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

NUCLEAR WASTE TECHNICAL REVIEW BOARD
JOINT PANELS ON HYDROGEOLOGY & GEOCHEMISTRY AND STRUCTURAL GEOLOGY & GEOENGINEERING

SUBJECT: DOE'S APPROACH TO COUPLED T-M-H-C PROCESSES

PRESENTER: DR. ARDYTH M. SIMMONS

PRESENTER'S TITLE AND ORGANIZATION: TEAM LEADER, GEOCHEMISTRY
YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
LAS VEGAS, NEVADA

TELEPHONE NUMBER: (702) 794-7998

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Outline

- Introduction
- Acceptable approach for demonstrating compliance with 10 CFR 60.133(i)
- Iterative approach
- Status and plans
- How performance assessment will use coupled T-M-H-C process models
- Conclusions

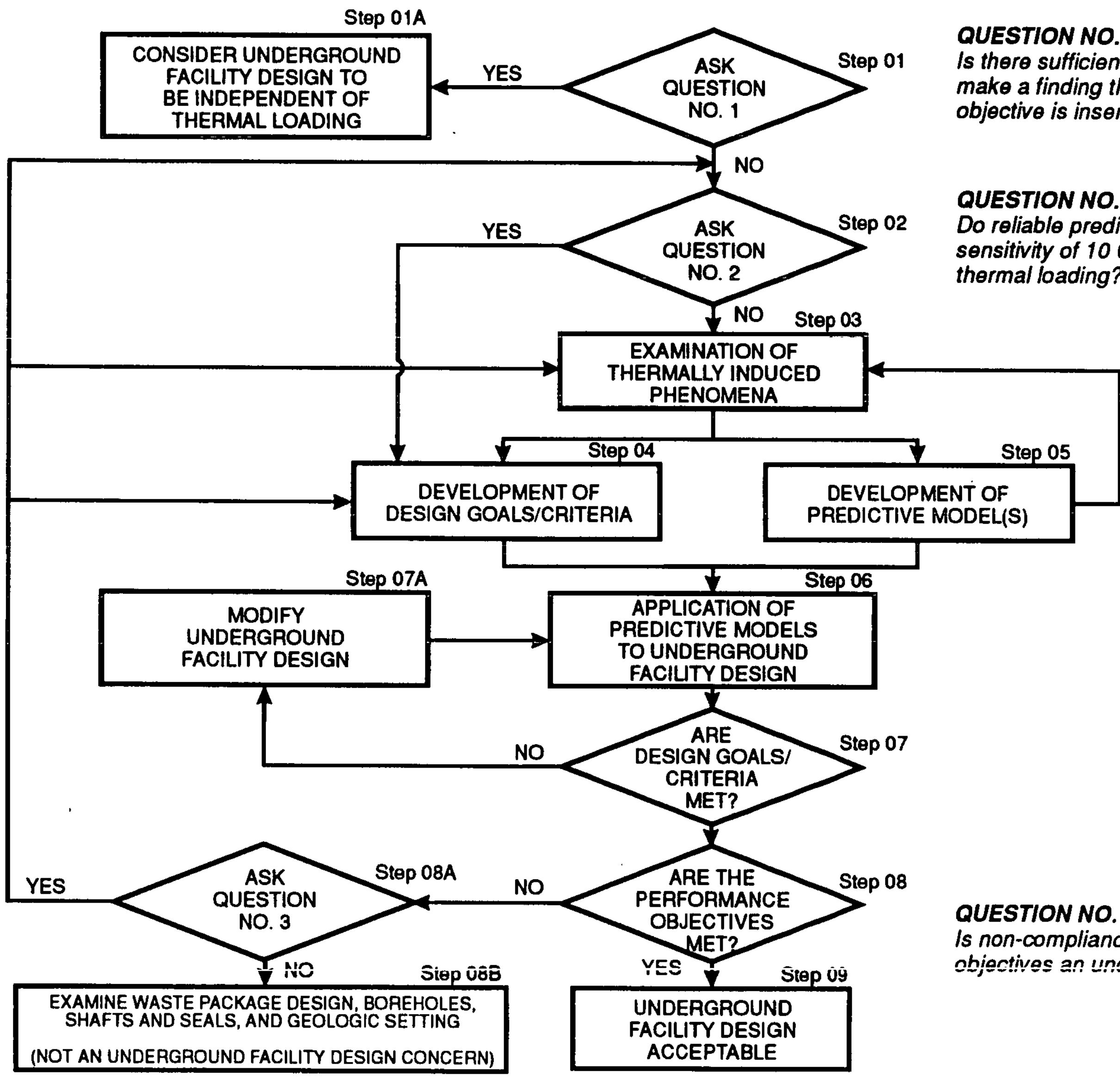
Introduction

- DOE must demonstrate a logical systematic understanding of coupled T-M-H-C* responses associated with a particular GROA** underground facility design
- This will be based primarily on a mechanistic understanding of highly coupled processes
- To demonstrate compliance with 10 CFR 60.133(i), DOE must consider coupling of T-M-H-C processes in a manner that is not likely to underestimate the unfavorable aspects of repository performance or overestimate the favorable aspects in the context of analyses and design
- Performance assessment models will be capable of incorporating predicted T-M-H-C responses associated with a GROA underground facility design

* *T-M-H-C = Thermal-Mechanical-Hydrological-Chemical*

** *GROA = Geologic Repository Operations Area*

The Logic Flow of an Acceptable Methodology for Demonstrating Compliance with 10 CFR Part 60.133(i)



QUESTION NO. 1:
Is there sufficient understanding and/or experience to make a finding that a 10 CFR Part 60 performance objective is insensitive to thermal loading?

