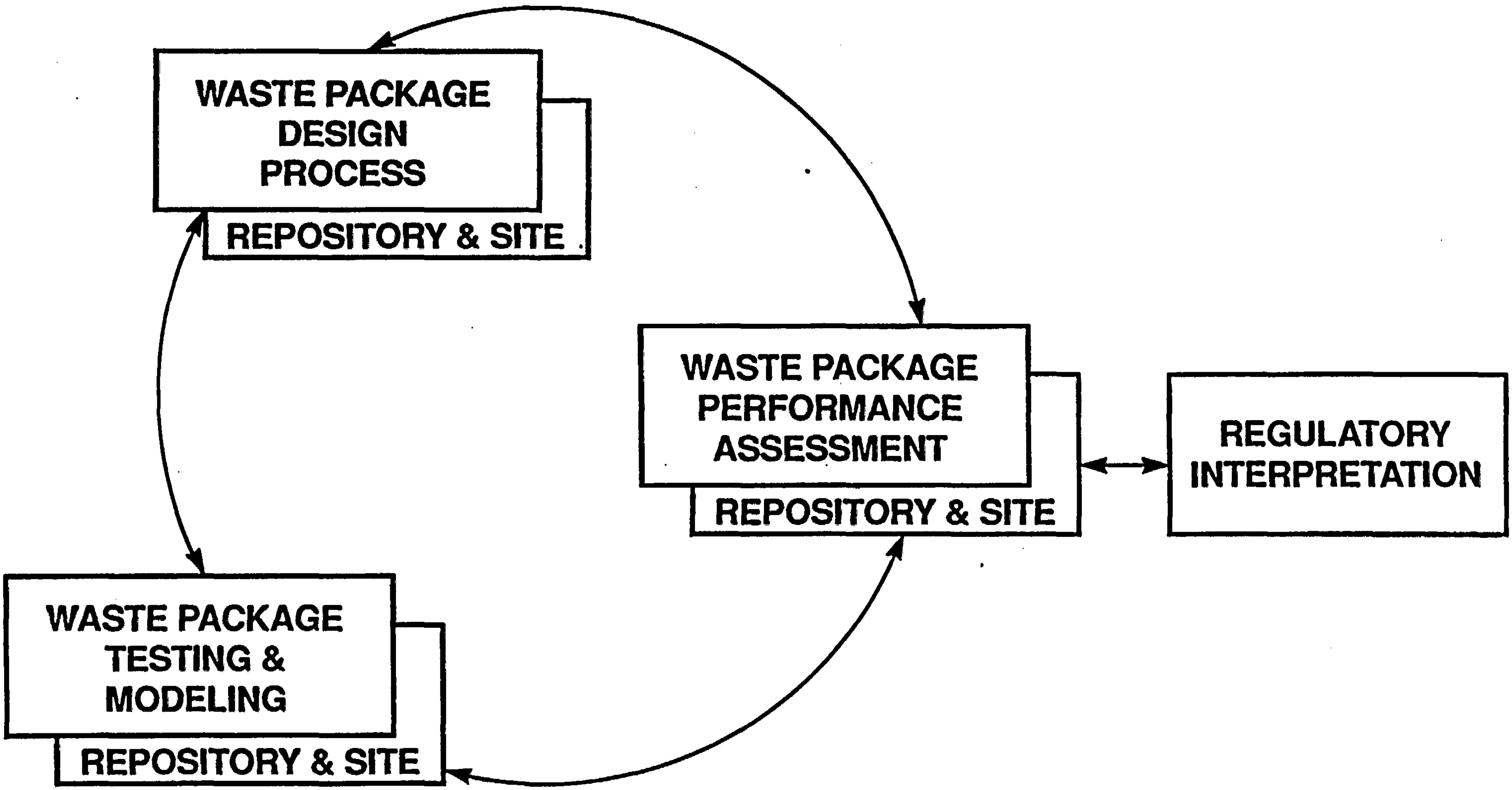
THE DEVELOPMENT AND DEMONSTRATION OF A CONSERVATIVE DESIGN THAT WILL MEET THE CONTENT AND INTENT OF THE REGULATORY REQUIREMENTS WITH SUFFICIENT MARGIN FOR UNCERTAINTY

THE WASTE PACKAGE STRATEGY:

- THE ATTAINMENT OF THE GOAL USING AN ITERATIVE PROCESS OF DESIGN DEVELOPMENT, CHARACTERIZATION, AND ASSESSMENT THAT RELIES ON:

  - A MULTI-BARRIER APPROACH
  - THE UNSATURATED NATURE OF THE YUCCA MOUNTAIN SITE
  - CONSIDERATION OF TECHNICAL AND REGULATORY ALTERNATIVES
  - SUFFICIENT RESOLUTION OF TECHNICAL/REGULATORY UNCERTAINTIES

MAJOR INTERFACES (TOOLS)



WASTE PACKAGE DESIGN REQUIREMENTS

- OPERATION
- RETRIEVAL
- CONTAINMENT
- ISOLATION
- RELIABILITY
- PERFORMANCE CONFIRMATION

MODELS AND TEST DATA

- COMPLEMENTARY EFFORTS
- EMPHASIS ON MECHANISTIC UNDERSTANDING
- FOCUS ON IMPORTANT RADIONUCLIDES

OBJECTIVES OF CONTAINER MATERIALS EFFORT

- SELECT CONTAINER MATERIALS
- ESTABLISH THE BASIS FOR MECHANISTIC PERFORMANCE MODELS
- PERFORM LONG-TERM TESTS TO SUPPORT PERFORMANCE ASSESSMENT
- PREDICT CONTAINER DEGRADATION AND FAILURE DISTRIBUTION WITH TIME

CANDIDATE MATERIALS

- ORIGINAL SCREENING OF 31 MATERIALS

- 17 MATERIALS CONSIDERED FURTHER

  - 4 AUSTENITIC ALLOYS CHOSEN
  - 3 COPPER BASE ALLOYS ADDED AND 1 AUSTENITIC ALLOY DROPPED

- 6 CANDIDATE ALLOYS STUDIED EXTENSIVELY

  - TYPE 304L STAINLESS STEEL
  - TYPE 316L STAINLESS STEEL
  - ALLOY 825 (HIGH NICKEL ALLOY)
  - HIGH PURITY COPPER
  - ALUMINUM BRONZE (7 WT.% AL)
  - COPPER-NICKEL (70 WT.% CU - 30 WT.% NI)

INPUTS TO MATERIALS SELECTION

- EXPECTED CONTAINER ENVIRONMENT
- DEGRADATION MODE SURVEYS
- REGULATORY PERFORMANCE REQUIREMENTS
- MODELING CAPABILITY (PREDICTABILITY)
- ENGINEERING DESIGN INFORMATION
- COST AND FABRICATION DATA

OVERALL CONTAINER MATERIAL SELECTION STRATEGY

- OBTAIN ADDITIONAL INFORMATION ON ALLOY 825, COPPER, AND CU-NI IN PRE-ACD PHASE TO ASSIST SELECTION
- IDENTIFY AND SCREEN CANDIDATES FOR ALTERNATE MATERIAL/DESIGN CONCEPTS IN PRE-ACD PHASE
- DEVELOP ALTERNATE MATERIAL/DESIGN CONCEPTS IN PARALLEL WITH METAL BARRIER MATERIALS THROUGH ACD
- SELECT CONTAINER MATERIAL FOR LAD STUDIES BASED ON AVAILABLE SITE AND CONTAINER PERFORMANCE DATA
- EVALUATE/VERIFY LAD CONTAINER MATERIAL AND DESIGN PERFORMANCE PRIOR TO LICENSE APPLICATION USING AVAILABLE SITE DATA AND CONTAINER PERFORMANCE MODELS

(ACD = ADVANCED CONCEPTUAL DESIGN)
(LAD = LICENSE APPLICATION DESIGN)

NWMODEL5P.A18/10-26-89

ALTERNATE MATERIAL/DESIGN CONCEPT DEVELOPMENT

- SELECTION PROCESS PARALLELS THAT FOR METAL BARRIER MATERIALS

- RATIONALE FOR SELECTION OF ALTERNATES
  - SITE DATA
    * MORE WATER THAT EXPECTED
    * MORE AGGRESSIVE WATER CHEMISTRY
    * HIGHER MECHANICAL LOADS

  - PERFORMANCE
    * ASSURANCE UNCERTAIN THAT CONTAINMENT AND RELEASE REQUIREMENTS ARE MET BY THE METAL BARRIER
    * ALLOCATION OF GREATER PERFORMANCE TO THE CONTAINER

ALTERNATE MATERIALS/ DESIGN CONCEPTS

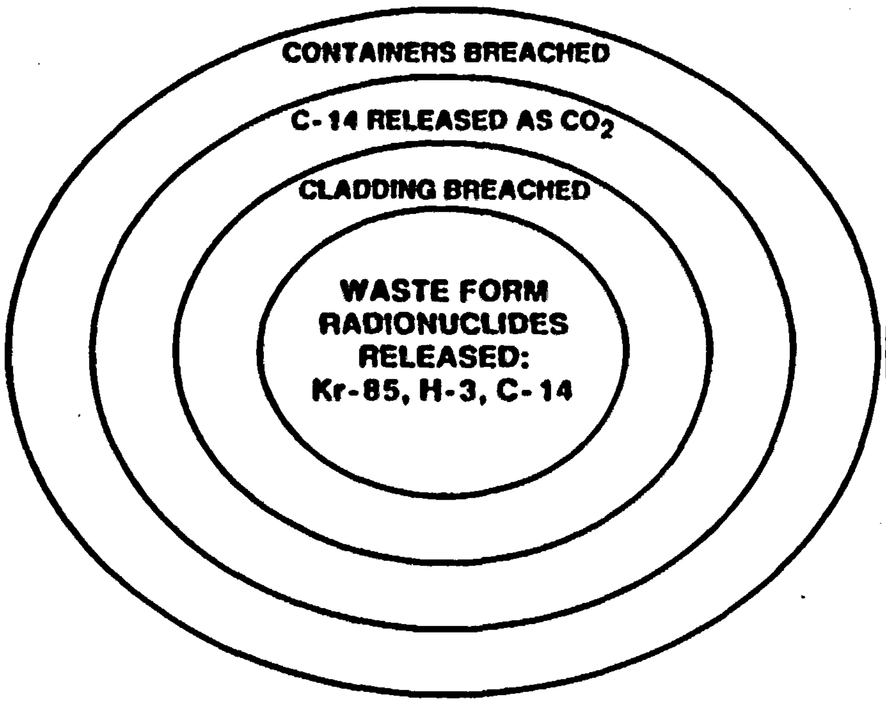
- **CERAMIC-METALS**
  (OXIDE OR GRAPHITE CONTAINERS WITH METALLIC OVERPACKS)
- **BIMETALS**
  (ONE EXAMPLE: OUTER HIGH-NICKEL BASE ALLOY AND INNER HIGH PURITY COPPER)
- **ALTERNATE SINGLE METALS (THIN/THICK WALLS)**
  (TITANIUM ALLOYS, HIGH-NICKEL BASE ALLOYS, ETC.)
- **COATINGS**
  (METALLIC OR CERAMIC)
- **FILLERS**
  (STABILIZERS OR MONOLITHS)

PERFORMANCE ALLOCATION

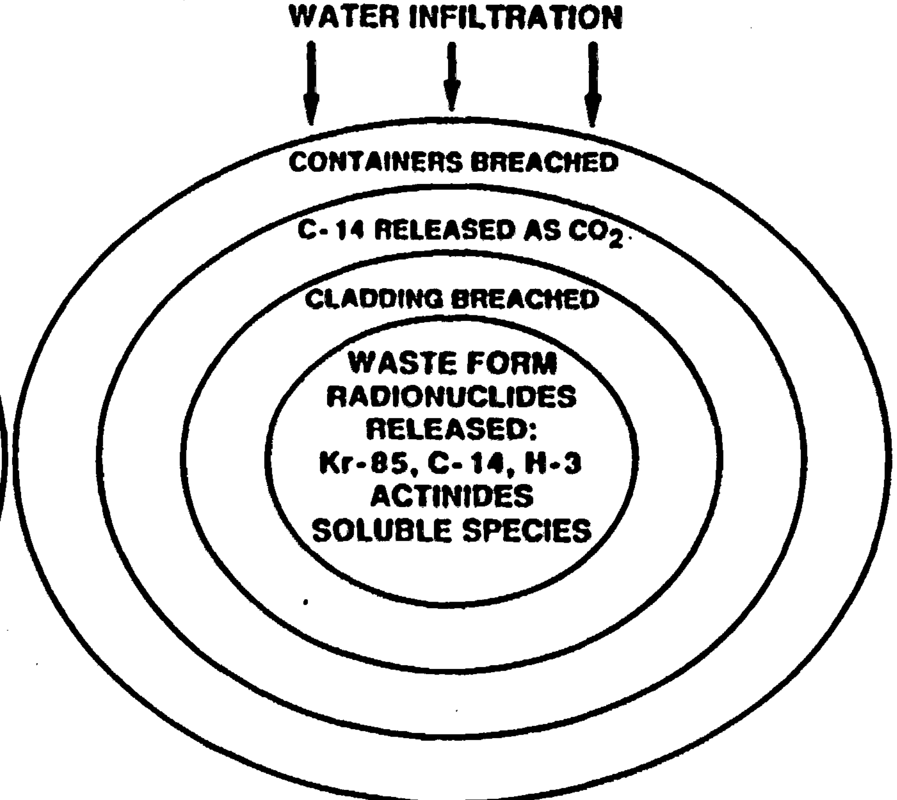
- SYSTEM ELEMENTS SELECTED AND TOP-LEVEL FUNCTIONS IDENTIFIED FOR EACH EBS ELEMENT
- ALLOCATIONS EXPRESSED AS FAILURE RATES, FRACTIONS OF FAILED CONTAINERS, FAILED CLADDING, WATER-CONTACTED CONTAINERS, INVENTORY RELEASABLE, ETC.
- PRODUCT OF THESE FRACTIONS MUST YIELD A VALUE NOT EXCEEDING THE RELEASE RATE GOALS AND PERFORMANCE REQUIREMENTS
- PERFORMANCE GOALS DIVIDED INTO TIME SEGMENTS, TO REFLECT CHANGING ENVIRONMENTAL CONDITIONS AND INVENTORY MIX

