NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: EXPERIENCE IN NUMERICAL MODELING OF GEOTHERMAL SYSTEMS

PRESENTER: GUDMUNDUR S. BODVARSSON

PRESENTER'S TITLE AND ORGANIZATION: STAFF SCIENTIST
LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA

PRESENTER'S TELEPHONE NUMBER: (510) 486-4789

DENVER, COLORADO
JULY 13-14, 1993
Outline

• Major objectives in modeling of geothermal systems
• General approach in the modeling of geothermal systems
• Available data/history matching
• Major data deficiencies
• Uncertainties and limitations of numerical models
• Olkaria, Kenya, example
• Implications for modeling of Yucca Mountain
Major Objectives in Modeling Geothermal Systems

• To assess the generating capacity of the system
  – How large a power plant

• To guide in the development of the field
  – Where to drill production wells
  – Where to inject the waste-water

• To predict the future power generation
  – For input into economic forecast models
Schematic of Different Physical Processes Occurring in Geothermal Systems

- Wastewater for Reinjection
- Injection Well
- Subsidence
- Production Wells
- Separator
- Steam to Power Plant
- Water Table
- Caprock
- Lense
- Cold Water Recharge
- Natural Convection
- Chemical Mixing
- Chemical Precipitation
- Forced Convection
- Conductive Heat Source
- Hot Water
- Boiling Water
- Steam Moving
- Water Moving

(Best Available Copy)
Reservoir Evaluation
General Approach

Field Data

Conceptual Model

Natural-State Model

Well Test Data

Reservoir Model

Production History

Sensitivity Studies

Conservative Reservoir Model

Performance Model
Ahuachapán Model Development

Grid Design  Calibration  Performance Predictions

Geological Model  Reservoir Boundaries  Geochem. Data  Recharge/Discharge Areas  Temperature Distribution  Pressure Distr.  2-Phase Zone  Spring Outflows  Location of New Wells  Flow Capacity of New Wells  Sequence of New Wells

Ahuachapán 3-D Model

Temperature Distribution  Pressure Distr.  2-Phase Zone  Spring Locations  Flow Rate Changes  Enthalpy Changes  Pressure Changes  Spring Flow Changes  Power Output  Injection %  Economics

DCNMGB5P5.125NWTRB/7-13/14 93
Most Important "Available" Data

- Temperature and pressure distributions in 3D
- Horizontal transmissivity distribution
- Porosities and permeabilities of cores (matrix properties)
- Flow rate, enthalpy, and chemistry histories of production wells
- Injection rates and temperatures
- Reservoir pressure decline
- Repeat gravity surveys
Most Important “Missing” Data

- Reservoir thickness
- In-place liquid saturation (vapor-dominated system)
- Vertical transmissivities
- Relative permeability and capillary pressure curves
History Matching:
Iterative Matching of Natural-State and Exploitation Data

- Temperature and pressure distribution (natural state)
- Horizontal transmissivity distributions
- Exploitation histories of production wells
  - Flow-rate histories
  - Enthalpy histories
  - Chemical concentration histories (non-condensible gases, chlorides, etc.)
- Pressure decline at observation wells
- Repeat gravity surveys (development of two-phase zones)
Location of the Olkaria Geothermal Field in the Rift Valley
Uncertainties and Limitations of Numerical Models

- Depend on
  - Reliability of the conceptual model
  - Importance of the “missing” data
  - Quantity and quality of the “history match” data
  - Modeler

- Generally, can predict reasonably and reliably the power generation of a geothermal system with significant exploitation history

- Predictions of chemical transport in geothermal systems are very uncertain
Conclusions

• Numerical modeling of multi-phase, multi-component systems is very complex
  - Unless verified, results, are only unproven hypothesis

• Experience from geothermal modeling shows many examples of poor hypothesis, with power plants running at fraction of installed capacity

• Current methodology in modeling geothermal systems is solid and generally yields reasonable predictions for extraction rates; hence, for power output

• The modeling of chemical or heat transport is much less certain than for modeling geothermal systems because of the lack of understanding of processes and the geohydrological structure