U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

NUCLEAR WASTE TECHNICAL REVIEW BOARD
PANEL ON THE ENGINEERED BARRIER SYSTEM

SUBJECT: EFFECTS OF THERMAL LOADING ON ENGINEERED BARRIER SYSTEM

PRESENTER: RICHARD P. MORISSETTE

PRESENTER'S TITLE AND ORGANIZATION: SENIOR ENGINEER,
SCIENCE APPPLICATIONS INTERNATIONAL CORPORATION
LAS VEGAS, NEVADA

PRESENTER'S TELEPHONE NUMBER: (702) 794-7783

AUGUSTA, GA
FEBRUARY 10, 1992

Outline

- Prior meetings where thermal loading discussed
- SCP thermal goals
- Near-field & far-field temperatures for various thermal loads
- Effects of thermal loading on Engineered Barrier System

NWTRB Meetings on Thermal Loading

- March 1990 - Development of Design Requirements for Repository and Waste Package
  - Influence of thermally induced effects and thermal design approach
- October 1991 - Evaluation of Ranges of Thermal Loading for HLW Disposal in Geologic Repositories
  - Current reference thermal load for a repository in Yucca Mountain
  - Thermal loading basis of other repositories
  - Issues, considerations, and implication of lower and higher thermal loads

SCP Thermal Goals

page 19 xcript

Performance Measure	Goal
Cladding Integrity	Container Centerline $T < 350\ ^{\circ}C$ Borehole Wall $T < 275\ ^{\circ}C$
Near-Field Rock Mass Integrity	One Meter from Borehole $T < 200\ ^{\circ}C$
Access Drift Wall Temperature	$T_{wall} < 50\ ^{\circ}C$ for 50 years
Temperature Change in Adjacent Strata	TSw2 - TSw3 Interface $T < 115\ ^{\circ}C$
Surface Environment	Temperature Change $< 6\ ^{\circ}C$
Limit Corrosiveness of Canister Environment	Maximize Time Spent Above Boiling in Borehole Environment

Bases for 200 °C Temperature Limit at One Meter from Borehole

xcript p21

- Requirement
  - Reduce potential for borehole collapse

- Bases
  - Welded tuff phase change around 200 °C to 250 °C
  - 5 mm radial displacement predicted at borehole wall indicates insignificant rock movement in borehole

- Need for further evaluation
  - True magnitude of phase change
  - Actual stress/strain state at borehole surface and predict potential for borehole failure

Ref: SAND89-1989

Peak Fuel Cladding Temperature

P2 2

- Creep/stress rupture is dependent on time-at-temperature/environment

- 1986 PNL study (1) indicated a 380 °C max. Zircaloy cladding temperature for long-term dry storage in an inert environment

- 1990 LLNL study (2) indicated 300-340 °C max. Zircaloy cladding temperature for 1000-year life in dry environment 1000 yrs

Ref: (1) Chin, B. A., et al., PNL-5998, Deformation and Fracture Map Methodology for Predicting Cladding Behavior During Dry Storage, September 1986

(2) Chin, B. A., et al., UCRL-100212, Zircaloy Cladding Degradation under Repository Conditions, December 1990

Outline

- Prior meetings where thermal loading discussed
- SCP thermal goals
- Near-field & far-field temperatures for various thermal loads
- Effects of thermal loading on Engineered Barrier System

Repository Design Scenarios

Feature	SCP-CDR Design	Modified Design (SNL)	Drift Emplacment (LLNL)
Orientation	Vertical/Horizontal	Vertical	Drift
Available Panels	17	15	17
Start Date	1998	2010	2010
Receipt Schedule	FIFO	Levelized	Levelized
Treatment of DHLW	Commingled	Segregated	Commingled
DHLW Initial Power Output	0.2 to 0.4 kW/ Container	0.2 kW/Container	0.2 kW/Container
SF Container Configuration	Consolidated	Intact Hybrid (4 BWR, 3 PWR)	Intact (5-26 PWR)
# of SF Containers	~25,000	~31,000	~7,000 (26 PWR)
Average SF Age	10 years	30-90 years	30-60 years
Average SF Initial Power Output	3 kW/Container	1.5-0.66 kW/ Container	1.6-5 kW/ Container
Design-Basis APD	57 kW/acre	80-22 kW/acre	20-114 kW/acre
Drift Spacing	126 ft	53 ft	126 ft
Container Spacing	15 ft	Variable	End to End
Standoffs from Mains	200 ft	150 ft	TBD