CONSIDERATIONS FOR WASTE PACKAGE COMPONENT GOALS

NO LIQUID WATER CONTACTS WASTE PACKAGE (EXPECTED CASE)



SOME LIQUID WATER CONTACTS WASTE PACKAGE (BOUNDING CASE)



CONTAINER BEHAVIOR MODELING ACTIVITIES

- **CONTAINER**
  - IDENTIFY DEGRADATION MODES
  - ESTABLISH PHENOMENOLOGICAL MECHANISMS
  - DEVELOP PARAMETRIC DEPENDENCIES
  - COMPARE PREDICTIONS TO DATA AND ITERATE
  - COMBINE ALL MECHANISMS INTO SINGLE MODEL

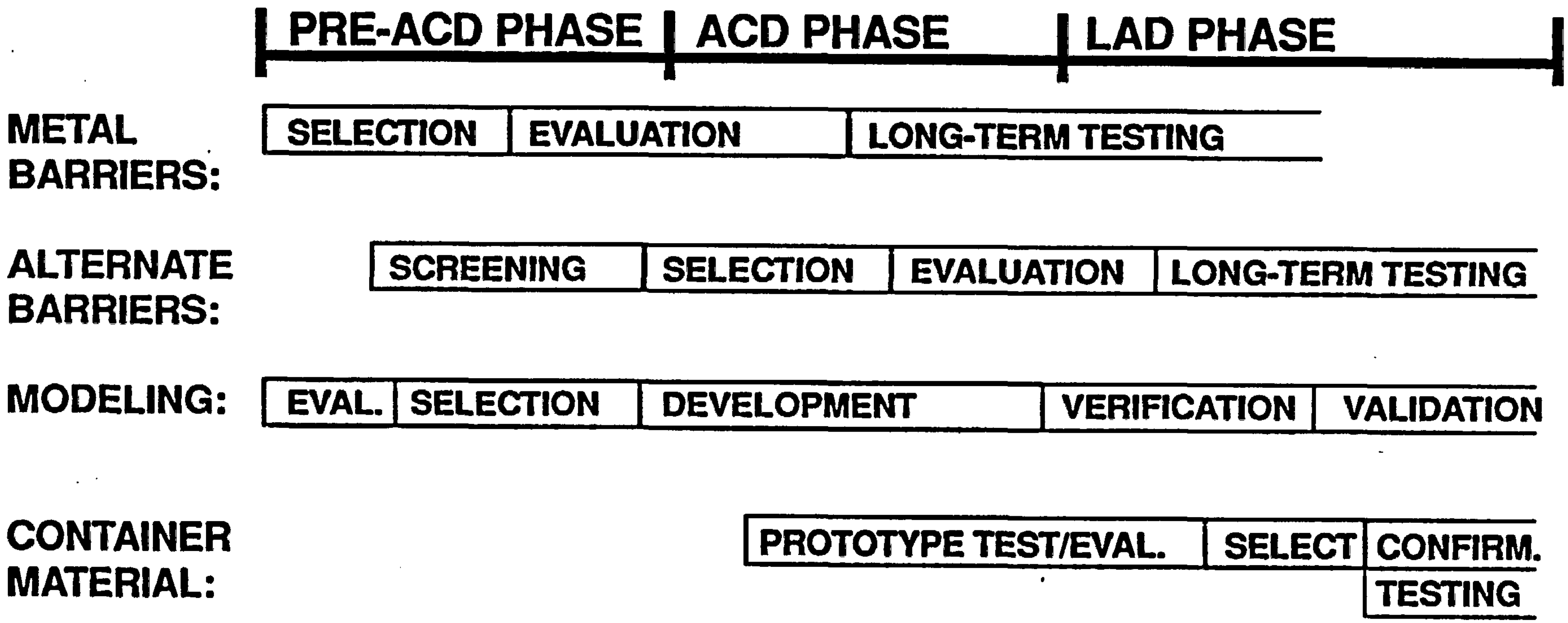
- **SYSTEM**
  - PREDICT BEHAVIOR OF ENSEMBLE OF CONTAINERS UNDER REPOSITORY CONDITIONS
  - PERFORM UNCERTAINTY AND SENSITIVITY ANALYSES

PERFORMANCE ASSESSMENT RESULTS

- IF THE DESIGN MEETS THE REQUIREMENTS, THEN LICENSE APPLICATION ACTIVITIES CAN PROCEED (ISSUE IS RESOLVED)

- IF DESIGN DOES NOT MEET REQUIREMENTS, EVALUATE AND SELECT ALTERNATIVE ACTIONS
  - ASSIGN PERFORMANCE GOALS TO ADDITIONAL COMPONENTS
  - MODIFY THE CONCEPTUAL AND/OR COMPUTATIONAL MODELS
  - PERFORM MORE TESTS TO IMPROVE DATABASES
  - CHANGE WASTE PACKAGE DESIGN OR MATERIALS
  - REVISE THE REGULATORY DESIGN BASES AS PROVIDED IN 10 CFR 60.113(b)

OVERVIEW SCHEDULE



PRESENTATION FOR DOE/NRC TECHNICAL EXCHANGE ON CONTAINER MATERIALS

26 October 1989

Yucca Mountain Project
Metal Barrier Selection and Testing Task (WBS 1.2.2.3.2)
Container Modeling and Testing Technical Area

W. L. Clarke
R. D. McCright
W. G. Halsey
J. C. Farmer
Lawrence-Livermore National Laboratory

Attachment 3

DOE/NRC TECHNICAL EXCHANGE ON CONTAINER MATERIALS

26 October 1989

OUTLINE OF YUCCA MOUNTAIN PROJECT PRESENTATION

A. Background

B. Structure of Planning Documents

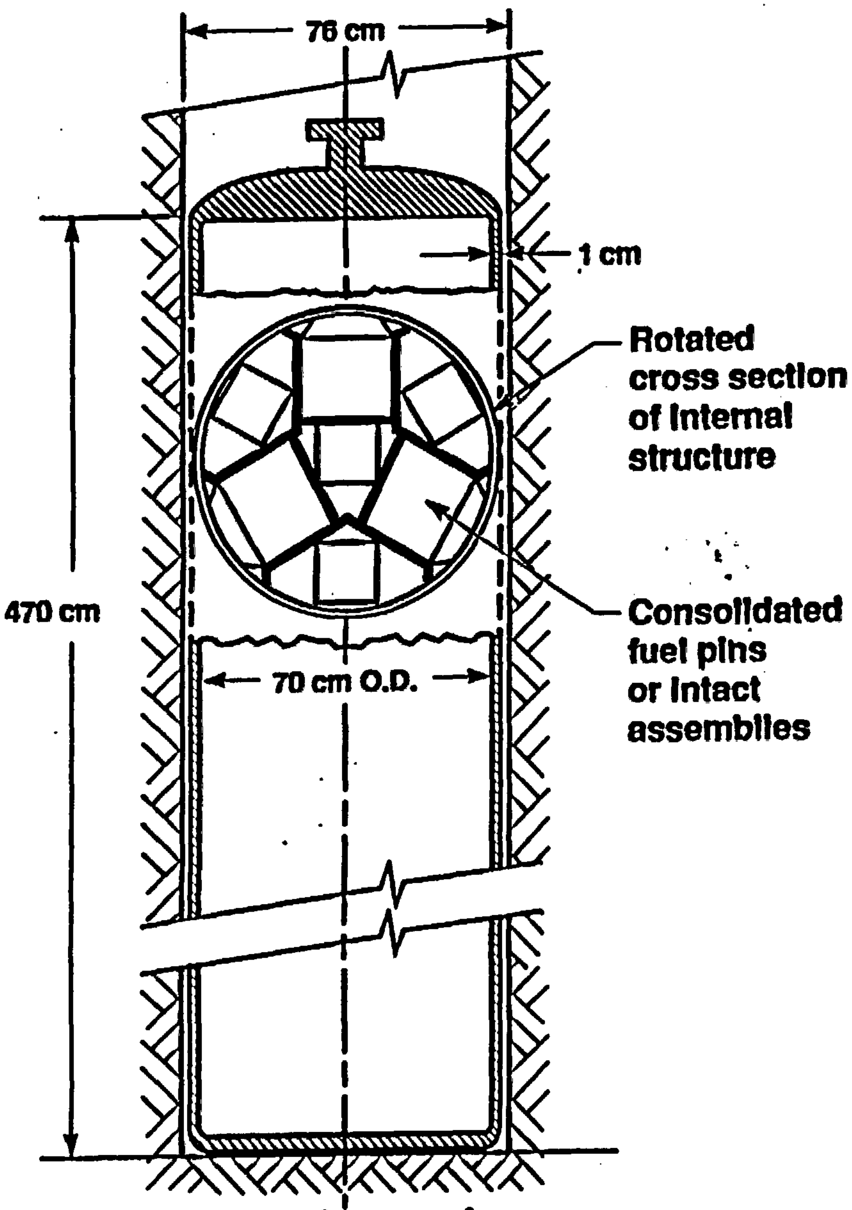
C. Material Selection Process

D. Input Data for Selection

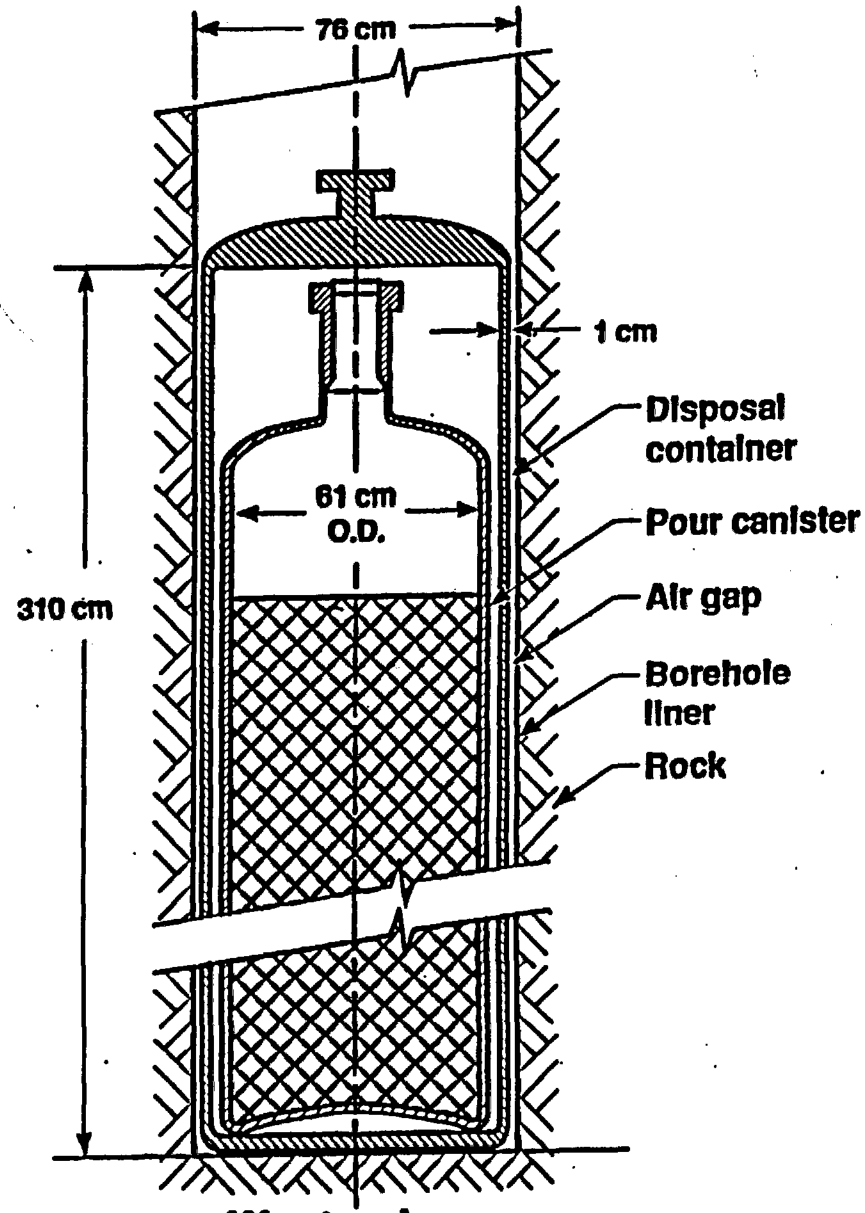
E. Plans for Testing Selected Material(s)

