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

PRESENTATION TO
THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: NEAR-FIELD THERMAL FLUID EFFECTS

PRESENTER: DR. JOHN J. NITAO

PRESENTER'S TITLE AND ORGANIZATION: HYDROLOGIST,
LAWRENCE LIVERMORE NATIONAL LABORATORY
LIVERMORE, CALIFORNIA

PRESENTER'S TELEPHONE NUMBER: (415) 423-0297

MARCH 19-20, 1990
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OBJECTIVE OF STUDY

- PREDICT FLUID FLOW AND TEMPERATURE DISTRIBUTIONS AROUND THE WASTE PACKAGE USING NUMERICAL MODELS

- QUANTIFY THE EFFECT OF ADDING FLUID FLOW TO CONDUCTION-ONLY ANALYSES

- FIND WHAT PROCESSES GIVE RISE TO THESE TEMPERATURE DIFFERENCES

- PERFORM EXPERIMENTS TO VALIDATE MODELS
EFFECT OF CONVECTIVE AND LATENT HEAT ON TEMPERATURE DISTRIBUTIONS

- VAPORIZATION AND MOVEMENT OF PORE WATER AND ITS CONDENSATION IN FRACTURES WILL AFFECT NEAR-FIELD TEMPERATURES

- BUT, BECAUSE OF COMPUTATIONAL COST, ANALYSES OF MULTIPLE WASTE PACKAGE GEOMETRIES WITH REALISTIC EMPLACEMENT SCHEDULES CAN ONLY BE DONE USING THERMAL CONDUCTION-ONLY MODELS

- HOWEVER, IT IS POSSIBLE TO DETERMINE THE RELATIVE IMPORTANCE OF THESE EFFECTS BY SIMULATING SINGLE WASTE PACKAGE GEOMETRIES
INFLUENCE OF NEAR-FIELD TEMPERATURE DISTRIBUTIONS AND THERMALLY-DRIVEN WATER MOVEMENT

- WASTE PACKAGE CORROSION RATES
- WASTE FORM DISSOLUTION RATES
- GEOCHEMISTRY
- HYDROLOGY
- BOREHOLE STABILITY
- BUOYANCY-DRIVEN GAS FLOW
APPROACH TO PREDICTING NEAR-FIELD FLUID AND ENERGY MOVEMENT

- MODEL DEVELOPMENT
- PRELIMINARY SCOPING CALCULATIONS
- LABORATORY EXPERIMENTS
- FIELD TESTS
LONG-TERM COMPUTER SIMULATIONS USING THE VTTOUGH CODE

- FINITE DIFFERENCE
- THERMAL CONDUCTION AND RADIATION
- LATENT HEAT OF BOILING
- CONVECTIVE HEAT TRANSFER BY AIR, LIQUID, AND WATER VAPOR
THERMAL LOADING USED IN THE NUMERICAL SIMULATION

- 8.6 YEAR-OLD PWR SPENT FUEL
- 5.05 m-LONG WASTE PACKAGE
- 3.4 kW INITIAL OUTPUT
- 57 kW/ACRE INITIAL LOADING
MODEL GEOMETRY - INFINITE ARRAY OF HORIZONTAL WASTE PACKAGES

0.1 mm/yr

38 m

ground surface

symmetry plane

horizontal WP

midplane between drifts

water table

19 m

Problem Domain
PREDICTION OF DRYING AROUND THE WASTE PACKAGE

LIQUID SATURATION ALONG VERTICAL CENTER LINE THROUGH WASTE PACKAGE

PRE-EMPLACEMENT

WASTE PACKAGE

400 800 YR
SHADED REGION DENOTES WATER IN FRACTURES AT 30 YEARS

HORIZONTAL DISTANCE FROM WASTE PACKAGE (m)

VERTICAL DISTANCE FROM WASTE PACKAGE (m)
COMPARISON OF TEMPERATURE AT BOREHOLE WALL 0-160 YRS

TIME (YEARS)

TEMPERATURE (°C)

--- INC. FLUID FLOW
--- NO PORE FLUID (THERMAL CONDUCTION ONLY)
COMPARISON OF TEMPERATURE AT BOREHOLE WALL 0-2000 YRS

- INC. FLUID FLOW
- NO PORE FLUID (THERMAL CONDUCTION ONLY)
HEAT PIPE EFFECT - THE PRINCIPAL EFFECT ON THERMAL FIELD CAUSED BY FLUID FLOW
COMPARISON OF TEMPERATURE ALONG VERTICAL THROUGH WASTE PACKAGE AT 100 YRS

INC. FLUID FLOW
THERMAL CONDUCTION ONLY

HP
HP REGION
BOILING POINT

TEMPERATURE (°C)
VERTICAL DISTANCE RELATIVE TO WASTE PACKAGE (m)
COUNTER-FLOWING FLUID VELOCITY VECTORS AT 400 YEARS

GAS PHASE VELOCITY

LIQUID PHASE VELOCITY

WASTE PACKAGE

HORIZONTAL DISTANCE FROM WASTE PACKAGE CENTER (m)

VERTICAL DISTANCE FROM WASTE PACKAGE CENTER (m)
FIELD EXPERIMENT - PROTOTYPE HEATER TEST AT G-TUNNEL

- 1.1 kW/m HEAT LOADING FOR 130 DAYS
- 65 DAYS LINEAR RAMPDOWN
COMPARISON OF TEMPERATURES
MODEL vs. EXPERIMENT

LOWER BOREHOLE WALL

R = 0.55m

R = 2.4m

MODEL
EXPERIMENT
LIQUID SATURATION IN MATRIX AT 70 DAYS

SORPTION OF CONDENSED WATER IS OVER PREDICTED

PREDICTION OF DRYING IS GOOD

CALCULATED
MEASURED ne2a
SUMMARY

- **PEAK WASTE PACKAGE TEMPERATURE IS NOT STRONGLY AFFECTED BY FLUID FLOW EFFECTS**

- **EFFECT OF FLUID FLOW ON THERMAL FIELD IS NOT SIGNIFICANT UNTIL THE COOL-DOWN PERIOD; RESULTS IN COOLER TEMPERATURES AROUND WASTE PACKAGE BY ABOUT 10°C**

- **THE DIFFERENCE BETWEEN CONDUCTION-ONLY MODELS AND CONDUCTION PLUS FLUID MODELS IS CAUSED PRIMARILY BY HEAT PIPE EFFECTS**
SUMMARY

- FLUID EFFECTS MOVE THE LOCATION OF THE BOILING ISOTHERM SIGNIFICANTLY CLOSER TO THE WASTE PACKAGE THAN THAT PREDICTED BY THERMAL CONDUCTION-ONLY ANALYSES

- RETURN OF WATER TO BOREHOLE OCCURS SEVERAL HUNDRED YEARS AFTER THE TIME PREDICTED BY THE THERMAL CONDUCTION MODEL

- FIELD TESTS PARTIALLY CONFIRM MODEL'S ABILITY TO PREDICT TEMPERATURES AND DRYING AROUND WASTE PACKAGE; HEAT PIPE PHENOMENA VALIDATION WILL REQUIRE FURTHER TESTING
CURRENT WORK

- COMPUTER MODELS ARE CURRENTLY BEING VALIDATED BY COMPARISON WITH FIELD AND LABORATORY EXPERIMENTS

- SIMULATIONS FOR VERTICAL EMPLACEMENT GEOMETRY ARE BEING CONDUCTED

- ANALYTICAL TECHNIQUES ARE BEING DEVELOPED FOR PREDICTING THE EFFECT OF FLUID FLOW ON MULTIPLE WASTE PACKAGES