SOME OBSERVATIONS BASED ON UNSATURATED ZONE FLOW MODEL EXPERT ELICITATION PROJECT YUCCA MOUNTAIN, NEVADA

by

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PROJECT OBJECTIVE

Identify and assess ***model/parameter uncertainties*** associated with key aspects of unsaturated zone flow system at Yucca Mountain (YM) which affect

- ✓ ***ambient percolation flux*** through repository horizon (primary goal);
- ✓ ***seepage*** into open repository (secondary goal).

METHODOLOGY

Individual assessments by seven ***experts*** based on

- ***Workshops*** on
  - ✓ Significant issues and available data;
  - ✓ Alternative models and interpretations;
  - ✓ Preliminary expert assessments.
- YM ***Field Trip***.
- Supporting ***literature*** and copies of overheads.
- Elicitation ***interview***.
- ***Review/revision*** of written elicitation summary.

Opportunity for

- ✓ ***Interaction*** among experts and presenters;
- ✓ ***Revisions*** based on all expert opinions;

without attempt to generate ***consensus***.

INTRODUCTORY OBSERVATIONS

- ***No precedence*** for assessing unsaturated flow under comparable ***rock/climate conditions*** on comparable ***space-time scales***.
- Rich ***generic knowledge*** which, with proper ***site data***, should allow one to make ***intelligent inferences*** about subsurface flow at YM.
- To be ***credible***, such inferences should be based on ***theories/models*** supported by, and compatible with, ***experimental and site data***.

- Among the ***better understood*** processes of relevance to YM is ***heat flow***.
  - ✌ ***Enough/reliable data*** (temperature, heat flux, conductivity) could yield ***credible estimates*** of ***moisture flux*** on various spatial scales.
  - ☹ Available data may ***not*** be of ***sufficient quantity/quality*** for this purpose. More on this later.

- Among the ***least understood*** processes is the ***transformation of precipitation*** (rain/snow) ***into deep percolation*** below the root zone.
  - ☹ ***Assessments*** to date based on ***near-surface*** measurements/models seem ***unconvincing***. More on this later.
  - ☹ ***Nowhere*** have such assessments been ***verified*** on space-time scales comparable to YM.

CONCLUSION: The ***key*** to unraveling the nature and rates of ***subsurface flow*** at YM lies ***at depth***.

PROPOSED CONCEPTUAL FRAMEWORK

- Among the ***more reliable*** YM ***models/data*** are those concerning ***pneumatic monitoring/injection***. These suggest/reveal:
  - ✓ In ***welded units***, pneumatic data represent ***fractures/faults*** at ***low water saturation*** which are thus ***open to air flow***.
  - ✓ ***TCw/TSw*** are spanned by pneumatically ***interconnected networks of fractures/faults*** that ***conducts air with relative ease*** across considerable distances (more in some directions than others).
  - ✓ Pneumatic ***monitoring/injection*** data provide ***self-consistent*** (***high***) network ***permeabilities***.
  - ✓ Due to low saturation, these are probably ***close to*** the ***network intrinsic permeabilities***.
  - ✓ As matrix permeability of ***TCw/TSw*** is orders lower, ***flow*** in these units is ***dominated by fractures and faults***.
  - ☞ As at Apache Leap, pneumatic injection tests ***should*** yield ***air-filled porosity of fractures***.

☹ There is ***no information*** to evaluate directly the ***modes/rates/directions*** of ***water flow*** through ***fractures/faults*** in ***TCw/TSw***. Little is known about ***mechanisms/parameters*** that control flow

- in open vs filled fracture spaces;
- along fracture planes vs intersections;
- across wide areas vs channels/rivulets;
- in capillary films;
- between fractures and matrix blocks.

CONCLUSION: The ***key*** to assessing repository-level ***percolation flux*** lies within the overlying ***PTn*** where flow is ***matrix-dominated***, and within the ***ESF***.

- Evidence for ***matrix-dominated PTn flow***:
  - ✓ Relatively high matrix porosity/permeability;
  - ✓ Low enough saturation to cause imbibition from fractures/faults into matrix;
  - ✓ Relatively low fracture density;
  - ✓ Faults relatively narrow and difficult to identify;
  - ✓ Pronounced attenuation of pneumatic pressure signals across PTn.

- ***Bomb-pulse isotopes*** in waters ***within/below PTn*** imply some ***rapid flow paths*** through it.
  - ✓ ***Mean seepage*** velocity ***through PTn*** matrix is ***too slow*** to account ***for bomb signatures***;
  - ✓ Bomb-pulse isotopes in PTn matrix suggest ***fast paths in matrix***, not only fractures/faults;
- ***Fast flow in matrix*** (or fractures/faults) can take place through ***narrow channels*** of locally ***elevated hydraulic conductivity*** due to
  - ✎ ***Focused episodic infiltration*** causing
  - ✎ ***buildup of saturation*** (and thus ***conductivity***) along ***narrow paths***, without time to fully dissipate between events;
  - ✎ ***Spatial variations*** in matrix permeability;
  - ✎ ***Instability*** at layer interfaces and ***fingering***.
- Such ***preferential flow channels*** may ***persist*** or ***adjust dynamically*** to variable surface infiltration.
- Regardless of whether they develop within fractures, faults or the matrix, such flow channels ***occupy a minute proportion of the rock*** volume and are thus ***unlikely to be observed*** in the field.

- ***No*** clear ***evidence to support/deny*** extensive ***lateral flow within PTn***. Probably dampened by heterogeneities, hence ***vertical flow dominates***.

"BACK-OF-THE-ENVELOPE" BOUNDINC CALCULATIONS OF FLUX AND VELOCITY

- Water ***fluxes/velocities vary considerably*** in ***space-time*** and with ***direction/scale***.
- We ***consider*** only
  - ✓ space-time ***mean vertical flux/velocity***,
  - ✓ one for ***bulk rock (slow)***, one for ***preferential channels (fast)***.

Lower Bound on Percolation Flux

- Table 7 in Flint (1996) contains ***summary*** info about ***matrix properties*** and ***state variables*** of seven ***PTn*** units. We ***average*** these to obtain
  - ✎ Porosity $\phi \approx 0.4$
  - ✎ Saturation $S \approx 0.5$
  - ✎ Saturated conductivity $K_s \approx 3.25 \times 10^3$ mm/yr (geometric average).
- ☹ To date, ***no*** reliable ***experimental data*** on ***K(S)*** or ***$K(S_{ambient})$***, ***only*** indirectly ***calculated "data"*** from moisture retention curves.
  - ✌ L.E. Flint provided recent data on two rock samples. From these
  - ✎ $K(S=0.5) \approx 6$ mm/yr.

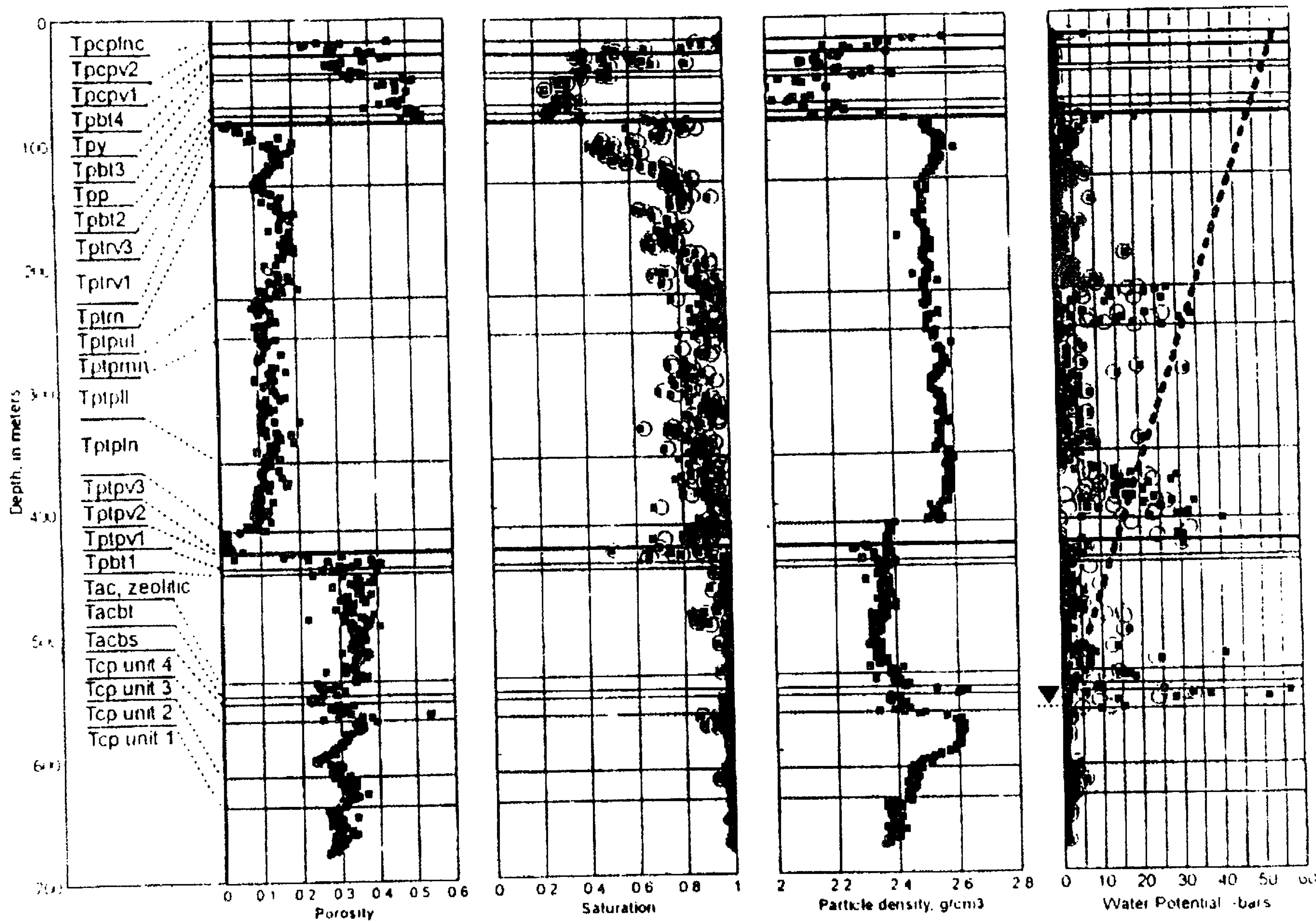

Figure 4 Porosity, saturation, particle density, and water potential with calculated no-flow conditions in equilibrium with the water table (dashed line), positioned with depth for borehole SD9. Open circles are saturation and water-potential values corrected for drilling and sample handling damage. Shading corresponds to formation, and lithostratigraphic unit assignment is from Engstrom and Rautman (1996)

- Uniformly low suction in ***PTn*** implies ***flow*** is ***gravity-dominated*** at near ***unit vertical gradient***.
  - ☞ ***Matrix flux*** $q_m \approx$ ***6 mm/yr***.
  - ☞ This is a ***lower bound*** because it
    - ✓ disregards fractures/faults;
    - ✓ disregards fast-flow channels in matrix;
    - ✓ cannot account for bomb-pulse signatures;
    - ✓ disregards increase of K with scale.
  - ✌ ***Independent calculations*** by Fabryka-Martin et al. (1996; Tables 8-3 to 8-6) suggest that a ***minimum flux of 1 - 5 mm/yr*** is needed to reproduce bomb-pulse ^{36}Cl signatures in ESF.
  - ✌ ***Agrees*** with ***Cl mass balance***.
- Average ***volumetric water content*** in ***PTn matrix*** is $\theta = S\phi \approx (0.5)(0.4) = 0.2$.
  - ☞ ***Velocity*** $v_m = q_m/\theta \approx$ ***30 mm/yr***.
  - ☞ At such velocity, it takes ***10,000 years*** to travel ***300 m***, over 13,000 years 400 m.
  - ✌ ***Agrees with*** elevated reconstructed atmospheric ***$^{36}Cl/Cl$ ratios*** (Fabryka-Martin et al., 1996, Figure 2-2) prior to about 10,000 years (at end of Pleistocene) and many corresponding ratios (Fig 5-1) in ESF .
  - ☞ Much ***too slow*** to account ***for bomb-pulse*** signatures; ***requires postulating fast paths***.

Table 8-3. Simulated transport of ^{36}Cl to the ESF using the original parameter set at Station 35

	CASE	PTn Fracture Properties (normalized to base-case value)				Infiltration Rate (mm/yr)				
		Assumed		Calculated		0.1	1	5	10	50
		Density	Aperture	Permeability	a_{fm} (m^{-1})					
Non Fault Zone Properties	Base	1	1	1	1	No 280814 281931	No 12067 22761	No 2500 4808	No 1221 2360	No 245 275
Modified PTn Fault Zone Fracture Properties	A Bomb Pulse? 1% 50%	2	1	2	1		No	No 2492 4903	No 1279 2367	No
	B Bomb Pulse? 1% 50%	1	2	8	2		No 12054 22437	Yes 2241 4631		
	C Bomb Pulse? 1% 50%	1	2.5	16	2.5	Not performed	Not performed	Not performed	Not performed	Not performed
	D Bomb Pulse? 1% 50%	2	2	16	2		No 12047 22447	No 2401 4547	Yes 1135 2334	
	E Bomb Pulse? 1% 50%	1	1	1	0.1		No 11518 22225	Yes 2335 4506		
	F Bomb Pulse? 1% 50%	2	2	16	0.1	No	Yes 10751 22626	Yes 1070 4507		

Bomb Pulse: Indicates the arrival of any solutes at ESF in less than 50 years.

1% : Indicates the breakthrough at the ESF of 1% of a pulse injected at the surface.

50% : Indicates the breakthrough at the ESF of 50% of a pulse injected at the surface.

1% and 50% also represent the maximum age of the first 1% and 50%

of a simulated water sample at the ESF

Table 8-4. Simulated transport of ^{36}Cl to the ESF using the original parameter set at Station 59

	CASE breakthrough simulation results	PTn Fracture Properties (normalized to base-case value) Assumed: Density	Assumed: Aperture	Calculated: Permeability	Calculated: a_{fm} (m^{-1})	Infiltration Rate (mm/yr) 0.1	1	5	10	50
Non Fault Zone Properties	Base Bomb Pulse? 1% 50%	1	1	1	1	No 208520 209586	No 6671 15495	No 1246 3057	No 628 1492	No 130 142
Modified PTn Fault Zone Fracture Properties	A Bomb Pulse? 1% 50%	2	1	2	1		No 6660 15599	No 1347 3053	No 628 1490	No 130 141
	B Bomb Pulse? 1% 50%	1	2	8	2		No 6818 15019	Yes 1156 3109		
	C Bomb Pulse? 1% 50%	1	2.5	16	2.5		No 6819 14891	Yes 835 3024	Yes 304 1487	
	D Bomb Pulse? 1% 50%	2	2	16	2		No 6823 15039	No 1257 3072	No 577 1507	Yes 108 147
	E Bomb Pulse? 1% 50%	1	1	1	0.1		No 5841 15624	Yes 1205 2963	Yes 560 1494	
	F Bomb Pulse? 1% 50%	2	2	16	0.1	No 58431 213438	Yes 5051 15302	Yes [illegible] 2902	Yes 380 1445	

Bomb Pulse: Indicates the arrival of any solutes at ESF in less than 50 years.