F. Test Methods

Two types of waste packages will be placed in the repository at Yucca Mountain



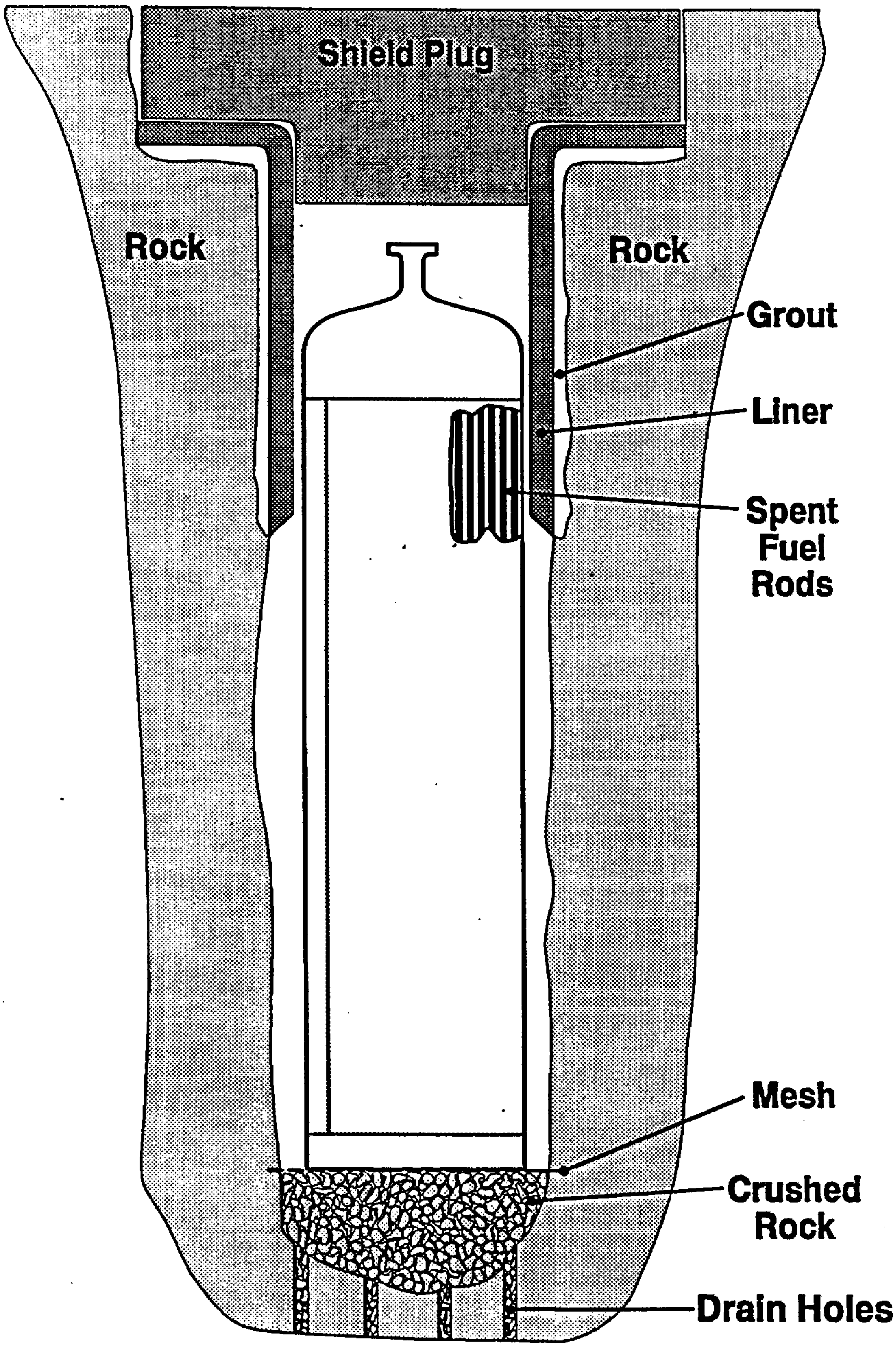
Spent fuel containers (25,000 to 35,000)



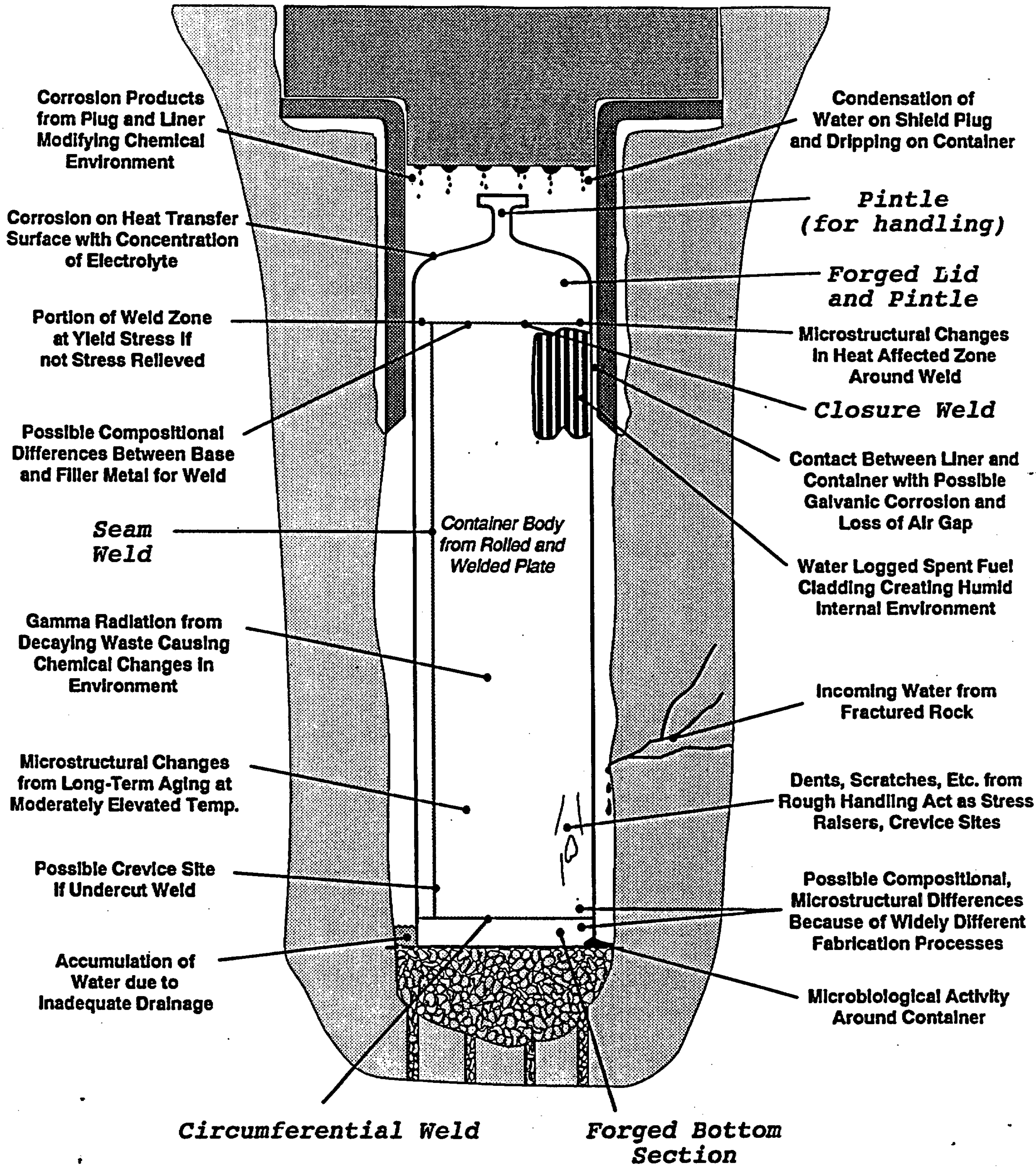
Waste glass containers (~14,000)

ES-2/21/89-BC-02

Vertical Waste Package Emplacement



Possible Problem Areas of Vertical Waste Package



PRESENTATION FOR DOE/NRC TECHNICAL EXCHANGE ON CONTAINER MATERIALS

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Container Modeling and Testing Technical Area

W. L. Clarke
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J. C. Farmer
Lawrence-Livermore National Laboratory

Attachment 4

DOE/NRC TECHNICAL EXCHANGE ON CONTAINER MATERIALS

10/26/89

BILL HALSEY - LLNL

C. MATERIAL SELECTION PROCESS

Purpose

Selection Criteria

Pass/Fail, Rankings

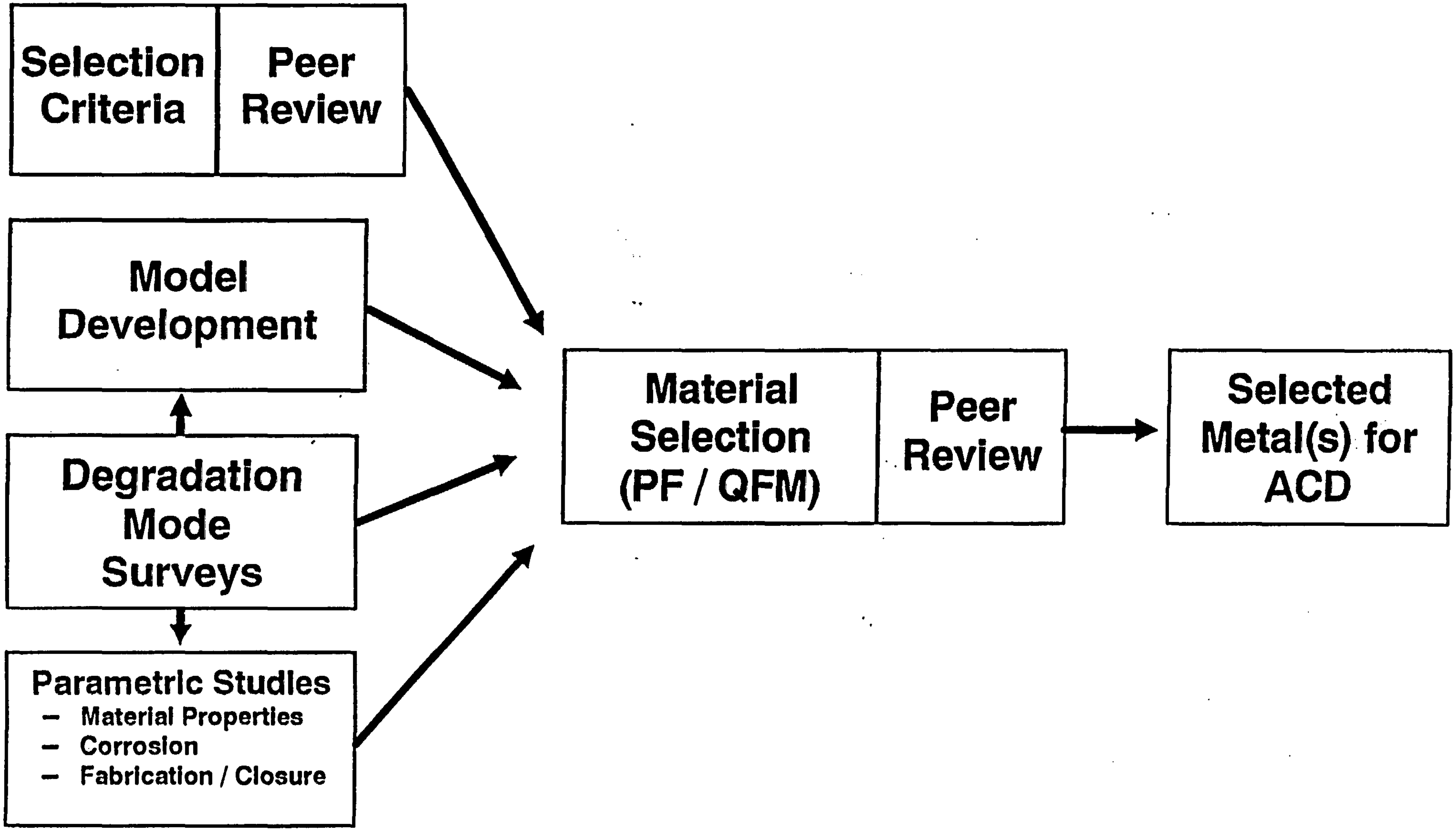
Independent Peer Reviews

Container Material Selection Process

- Select material for advanced studies (ACD) from list of six candidates by April 1990 based primarily on existing requirements, material performance information, and expected waste package service environment.
- Develop material performance models and perform parametric testing in parallel with site characterization activities (ACD). Iterate with container design and performance assessment.
- Confirm or revise material selection prior to LAD based on site data and performance assessment.
- Perform long term confirmation tests and validate models (LAD on).

WASTE PACKAGE CONTAINER MATERIAL FOR ADVANCED STUDIES

SELECTION PROCESS



Inputs to Material Selection.

- Selection criteria.
- Candidate materials.
- Expected container environment.
- Degradation mode surveys.
- Parametric studies.
- Regulatory performance requirements.
- Modeling capability (predictability).
- Engineering design information.
- Cost and fabrication data.