Models Used for Thermal Loading Studies

- Conduction model (SNL)
  - 3-D linear superposition of heat generators
  - Stepped emplacement of SF
  - Complete geometric model
  - Scaling of emplacement densities
  - Conduction only

- Two-phase hydrothermal models (LLNL)
  - Repository-scale model using finite disk heat source
  - Drift-scale model using infinite repository with axial heat source
  - Instantaneous thermal load
  - V-TOUGH code with conduction, convection, radiation, boiling and condensation

Normalized Area Required for Repository as a Function of Initial APD and Spent Fuel Age*

	20 kW/acre	36 kW/acre	57 kW/acre	80 kW/acre	100 kW/acre
10-year-old fuel	2.85	1.57	1.00	0.71	0.57
30-year-old-fuel	1.81	1.00	0.64	0.45	0.36
60-year-old fuel	1.14	0.63	0.40	0.29	0.23
100-year-old fuel	0.73	0.40	0.25	0.18	0.15

* Areas are divided by area for the reference SCP-CDR design

Modified SCP-CDR Design Peak Temperatures*

Design-Basis APD (kW/acre)	80	57	48	30	22
Average Waste Age (years)	30	30	30	60	90
Average Initial Power Output (kW/container)	1.52	1.52	1.52	0.95	0.66
Location	Temperature (° C)				
Borehole Wall	170	147	132	103	95
1-meter Radially	158	135	118	97	91
Depth Below waste					
50 m	107	94	86	77	74
70 m	100	89	81	74	71
90 m	94	84	77	60	59
Time to Boiling Front Coalescence Betw. Drift (yrs)	12	19	31	n/a	n/a

* Source: E. Ryder, SNL (Conduction model)

Drift Emplacement Design Peak Temperatures and Extent/Saturation of Dry Out Zone*

Design-Basis APD (kW/acre)	114	100	80	57	36
Average Waste Age (years)	60	30	30	30	30
	Temperature (° C)				
Drift Wall	277	180	150	123	90
Waste Package Wall	283	202	174	137	102
60 m Below Waste	212	136	115	94	71
	Dry Out Zone (m)				
Above Waste @ 1000 years	205	130	104	50	0
Below Waste @ 1000 years	157	115	106	50	0
Above Waste @ 5000 years	190	120	96	40	0
Below Waste @ 5000 years	166	166	166	50	0
	Rock Saturation (%)				
Drift Wall @ 1000 years	0	0	4	11	66
Drift Wall @ 10,000 years	0	9	12	30	67
Drift Wall @ 100,000 years	15	46	55	66	67

* Source: T. Buscheck, LLNL (Hydro-thermal model)

Outline

- Prior meetings where thermal loading discussed
- SCP thermal goals
- Near-field & far-field temperatures for various thermal loads
- Effects of thermal loading on Engineered Barrier System

Effects of Thermal Loading on EBS

- Effects on EBS Environment
  - Geomechanical
  - Geochemical
  - Hydrogeological

- Effects on EBS components
  - Containers
  - Waste form
  - Other EBS Components

Potential Geomechanical Effects of Thermal Loading

- Rock mass
  - Rock Mass modulus and stress changes with temperature/time
  - Stability of usable areas changes due to changes in modulus and stress

- Fractures
  - Open fractures in regions of tensional stress
  - Close fractures in region of compressive stress
  - Fracture permeability changes due to changes in fracture size

Resolution of Uncertainties Due to Geomechanical Effects

- Existing scientific plans address uncertainties associated with geomechanical effects
- Thermal loads must be incorporated into the design
- Design methodology is independent of degree of thermal load
- Available experience in underground excavations with comparable stress magnitudes will be considered
- Joint slip or fracture propagation will be evaluated through analysis and testing

Potential Geochemical Effects of Thermal Loading

- Dissolution/precipitation (under aqueous conditions)
  - Increase fracture healing
  - Increase dissolution/precipitation in fracture networks
  - Change silica activities which influence the development of assemblages
  - Form additional zeolites and clays
  - Alter permeability and porosity
  - Potential for oxidation of mineral phases