1% : Indicates the breakthrough at the ESF of 1% of a pulse injected at the surface.

50% : Indicates the breakthrough at the ESF of 50% of a pulse injected at the surface.

1% and 50% also represent the maximum age of the first 1% and 50% of a simulated sample of water at the ESF

Table 8-5. Simulated transport of ^{36}Cl to the ESF using the updated parameter set at Station 59

	CASE breakthrough simulation results	PTn Fracture Properties (normalized to base-case value) Assumed: Density	Assumed: Aperture	Calculated: Permeability	Calculated: a[illegible] (m^{-1})	Infiltration Rate (mm/yr) 0.1	1	5	10	50
Non Fault Zone Properties	Base	1	1	1	1	No 50005 104580	No 5579 10282	No 1204 2277	No 620 1191	No 132 270
Modified PTn Fault Zone Fracture Properties	A Bomb Pulse? 1% 50%	2	1	2	1		No 5577 10281	No 1203 2276	No 619 1190	No 132 270
	B Bomb Pulse? 1% 50%	1	2	8	2		No 5604 10307	No 1211 2284	No 624 1195	No 123 271
	C Bomb Pulse? 1% 50%	1	2.5	16	2.5		No 5634 10337	No 1221 2293	No 630 1201	Yes 124 273
	D Bomb Pulse? 1% 50%	2	2	16	2		No 5587 10290	No 1206 2279	No 621 1192	No 133 270
	E Bomb Pulse? 1% 50%	1	1	1	0.1		No 5464 10400	No 1137 2371	No 589 1258	No 94 269
	F Bomb Pulse? 1% 50%	2	2	16	0.1	No	No 5334 10535	Yes 870 2499		

Bomb Pulse: Indicates the arrival of any solutes at ESF in less than 50 years.

1% : Indicates the breakthrough at the ESF of 1% of a pulse injected at the surface.

50% : Indicates the breakthrough at the ESF of 50% of a pulse injected at the surface.

1% and 50% also represent the maximum age of the first 1% and 50% of a simulated sample of water at the ESF

Table 8-5. Simulated transport of ^{36}Cl to the ESF using the updated parameter set at Station 35 (continued)

	CASE	PTn Fracture Properties (normalized to base-case value): Assumed: Density	Assumed: Aperture	Calculated: Permeability	Calculated: A_{fm} (m^{-1})	Infiltration Rate (mm/yr): 0.1	1	5	10	50
Non Fault Zone Properties	Base	1	1	1	1	No 50005 104580	No 5579 10282	No 1204 2277	No 5370 10280	No 132 270
Modified PTn Fault Zone Fracture Properties	G Bomb Pulse? 1% 50%	1	2.9	25	1			No 1233 2306	Yes 637 1208	
	H Bomb Pulse? 1% 50%	4	2	128	1			No 1242 2315	Yes 584 1214	
	I Bomb Pulse? 1% 50%	1	3.1	30	1		No 5693 10396	Yes 1240 1213		
	J Bomb Pulse? 1% 50%	1	4	64	1		No 5287 10555	Yes 971 2369		
	K Bomb Pulse? 1% 50%	1	4.6	100	1		No 2942 10770	Yes 15 2447		
	L Bomb Pulse? 1% 50%	1	5	125	1	No	No 79 10902	Yes 15 2495		
	M Bomb Pulse? 1% 50%	1	3.1	30	3.1	No	No 5681 10385	No 1237 2310		

Bomb Pulse: Indicates the arrival of any solutes at ESF in less than 50 years.

1% : Indicates the breakthrough at the ESF of 1% of a pulse injected at the surface.

50% : Indicates the breakthrough at the ESF of 50% of a pulse injected at the surface.

1% and 50% also represent the maximum age of the first 1% and 50% of a simulated sample of water at the ESF.

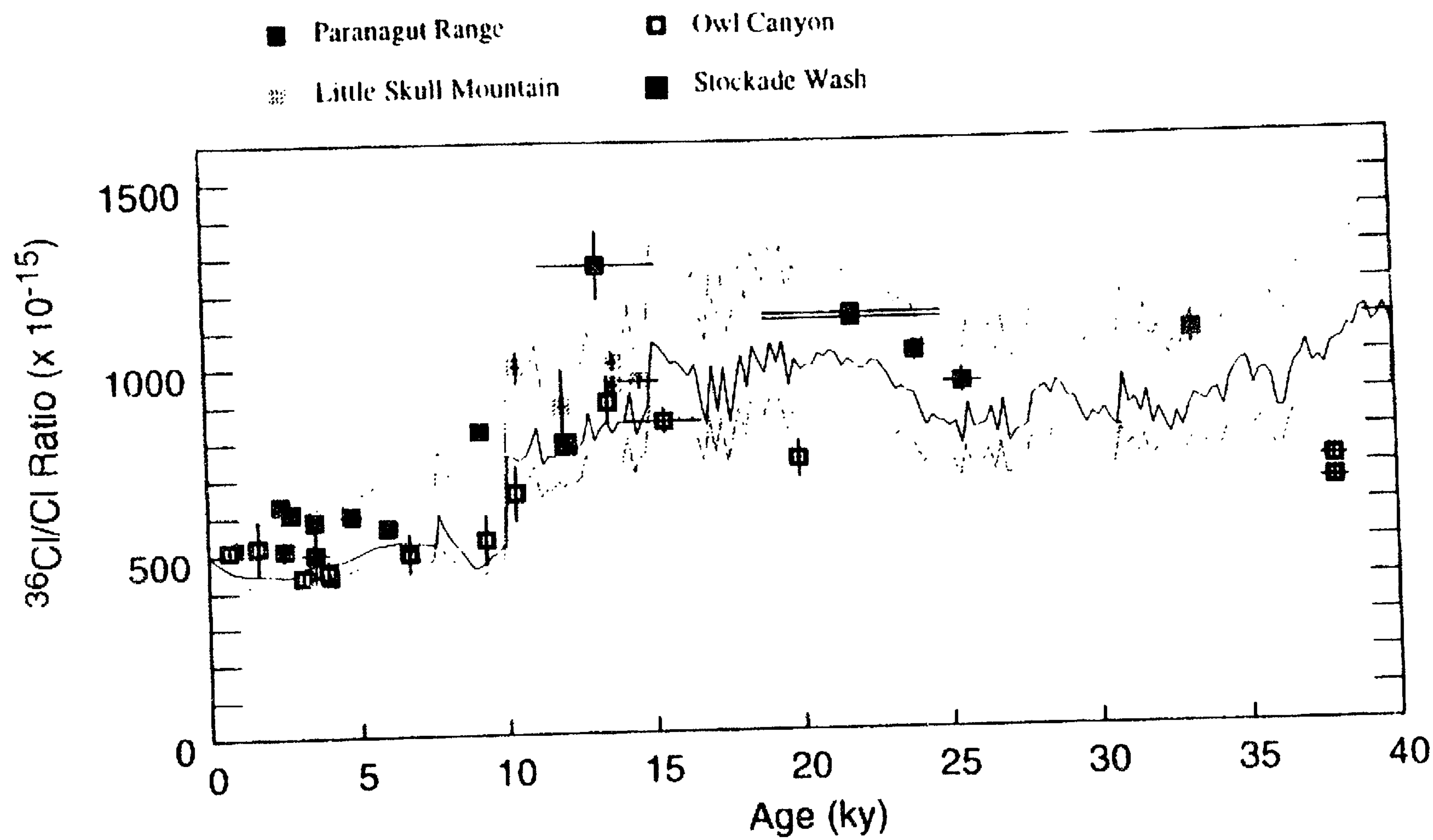

Figure 2-2. Reconstructed production rate of chlorine-36 in the atmosphere, compared against measured data for packrat middens from the vicinity of the Nevada Test Site. The reconstructed $^{36}Cl/Cl$ ratio shown by the solid line assumes that the deposition rate of stable chloride was constant at present day rates during the Holocene (i.e., ages less than 10 ky) but 33% lower throughout the Pleistocene. Lower and upper limits shown by the gray lines assume present-day $^{36}Cl/Cl$ ratios of 450×10^{-15} and 650×10^{-15}, respectively. See section 2.1 for a discussion of these reconstructions.

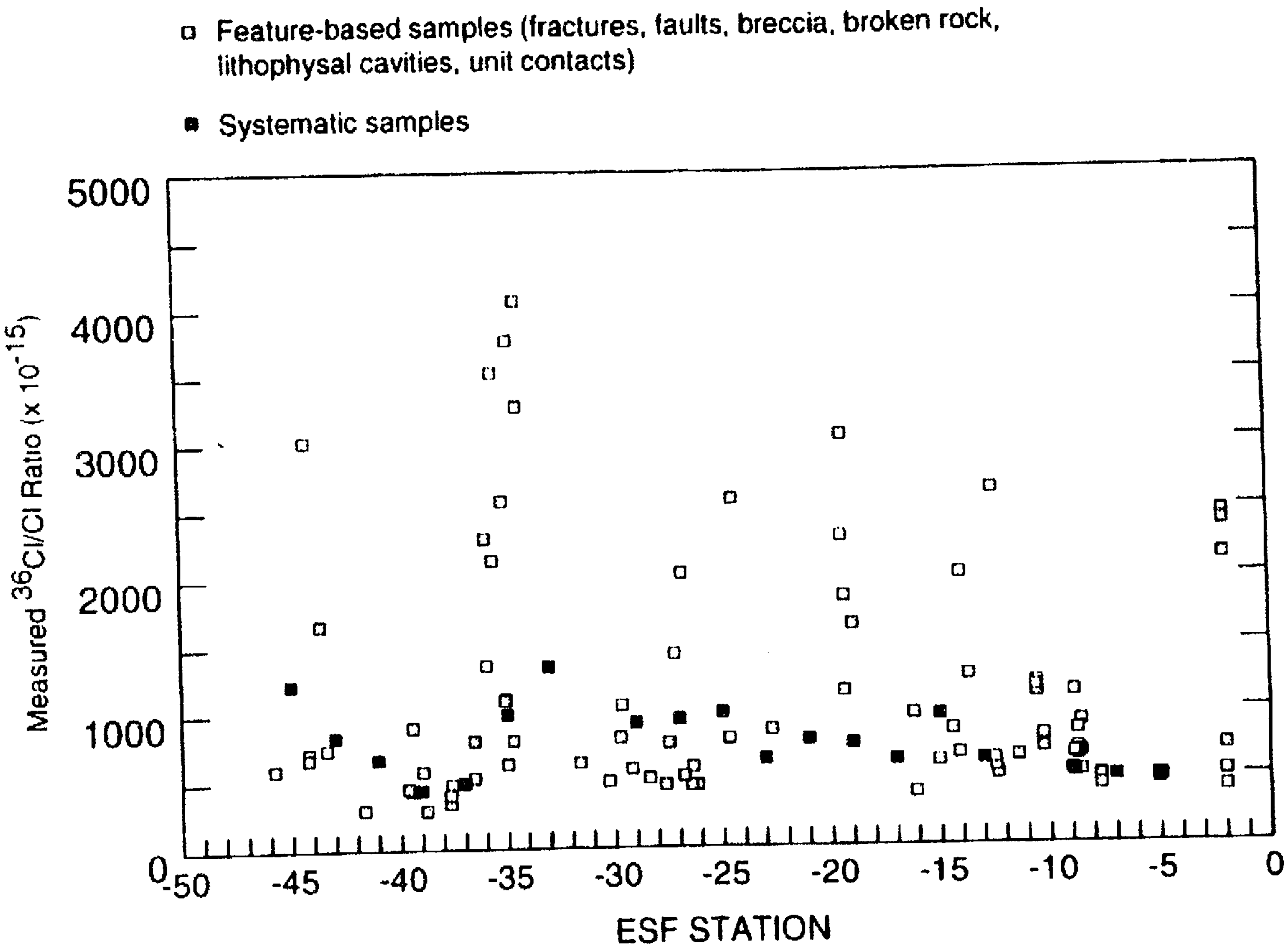

Figure 5-1. Distribution of ^{36}Cl/Cl ratios measured for rock samples, as a function of distance along the ESF North Ramp and Main Drift. ESF stations are marked in 100-m increments. Samples with ratios exceeding 1500 x 10^{-15} are considered to contain a component of bomb-pulse ^{36}Cl. Data from Table 5-3.

Upper Bound on Percolation Flux

- When ***ESF ventilation*** is ***shut off*** on weekends, moisture ***flux*** from rock averages about ***50 mm/yr*** (J.S.Y. Wang, personal communication).
  - ☞ This yields an ***upper bound*** on ***percolation flux*** across repository horizon.
  - ☞ Flux in ***excess of 6 mm/yr*** is associated with ***fast paths***.
  - ☞ Such paths ***can be unsaturated*** and ***need not form visible seeps*** in ESF or open repository.
  - ☞ There seem to be ***no*** other ***data to further constrain flux*** through fast paths ***from above***.

Matrix vs Fracture Flux in TSw

- TSw ***matrix permeability*** varies about a ***nominal*** value of $5 \times 10^{-18}\ m^2$ (Birkholzer et al. 1996).
  - ☞ As $S \approx 1$, $K \approx 1.5$ mm/yr.
  - ☞ Under unit gradient, ***matrix flux*** $\approx$ ***1.5 mm/yr***.
  - ☞ ***Flux through fractures/faults*** varies between
    - ✓ nominal ***lower bound*** of ***4.5 mm/yr***,
    - ✓ nominal ***upper bound*** of ***48.5 mm/yr***.
  - ☞ ***Fractures/faults*** thus ***carry*** part of ***slow*** and all ***fast flow***.

Effective Porosity ϕ_f of Fast Paths

- ϕ_f = (rock volume occupied by fast paths)/ (bulk rock volume)
  = ***Probability of*** encountering a ***fast flow path***.
  = q_f/v_f = (fast flux)/(fast velocity).
- Atmospheric bomb-pulse released 1952 - 1963. Allow signatures within depth range 100 - 450 m.
  - ☞ $v_f \approx 2.5 \times 10^3 - 1.5 \times 10^4$ mm/yr.
  - ☞ In ***TSw*** $q_f \approx 4.5 - 48.5$ mm/yr implies ***$\phi_f \approx 3 \times 10^{-4} - 2 \times 10^{-2}$***.
  - ☹ ***No data*** to estimate ϕ_f in ***PTn***.
- $\phi_f = A_f N_f$ = (mean x-sectional ***area of fast path***)/ (***number of fast paths*** per unit x-area)
  - ☹ ***Cannot evaluate*** A_f or N_f without knowing one of them.