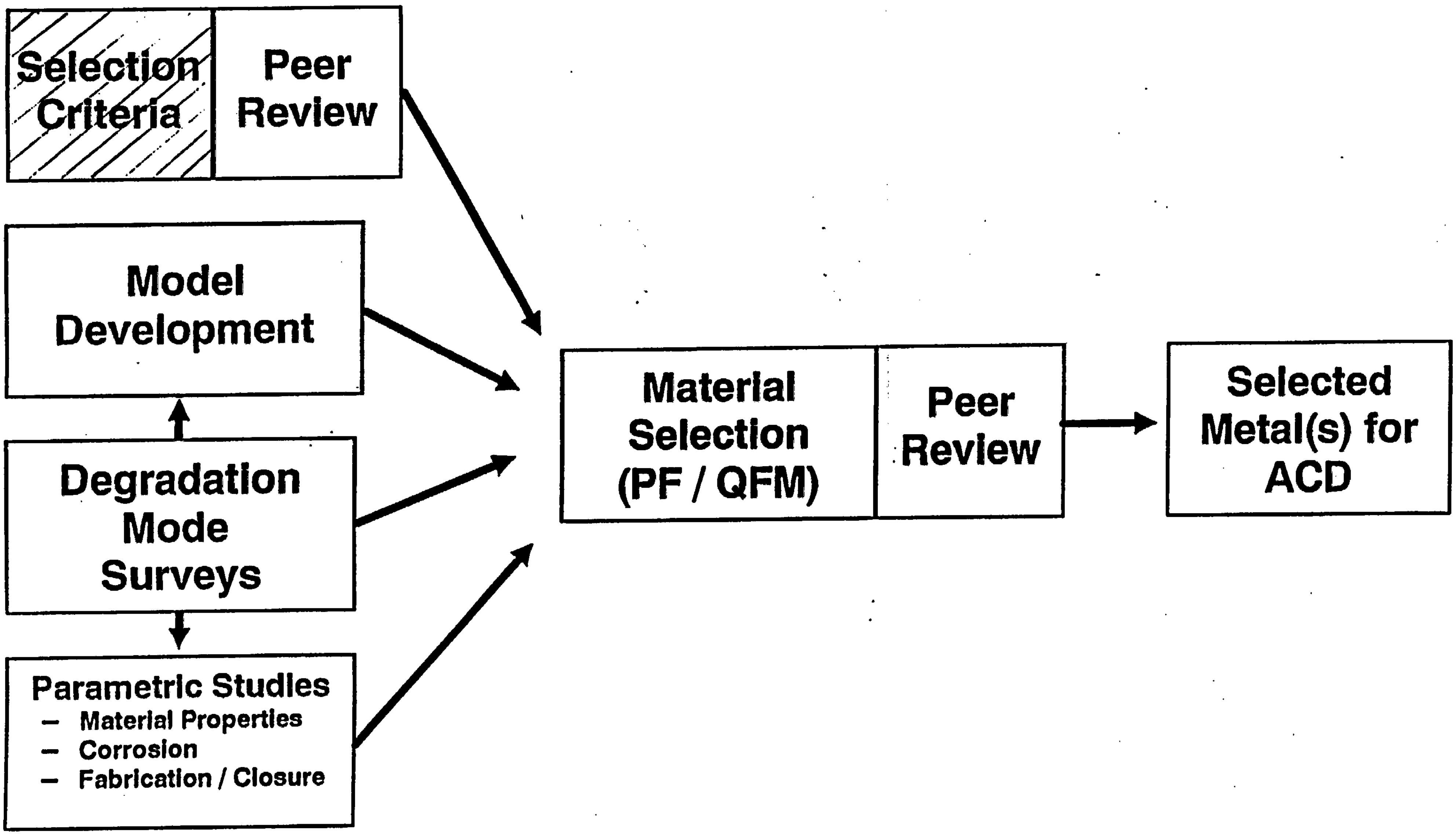
Candidate Materials

- Original screening of 31 materials (1982).
- 17 materials considered further (1983).
- 6 candidate alloys studied extensively (1984 →).

  Type 304L stainless steel.
  Type 316L stainless steel.
  Alloy 825 (high nickel alloy).
  High purity copper.
  Aluminum bronze (7 wt.% Al).
  Copper-nickel (70 wt.% Cu - 30 wt.% Ni).

WASTE PACKAGE CONTAINER MATERIAL FOR ADVANCED STUDIES

SELECTION PROCESS



Preliminary Selection Criteria (SCP 8.3.5.9.2.1.1)

- Which material will meet the performance allocated to the container in achieving the containment objectives (substantially complete containment under anticipated processes and events occurring in the repository)?
- Can the performance of the material under repository conditions be adequately predicted?
- Will the container material interact favorably with other components?
- Can a container be made of this material?
- Are the container material and process for fabricating it practicable?
- How can confidence in the selection be gained?

Selection Criteria

Draft

- Divided into 34 separate criteria covering 7 topics.
- Criteria address engineering, performance and regulatory requirements.
- Each criterion has a relative weighting factor.
- Each criterion has Pass/Fail and quantitative score.
- Extensive use of professional judgement.

Material - Independent Selection Criteria

Draft Topic Areas

- PART A: MATERIAL PERFORMANCE

  A) Mechanical performance

  B) Chemical performance (corrosion)

  C) Predictability of performance

  D) Compatibility with other materials

- Part B: FABRICABILITY, COST, AND OTHER CONSIDERATIONS

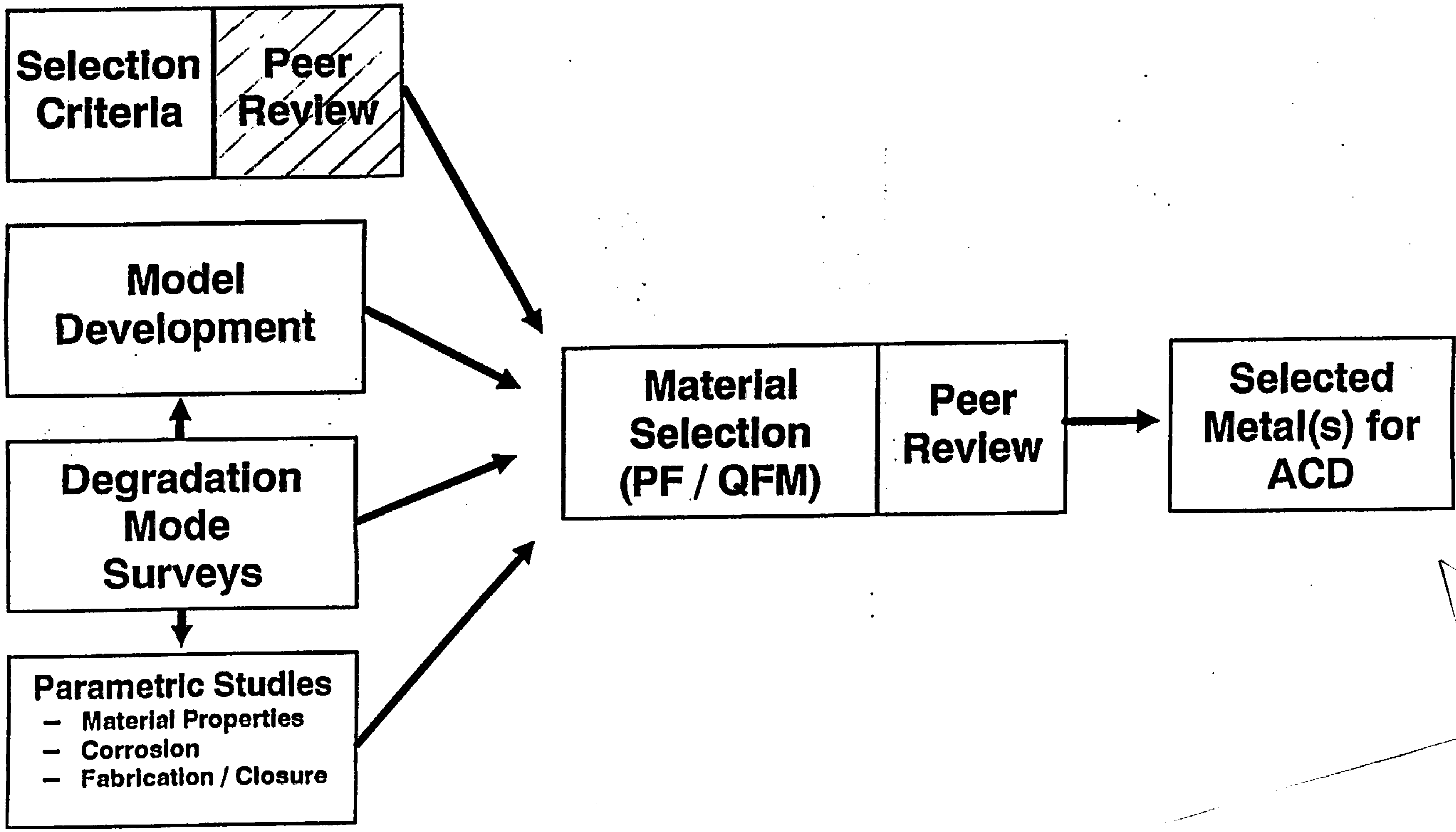
  E) Fabricability

  F) Cost

  G) Previous experience with the material

WASTE PACKAGE CONTAINER MATERIAL FOR ADVANCED STUDIES

SELECTION PROCESS



METAL BARRIER SELECTION CRITERIA REVIEW PANEL

- Convened, September 1988
- Composed Panel Report, December 1988
- Follow-up Review of Selection Criteria, 1989
    - *Sought membership to represent:*

Areas of Expertise	Viewpoints
Material degradation processes	Academic R&D community
Predictive modeling	Industrial R&D community
Fabrication and joining technology	Nuclear utility management
Component performance assessment	Independent consultants
Failure analysis	Regulatory
Nuclear engineering practices	Licensing

MEMBERSHIP OF METAL BARRIER SELECTION CRITERIA PEER REVIEW PANEL (September, 1988)

Name	Affiliation
Dr. Robin Jones (Chairman)	Electric Power Research Institute (EPRI)
Dr. Geoffrey Egan	Aptech Engineering
Dr. Martin Prager	Materials Properties Council
Dr. Robert Long	GPU Nuclear
Dr. Richard Gangloff	University of Virginia
Dr. Roger Staehle*	Consultant / University of Minnesota

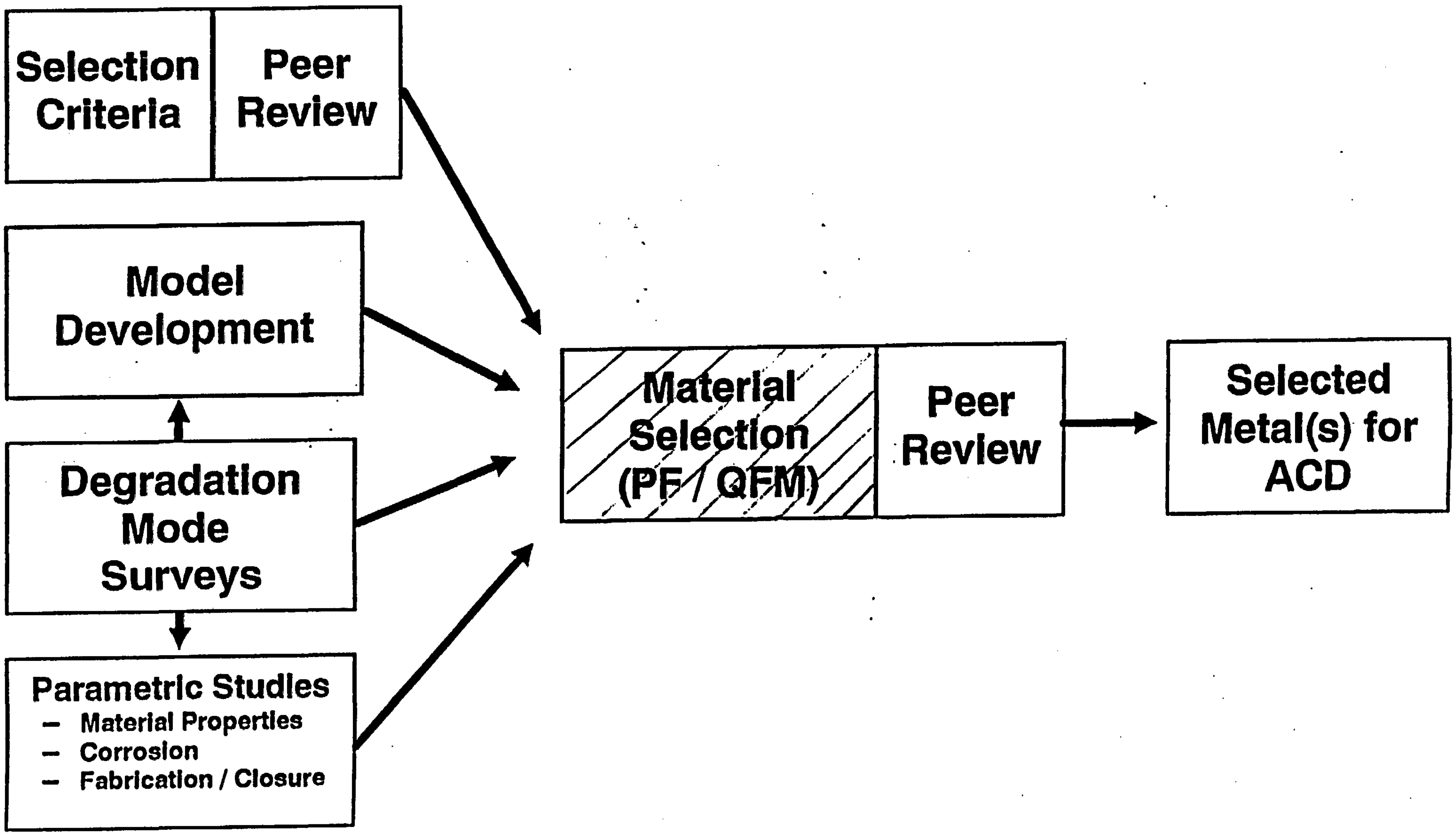
* Resigned

GENERAL COMMENTS ON THE PEER REVIEW PROCESS

- Structure review consistent with NRC technical position (NUREG).
- Logistics:
  - — Keep panel small.
  - — Advance work via mail / fax.
  - — Reasonable working quorum.
- Independent technical / logistic support for chairman.
- Written procedure for comment closure.
- Separation of peer review and program documents.
- Precise focus for scope and purpose.
- Provide for open commentary beyond scope of review.