- Cation exchange
  - Alter sorption capability

- Radiolysis effects

Resolution of Uncertainties Due to Geochemical Effects

- Existing scientific plans address uncertainties associated with geochemical processes
- Geochemistry and hydrology is being integrated
- Elements of a near-field geochemistry program required to resolve issues:
  - Modeling applications
  - Experimental-rock/water interaction
  - Thermodynamic and kinetic data acquisition and development
  - Model development
  - Natural analogue studies

Potential Hydrogeologic Effects of Thermal Loading

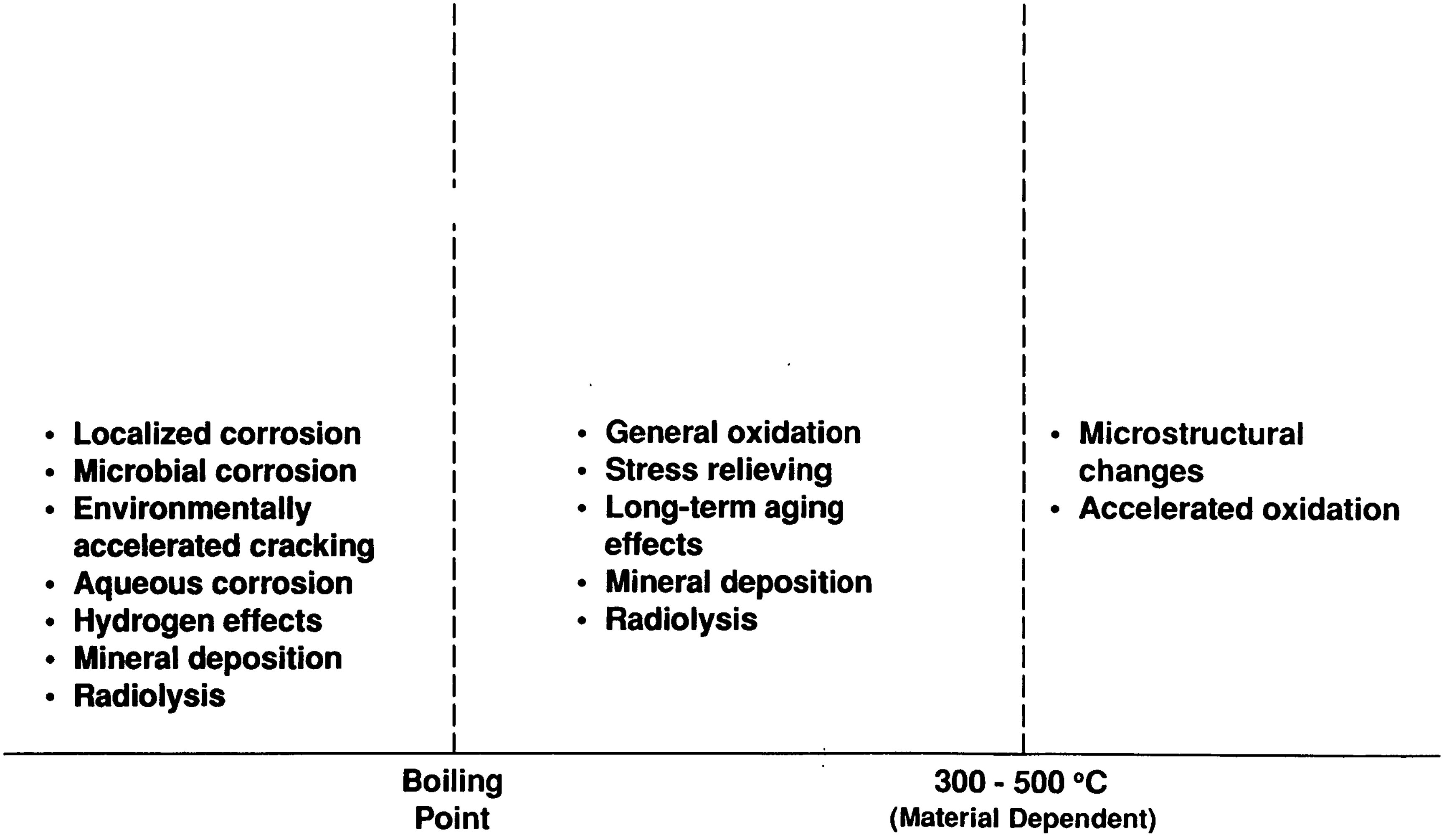
- Fracture flow
  - Increase matrix imbibition
  - Alter flow and transport properties
  - Attenuate episodic fracture flow
  - Promote rapid condensate drainage around and below waste