Probability Distribution of Percolation Flux

- Under a unit mean hydraulic gradient, flux is proportional to K.
  - ☞ Taking ***K log normal*** renders ***flux log normal***.
  - ☞ Taking ***lower/upper bounds*** to represent ***5/95 percentiles*** yields the ***shown pdf/cdf*** and a
  - ☞ ***Maximum likelihood flux ≈ 17 mm/yr***.

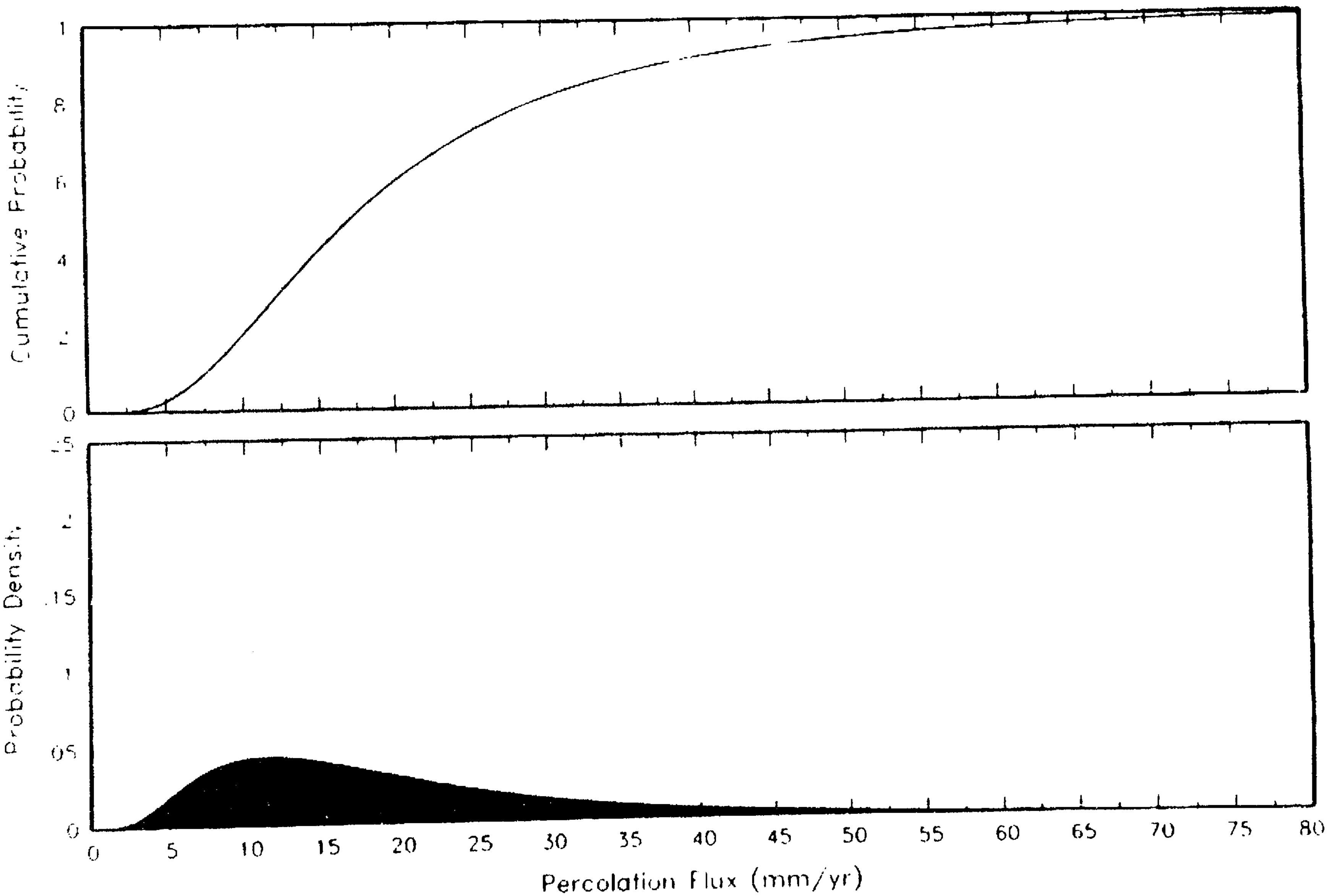

Figure SN-1 Assessed distribution for percolation flux at the repository level developed by Shlomo Neuman. The top plot shows the cumulative distribution function and the bottom plot the corresponding probability density function

PROSPECTS FOR REFINED ANALYSES

- The above crude ***estimates*** could be ***refined*** by
  - ✓ Creating a ***more complete/reliable data*** base concerning ***PTn matrix*** properties/states;
  - ✓ Using it to estimate ***spatial variability*** of flow within ***PTn*** and to assess related ***uncertainty***.
- ***Existing*** UZ flow ***models***, though more ***detailed***, do ***not necessarily*** provide ***more reliable*** estimates of percolation flux ***at this time***. They
  - ✓ Suffer from same lack of K(S) data for PTn matrix as the above crude calculations;
  - ✓ Incorporate fractures/faults without adequate information about their flow properties and behavior across the site;
  - ✓ Are either driven by surface-based infiltration estimates of unknown reliability or
  - ✓ Show lack of sensitivity when fluxes are estimated by calibration against measured pressure heads and saturations;
  - ✓ Do not quantify uncertainties in model structure (conceptual framework), parameters (material properties), inputs (forcing terms), or outputs (predictions).

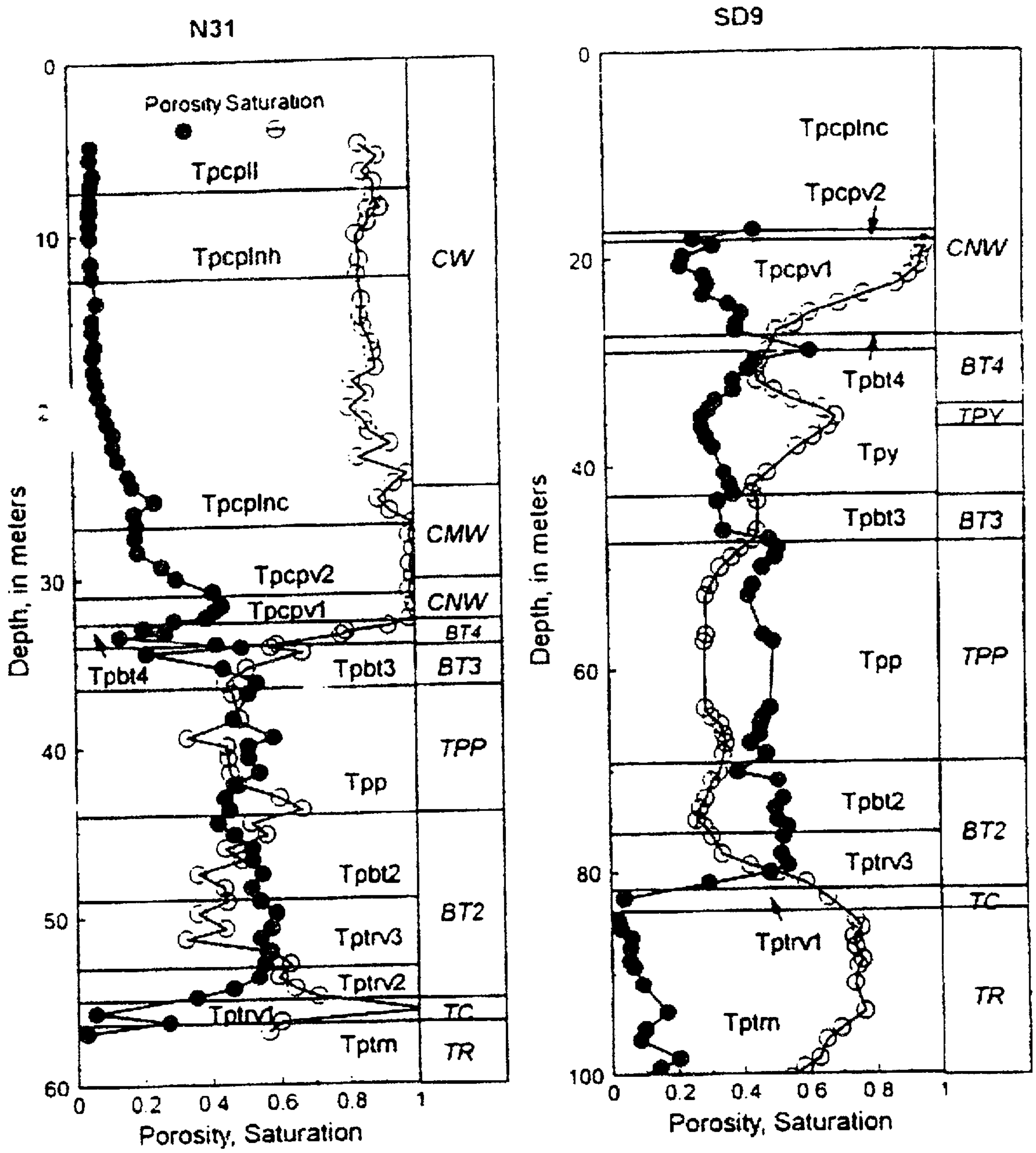

Figure 7. Oven-dry porosity and saturation of rocks from the Paintbrush Group between the lower Tiva Canyon Tuff and upper Topopah Spring Tuff in boreholes N31 and SD9. Lithostratigraphic unit assignment for N31 is from Geslin and others (1995) and SD9 is from Engstrom and Rautman (1996)

Calculations Based on Temperature Data

- ***Percolation fluxes*** were obtained by ***two methods***:
  1. Estimating vertical conductive heat fluxes in UZ and SZ from vertical T° profiles, then setting conductive + convective flux in UZ equal to conductive flux in SZ;
  2. Filtering out heat flux by considering variations along the vertical in UZ.
- A variant of Method 1 additionally considers lateral variations in heat flux and T° in UZ.
- ☹ ***Method 1*** is ***sensitive to*** errors and uncertainties in ***heat flux***, ***heat conductivity***, and ***1st-order variations in T°***.
- ☹ ***Method 2*** is ***sensitive to*** errors and uncertainties in ***1st-order variations in heat conductivity*** and ***1 st- as well as 2nd-order variations in T°***.
- ☹ ***In no case have*** such ***errors and uncertainties been quantified*** through a transparent statistical analysis of available data.

Comments on Estimates of Net Infiltration

- Net infiltration ***varies strongly in space-time*** in a manner which is ***very difficult to assess***.
- ☹ ***Existing estimates*** are based in part on ***1-D*** interpretations of neutron-probe data in shallow boreholes at a few sites which ***disregard runoff and lateral subsurface flow***.
  - ☞ ***Lateral subsurface flow*** occurs when runoff from bedrock slopes seeps into alluvium along its margins, then propagates ***along a sloping bedrock-alluvium interface***;
  - ✌ The phenomenon is ***evidenced by bomb-pulse*** ^{36}***Cl*** at the base of the alluvium in borehole UZ-16, without being found in the alluvium;
  - ☞ Shallow lateral subsurface flow may also take place ***along hillslopes in bedrock terrain*** (by virtue of the "thatched-roof" effect);
- ☹ ***Some estimates*** are based on a ***1-D "bucket model"*** whose ***reliability*** is ***open to debate***;
- ☹ ***Some estimates*** are based on ***bedrock permeabilities*** that are ***not measured but calculated*** on the basis of fracture densities and apertures, an approach known to be ***generally unreliable*** (Neuman, 1987);

- ☹ There has been ***no attempt to quantify*** the ***uncertainty*** associated with published YM ***infiltration maps***;
- ☹ The ***premise*** behind these maps that net ***infiltration*** rate is always ***higher along hilltops than along washes*** seems ***counter intuitive***;
- ☹ That net ***infiltration*** rates on these maps have been ***modified upward*** in recent years, ***by more than an order*** of magnitude, ***throws into question*** the methods used to develop ***these maps***.

Expert Elicitation: Viewpoint on the Process and Results

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Yucca Mountain UZ Flow

- Can it be understood?
- Can it be understood by "outside experts"?
- Can it be understood by public?

Specific UZ Flow Questions

- What approaches have been used to estimate percolation flux in YM?
- How reliable are the models that are being used for these estimates?
- What is the percolation flux in the mountain and what are the uncertainties?

Modeling UZ Flow in YM

- Modeling water flow using numerical simulation and computer codes
- Modeling water flow by observation and measurements in the mountain
- Modeling water flow using tracer studies

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UZ Codes for Percolation

- USGS Surface water balance models
- LBNL Tough2 Finite difference multiphase fluid and heat flow model
- LANL Finite element water, heat, and solute model

UZ Flow from Observations

- Observations of weeps and moisture in ESF
- Measurements of water potential and hydraulic properties in PTn

UZ Flow from Tracers

- ^{36}Cl tracer studies
- Tritium distributions
- ^{14}C tracer studies
- Heat flow and temperature gradients
- Calcite and opal deposition

Surface Water Balance

Percolation =
  Precipitation
    - Evaporation
    - Transpiration
    - Runoff

Surface Water Balance

Important Site Factors

- Soil depth
- Soil water holding capacity
- Plant root depth
- Topography
- Infiltrability

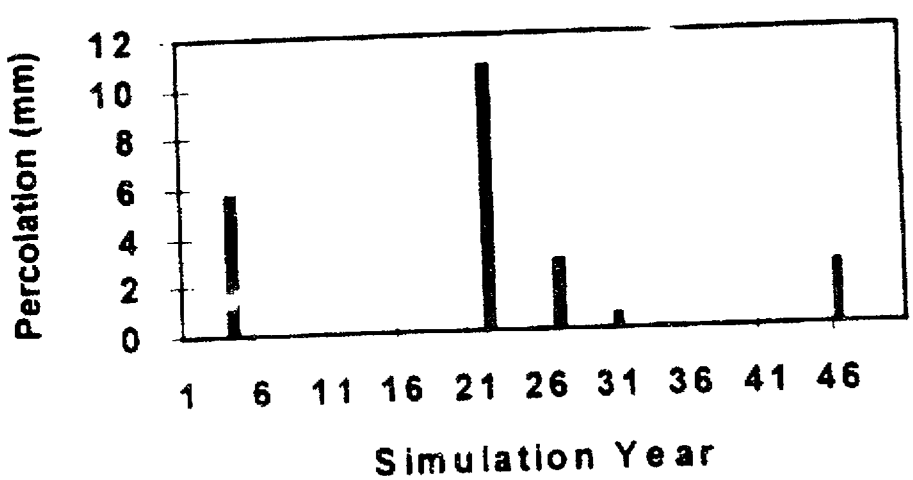
Environmental Factors

- Precipitation
- Potential evapotranspiration
- Solar radiation
- Temperature
- Vapor pressure
- Wind