WASTE PACKAGE CONTAINER MATERIAL FOR ADVANCED STUDIES

SELECTION PROCESS



Material Selection

- Assess the candidates against established criteria using available information.

- A.Pass/Fail

  Examine each alloy and eliminate those that do not have a reasonable expectation of meeting the performance requirements.

- B.Quantitative Figure of Merit

  Apply a quantitative grading scale of established criteria and weighting factors to select the material for advanced work.

DOE/NRC Technical Exchange on Container Materials

Part E.

Plans for Testing Selected Material(s)

Joseph C. Farmer

Mail Station L-370
Lawrence Livermore National Laboratory
P.O.Box 808
Livermore, California 94550
Phone: FTS 543-9777

Attachment 5

Outline of presentation

- Description of anticipated environment
- Documentation of existing models
- Modeling containers in vapor-phase environment

  Uniform oxidation and corrosion

- Modeling containers in aqueous environment

  Pit and stress corrosion cracking
  - Initiation
  - Propagation

- Experiments for the determination of model parameters
- Summary

Waste package environment

- First 1000 years
  - Temperature of spent-fuel container will drop from 250 to 120°C
  - Radiolytic formation of NO_2 in dry air
  - Radiolytic formation of HNO_3 and some NH_3 in moist air
  - Possible formation of salt crust on container surface
- After 1000 years
  - Temperature of spent-fuel container will drop below boiling point
  - Possible formation of concentrated electrolyte
  - Radiolytic formation of H_2O_2 in aqueous phase
  - Radiolytic formation of HNO_3 in vapor phase

Documentation of existing models and data

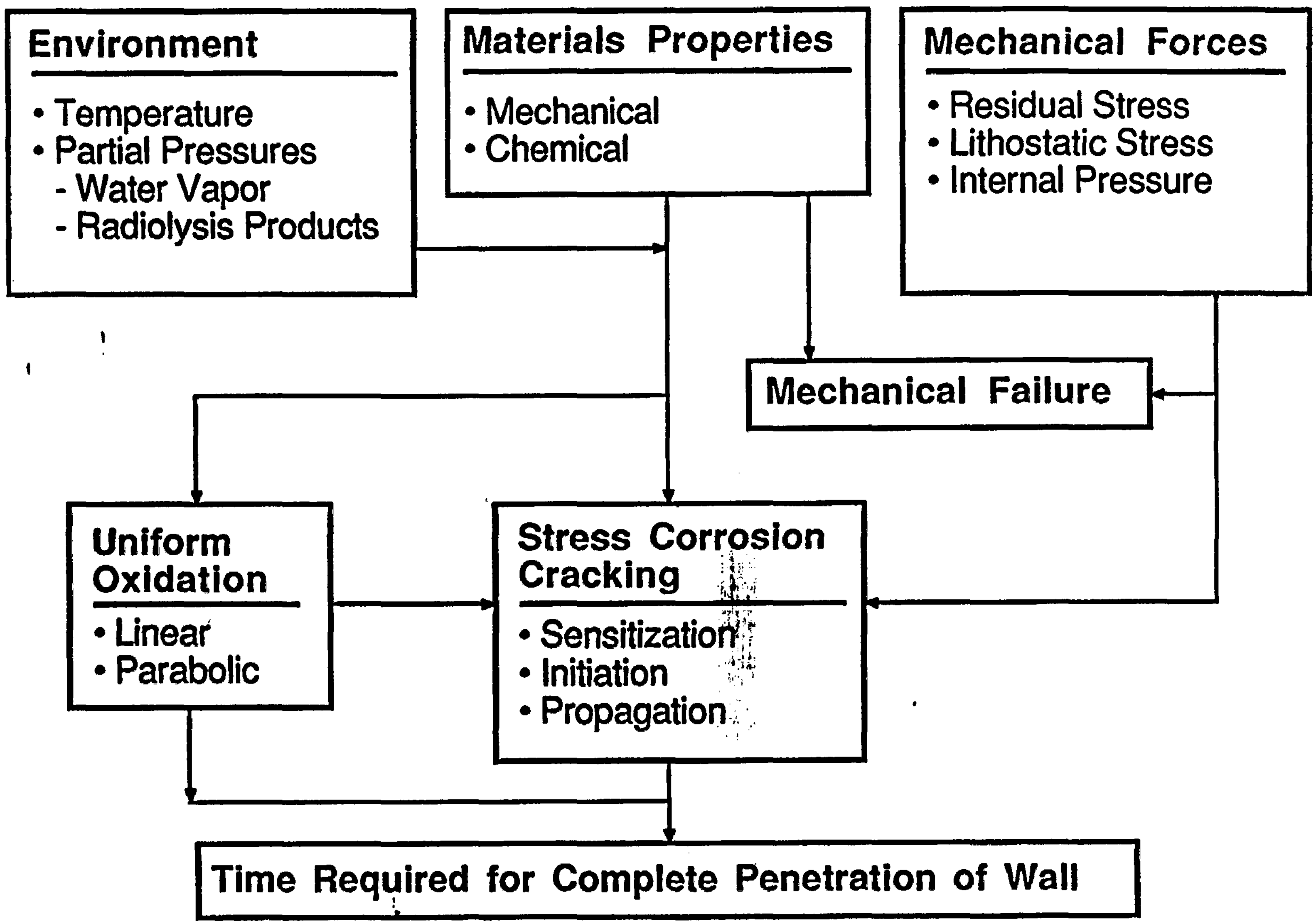
Corrosion Models for Performance Assessment of High-Level Radioactive Waste Containers, SMiRT-10 Conference Seminar No. 11 on Structural Mechanics and Materials Properties in Radioactive Waste Repository Technology, Anaheim, California, August 21-22, 1989, to be published in Nuclear Engineering Design (1990).

A Review of Models Relevant to the Prediction of Performance of High-Level Radioactive Waste Disposal Containers, Paper No. 519, Corrosion 89, National Association of Corrosion Engineers (1989).

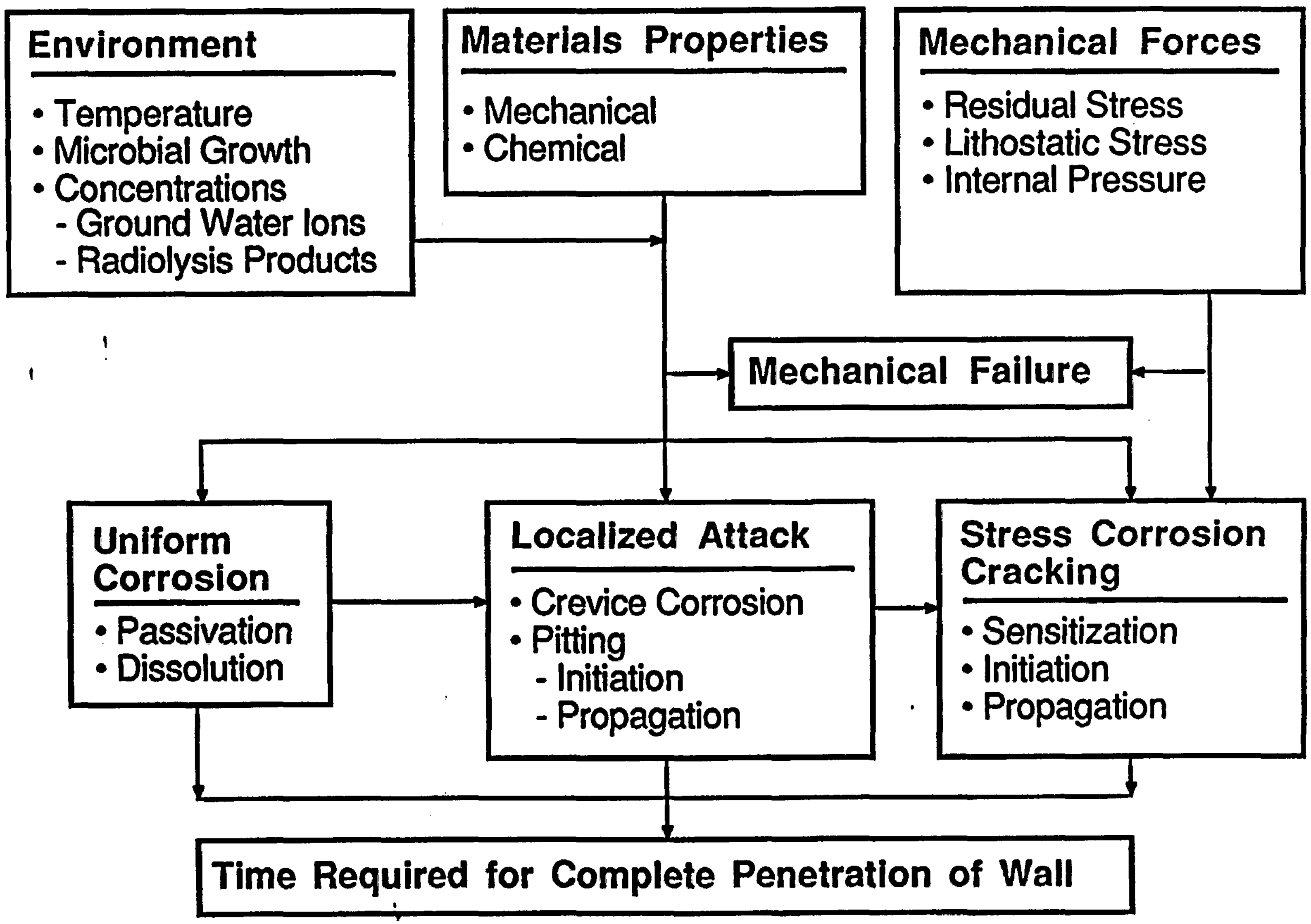
Localized Corrosion and Stress Corrosion Cracking of Candidate Materials for High-Level Radioactive Waste Disposal Containers in U.S.: A Critical Literature Review, Materals Research Society Symposium Proceedings, Vol. 127, pp. 359-371 (1989).

Survey of Degradation Modes of Candidate Materials for High-Level Radioactive-Waste Disposal Containers, Overview and Vols. 1-8, UCID-21362 (1988).

Containers exposed to vapor-phase environments



Containers exposed to aqueous environments



Pitting models

- Initiation on passive surfaces of austenitic alloys

  1. Halide nuclei theory (Okada, 1984)
  2. Point defect model (Chao et al., 1981)
  3. Critical suppression of pH (Galvele, 1976)
  4. Electrostriction model (Sato, 1971)
  5. Inclusion model (Manning et al., 1980)
  6. Stochastic theory (Shibata and Takeyama, 1977)

- Propagation of pits in austenitic alloys

  1. Quasi-steady-state mass-transport model assuming active surface at base of pit (Pickiering and Frankenthal, 1972; Galvele, 1976)

  2. Transient mass-transport model assuming highly resistive salt film at base of pit (Beck and Alkire, 1978)

Stress corrosion cracking models

- Initiation of cracks

  1. Linear-elastic fracture mechanics model for initiation of fatigue crack at pit (Hagn, 1983)
  2. Crack-tip-opening displacement model for initiation of stress corrosion crack at pit (Buck and Ranjan, 1984)
  3. Spontaneous initiation (Andresen and Ford, 1985)

