

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

**PRESENTATION TO
THE NUCLEAR WASTE TECHNICAL REVIEW BOARD**

**SUBJECT: SUMMARY OF
SATURATED-ZONE TESTING**

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**PRESENTER'S TITLE
AND ORGANIZATION: ASSOCIATE CHIEF
HYDROLOGIC INVESTIGATIONS SECTION
YUCCA MOUNTAIN PROJECT
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STUDIES OF REGIONAL GROUND-WATER FLOW SYSTEM

(SCP SECTIONS 8.3.1.2.1.3 AND 8.3.1.2.1.4)

OBJECTIVES:

- **REFINE KEY HYDROLOGIC VARIABLES TO ALLOW COMPARISON OF CURRENT AND ALTERNATIVE REPRESENTATIONS OF SYSTEM**
- **OBTAIN HYDROLOGIC, HYDROCHEMICAL, AND GEOPHYSICAL DATA FOR MODELS OF GROUND-WATER FLOW TO DETERMINE MAGNITUDE AND DIRECTION OF FLOW**
- **SYNTHESIZE DATA INTO CONCEPTUAL MODELS OF REGIONAL AND SUB-REGIONAL FLOW SYSTEMS**
- **CONSTRUCT AND APPLY NUMERICAL MODELS OF FLOW**

STUDIES OF REGIONAL GROUND-WATER FLOW SYSTEM

(CONTINUED)

USE OF INFORMATION:

- **DETERMINATION OF FLOW PATHS AND VELOCITIES FOR RADIONUCLIDE TRANSPORT IN SATURATED ZONE**
- **INITIAL AND BOUNDARY CONDITIONS FOR DETAILED SITE-SCALE STUDIES AND MODELS**
- **BASIS FOR ASSESSING EFFECTS OF POSSIBLE FUTURE CLIMATIC AND TECTONIC CHANGES ON SATURATED-ZONE FLOW**

STUDIES OF REGIONAL GROUND-WATER FLOW SYSTEM

(CONTINUED)

GEOMETRY OF GROUND-WATER FLOW CURRENT UNDERSTANDING

- **RECHARGE AT PAHUTE AND RAINIER MESAS NORTH OF YUCCA MOUNTAIN**
- **SOUTHWARD FLOW THROUGH TERTIARY VOLCANIC ROCKS BENEATH YUCCA MOUNTAIN**
- **SOUTHWARD FLOW THROUGH TERTIARY SEDIMENTARY ROCKS BENEATH AMARGOSA DESERT**
- **DISCHARGE AS EVAPOTRANSPIRATION AT FRANKLIN LAKE PLAYA**
- **DEEPER NORTHEAST-TO-SOUTHWEST FLOW IN PALEOZOIC CARBONATES WITH SPRING DISCHARGE AT ASH MEADOWS AND DEATH VALLEY**

STUDIES OF REGIONAL GROUND-WATER FLOW SYSTEM

(CONTINUED)

MAJOR UNCERTAINTIES:

- **SUBBASIN BOUNDARIES NORTH OF YUCCA MOUNTAIN**
- **DEGREE OF CONTINUITY OF FLOW FROM PAHUTE MESA TO YUCCA MOUNTAIN; POSSIBLE PRESENCE OF SHALLOW AND DEEP FLOW SYSTEMS**
- **RELATIVE CONTRIBUTION TO TOTAL RECHARGE OF PAHUTE/RAINIER MESAS, FORTY MILE WASH, UPWARD FLOW FROM PALEOZOICS, AND PALEORECHARGE**
- **NATURE AND SIGNIFICANCE OF LARGE HYDRAULIC GRADIENT NORTH OF POTENTIAL REPOSITORY**
- **AREALLY DISTURBED DISCHARGE BY ET AT FRANKLIN LAKE PLAYA**

STUDIES OF REGIONAL GROUND-WATER FLOW SYSTEM

(CONTINUED)

STUDIES TO RESOLVE MAJOR UNCERTAINTIES:

- **ADDITIONAL TEST HOLES NORTH OF YM TO MEASURE POTENTIOMETRIC HEAD**
- **HYDROCHEMICAL SAMPLING AND ANALYSES TO DETERMINE SOURCE AND FLOW PATH**
- **STUDY OF FORTYMILE WASH TO DETERMINE MODERN AND PALEO RECHARGE**
- **ADDITIONAL TEST HOLES AND GEOPHYSICAL SURVEYS TO INVESTIGATE LARGE HYDRAULIC GRADIENT**
- **CONTINUED MODEL SIMULATION OF HYPOTHESES AND SCENARIOS REGARDING LARGE HYDRAULIC GRADIENT**
- **PIEZOMETER NESTS, BOWEN-RATIO STATIONS, AND PHREATOPHYTE MAPPING TO MEASURE ET DISCHARGE AT FRANKLIN LAKE PLAYA**