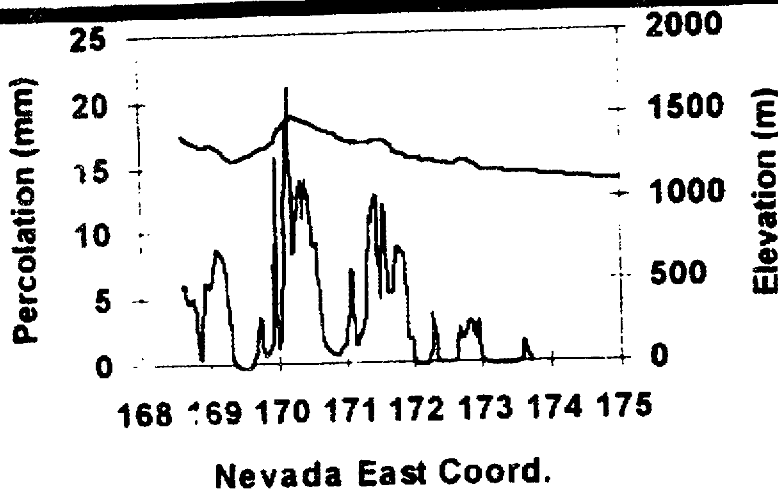
Water Balance Simulation

- Temperature from 50 year Beatty, NV record
- Precipitation from 15 year Yucca Mountain record
- Soils map of YM: depths and water holding capacity

Temporal Distribution



Spatial Distribution



Surface Water Balance

	max	min	mean
Precipitation	300	71	170
Evaporation	187	62	119
Transpiration	115	13	52
Percolation	11	0	0.5

0.5 m deep profile

Unsaturated Flow in PTn

- Psychrometers and core samples show zero matric potential gradient
- High porosity (0.5) and high permeability makes fracture flow unlikely
- Flow must be at least as high as matrix flow estimate

Unsaturated Flow Equations

$$q_w = k\left(\frac{dh}{dz} + 1\right)$$

$$k = k_s\left(\frac{h_e}{h}\right)^n$$

k	*hydraulic conductivity*
k_s	*saturated conductivity*
h	*water potential*
h_e	*air entry potential*

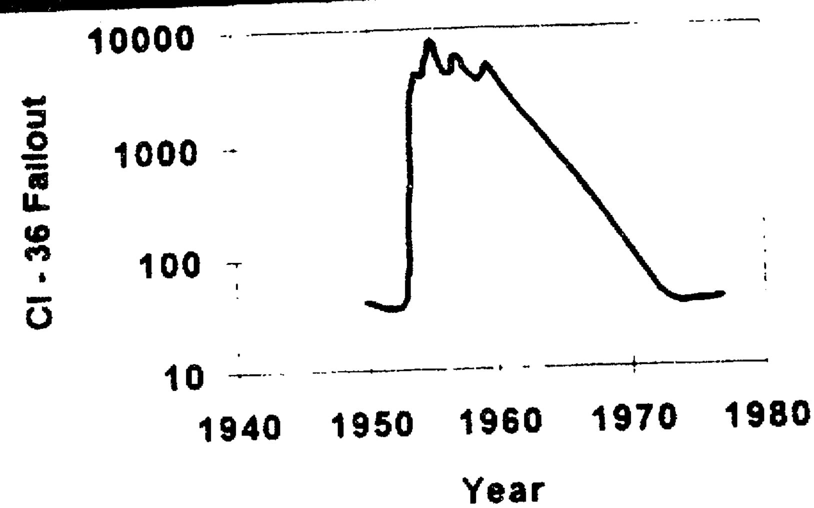
Estimated Flux in PTn

Potential - Bars	Flux - mm/yr
0.1	100
0.2	17
0.5	1.7
1	0.3
2	0.05
5	0.005

^{36}Cl as a Water Tracer

- Generated by cosmic rays
- Half life of 301,000 years
- Modern $^{36}Cl/Cl$ ratio 5×10^{-13}
- Levels 10,000 years ago were 2 to 3 times present
- Nuclear tests elevated levels by a factor of 400 from 1952-1972

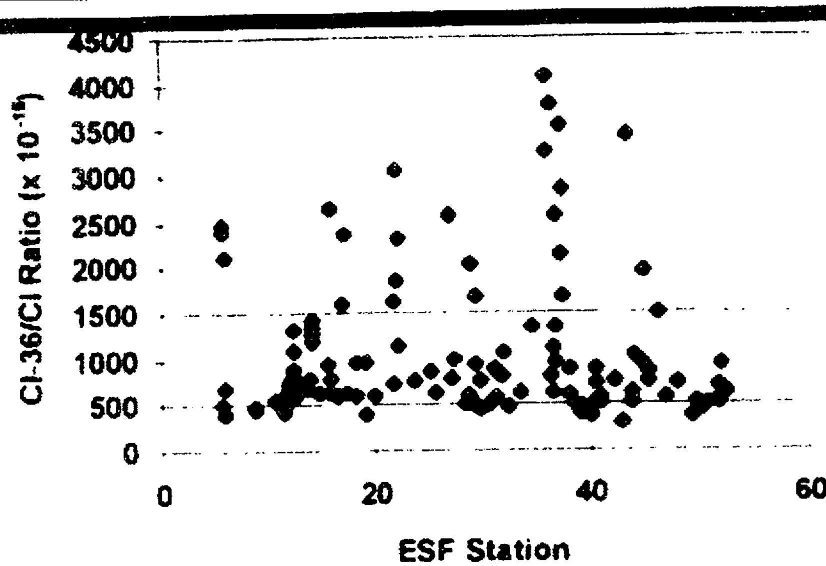
^{36}Cl Bomb Pulse



^{36}Cl Sampling

- Bore hole sampling
- Samples every 100 m in ESF
- Feature-based sampling in ESF (faults and fractures)

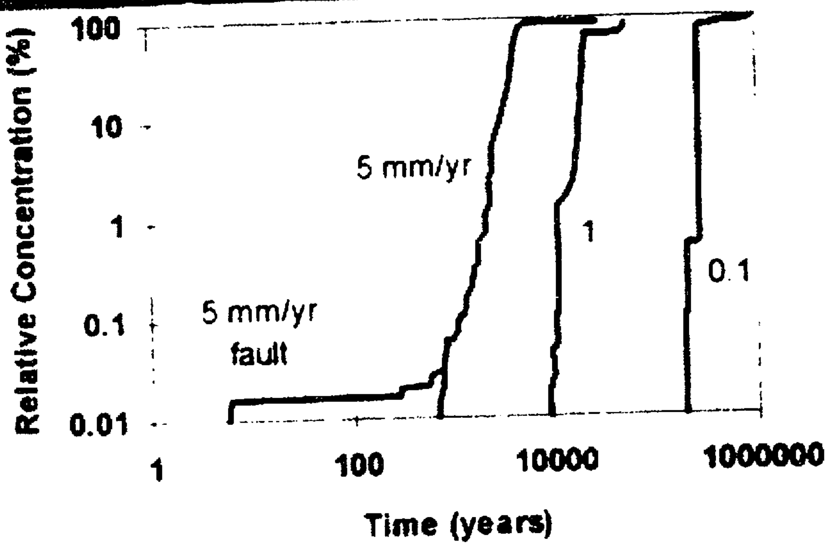
^{36}Cl/Cl Ratios in ESF Tunnel



^{36}Cl: Flux from Simulation

- Finite element heat and water model
- Dual permeability implementation (flow in matrix and fractures; equilibrium not required)
- Can implement fast flow in fault regions

Chloride Breakthrough



Conclusions

- There is downward flow of water under Yucca Mountain
- Some water reaches repository levels within decades
- Fast flow of water in faults and fractures is likely

More Conclusions

- Recharge is highly variable in space and time
- Recharge occurs about 1 year in ·
- Recharge occurs under shallow soils
- Flow mostly in fractures except in PTn non-welded tuff layer
- Probable range 1 - 20 mm/yr

What is Most Needed Now

- Accurate water potential measurements of rocks in ESF
- Unsaturated hydraulic conductivity measurements, especially in PTn
- Inverse modeling to understand perched water

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Studies

Use of Unsaturated Zone Flow Model Expert Elicitation Results in TSPA-VA

Presented to:
Nuclear Waste Technical Review Board

Presented by:
Robert W. Andrews
Manager, M&O Performance Assessment
Management and Operating Contractor

U.S. Department of Energy
Office of Civilian Radioactive Waste Management

June 25-26, 1997

Methods used to incorporate results of expert elicitation in TSPA-VA

- Conduct sensitivity studies to evaluate the potential effect of the issue
- Incorporate recommendation directly
  - Evaluate significance of alternative models or parameters
  - Weight distributions according to elicitation

Key output of UZ flow model expert elicitation and incorporation into TSPA-VA

Net average infiltration rate	Use PDF to define representative infiltration rates (and weights) and "re-calibrate" the UZ flow model
Spatial / temporal variability of infiltration rate	Use alternate infiltration rate distributions defined by expert elicitation in UZ flow model

Key output of UZ flow model expert elicitation and incorporation into TSPA-VA

(Continued)

Lateral diversion of flux and spatial/temporal variability of percolation flux	Use alternate infiltration rates and UZ flow model to confirm dampening of flux variability with depth as elicited from experts
Net average percolation flux and fracture/matrix flux distribution	Use results of UZ flow model with uncertain net average infiltration rate PDF to confirm percolation flux PDF and % fracture flux from expert elicitation

Key output of UZ flow model expert elicitation and incorporation into TSPA-VA

(Continued)

Seepage flux	Use results of drift-scale models with variable matrix and fracture properties to confirm expected range of seepage between 0.1 to 10% of repository area. Correlate seepage flux and area to percolation flux and properties variability

Conclusions

- Expert elicitation provided another means to develop reasonable ranges of key input values for the unsaturated zone flow model
- These ranges (appropriately weighted) will be used in TSPA-VA, as confirmed by UZ flow model
- Additional elicitations are underway in other key aspects of total system performance (e.g., waste package degradation and saturated zone flow and transport)

Example application of results of expert elicitation

- Uncertainty in average percolation flux
- Variability in average percolation flux
- Variability in average seepage flux

Example discrete appropriation of average percolation flux PDF

	Percentile	Weight	Spatial and Temporal Average
Model 1	3.5	0.1	1 mm/yr
Model 2	21	0.24	4 mm/yr
Model 3	50	0.32	7 mm/yr
Model 4	79	0.24	15 mm/yr
Model 5	96.5	0.1	34 mm/yr

Example spatial percolation flux variability

Model	Area 1 % Total Area	Area 1 % Total Flux	Area 1 Avg. Flux in Area	Area 2 % Total Area	Area 2 % Total Flux	Area 2 Avg. Flux in Area	Area 3 % Total Area	Area 3 % Total Flux	Area 3 Avg. Flux in Area
3.1	30	30	7	30	30	7	40	40	7
3.2	30	60	14	30	30	7	40	10	1.8
3.3	30	90	21	30	0	0	40	10	1.8
3.4	20	60	21	30	30	7	50	10	1.4
3.5	20	90	31	30	0	0	50	10	1.4
3.6	10	60	42	30	30	7	60	10	1.2
3.7	10	90	63	30	0	0	60	10	1.2

Example spatial percolation flux components in fractures

	Area 1		Area 2		Area 3		
Model	% Total Area	% Area w/ Seeps	% Total Area	% Area w/ Seeps	% Total Area	% Area w/ Seeps	Total % Area w/ Seeps
3.1	30	1	30	1	40	1	1
3.2	30	3	30	1	40	0	1.2
3.3	30	6	30	0	40	0	1.8
3.4	20	6	30	1	50	0	1.5
3.5	20	12	30	0	50	0	2.4
3.6	10	18	30	1	60	0	2.1
3.7	10	36	30	0	60	0	3.6

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Studies

Saturated Zone (SZ) Flow and Transport Uncertainties

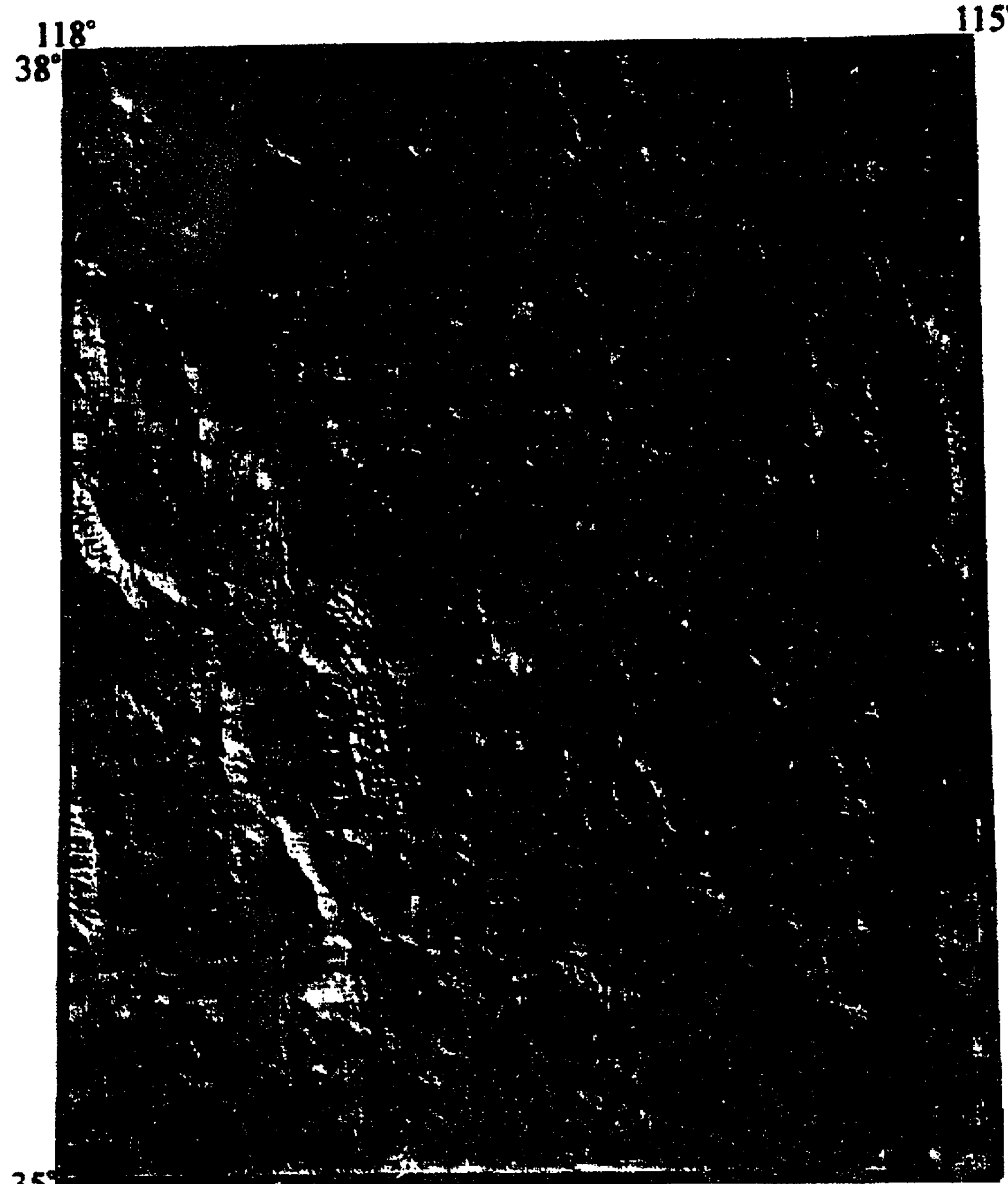
Presented to:
Nuclear Waste Technical Review Board