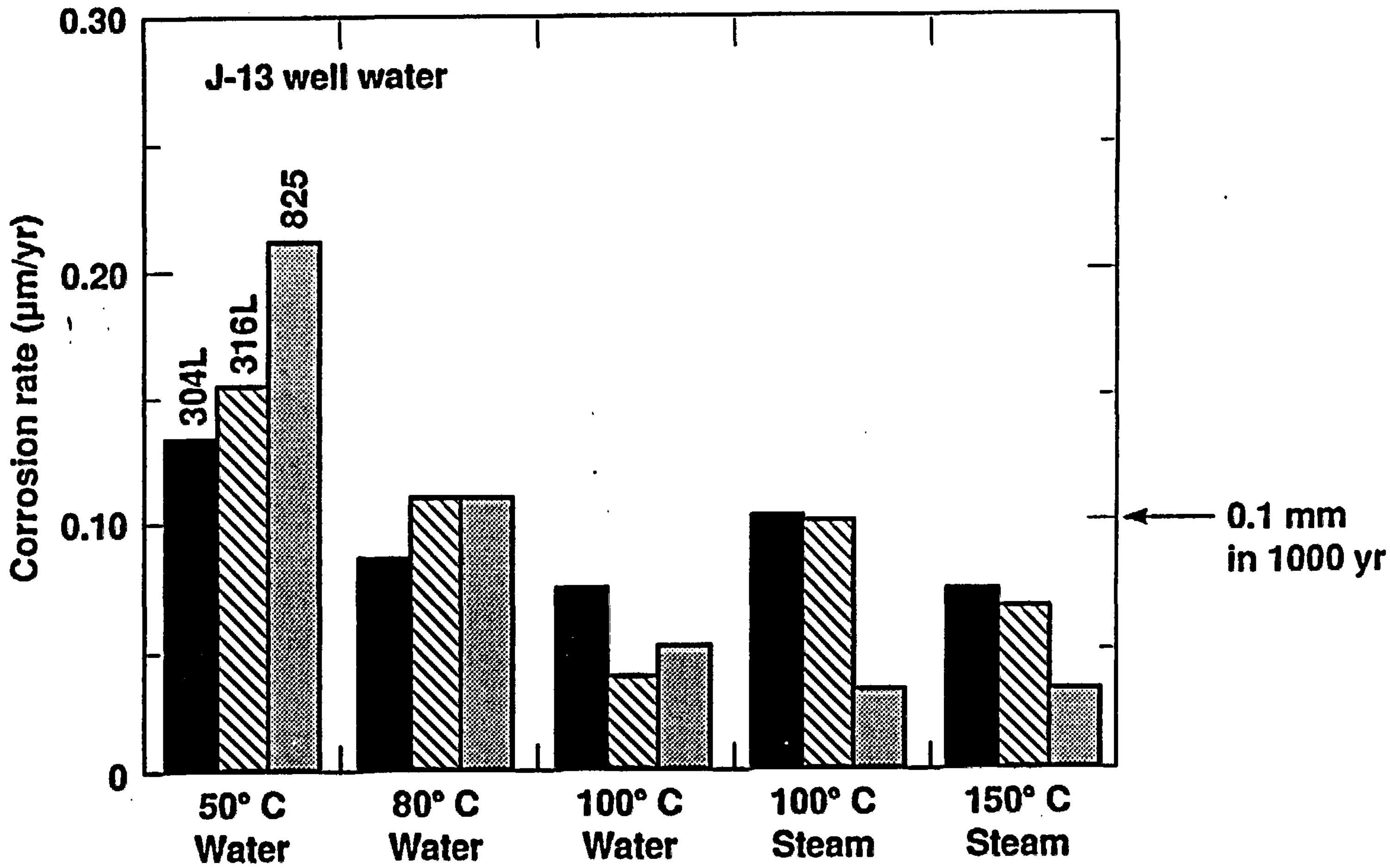
- Propagation of cracks

  1. Anodic dissolution of active crack tip (Turnbull and Thomas, 1982)
  2. Periodic fracture of passive film at crack tip (Andresen and Ford, 1982-1988)
  3. Film-induced cleavage of base metal (Paskin et al., 1980-83)

Experiments supporting predictive models for uniform oxidation and corrosion

- Rates of uniform oxidation
  - Weight gain of coupons in water and steam
  - Temperature from 50 to 150°C
  - Effects of γ irradiation
- Corrosion potential
  - Effects of γ irradiation
- Corrosion resistance in aqueous phase
  - Potentiodynamic linear-sweep polarization
  - AC impedance spectroscopy

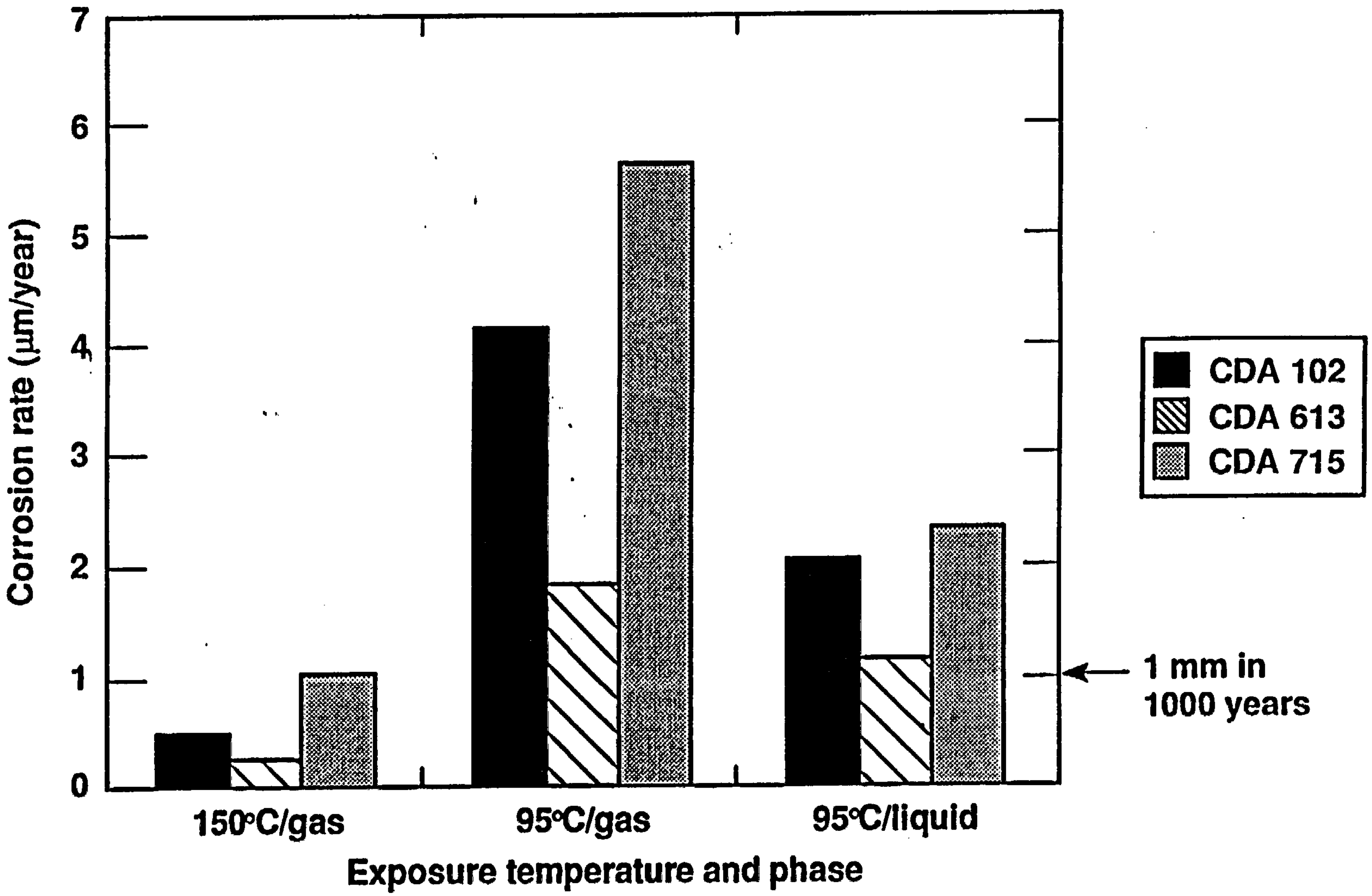
Container life is not limited by uniform corrosion and oxidation of the austenitic alloys



From McCright et al., UCID–21044, December 1987 (Table 2)

010-1131-u-8a

Container life *may* be limited by uniform corrosion of the copper-based alloys in saturated steam at 95°C



From McCright et al., UCID-21044, December 1987 (Table 13)

AH-004-U-1131-1

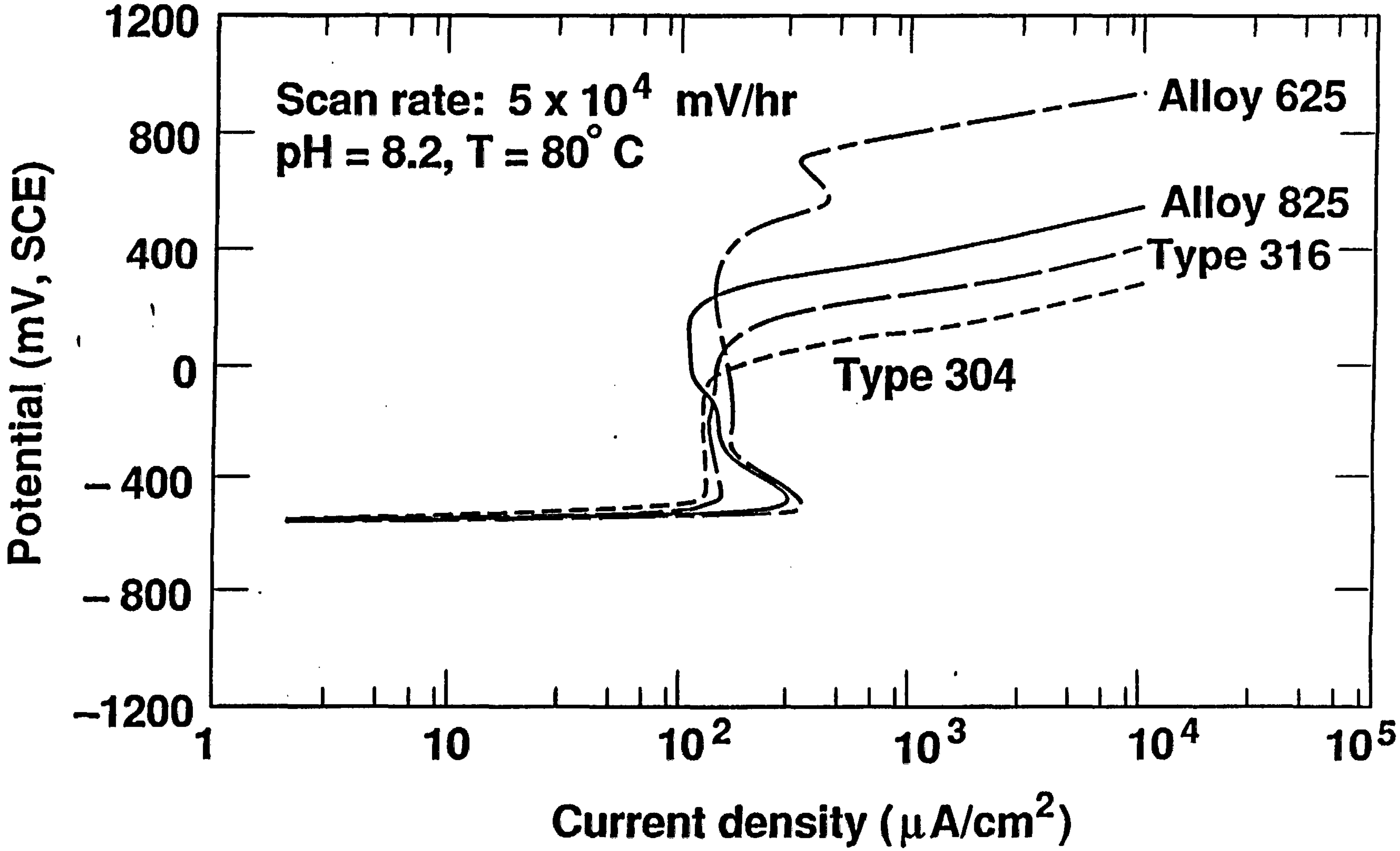
Experiments supporting predictive models for uniform oxidation and corrosion (continued)

- Identification of corrosion products
  - Effects of γ irradiation; identification of corrosion products by X-ray diffraction
  - In situ Raman spectroscopy of copper-based alloys

Experiments supporting predictive models for the initiation of pits

- Critical pitting potential (E_c)
  - Potentiodynamic linear-sweep polarization
- Incubation time (τ)
  - Potentiostatic polarization
- Application of statistics
  - Factorial designs to determine the dependence of E_c and τ on chloride, pH and temperature
  - Stochastic theory to determine probability density functions for E_c and τ; polarization of multiple samples (Shibata and Takeyama, 1977)

Pitting potentials were determined by linear sweep anodic polarization



Slow scan tests in deaerated seawater. From Scarberry et al., Paper No. 245, Corrosion 79, Atlanta, Ga., March 12-16, 1979.

CC-U-005-7098-2-A

Factorial designs minimize the number of experiments required to determine the coefficients in linear equations

- Most general form of the equation for pitting potential

$$Ec = a_0 + a_1 \cdot \ln[Cl^-] + a_2 \cdot pH + a_3 \cdot T + a_{12} \cdot \ln[Cl^-] \cdot pH + a_{13} \cdot \ln[Cl^-] \cdot T + a_{23} \cdot pH \cdot T + a_{123} \cdot \ln[Cl^-] \cdot pH \cdot T$$

- Important two-and three-factor interactions are included
- Only eight experiments are required to determine eight parameters
- A similar approach can be used to determine parameters in the equation for the incubation tim

Experiments supporting predictive models for the propagation of pits

- Determination of pit depth (x or a_p) as a function of time (t)
  - Exposure of specimens to environment
  - Optical microscopy to measure focal distance at base of pit
  - Optical microscopy of metallographic cross-section
- Fractional coverage of surface by pits
  - Optical microscopy with video camera
  - Use of digital image processing for quantification
- Overall loss of material due to pitting
  - Weight loss measurements

Experiments supporting predictive models for initiation of SCC

- Threshold stress intensity factor for SCC (K_{ISCC})
  - Modified Wedge-Opening-Loading (WOL) fracture specimen (Novak and Rolfe, 1969)
- Effects of environment on incubation time (t_{inc})
  - Load specimen in screw-driven tensile machine (Buck and Ranjan, 1984)
  - Vary chemistry of environment, electrochemical polarization and temperature
  - Measure time required for reduction in stress at constant displacement
  - Monitor stress with load cell
  - Simultaneous detection of acoustic emissions

Experiments supporting predictive models for the propagation of SCC

- Crack length (a) and crack extension between film-fracture events (Δa)
  - In situ monitoring with reverse dc technique
  - Electrochemical and acoustical detection of periodic fracture
  - Electron microscopy of striations near crack tip
- Fracture strain of film (ε_f)
  - Slow strain rate testing of wire electrode
  - Electrochemical and acoustical detection of periodic fracture

Experiments supporting predictive models for the propagation of SCC (continued)