- Rock dry out/water availability
  - Increase boiling and water transport away from EBS
  - Increase extent of rock dry-out
  - Produce a dry steam environment

Resolution of Uncertainties Due to Hydrogeologic Effects

- Thermal hydrogeologic coupled models will address range of thermal loads
- Hydrogeologic uncertainties are reduced for high thermal loads
- Testing at higher temperature conditions provides better experimental basis for model validation
- Site characterization testing will support model validation

Potential Effects of Thermal Loading on Container Degradation



- Localized corrosion
- Microbial corrosion
- Environmentally accelerated cracking
- Aqueous corrosion
- Hydrogen effects
- Mineral deposition
- Radiolysis

- General oxidation
- Stress relieving
- Long-term aging effects
- Mineral deposition
- Radiolysis

- Microstructural changes
- Accelerated oxidation

Potential Effects of Thermal Loading on Waste Form Degradation

- No glass devitrification below 450 °C
- Under wet conditions glass vapor hydration rate increases with temperature
- Under wet conditions SF pellet and glass dissolution rate increases with temperature
- SF pellet oxidation rate increases with temperature
- Dissolution rate dependent on environmental history of waste form prior to liquid contact
- Zircaloy fuel rod cladding degradation reduced in the 100 - 300 °C temperature range

Resolution of EBS Component Uncertainties Due to Effects of Thermal Loading

- Long-term material testing under range of anticipated environments is necessary
- Characterization of post-emplacement waste-form behavior will continue
- Studies will be performed that will consider waste-form behavior and containment design under range of anticipated environment
- Performance confirmation testing through retrievability period will reduce remaining uncertainties

Summary

- DOE continues to analyze the range of thermal loads and is developing thermal management scenarios
- Selection of a repository thermal management strategy will consider impacts on the total civilian radioactive waste management system (CRWMS)
- The CRWMS M&O has initiated a study of these system implications

RICHARD P. MORISSETTE

EDUCATION: M.B.A., San Diego State University, (1979)
B.S., Mechanical/Nuclear Engineer,
San Jose State Univ., (1961)

EXPERIENCE:

5 YEARS WITH SAIC-YUCCA MOUNTAIN PROJECT: Currently a Senior Engineer in the Field Test Facility Support Department providing technical and management support to the Yucca Mountain Project Office (YMPO). Provided integration of the U.S. waste package program and repository program ongoing at Lawrence Livermore National Laboratory and Sandia National Laboratory. Provided input to and review of the program budget and schedule, design and testing activities, and materials development. Prepared and maintained management, task plans, and design interfaces between the repository and the waste package.

20 YEARS WITH GENERAL ATOMICS: As a nuclear waste and fuel engineer, developed characterization data for the Oak Ridge National Laboratory on spent fuel from gas-cooled and experimental reactors. Developed a universal canister concept for handling spent fuel from light water reactors to MRS to repository. Prepared the initial evaluation of an MRS including initial siting and transportation evaluations, system objectives, functional requirements and system descriptions, and concept evaluations. Developed business strategies involving uranium and nuclear fuel. Participated in Fort St. Vrain Nuclear Generating Station fuel and core component design, fabrication, and initial core loading and was responsible for planning and coordinating the total fuel cycle. Lead Engineer on the fuel test program conducted in Peach Bottom HTGR.

5 YEARS WITH GENERAL ELECTRIC: As a Design and Test Engineer at Vallecitos Atomic Laboratory, was involved in all phases of nuclear facility operation. Activities included design and safety analysis of in-reactor fuel testing systems, underwater inspection and disassembly equipment, reactor coolant cleanup systems, reactor fuel and core components. A Licensed Reactor Operator at the General Electric Test Reactor and Radiation Monitor at Vallecitos Boiling Water Reactor. Coordinated hot cell repair of reactor equipment and participated in reactor reload operations, outage maintenance, and spent fuel handling and shipping.