Presented by:
Dr. Dwight T. Hoxie
Manager, Process Modeling and PA Support
Site Evaluation Program Operations
Management and Operating Contractor
Las Vegas, Nevada

June 25-26, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Estimated Potentiometric Surface of the Death Valley Region



0 10 20 30 40 50 KILOMETERS
0 10 20 30 40 50 MILES

EXPLANATION

Death Valley ground-water flow system boundary

Nevada Test Site boundary

Model boundary

—1000— Potentiometric contour - shows altitude of potentiometric surface Contour interval 100 meters Datum is sea level

Key Uncertainties

- Saturated Zone Flow and Transport Abstraction/ Testing Workshop, April 1-3, 1997, Denver, CO, identified issues related to key flow and transport uncertainties affecting repository-system performance assessment:
  - Spatial distribution of advective flux
  - Alternative conceptual models
  - Effective transport properties
  - Future climate change

Spatial Distribution of Advective Flux

- Regional recharge and discharge
- Channelization of flow
- Vertical flow

<u>Significance:</u>
Ground water moving beneath the site will be principal means for radionuclide transport to the accessible environment

Regional Recharge and Discharge

- Spatially distributed recharge estimated by modified Maxey-Eakin method
- Discharge measurable at discrete locations:
  - Springs
  - Playa evapotranspiration
  - Pumpage from wells

Significance:
Inflows and outflows determine overall regional flow system

Flow Channelization

- Consequence of heterogeneity within hydrogeologic framework
  - Spatial distribution of hydraulic conductivity
  - Large-scale structural features (e.g., faults)
  - Fracture network connectivity

<u>Significance:</u>
Defines flow and transport pathways to accessible environment

Vertical Flow

- Limited data indicate potential for vertical flow upward into the volcanic aquifer near the site
  - Increasing head with depth in boreholes (e.g., UE-25 p#1)
  - Thermal data suggesting upwelling along major bounding faults (e.g., Solitario Canyon fault)

<u>Significance:</u>
Downstream mixing and dilution of radionuclide concentrations

Alternative Conceptual Models

- Steady-state hypothesis
- Equivalent continuum representation
- Explanations for large hydraulic gradient north of site

<u>Significance:</u>
Represents uncertainty in understanding of flow and transport processes and their numerical simulation

Transport Issues

- Dispersivity
  - Transport parameter to quantify longitudinal and lateral spreading of a solute plume
- Matrix diffusion (Effective porosity)
  - Process of diffusion of solute into rock matrix from fracture pathways
- Sorption
  - Process of retardation of solute by chemical interaction with rock-mass constituents (e.g., zeolites)

Transport Issues
(Continued)

Significance:

- Reduce downstream radionuclide concentrations
- Delay arrival times to the accessible environment

Future Climate Change

- Future pluvial episodes are expected to occur in next 10,000 to 100,000 years with periods of increased regional recharge

Significance:

- Potential water-table rise beneath the site
- Increased advective transport velocities
- Possible enhanced mixing and dilution within SZ

Addressing Key Uncertainties

- Laboratory testing
  - Solubility and speciation experiments for Np
  - Column and diffusion-cell experiments for selected radionuclides
  - Hydrologic property measurements
    - » Saturated hydraulic conductivity
    - » Porosity

Addressing Key Uncertainties
(Continued)

- Field testing
  - Hydraulic and tracer testing at c-holes complex
  - Completing Fortymile Wash recharge study
  - Planned WT-24 penetration of large hydraulic gradient
  - Planned hydraulic and hydrochemical testing in boreholes (e.g., Eh measurements in WT-17; new boreholes SD-6, SD-11, SD-13)
  - Planned second SZ testing complex
  - Paleodischarge investigations

Addressing Key Uncertainties
(Continued)

- Modeling studies
  - Conducting sensitivity analyses for key processes and parameters using SZ flow and transport numerical models
  - Completed modeling of selected climate states to estimate bounds on possible future climate change and increased recharge

Addressing Key Uncertainties
(Continued)

- Conducting SZ flow and transport expert elicitation to quantify uncertainty bounds on key parameters and conceptual models
  - Expert panel members:
    - » Dr. R. Allan Freeze
    - » Dr. Lynn Gelhar
    - » Dr. Donald Langmuir
    - » Dr. Shlomo Neuman
    - » Dr. Chin-Fu Tsang

Testing Program Support for Addressing Key Flow and Transport Issues

ISSUES	Laboratory Testing			Field Testing						Modeling Studies	
	Solubility Experiments	Column Experiments	Hydraulic Properties	C-Holes	Fortymile Wash Recharge	WT-24	WT-17, SD-6, SD-11, SD-13	SZ Testing Complex	Paleo-discharge Studies	Sensitivity Analyses	Future Climate
Advective Flux Recharge and Discharge Flow Channelization Vertical Flow			X X	X X	X X		X X	X X	X	X X X	X
Alternative Conceptual Models Steady-State Hypothesis Equivalent Continuum Model Large Hydraulic Gradient				X	X	X		X		X X X	
Transport Issues Dispersivity Matrix Diffusion Sorption	X	X X		X X X				X X X		X X X	
Future Climate Change									X	X	X

Conclusion

- We will establish quantified bounds on key parameter and model uncertainties for VA

- We will reduce key uncertainties through additional testing for LA

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Additional Work Through License Application

Presented to:
Nuclear Waste Technical Review Bc -a

Presented by:
Dr. Jean L. Younker
Manager, Regulatory Operations
Civilian Radioactive Waste Management System
Management and Operating Contractor

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Iune 75-76. 1997

Outline

- Overview
- Information available at Viability assessment
- Additional work supporting the License Application
  - Site testing
  - Repository/waste package design
  - Total system performance assessment
  - Regulatory activities
- Documentation of future plans

Information Available at VA

- A basic understanding of site processes
  - Geologic framework
  - Hydrologic flow
  - Geochemical environment
- Preliminary design concept of key design features
  - Concept of operations
  - Reference repository and waste package designs
  - Identification and partial evaluation of available design options

Information Available at VA
(Continued)

- Total system performance assessment
  - Based on preliminary site/design process models
  - Evaluation of reference design concept
- Preliminary safety case
  - Preclosure
  - Postclosure

Additional Work Supporting the LA

[illegible]

- Drift scale heater test
- UZ flow & transport tests
- SZ flow & transport tests
- Rock mechanics/hydrologic lab tests
- E-W drift

[illegible]

[illegible]

- Conduct EBS lab testing
- Evaluate design options
- Select /design these options
- Complete details of operational concept

[illegible]

- Address Peer Review comments
- Incorporate updated data/process models
- Conduct analyses

[illegible] ☆ 8/00

[illegible] ☆ 7/01

[illegible] ☆ 3/02

Key Site Testing Activities

- Drift-scale heater test
  - Start in December 1997 and continue for several years
  - Information on coupled processes
- UZ flow and transport tests
  - Tests to be conducted in ESF, including E-W drift
  - Four new boreholes in vicinity of repository block
- SZ flow and transport tests
  - Data obtained from four boreholes south of the repository block
- Rock mechanics/hydrologic lab tests
  - Tests done on samples obtained from E-W drift
- Update site process models for TSPA input

Key Repository/Waste Package Design Activities

- Conduct EBS lab testing
  - Waste package materials
  - Waste package/waste form degradation processes
- Evaluate design options
  - Complete evaluation of EBS options to enhance performance
  - Evaluate costs associated with these options
- Select /design these options
  - Focus on items important to safety and waste isolation, especially those with no regulatory precedence
- Update EBS process models for TSPA input
- Complete details of operational concept

Key Total System Performance Assessment Activities

- Address Peer Review comments
  - Comments on TSPA-VA; used to strengthen analysis for TSPA-LA
  - Final TSPA Peer Review report due March 1999
- Incorporate updated data and process models
  - Site, EBS, and biosphere data and models
  - Abstraction process similar to what is being done for TSPA-VA
- Conduct analyses
  - Includes sensitivity analyses of EBS options

Key Regulatory Activities

- Prepare Final EIS
  - Includes development of Draft EIS and public comment period
  - Final EIS must accompany the site recommendation and the license application
- Prepare site recommendation
  - Documents site suitability determination (10 CFR 960)
  - A key requirement is NRC's preliminary comments on sufficiency of information for the LA
- Prepare license application
  - Project Integrated Safety Assessment (PISA) will be used as starting point for Draft LA
  - Extensive interaction with NRC needed to facilitate docketing and to expedite detailed licensing review

Documentation of Future Plans

- License Application Plan will document the plan and cost estimate to complete the LA
  - One of the four VA products
- LA Plan will contain
  - Overall strategy for LA development
  - Work to be conducted between VA and LA
  - Cost and schedule for that work
  - Description of the Performance Confirmation Program
- Draft Plan in 9/97; Final Plan in 8/98

Summary

- The work done for VA will help to focus remaining work needed to support the LA
- The LA Plan will document what will be done between VA and LA
  - Workscope, schedule, and cost
- Interactions with NRC will help to further focus the remaining work on the critical issues

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Studies

Performance Confirmation (PC) Program

Presented to:
Nuclear Waste Technical Review Board

Presented by:
Richard Wagner
Manager, Systems Engineering/Integration
Management and Operating Contractor
Las Vegas, Nevada

June 25-26, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Outline

- Regulatory Background for Performance Confirmation (PC) Program
- PC is Part of Test and Evaluation Program
- PC Program Approach
- Identification of PC Parameters
- Important Processes and Parameters
- Performance Confirmation Concepts
- Design Implementation of PC
- Transition to PC Program Testing
- Planned Activities

Regulatory Background for PC Program

Consists of tests, experiments, and analyses to evaluate whether or not the performance objectives will be met for the period following permanent closure

Provides data which indicates that

- Actual subsurface conditions encountered and changes in those conditions are within the limits assumed in the licensing review [10CFR60.140(a)(1)]

Regulatory Background for PC Program

(Continued)

Provides data which indicate that

- Natural and engineered systems and components either required for repository operation or that are either designed or assumed to operate as barriers after permanent closure, are functioning as intended and anticipated [10CFR60.140(a)(2)]

Starts during site characterization and continues to permanent closure [10CFR60.140(b)]

PC is Part of Test and Evaluation Program

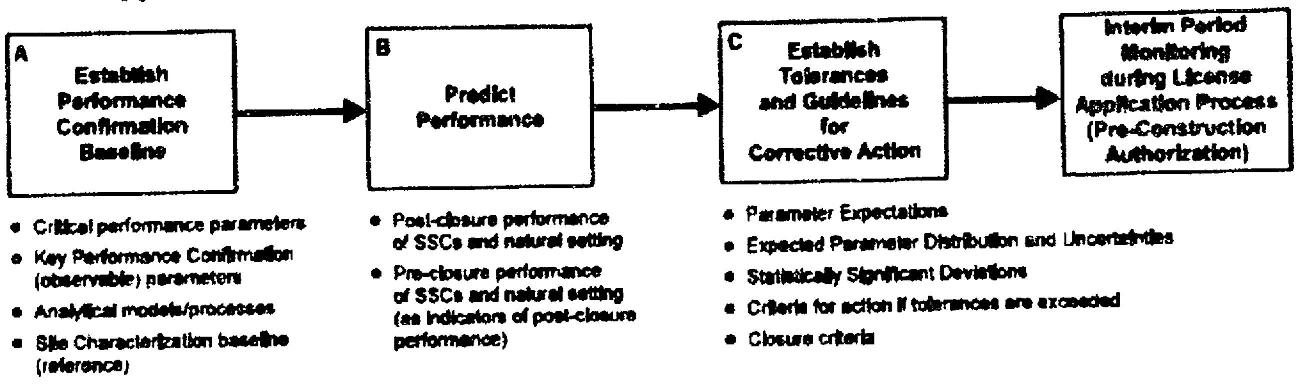
Test and evaluation program will

- Perform necessary system verification throughout MGDS life cycle to validate the MGDS for receipt, handling, retrieval, disposal, and isolation of waste

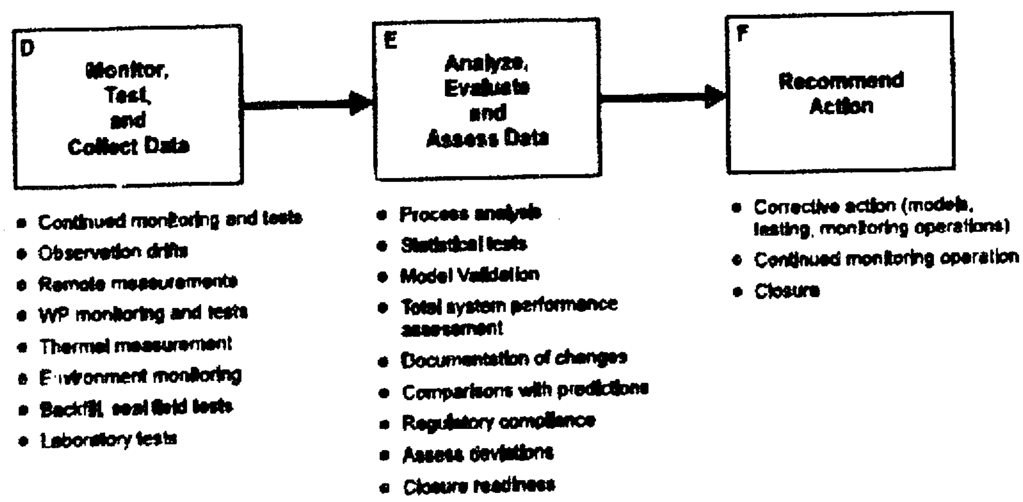
PC focuses on system verification for the isolation of waste function