- Anodic charge density for repassivation of crack tip (Q_f)
  - Slow strain rate testing of wire electrode
  - Measurement of electrochemical transient
- Crack propagation rate (da/dt) and crack-tip strain rate ($d\varepsilon_{ct}/dt$)
  - Fitting data to Andresen-Ford model

Summary

- Description of waste package environment
  - Effects of γ irradiation
  - Roles of various ions in localized attack of container materials
- Review of models for vapor-phase and aqueous corrosion
  - Uniform oxidation and corrosion
  - Pit initiation and propagation
  - SCC initiation and propagation
  - Effects of crevice corrosion

Summary (continued)

- Experimental strategy for determining parameters in predictive models
  - Rates of oxidation and corrosion
  - Corrosion and pitting potentials, incubation time for pitting, rate of pit penetration
  - Threshold stress intensity factor for SCC, rate of crack propagation, etc.
- Overall
  - LLNL has established a sound theoretical basis for predictive modeling of container performance
  - An experimental strategy is being implemented to determine model parameters
  - All work is being done in accordance with the quality assurance requirements of 10CFR60

NRC WASTE PACKAGE RESEARCH

- RESEARCH SPONSORED BY:
  1. OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS (NMSS)
  2. OFFICE OF RESEARCH (RES)
- RESEARCH PERFORMED BY:
  1. NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST)
  2. CORTEST COLUMBUS
  3. CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES (CNWRA)
- RESEARCH FOCUS
  1. MATERIALS STUDIES (E.G., CORROSION)
  2. NEAR FIELD ENVIRONMENT (E.G., ADSORPTION CHARACTERISTICS)

Attachment 6

NIST RESEARCH TOPICS

- STUDY OF OVERPACK/BACKFILL CORROSION INTERACTION IN DISPOSAL OF HLW

  1. MASS TRANSPORT OF RADIONUCLIDES THROUGH TUFF
  2. MICROBIALLY ACCELERATED CORROSION OF CONTAINER MATERIALS
     - A. REFERENCE MATERIAL (304L)
     - B. OTHER CANDIDATE MATERIALS
  3. ARCHEOLOGICAL ANALOGS OF CONTAINER MATERIALS

- ASSESSMENT OF METROLOGIC UNCERTAINTIES FOR WASTE PACKAGE TESTING

  1. DEMONSTRATE TECHNOLOGY AVAILABLE TO MEASURE PH AT ELEVATED TEMPERATURES

NIST RESEARCH TOPICS (CON'D)

- EVALUATION AND COMPILATION OF DOE WASTE PACKAGE TEST DATA

  1. EVALUATION OF METHODS (ACOUSTIC EMISSION) FOR DETECTION OF STRESS CORROSION CRACK PROPAGATION IN FRACTURE MECHANICS SAMPLES

     A. A36 AND A387-9 STEEL ALLOYS

     B. DOE CANDIDATE MATERIALS (LATER)

  2. EFFECT OF ELECTRICAL RESISTIVITY AND RATE OF OXYGEN TRANSPORT ON CORROSION OF WASTE PACKAGE MATERIALS

     A. LOW CARBON (0.2%) STEEL

  3. CORROSION BEHAVIOR OF ZIRCALOY NUCLEAR FUEL CLADDING (CORROSION RATES, PASSIVITY, BREAKDOWN POTENTIAL, SUSCEPTIBILITY TO LOCALIZED CORROSION)

     A. ZIRCALOY - 2

     B. ZIRCALOY - 4

CORTEST COLUMBUS RESEARCH TOPICS

- CONTAINER CORROSION IN HIGH LEVEL NUCLEAR WASTE REPOSITORIES
  1. REVIEW OF PROBLEMS IN REPOSITORIES (TUFF)
  2. POTENTIODYNAMIC POLARIZATION STUDIES
  3. VAPOR-PHASE CORROSION STUDIES
  4. PITTING CORROSION STUDIES
  5. STRESS CORROSION CRACKING STUDIES
  6. STUDIES OF OTHER FAILURE MODES (E.G., DEALLOYING OF COPPER, BOREHOLE LINER-CONTAINER INTERACTIONS)
  7. LONG-TERM EXPOSURE STUDIES
  8. EXAMINATION OF MODELING EFFORTS
- RESEARCH FOCUS ON FOUR ALLOYS
  1. 304L
  2. ALLOY 825
  3. CDA 102
  4. CDA 715

CNWRA RESEARCH TOPICS

- INTEGRATED WASTE PACKAGE EXPERIMENTS-TUFF

  1. LITERATURE SURVEY ON METAL CORROSION AND METAL DEGRADATION PROCESSES
  2. ASSESS STATUS OF YMP WASTE PACKAGE PROGRAM
  3. CONDUCT WASTE PACKAGE STUDIES ON KEY PARAMETERS AFFECTING MATERIAL PERFORMANCE
  4. EXPERIMENTALLY ASSESS SELECTED WASTE PACKAGE MATERIALS

- MATERIALS STUDIES INCLUDE ALL SIX CANDIDATE METALS (304L, 316L, ALLOY 825 CDA 102, CDA 613, CDA 715) AND HASTELLOY

IWPE PROJECT OVERVIEW PRESENTATION OUTLINE

PROGRAMMATIC BACKGROUND

- Regulatory Framework
- Implications of Regulations to Waste Package Performance
- Integrated Waste Package Experiment Project Approach
  - Uncertainty Reduction Concepts
  - Controlled Test Environments
  - Stepwise Testing Strategy
  - Baseline Evaluations
  - Reference Material – Hastelloy C-22

TECHNICAL SCOPE

- Specific Objectives
- Technical Program
- Technical Approach

Attachment 7

REGULATORY FRAMEWORK

10CFR60.113(a)(ii)

Containment of HLW within the waste packages will be substantially complete for a period to be determined by the Commission taking into account the factors specified in 60.113(b), provided that such period shall be not less than 300 years nor more than 1000 years after permanent closure of the geologic repository;

10CFR60.21(c)(1)(ii)(D)

. . . The analysis shall also include a comparative evaluation of alternatives to the major design features that are important to waste isolation, with particular attention to the alternatives that would provide longer radionuclide containment and isolation

IMPLICATIONS OF THE REGULATIONS

<u>10CFR60.113(a)(ii) Related</u>

- Technical Interpretation of "Substantially Complete" Containment
  - Waste Package Material/Design Evaluation
    - Mechanisms of Degradation (Qualitative)
    - Performance Assessment (Quantitative)
  - Technical Criteria to be Met by DOE
    - Guidance Requirements
- Compliance Determination Strategy for Containment
  - Containment Period Rationale (300-1000 yrs)
    - Technical
    - Regulatory
  - Criteria to be Met by DOE

IMPLICATIONS OF THE REGULATIONS (CONT'D)

<u>10CFR60.21(c)(1)(ii)(D) Related</u>

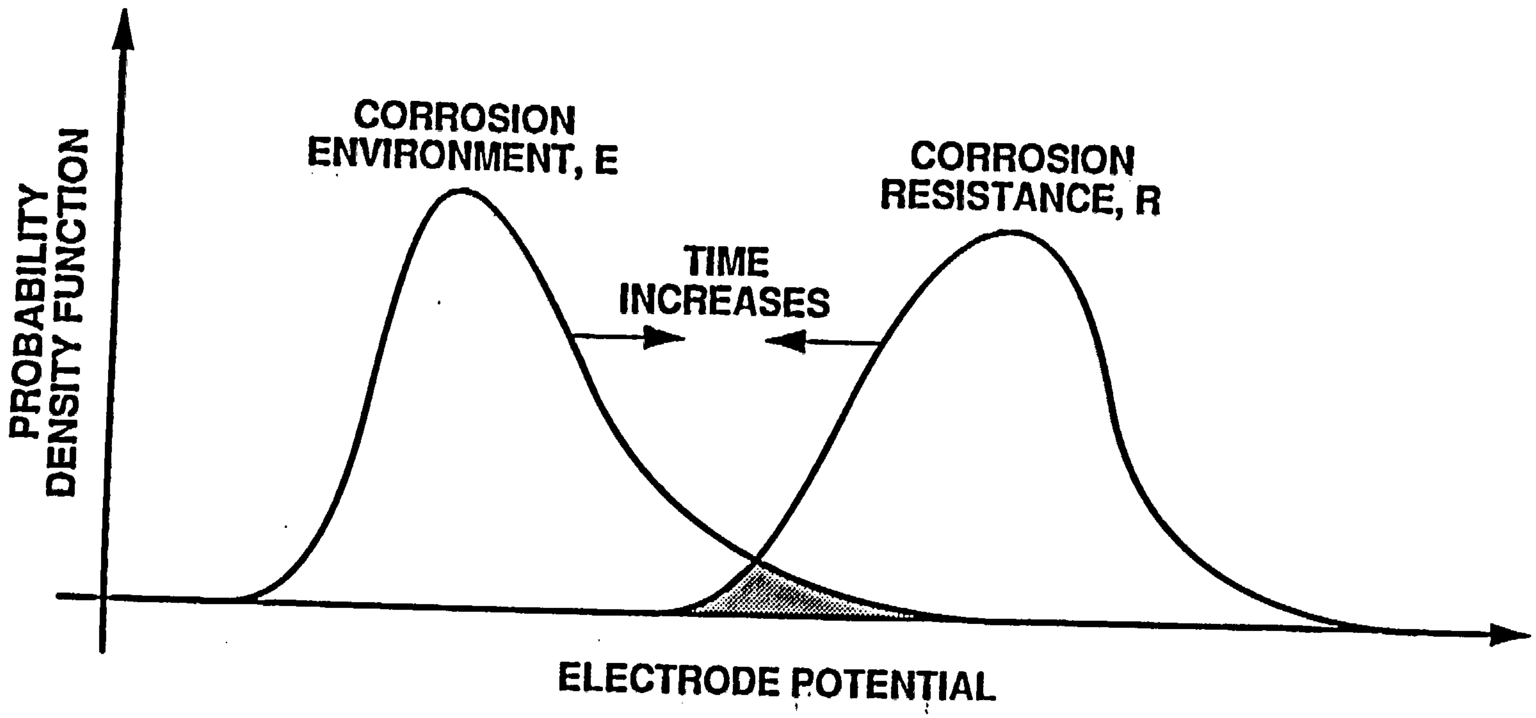
- Comparative Evaluation of Alternatives
  - Technical Basis of Comparison
  - Standards of Comparison (Reference Material/Design)
- Alternatives Requiring "Longer Radionuclide Containment"
  - A Technical Requirement Incorporating Material Selection and Design of Waste Packages.
  - Requires a Technical Approach to Bound Alternatives

INTEGRATED WASTE PACKAGE EXPERIMENTS

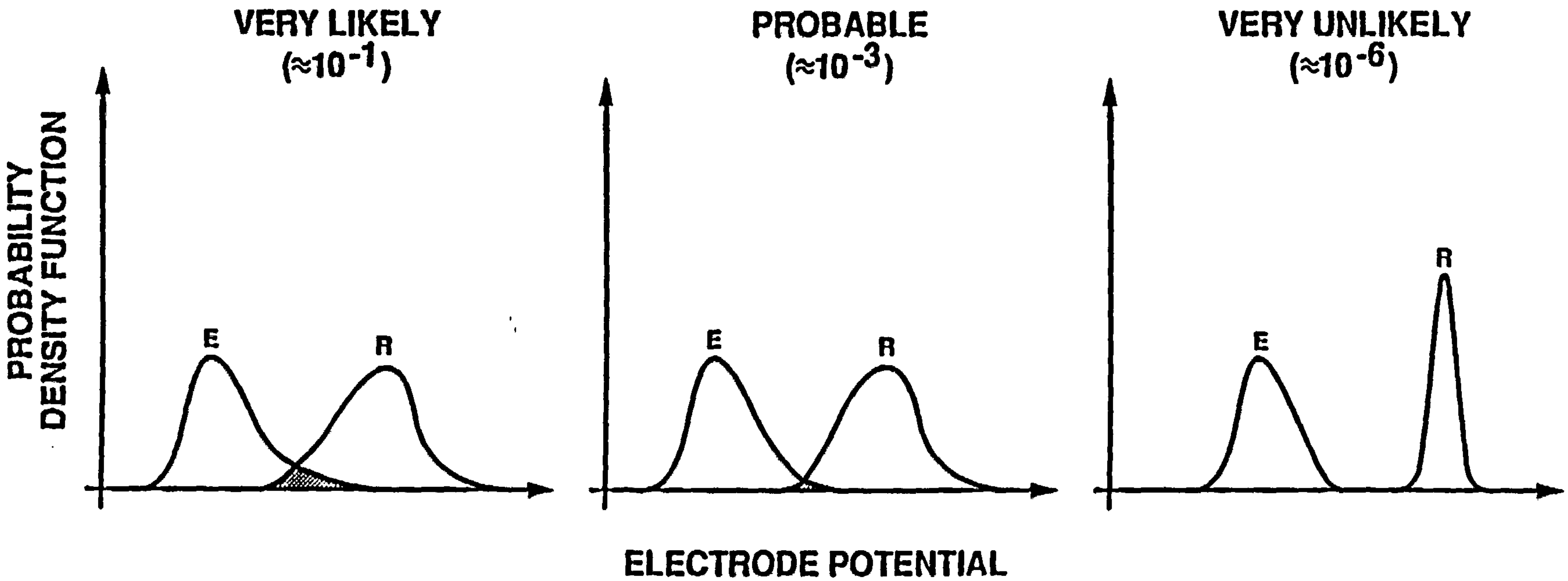
- Regulatory Basis
  - 10CFR60.113
  - 10CFR60.21(c)(1)(ii)(D)
- Uncertainty Reduction Concepts
- Controlled Test Environments
- Stepwise Testing Strategy
- Baseline Evaluations