QUESTION NO. 2:
Do reliable predictive models exist to quantify the sensitivity of 10 CFR Part 60 performance objectives to thermal loading?

QUESTION NO. 3:
Is non-compliance with 10 CFR Part 60 performance objectives an underground facility design-related problem?

Development of Detailed and Alternative Predictive Models

- Develop models that approximate coupled behavior in a manner that is not likely to underestimate the unfavorable aspects or overestimate the favorable aspects of repository performance; and
- Present such plans for *in situ* and laboratory monitoring and testing, and for additional model development/refinement, as may be appropriate to confirm the adequacy of the analytical methods used to support the application for construction authorization
- Develop models to predict the thermal and thermo-mechanical response of the host rock, surrounding strata, and groundwater system, based on a mechanistic understanding of coupled T-M-H-C behavior
- Balance mechanistic/deterministic with empirical/probabilistic approaches

Iterative Approach

- **Development of coupled T-M-H-C models will be based on an understanding *proportional to the impact of coupling* on overall performance of repository**

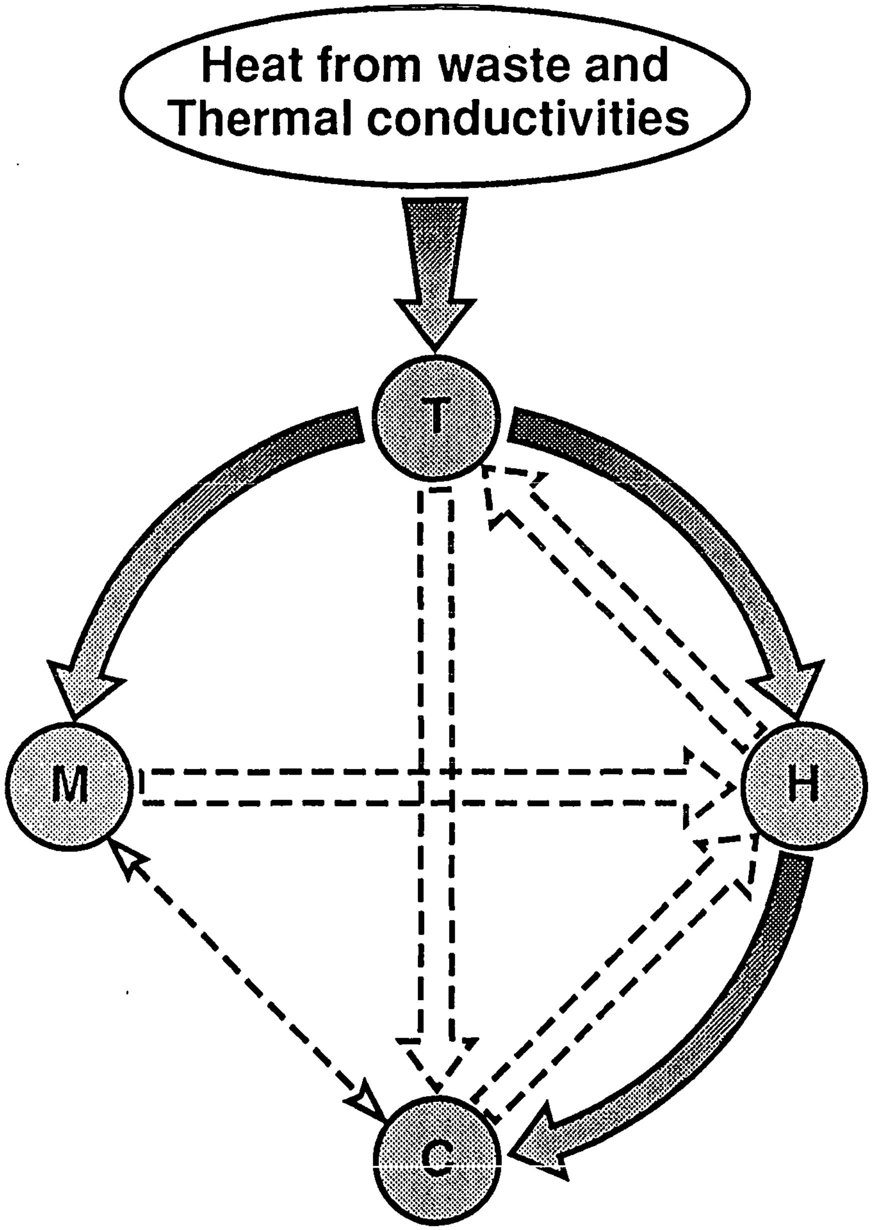
- **Advanced Conceptual Design considering two thermal regimes that have different couplings**