PC Program Approach

Site Characterization/License Application/Pre-Construction Phases



Construction/Operation/Caretaker Phases



Important Process and Design Features

Site

- Near-field environment
- Far-field environment

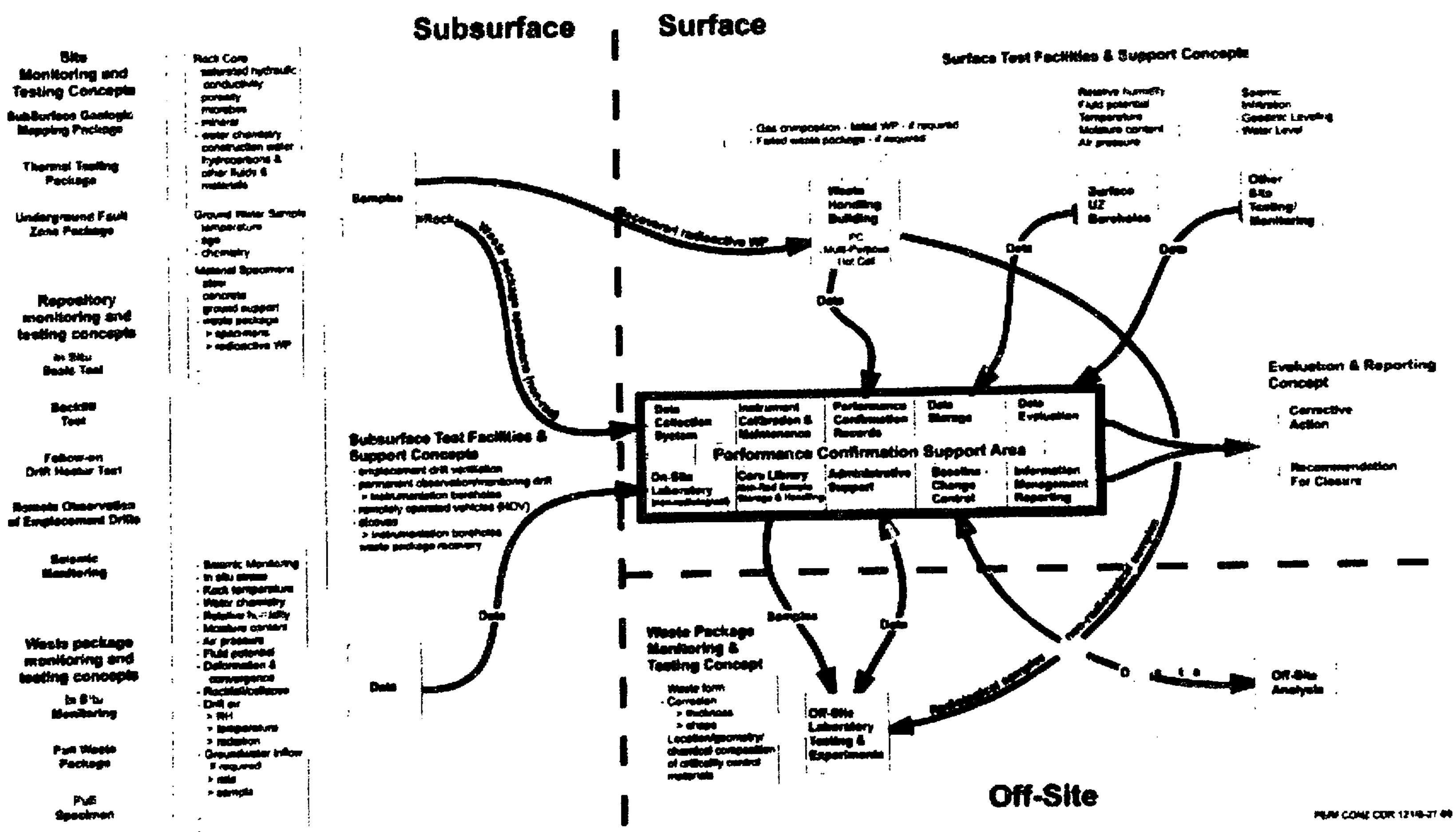
Repository

- In-drift environment
- Emplacement drift liner

EBS

- Waste package degradation

PC Concepts


Subsurface
Surface
Off-Site
Surface Test Facilities & Support Concepts
Subsurface Test Facilities & Support Concepts
Performance Confirmation Support Area
Data Collection System
Instrument Calibration & Maintenance
Performance Confirmation Records
Data Storage
Data Evaluation
On-Site Laboratory
Core Library
Administrative Support
Baseline Change Control
Information Management Reporting
Waste Handling Building
Surface UZ Boreholes
Other Site Testing/ Monitoring
Evaluation & Reporting Concept
Corrective Action
Recommendation For Closure
Waste Package Monitoring & Testing Concept
Off-Site Laboratory Testing & Experiments
Off-Site Analysis
Samples
Data
Site Monitoring and Testing Concepts
Thermal Testing Package
Underground Fault Zone Package
Repository monitoring and testing concepts
Backfill Test
Seismic Monitoring
Waste package monitoring and testing concepts

Design Implementation of PC

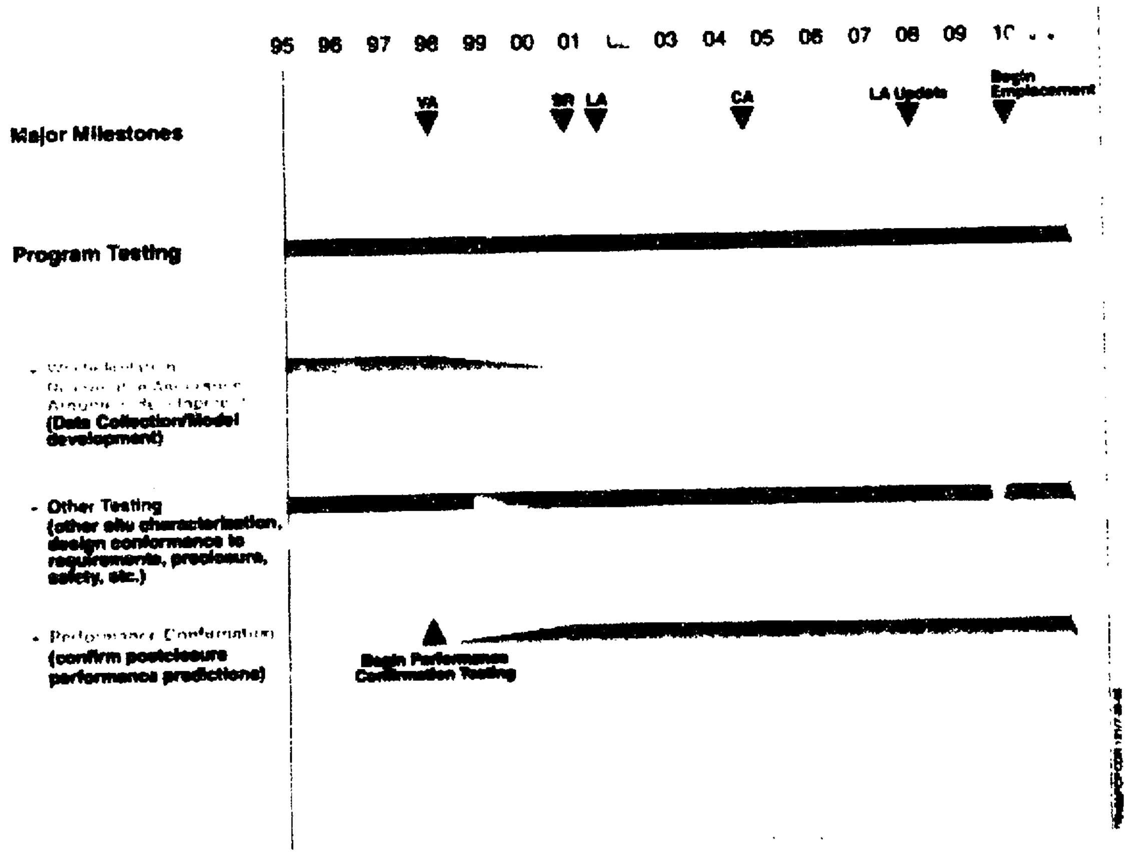
Observation Drift

- Borehole Instruments in the Altered Zone (examples of parameters for data acquisition)
  - » Rock temperature
  - » Rock stress and strain
  - » Ground-water chemical composition; Eh & pH
  - » Moisture content
  - » Water vapor content/humidity

Remote Inspection Gantry

- Techniques for data acquisition or examples of parameters for data acquisition
  - » Waste package temperature
  - » Retrieval of waste package material coupons or other EBS materials - corrosion rates
  - » Visual inspections of drifts for seepage

Transition to PC Program Testing



Planned Activities

Near Term

- Completion and Approval of PC Plan
- Preparation for Implementation of PC Program
- Begin PC Program Baseline Phase
- Shake-out of PC Approach using the Enhanced Characterization of the Repository Block Effort

Far Term

- Develop PC Baseline Information
- Conduct Design for Tests and Facilities
- Implement Planned Activities
- Update PC Plan, in Response to Changes in Design, TSPA, Process Models, and Data Collection

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Mined Geologic Disposal System Viability Assessment Cost Estimate Plan

Presented to:
Nuclear Waste Technical Review Board

Presented by:
Mitchell G. Brodsky
General Engineer
U.S. Department of Energy
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June 25-26, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Outline

- Why we are doing the MGDS VA cost estimate
- Components of the estimate
- Estimating approach
- Cost control process and review plans
- Example draft estimate
- Key milestones on path to final MGDS VA cost estimate
- Issues and challenges

VA Cost Estimate Requirement

- **MGDS-VA cost estimate required by the Energy and Water Development Appropriation Bill, 1997 (became law 9/30/97) H.R.3816**

Nuclear Waste Disposal Fund

".....That no later than September 30, 1998, the Secretary shall provide to the President and to the Congress a viability assessment of the Yucca Mountain site. The viability assessment shall include:

(1) the preliminary design concept for the critical elements for the repository and waste package;

(2) a total system performance assessment, based upon the design concept and the scientific data and analysis available by September 30, 1998, describing the probable behavior of the repository in the Yucca Mountain geological setting relative to the overall system performance standards;

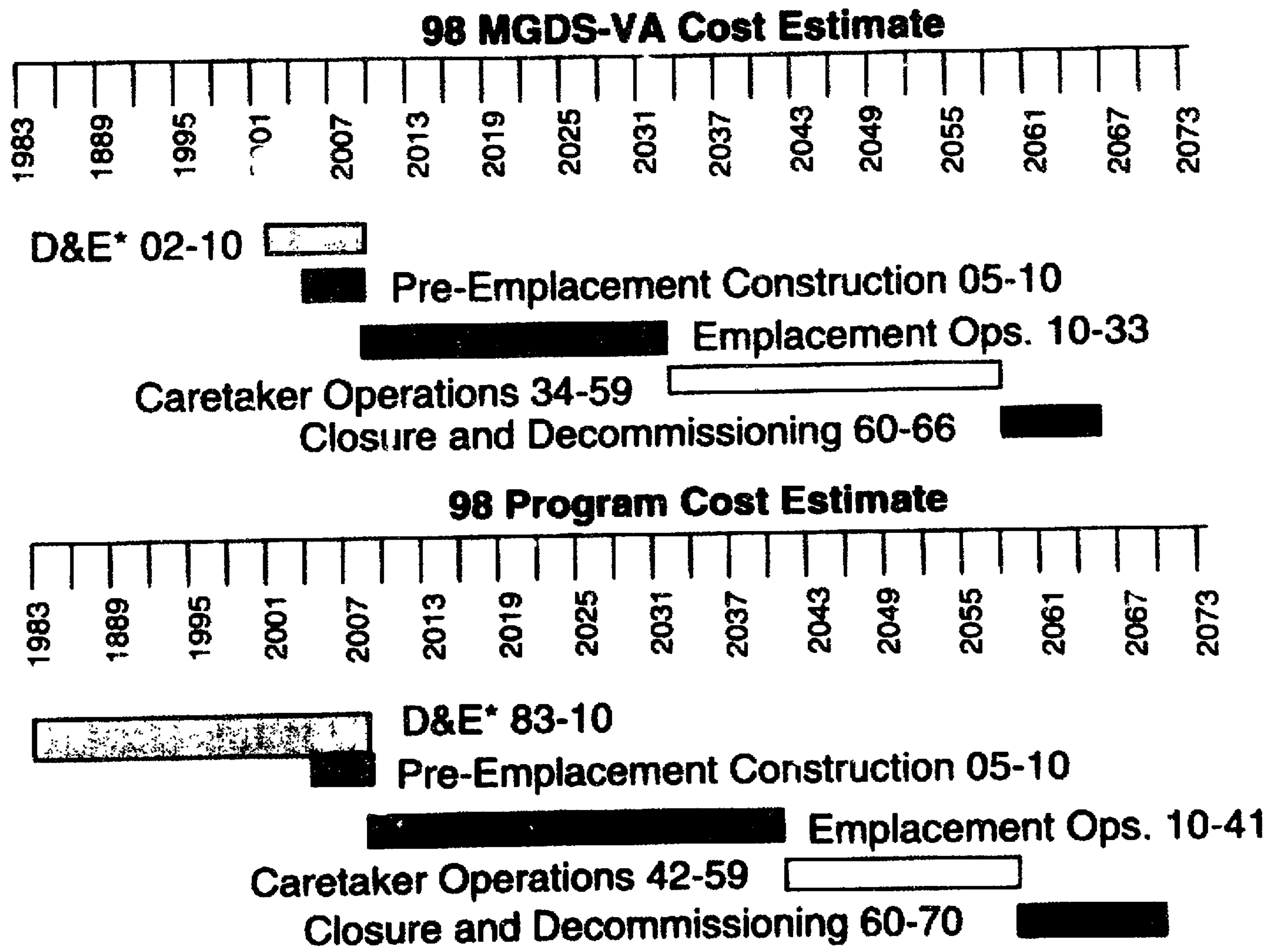
(3) a plan and cost estimate for the remaining work required to complete a license application; and

(4) ***an estimate of the costs to construct and operate the repository in accordance with the design concept."***

Program/Project Cost Estimates - Usage

- MGDS-VA cost estimate
  - Provides the cost of a reference repository design
  - Used as input into Program cost estimates
  - Supports project trade and optimization studies
- Program cost estimates are used to
  - Determine waste fund fee adequacy
  - Determine defense funding required
  - Compare available funding with anticipated near-term costs
  - Determine Program economic viability
  - Perform Program trade and optimization studies

MGDS VA Cost Estimate Time Phases



* Development and Evaluation

Elements Excluded From MGDS Estimate

- Historical MGDS D&E costs (prior to 1998)
  - Site characterization, prior design activities
- License application cost (10/98 - 3/02)
- Program costs
  - Waste acceptance
  - Storage
  - National transportation (Regional Servicing Agent (RSA) concept)
  - Other Program costs (NRC, NWTRB, misc.)