SITE POTENTIOMETRIC-LEVEL EVALUATION

(SCP SECTION 8.3.1.2.3.1.2)

OBJECTIVES:

- **DEFINE UPPER-MOST POTENTIOMETRIC SURFACE**
- **DETERMINE LONG-TERM TRENDS**
- **ANALYZE WATER-LEVEL FLUCTUATIONS: CAUSE AND HYDRAULIC PROPERTIES**
- **PROVIDE INPUT TO GWTT CALCULATIONS**

AVAILABILITY OF DATA:

- **BACKLOG OF HISTORIC WATER-LEVEL DATA PUBLISHED OR SUBMITTED FOR PUBLICATION APPROVAL**
- **PREPARATION OF DATA REPORTS NOW PROCEEDING CONCURRENTLY WITH DATA COLLECTION AND REDUCTION**

SITE POTENTIOMETRIC-LEVEL EVALUATION

(CONTINUED)

PERIODIC WATER-LEVEL NETWORK:

- **MONTHLY MEASUREMENTS SINCE 1981**
- **19 WELLS IN CURRENT NETWORK (JUNE 1991)**
- **WATER LEVELS MEASURED WITH STEEL TAPES**
- **DATA MOST USEFUL FOR LONG-TERM TREND ANALYSIS AND GWTT CALCULATIONS**
- **WATER LEVELS VERY STABLE; NO LONG-TERM TRENDS**

SITE POTENTIOMETRIC-LEVEL EVALUATION

(CONTINUED)

CONTINUOUS WATER-LEVEL NETWORK:

- **HOURLY MEASUREMENTS SINCE 1985**
- **12 WELLS; 19 ZONES IN CURRENT NETWORK (JUNE 1991)**
- **WATER LEVELS MEASURED WITH PRESSURE TRANSDUCERS AND RECORDED BY DATA LOGGERS**
- **ADAPTABLE FOR HIGH-FREQUENCY MEASUREMENTS**
- **EQUIPPED WITH SATELLITE DATA-COLLECTION PLATFORMS: NEAR REAL-TIME ACCESS TO DATA**
- **DATA MOST USEFUL FOR DETERMINING HYDROLOGIC PROPERTIES AND PROVIDING INSIGHT ON "STABILITY" OF POTENTIAL REPOSITORY SITE**

SITE POTENTIOMETRIC-LEVEL EVALUATION

(CONTINUED)

SHORT-TERM WATER-LEVEL FLUCTUATIONS:

- **OCCUR OVER PERIOD OF SEVERAL DAYS**
- **SHOWN TO COINCIDE WITH NORMAL FLUCTUATIONS
IN BAROMETRIC PRESSURE AND EARTH TIDES**

SITE POTENTIOMETRIC-LEVEL EVALUATION

(CONTINUED)

WATER-LEVEL EXCURSIONS:

- INVESTIGATED WHEN THEY OCCUR IN MULTIPLE WELLS OR MULTIPLE ZONES IN SAME WELL
- EXCURSIONS CLASSIFIED BASED ON AMPLITUDE, WHETHER OR NOT EXPECTED, AND CONCURRENCE WITH BAROMETRIC-PRESSURE CHANGES
- HAVE ESTABLISHED "ALERT" PROCEDURES TO VERIFY EXCURSIONS AS THEY OCCUR BY MAKING MANUAL MEASUREMENTS; USE SATELLITE DCP'S FOR "REAL-TIME WARNING"
- DRAMATIC CHANGES IN WATER LEVEL (0.3 METERS) POSITIVELY CORRELATED WITH DRAMATIC CHANGES IN BAROMETRIC PRESSURE
- SOME HIGH-AMPLITUDE EXCURSIONS (SEVERAL METERS) SHOWN UNLIKELY TO BE REAL WATER-LEVEL FLUCTUATIONS: ERRATIC TRANSDUCER BEHAVIOR
- SOME LOW-AMPLITUDE EXCURSIONS POSITIVELY DEMONSTRATED NOT TO BE REAL WATER-LEVEL FLUCTUATIONS
- OTHER LOW-AMPLITUDE EXCURSIONS REMAIN UNEXPLAINED; SOME MAY BE CAUSED BY FAULT CREEP