- **Modeling and testing at various scales to ensure that an appropriate level of detail will be included in the analysis**

- **The rigor of model confidence-building and testing against experiments will depend on temporal and spatial scales**

Iterative Approach
(CONTINUED)

- Balance between unworkable complexity and oversimplification of processes; however, some residual uncertainty will remain
- Assess effects of uncertainties associated with model assumptions on predicted results
- Will use conservative data and assumptions to compensate for uncertainties



Type of coupling

Primary coupling

Primary but judged lesser magnitude

Secondary or judged smallest magnitude

Coupling Investigations Sequence

Through testing identify which linkages are important. Work towards adequate coupling (full coupling may be unrealistic and unnecessary)

- Thermal-mechanical
- Thermal-hydrological
- Thermal-geochemical
- Mechanical-hydrological
- Hydrologic-geochemical
- Add second level of coupling
  - Thermo-hydrological-mechanical
  - Thermo-hydrological-geomechanical
  - Thermo-mechanical-geochemical

Status and Plans

- Needs for 1998, 2001, 2008, performance confirmation

Evolving Thermal Test Schedule

2008 • **Operating License**
- Increased confidence in pre- and post-closure coupled response

2001 • **Subsystem and Total System Performance Assessment (TSPA) for License Application**

• **Substantially complete containment demonstration**
- The most fundamental hydrothermal hypotheses tested
- Remaining hydrothermal hypotheses bounded
- Fundamental thermo-mechanical response measured

Evolving Thermal Test Schedule

(CONTINUED)

1997 • Begin early thermal testing

• Technical Site Suitability analysis (TSPA: postclosure performance, groundwater travel time)
  - Large block test data
  - ESF observations

1996 • First access to host rock for early test in ESF

• Preliminary data from small blocks

• Laboratory test data

• Technical Basis Report: Subsurface Geology

TSPA Will Use Coupled T-M-H-C Process Models

- TSPA has identified conceptual model/hypothesis testing needs as well as thermally dependent information needs
- Abstraction and sensitivity analysis will be developed at process level

Examples of TSPA Thermally Dependent Information Needs

- Hydrologic properties
  - Porosity, permeability
  - Capillary pressure *vs* saturation curve
  - Capillary pressure behavior at sub-residual saturations
- Geochemical properties
  - Solubility
  - Distribution coefficient

Examples of TSPA Conceptual Model/ Hypotheses Testing Needs

- Conductive _vs_ convective heat transfer
- Significance of enhanced vapor diffusion
- Vapor pressure lowering due to capillarity, increased salinity, etc.
- Potential for buoyant gas convection
- Potential for non-equilibrium fracture flow

Summary of *In Situ* Coupled Test Program

Test Name	Processes	Duration (yrs)	Temp (°C)	Information Needs	Perf. Obj.	Characteristics
Axisymmetric	T	<2	250	Fracture flow Dryout front Δ K	2001	Single heater Simple geometry
Heated Block	T-M	<2	200	Fracture prop. Rock mass strength, deformation thermal exp.	2001	Controlled boundary conditions
Thermal Stress	T-M-H	<2	To thermal stress failure	Rock mass behavior and Δ K, mmm, NFE	2001	Simulates in-drift emplacement
Abbreviated Heater	T-H	3	200	Fracture properties Δ K, NFE, dry-out	Post-2001	Isolated and sealed
Long-term Heater	T-M-H-C	4-7	200	Rock-mass behavior changes in mineralogy, water chemistry hydrologic properties	Post-2001	3-D access

Conclusions

- Sequential nature of repository licensing provides for *in situ* testing over long periods of performance-confirmation before final closure decision

- Confidence building in coupled models is the expected process for reasonable assurance

- Detailed information needs for thermal testing support performance assessment models which, in turn, support compliance strategies

Studies That Address M-H-C Processes Coupled with Heat

8.3.4.2.4.1	Chemical and Mineralogical Changes of the Post-Emplacement Environment
8.3.4.2.4.2	Hydrologic Properties of the Waste Package Environment
8.3.4.2.4.3	Mechanical Attributes of the Waste Package Environment
8.3.4.2.4.4	Engineered Barrier System Field Tests
SIP	Large Block Test
8.3.4.2.4.5	Effects of Man-Made Materials on Chemical and Mineralogical Changes of the Post-Emplacement Environment
8.3.1.20.1	Characterization of the Altered Zone
8.3.1.3.7.1	Retardation Sensitivity Analysis
8.3.1.3.3.2	Kinetics and Thermodynamics of Mineral Evaluation
8.3.1.3.3.3	Conceptual Model of Mineral Evolution
SIP	Integrated Radionuclide Release: Tests and Models
8.3.1.15.1.1	Laboratory Thermal Properties
8.3.1.15.1.2	Laboratory Thermal Expansion Testing
8.3.1.15.1.3	Laboratory Determination of Mechanical Properties of Intact Rock
8.3.1.15.1.4	Laboratory Determination of Mechanical Properties of Fractures
8.3.1.15.1.6	*In Situ* Thermomechanical Properties