Elements Included in MGDS Estimate

- MGDS development and evaluation (D&E)
- Surface facilities
- Subsurface facilities
- Disposal containers
- Performance confirmation
- Nevada transportation

Elements Included in MGDS Estimate

- MGDS development and evaluation (D&E)
- Surface facilities
- Subsurface facilities
- Disposal containers
- Performance confirmation
- Nevada transportation

Development and Evaluation: Cost Estimating Approach

- Multi-year project plan approach
  - Includes design activities, management, institutional, Payment Equal To Taxes (PETT), and planning for performance confirmation and Nevada transportation construction activities
  - Expansion of the planning horizon from historical five-year planning to include activities through 2010

Surface Facilities: Cost Estimating Approach

- Radiological facilities
  - Design-based bottoms-up
  - Equipment--commercial database and quotes
  - Manpower--manpower studies, means database and site unique factors
  - Closure and decommissioning--factoring
- Balance of plant
  - Capital costs--scaling (MRS design/cost base)
  - Operation costs--manpower studies based
  - Closure and decommissioning--factoring

Subsurface Facilities: Cost Estimating Approach

- Design layout based excavation modeling
  - Efficiency based progress
    - Tunnel Boring Machine (TBM) primary method
    - Road headers/ other excavation used
  - Ground support--bottoms-up
- Manpower based on crew assignment and schedules
  - Crew costs based manpower studies, crew efficiency considerations and NTS labor agreement rate bases
- Materials and equipment based on industrial reference databases
  - Dataquest
  - Western Mining Engineering
  - US Army Corps of Engineers

Disposal Containers: Cost Estimating Approach

- Unit costs
  - Design-based quantity takeoffs
  - Material costs based on supplier quotes
  - Other contributors include
    - Nye County sales tax
    - Factors for transport, project management
    - Contingency
- Disposal container quantities
  - Waste stream based

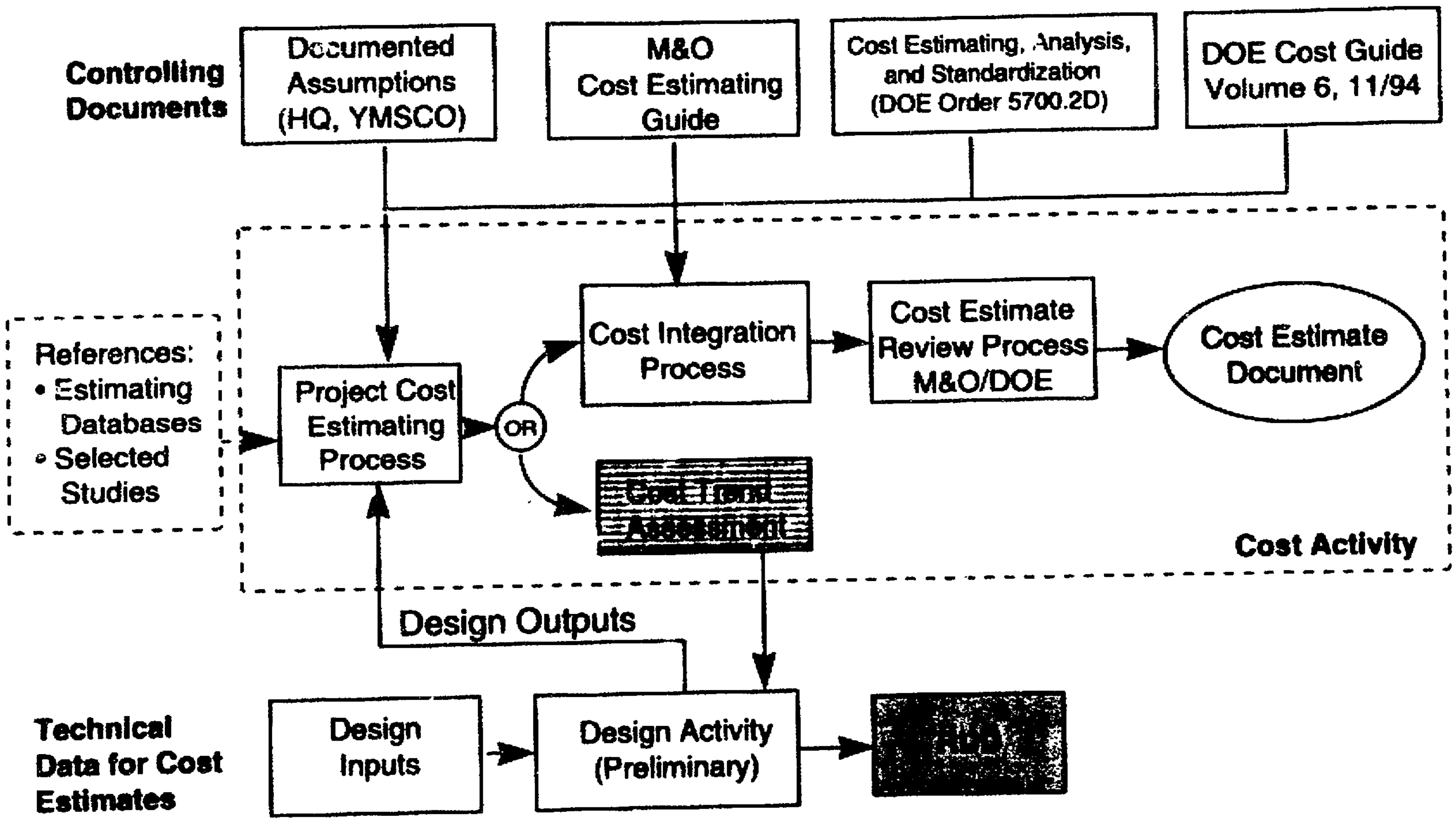
Performance Confirmation - Cost Estimating Approach

- Capital costs
  - Facilities estimated by Surface--capacity factoring; and Subsurface--bottoms-up
  - Boreholes scaled from historical local database
- Operations
  - Based on scaling and factoring
  - Data analysis, new studies, and scaling from historical local database

Nevada Transportation: Cost Estimating Approach

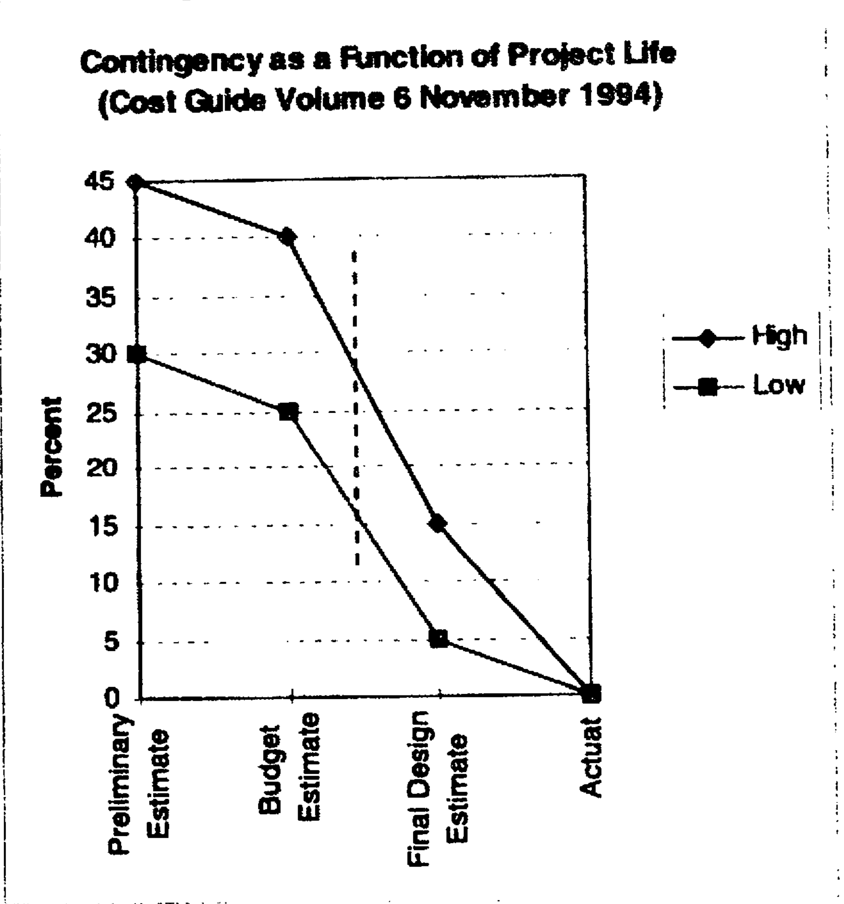
- Until such time that the transportation mode/route is selected, the following assumptions are made for cost estimating purposes
  - Assumes a government-owned and Regional Service Agency (RSA) operated rail line from a main railroad line to the repository
  - Route assumed to be the average of five rail route alternatives in EIS studies (in review)

Cost Control Process



Assessing Accuracy and Risk

- Developing a plan for assessing risk of the overall estimate
- Current estimating guide and industry experience provides for a range contingency levels, based upon design maturity, that which are applied to elements of the estimate

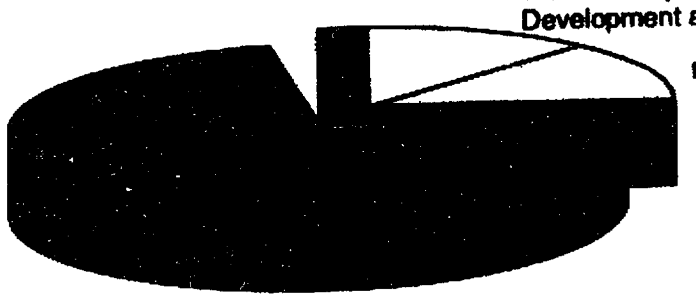


MGDS VA Estimate Reviews

- Yucca Mountain Project (YMP)
  - Multi-year planning January - February 1998
  - MGDS estimate April 1998 and July 1998
- External Review Team
  - Review completed segments and submit feedback at end of segment review
    - » Assumption segment - October 1997
    - » Disposal container segment - January 1998
    - » D&E (multi-year segment) - February 1998
    - » Repository and remaining elements - April 1998
    - » Draft Final report - June 1998

Yucca Mountain is the Largest Element of Total System Life Cycle Costs

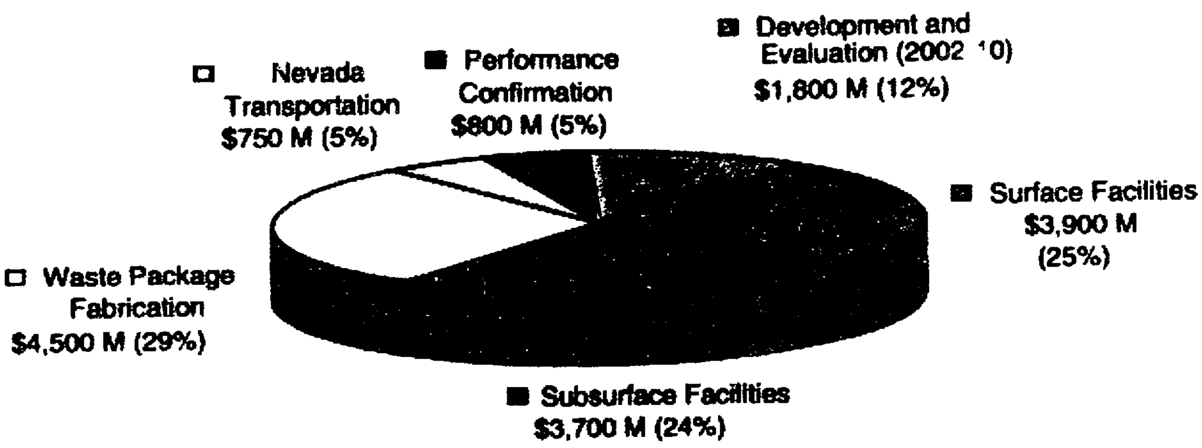
Relationships of Major Elements of Total Life Cycle Costs (Based on 1997 Program Cost Estimate)



Assumptions:
- **Disposal of total requirement in a single repository.**
- **Emplacement 2010-2041.**
- **Closure 50 years after start of emplacement.**
- **No centralized interim storage.**
- **Disposal in large waste packages.**
- **Rail and truck transport (13 truck sites).**

Repository Cost Drivers

70,000 MTU repository (scaled from 97 PCE)



Total = $15,450 M FY 97 Dollars

The MGDS estimate is presently in work, the data presented herein is result ~f a scaling effort to be replaced by the cost estimate of the RDD Rev. 0

Assumptions:
- **Disposal of 70,000 MTU in Yucca Mountain repository.**
- **Emplacement 2010-2033.**
- **Closure 50 years after start of emplacement.**
- **No centralized interim storage.**
- **Disposal in large waste packages.**
- **Rail and truck transport (13 truck sites).**

Key Milestones

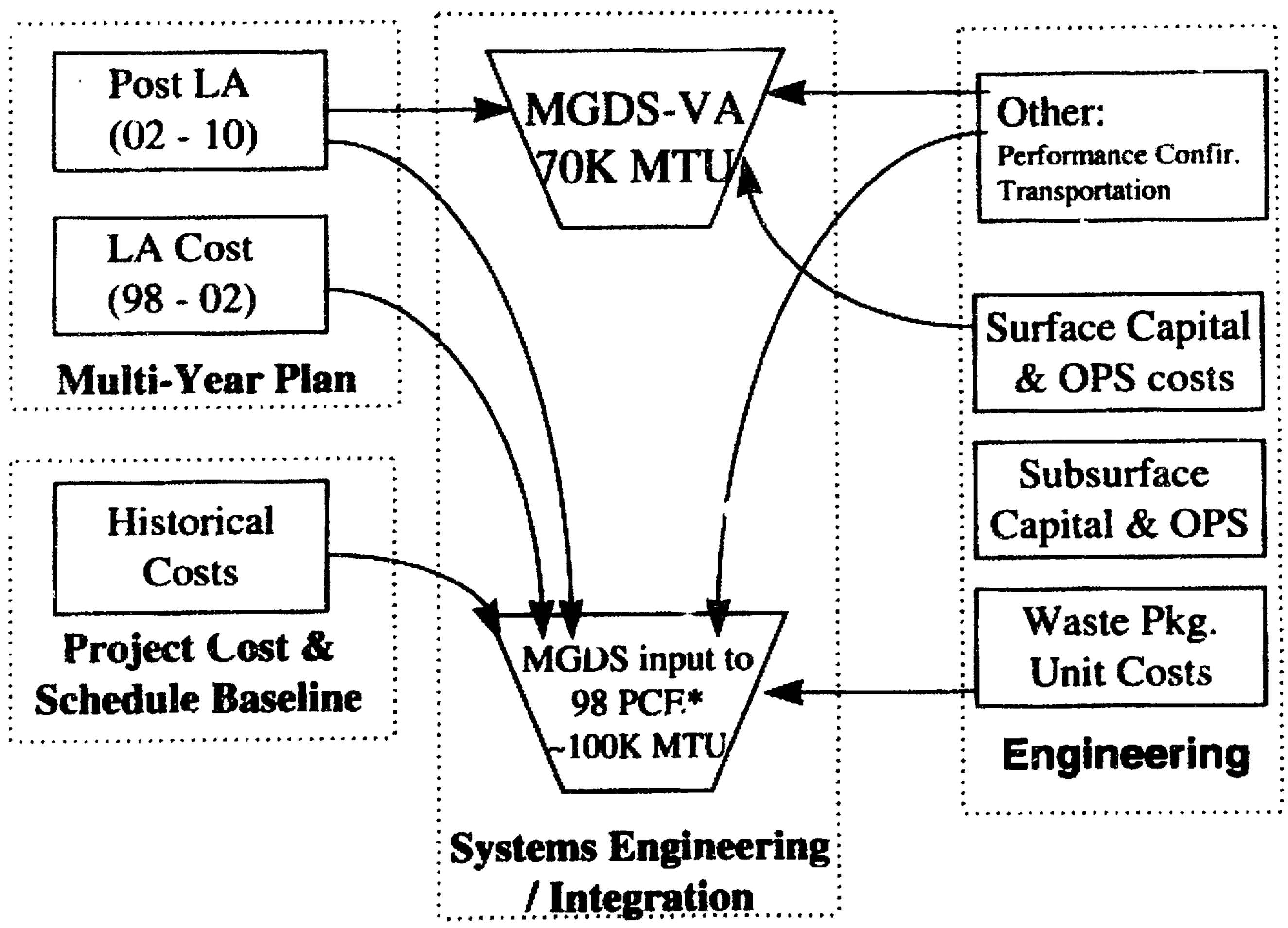
- Cost Analysis Report - VA assumptions 9/30/97
- Disposal container design freeze - 9/30/97
- Bin 3 freeze - 9/30/97
- Final design freeze (non-Bin 3) 2/10/98
- VA Document due - 8/28/98