PROBABILISTIC CORROSION PERFORMANCE ASSESSMENT

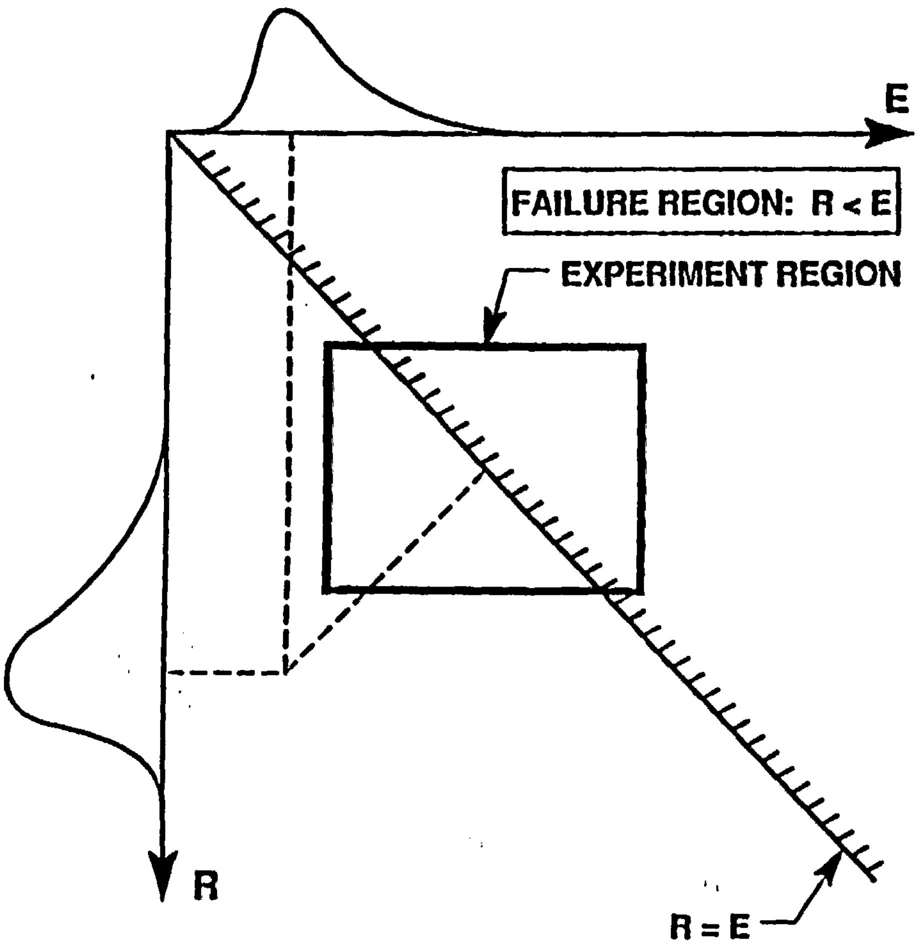
R = R (MATERIAL CHARACTERISTICS)
E = E (PH, TEMPERATURE, CHLORINE CONCENTRATION, . . .)
R, E ARE RANDOM VARIABLES



EXAMPLES OF PROBABILISTIC PERFORMANCE ASSESSMENT



SELECTION OF EXPERIMENTAL REGION TO SUPPORT PERFORMANCE ASSESSMENT



APPROACHES:

- EXPERIMENTS CONCENTRATE AT CRITICAL REGIONS
- RESULTS DIRECTLY CORRELATE WITH PROBABILITY OF FAILURE
- IDENTIFY CRITICAL PARAMETERS

CONTROLLED TEST ENVIRONMENTS

Constituents (Molal)	Field		EQ3/EQ6 Calculated				
	Yucca Mountain Vicinity	J_{13}	EQ3 25°C	EQ3 70°C	EQ3 95°C	EQ3 25°C Magnetite	EQ6 25°C Fe
Na^+	6.1×10^{-4} to 1.4×10^{-2}	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}
Cl^-	2.0×10^{-5} to 3.2×10^{-3}	1.8×10^{-4}	2.0×10^{-4}	2.0×10^{-4}	2.0×10^{-4}	2.0×10^{-4}	2.0×10^{-4}
HCO_3^-		2.7×10^{-3}	1.7×10^{-3}	1.5×10^{-3}	1.3×10^{-3}	1.7×10^{-3}	1.7×10^{-3}
fCO_2	$10^{-3.5}$ – $10^{-0.8}$	$10^{-1.8}$	$10^{-3.5}$	$10^{-3.5}$	$10^{-3.5}$	$10^{-3.5}$	$10^{-3.5}$
fO_2		Oxidizing	0.2 (bar)	0.2 (bar)	0.2 (bar)	0.2 (bar)	0.2 (bar)
pH	6.6 to 9.1	6.9	8.5	8.8	8.9	8.5	8.5

STEPWISE TESTING STRATEGY

- Scoping Tests
  - Literature Assessment
  - Other NRC/DOE Programs
  - Select Tests
- Short Term
  - Uncertainty Reduction Need Based
  - Baseline Tests
  - Performance Assessment and Statistically Valid Tests
- Long Term
  - Performance Confirmatory Tests

<u>TECHNICAL APPROACH</u>

<u>ASSESS STATE OF KNOWLEDGE</u>

- DEVELOP INFORMATION/DATA BASE -- YMP REPORTS; NRC REPORTS AND ONGOING WORK OF OTHER NRC CONTRACTORS; OPEN LITERATURE; OTHER COUNTRIES; AND CNWRA EXPERIENCE
- EVALUATE TECHNOLOGY WITH RESPECT TO YMP CURRENT WASTE PACKAGE PLANS

<u>MAJOR TOPICAL AREAS</u>

- DEFINITION OF REPOSITORY ENVIRONMENTS CONTAINERS ARE EXPECTED TO ENCOUNTER IN FIRST 1,000 YEARS -- INCLUDING LIQUID AND VAPOR PHASES AND GAMMA RADIATION
- CORROSION OF CONTAINER MATERIALS IN REPOSITORY ENVIRONMENTS -- UNIFORM CORROSION, PITTING, CREVICE CORROSION, STRESS CORROSION CRACKING (SCC), DEALLOYING, GALVANIC CORROSION, AND INTERGRANULAR CORROSION
- METALLURGICAL STABILITY -- e.g., LOW-TEMPERATURE SENSITIZATION (LTS) AND OTHER TIME-TEMPERATURE-DEPENDENT METALLURGICAL CHANGES
- OTHER FAILURE MODES -- e.g., HYDROGEN ATTACK, MICROBIOLOGICAL ACTION, AND FAILURE OF CONTAINER CLOSURES

<u>(CONTINUED)</u>

TECHNICAL APPROACH (CONTINUED)

EXPERIMENTAL PROGRAMS

OBJECTIVES

- DETERMINE FORMS OF CORROSION AND OTHER TYPES OF MATERIALS DEGRADATION THAT CAN OCCUR UNDER POSSIBLE REPOSITORY ENVIRONMENTAL CONDITIONS

- DEVELOP KINETICS DATA FOR CORROSION AND OTHER DEGRADATION MECHANISMS THAT CAN OCCUR IN THE YMP REPOSITORY

- IDENTIFY AND EVALUATE EFFECTS OF METAL-LURGICAL CHANGES THAT CAN OCCUR AS A RESULT OF FABRICATION HISTORY, THERMAL HISTORY, STRESS AND STRAIN, EXPOSURE TIME, AND ENVIRONMENTAL EXPOSURE

- DEVELOP PREDICTIVE MODELS

(CONTINUED)

CONTAINER CORROSION IN HIGH-LEVEL NUCLEAR WASTE REPOSITORIES

DR. J. A. BEAVERS and

Dr. N. G. THOMPSON

Cortest Columbus, Inc.
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Columbus, Ohio 43235

CORTEST COLUMBUS

Program Objective

Development independent experimental data to assist NRC in evaluating the uncertainties in DOE's claims concerning waste container corrosion.

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Experimental Scope

- Utilize accelerated test techniques to examine possible failure modes,
  - Electrochemical Techniques,
  - Slow Strain Rate, and
  - Mechanical Test Techniques.
- Confirm short-term test results with long term exposures.
- Expand range of environmental variables to consider processes that affect groundwater composition,
  - Rock-Water Interaction,
  - Local Boiling, and
  - Radiation.

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Program Tasks

Task 1 – Review Of Problems In The Tuff Repository,

Task 2 – Potentiodynamic Polarization Studies,

Task 3 – Vapor Phase Corrosion Studies,

Task 4 – Pitting Corrosion Studies,

Task 5 – Stress Corrosion Cracking Studies,

Task 6 – Studies Of Other Failure Modes,

Task 7 – Long Term Exposure Studies, and

Task 8 – Examination Of Modeling Efforts.

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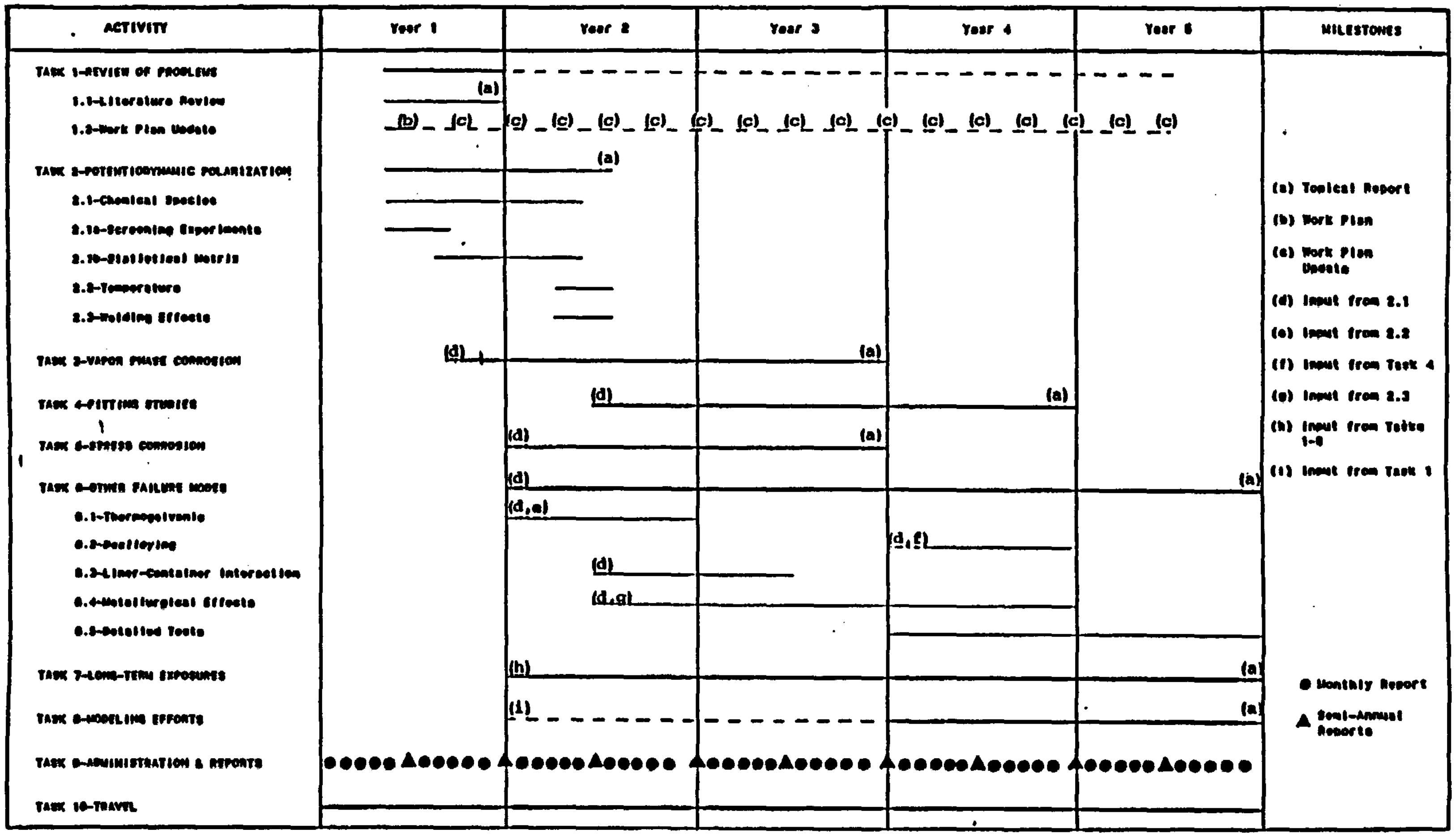

Figure 1. Schedule Of Work Plan For Each Task For The Five Year Project.

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POTENTIAL PROBLEM AREAS

- Repository Environment
  - Better Definition
  - Expansion Of Environmental Factor Space Considered in Laboratory Studies
- Metallurgical Issues
  - Stability Of Candidate Alloys
  - Effects Of Welding On Corrosion Behavior
- Pitting And Crevice Corrosion
  - Observed In Short-Term Tests For Four Alloys Considered
  - Long-Term Rates Of Propagation
  - Interpretation Of Cyclic Potentiodynamic Polarization Curves For Copper-Base Alloys

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POTENTIAL PROBLEM AREAS (CONTINUED)

- Stress Corrosion Cracking
  - Cracking Of Solution Annealed Alloy 304L Reported In Radiation Field
  - Validity Of Slow Strain Rate Test Method
  - Nitrogen Related Cracking Of Copper-Base Alloys

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