SITE POTENTIOMETRIC-LEVEL EVALUATION

(CONTINUED)

FUTURE PLANS:

- **CONTINUE HYDRAULIC-PROPERTIES AND TREND ANALYSES OF WATER-LEVEL FLUCTUATIONS**
- **DRILL ADDITIONAL WELLS**
- **CONTINUE INVESTIGATION OF EXCURSIONS AS THEY OCCUR**
- **INITIATE STRAIN MONITORING; INVESTIGATE FAULT CREEP**

ANALYSIS OF STRAIN-RELATED WATER-LEVEL FLUCTUATIONS

(SCP SECTION 8.3.1.2.3.1.3)

OBJECTIVES:

- **ASSESS APPLICABILITY OF METHODS TO OBTAIN AQUIFER PROPERTIES**
- **OBTAIN AQUIFER PROPERTIES BEFORE START OF WELL TESTING**

ADVANTAGES:

- **ALLOWS ANALYSIS AT LOCATIONS WHERE WELL TESTS NOT PRACTICAL**
- **OBTAIN DATA AT VARIOUS SCALES MUCH LARGER THAN WELL TESTS**
- **INEXPENSIVE**

DISADVANTAGES:

- **BOREHOLES MUST BE CASED INTO WATER TABLE**
- **METHODS ASSUME POROUS MEDIA**

ANALYSIS OF STRAIN-RELATED WATER-LEVEL FLUCTUATIONS

(CONTINUED)

ATMOSPHERIC-LOADING ANALYSIS YIELDS:

- **BAROMETRIC EFFICIENCY**
- **HYDRAULIC DIFFUSIVITY**
- **PNEUMATIC DIFFUSIVITY**

EARTH-TIDE ANALYSIS YIELDS:

- **MATRIX COMPRESSIBILITY AND AREAL STRAIN SENSITIVITY**
- **POROSITY AND SPECIFIC STORAGE**

ANALYSIS OF STRAIN-RELATED WATER-LEVEL FLUCTUATIONS

(CONTINUED)

ANALYSIS OF SEISMIC WAVES FROM EARTHQUAKES AND UNDERGROUND NUCLEAR EXPLOSIONS:

- **UNEs HAVE PRODUCED WATER-LEVEL RESPONSE OF ABOUT 60 MILLI-METERS AND CLOSED-IN, FLUID-PRESSURE RESPONSE OF ABOUT 1.3 METERS IN WELLS AT YUCCA MOUNTAIN**
- **CALIFORNIA EARTHQUAKE PRODUCED FLUID-PRESSURE RESPONSE OF ABOUT 140 MILLIMETERS AT YUCCA MOUNTAIN**
- **ANALYSIS YIELDS PEAK DYNAMIC STRAIN AND REASONABLE ESTIMATE OF TRANSMISSIVITY**

FUTURE PLANS:

- **EXPAND FLUID-PRESSURE MONITORING TO INCLUDE ADDITIONAL BORE-HOLES**
- **INITIATE ON-SITE STRAIN MONITORING TO IMPROVE ANALYSIS**
- **INSTALL ADDITIONAL STRIP-CHART RECORDERS TO OBTAIN COMPLETE DATA FOR EARTHQUAKES AND UNEs**

MULTIPLE-WELL INTERFERENCE TESTING AT C-HOLE COMPLEX

(SCP SECTION 8.3.1.2.3.1.4.)

OBJECTIVES:

- **DETERMINE HYDRAULIC PROPERTIES FOR QUANTITATIVE EVALUATION OF FLOW**
- **DETERMINE APPLICABILITY OF VARIOUS CONCEPTUAL MODELS: ANISOTROPIC POROUS MEDIA, FRACTURE NETWORK**
- **EXAMINE SCALE DEPENDENCY OF FLOW PARAMETERS**

MULTIPLE-WELL INTERFERENCE TESTING AT C-HOLE COMPLEX

(CONTINUED)

CROSS-HOLE TESTS:

- **NUMEROUS COMBINATIONS OF PUMPING FROM ONE INTERVAL IN ONE C-HOLE AND MONITORING RESPONSE IN OTHER INTERVALS IN OTHER C-HOLES**
- **USING 5-ZONE, MULTIPLE-PACKER SYSTEM IN EACH HOLE; CONTINUOUS MONITORING OF PRESSURE**
- **EACH TEST CONSISTS OF ABOUT 3 DAYS PUMPING AND 3 DAYS RECOVERY**
- **SELECT TEST INTERVALS BASED ON CROSS-HOLE SEISMIC SURVEYS, TEMPERATURE LOGS, TRACEJECTOR SURVEYS, AND PREVIOUS WELL-PERFORMANCE TESTS**
- **DETERMINE SPATIAL AND DIRECTIONAL VARIATION IN HYDRAULIC CONDUCTIVITY**
- **DETERMINE CONNECTION BETWEEN STRATIGRAPHIC UNITS**

MULTIPLE-WELL INTERFERENCE TESTING AT C-HOLE COMPLEX

(CONTINUED)

LARGE-SCALE PUMPING TEST:

- **PUMP ONE C-HOLE FOR ABOUT 30 DAYS; MONITOR OTHER C-HOLES AND MORE DISTANT HOLES AT YM**
- **DETERMINE HYDRAULIC PROPERTIES AT LARGER SCALE**
- **DETERMINE HYDROLOGIC SIGNIFICANCE OF FAULTS SUCH AS BOW RIDGE FAULT**

MULTIPLE-WELL INTERFERENCE TESTING AT C-HOLE COMPLEX

(CONTINUED)

ANALYSIS OF MULTIPLE-WELL INTERFERENCE TESTS:

- **INTERPRET TESTS USING ANALYTICAL AND NUMERICAL SOLUTIONS; START WITH SIMPLEST ASSUMPTIONS AND PROCEED TO MORE COMPLEX ASSUMPTIONS AS APPROPRIATE:**
 - **HOMOGENEOUS OR NON-HOMOGENEOUS, ANISOTROPIC POROUS MEDIA**
 - **DUAL-POROSITY POROUS MEDIA**
 - **"COMPOSITE" POROUS MEDIA**
 - **FRACTURE-NETWORK MODEL (LBL): APPLY DIFFERENT STATISTICALLY-GENERATED FRACTURE NETWORKS AND SEARCH FOR BEST MATCH TO FIELD TESTS**

- **COMPARE MULTIPLE-WELL TESTS WITH SINGLE-WELL TESTS:**
 - **DETERMINE APPLICABILITY OF SINGLE-WELL TESTS THROUGHOUT SITE**
 - **MAKE DECISION ON NEED FOR SECOND MULTIPLE-WELL COMPLEX**

TESTING OF THE C-HOLE SITES WITH CONSERVATIVE TRACERS

(SCP SECTION 8.3.1.2.3.1.5)

OBJECTIVES:

- **DETERMINE STORAGE AND TRANSPORT PROPERTIES**
- **COMPARE POROUS-MEDIA AND FRACTURE-NETWORK TECHNIQUES**
- **COMPARE TRANSPORT PROPERTIES FROM SINGLE-WELL AND MULTIPLE-WELL TESTS**
- **EVALUATE SPATIAL CORRELATION OF TRANSPORT PARAMETERS**
- **EXAMINE SCALE DEPENDENCY OF TRANSPORT PROPERTIES**

TESTING OF THE C-HOLE SITES WITH CONSERVATIVE TRACERS

(CONTINUED)

CONSERVATIVE TRACER TESTS:

- **MULTIPLE ORGANIC TRACERS (UNLV)**
- **INJECTION-PUMPBACK TESTS**
- **TWO-WELL RECIRCULATING TESTS**
- **MULTIPLE-WELL CONVERGENT TESTS**

ANALYSIS OF CONSERVATIVE TRACER TESTS:

- **ANALOGOUS TO INTERPRETATION OF MULTIPLE-WELL INTERFERENCE TESTS**
- **START WITH SIMPLEST ASSUMPTION BASED ON RESULTS OF HYDRAULIC TESTS**
- **PROCEED WITH MORE COMPLEX ASSUMPTIONS AS APPROPRIATE**

TESTING OF THE C-HOLE SITE WITH REACTIVE TRACERS

(SCP SECTION 8.3.1.2.3.1.7)

OBJECTIVES:

- **DEMONSTRATE LAB-SORPTION DATA APPLICABLE TO FIELD BEHAVIOR**
- **IMPROVE UNDERSTANDING OF TRANSPORT BEHAVIOR**
- **EVALUATE MOBILITY OF COLLOIDS**

TWO-WELL RECIRCULATING TRACER TEST:

- **EVALUATE AND VALIDATE CONCEPTUAL MODEL: FRACTURE FLOW WITH MATRIX DIFFUSION**
- **DUAL TRACER: LITHIUM BROMIDE**
- **DETERMINE SORBING-TRACER BEHAVIOR: LAB AND FIELD**
- **SENSITIVITY ANALYSIS FOR MATRIX DIFFUSION: IMPORTANT TO GWTT**

TESTING OF THE C-HOLE SITE WITH REACTIVE TRACERS

(CONTINUED)

COLLOID TRANSPORT THROUGH FRACTURES:

- **SIZE OF COLLOID IS CRITICAL TO PREDICTING MATRIX DIFFUSION OR FRACTURE-DOMINATED FLOW**
- **ENGINEER COLLOIDS OF VARIOUS SIZES: TEST IN LAB WITH FRACTURED CORES AND IN FIELD AT C-HOLES**

STATUS:

- **LAB ISOTHERM EXPERIMENTS FOR LITHIUM SORPTION DESIGNED; AWAITING CORE**
- **DEVELOPING APPLICATION OF SOFTWARE TO PREDICT SORBING-TRACER BEHAVIOR PRIOR TO FIELD TESTS**
- **PERFORMING DESIGN CALCULATIONS FOR FIELD TESTS; COORDINATING WITH USGS**

HYDROCHEMICAL CHARACTERIZATION OF THE SATURATED ZONE

(SCP SECTION 8.3.1.2.3.2)

OBJECTIVES:

- **DESCRIBE CHEMICAL COMPOSITION AND SPATIAL COMPOSITIONAL VARIATIONS**
- **IDENTIFY CHEMICAL AND PHYSICAL PROCESSES THAT INFLUENCE GROUND-WATER CHEMISTRY**
- **AID IN IDENTIFICATION AND QUANTIFICATION OF FLUXES TO, FROM, AND WITHIN SATURATED ZONE**

HYDROCHEMICAL CHARACTERIZATION OF THE SATURATED ZONE

(CONTINUED)

NETWORKS FOR SAMPLING:

- **230 SITES WITH AVAILABLE DATA IN REGION OF YM**
- **EPA MONITORING FOR WEAPONS PROGRAM**
- **YUCCA MOUNTAIN SITE:**
 - **14 EXISTING WT-HOLES; 11 MORE PLANNED**
 - **SOME EXISTING H-HOLES**
 - **PLANNED NEUTRON HOLES IN FORTY MILE WASH**
 - **FM SERIES HOLES**
- **VARIOUS WELLS AND SPRINGS REGIONALLY**
 - **NATIONAL PARK SERVICE MONITORING EFFORTS**
 - **MINING COMPANIES**

HYDROCHEMICAL CHARACTERIZATION OF THE SATURATED ZONE

(CONTINUED)

CONSTITUENTS:

- **INORGANIC CATIONS/ANIONS AND ORGANIC COMPOUNDS:
VARIATION, EVOLUTION, CARBON FLUX**
- **GASES: CONTAMINATION, FLUXES, PALEO-WATER TEMPERATURE**
- **ISOTOPIC RATIOS: RECHARGE TEMPERATURE/CLIMATE, FLOW
PATH, MIXING, SOLUTE SOURCES**
- **RADIOISOTOPES: AGE, CONTAMINATION, UZ FLUX MECHANISMS**

HYDROCHEMICAL CHARACTERIZATION OF THE SATURATED ZONE

(CONTINUED)

LOGISTICS OF SAMPLING:

- **GAS SAMPLING FROM PACKED-OFF, 10 METER INTERVAL ABOVE WATER TABLE**
- **WATER SAMPLING FROM ISOLATED INTERVALS BELOW WATER TABLE**
- **EXTRACT WATER FROM ROCK CORES FROM ABOVE AND BELOW WATER TABLE**
- **COLLECT WATER SAMPLES FROM 600-700 METERS DEEP:
BENNET PUMP**
- **IN SITU HYDROCHEMICAL MEASUREMENT AND SAMPLING TOOL**
 - **PORTABLE, TRAILER MOUNTED**
 - **ADJUSTABLE PACKERS FOR 5-20 METER SAMPLING INTERVALS**
 - **MEASURE pH, Eh, AND TEMPERATURE DOWNHOLE**
 - **VERY EXPENSIVE**