Challenges

- Reconcile external review comments
- Incorporate late design changes which have a significant impact on the cost estimate
- Integrate design and related costs details from design segments

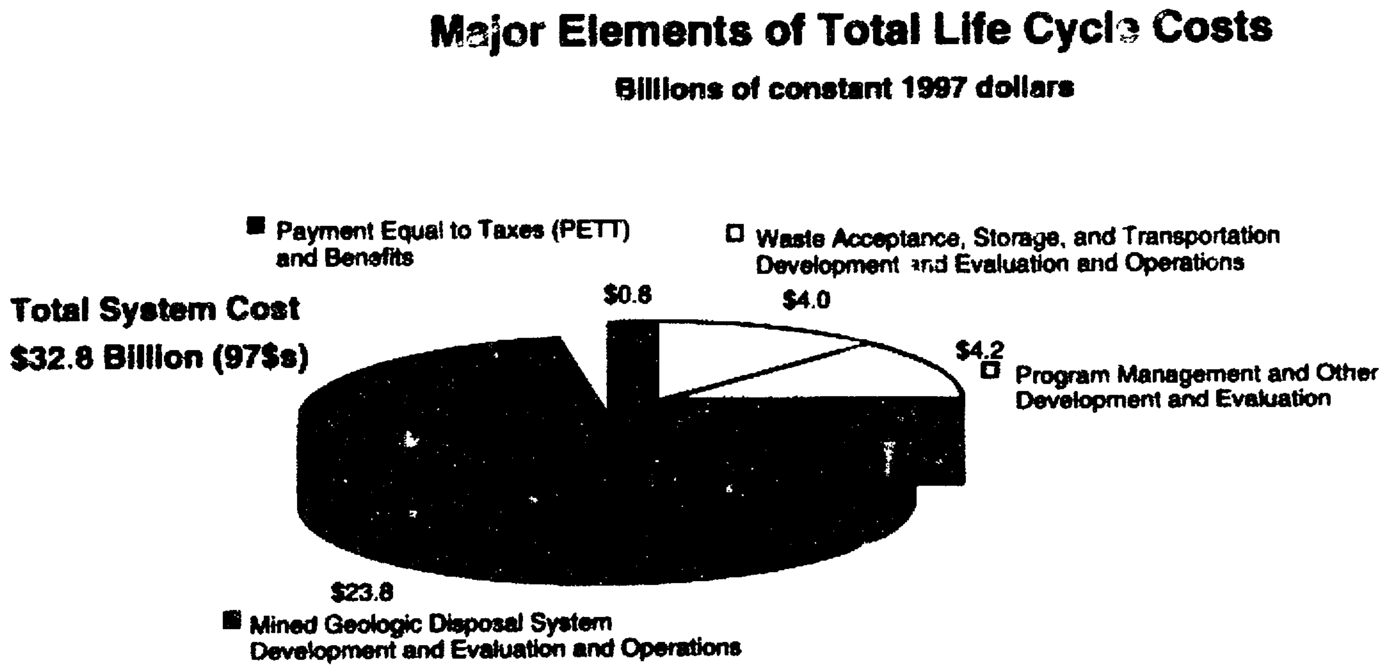
Backup Charts

98 MGDS Cost Products



* Program Cost Estimate

Total System Life Cycle Costs (Existing Estimate)



Assumptions:
- **Disposal of total requirement in a single repository.**
- **Emplacement 2010-2041.**
- **Closure 50 years after start of emplacement.**
- **No centralized interim storage.**
- **Disposal in large waste packages.**
- **Rail and truck transport (13 truck sites).**

Major Difference Between 95 TSLCC and 97 PCE

Item	95 TSLCC	97 PCE
Waste stream	SNF & DHLW	SNF, DHLW & DOE SNF
Mass Thermal Loading	100 MTU/acre	83 MTU/acre
Tunnel ground support	(minimal) Mesh & rock bolts	Concrete liner
Emplacement drift Diameter	5 meters	5.5 meters

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Studies

East-West Tunnel Crossing the Repository Block: Recommended Studies and their Objectives

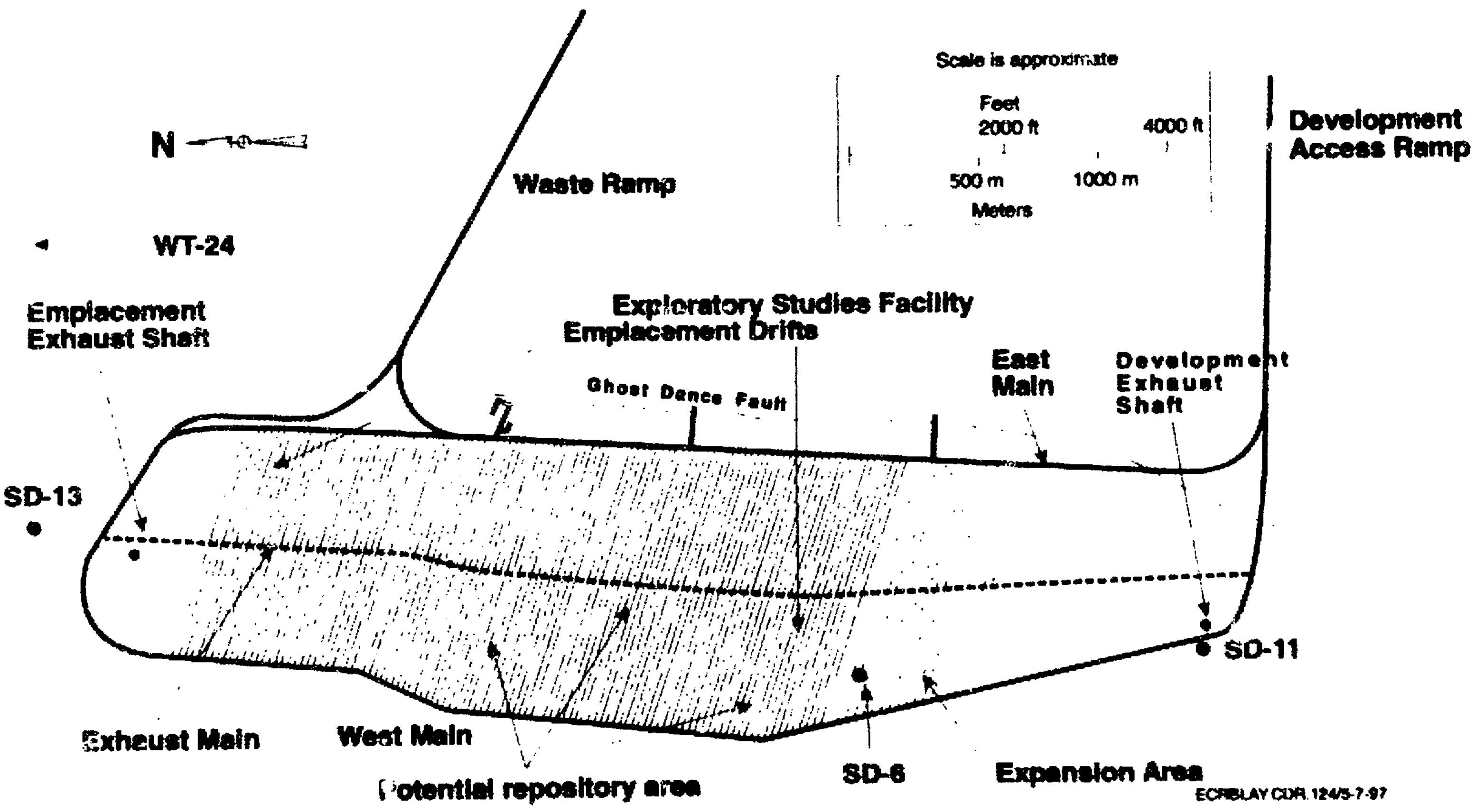
Presented to:
Nuclear Waste Technical Review Board

Presented by:
Dr. Michael D. Voegele
Management and Operating Contractor
Las Vegas, Nevada

June 25-26, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Preliminary East-West Drift Layout - - Recommended



Borehole locations are approximations for illustration only

Testing to Support Design/Construction

- Monitoring construction water usage and ventilation impacts
- Evaluation of dust suppression strategies
- Mapping fracture distribution, frequency, and physical attributes
- Investigation of footwall deformation of the Solitario Canyon Fault
- Characterization of hazardous mineral distributions
- Location of basal vitrophyre of the Topopah Spring formation
- Predict geologic features of engineering and construction significance, and anticipated ground conditions

Testing to Support Hydrologic Model

- Saturation profiles and hydrologic properties from surface boreholes
- Niche and alcove studies to characterize percolation flux, seepage into drifts, and fracture-matrix interactions
- Saturation and water potential measurement from the crossdrift to characterize the spatial variability of percolation flux
- Characterization of environmental isotope distributions and fracture fillings to evaluate flow pathways

Testing to Support Hydrologic Model
(Continued)

- Boreholes in the crossdrift to evaluate tracer migration rates
- Characterize the hydrologic properties of the Solitario Canyon fault
- Testing of any perched water encountered in surface boreholes
- Predict ambient moisture, gas, heat, and geochemical conditions along the recommended crossdrift using the calibrated 3-D site scale UZ flow model

Reducing Hydrologic Uncertainties

- Characterizing percolation of water at the repository horizon in different host rock units
- Characterizing effects, at depth, of varying surface infiltration rates
- Characterizing seepage into drifts through *in situ* testing in niches
- Characterizing movement of water below drift inverts

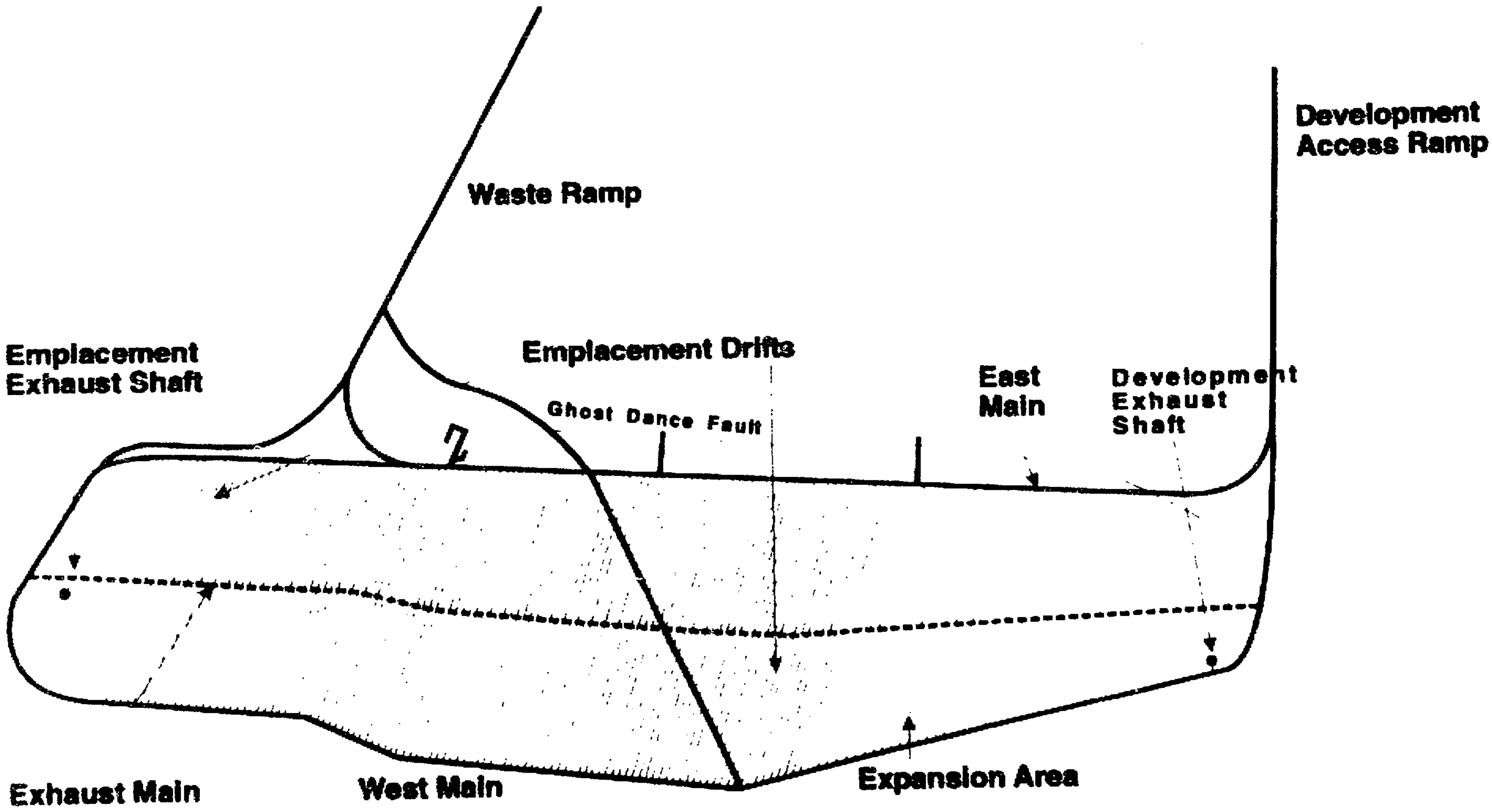
Reducing Hydrologic Uncertainties
(Continued)

- **Help discriminate between different models for fracture/matrix interaction and seepage into drifts**
  - Dye infiltration in niches
  - Progressively increasing water injection above excavated niche to evaluate seepage threshold
  - East-West Drift construction water monitoring from launch bay to crossing of the ESF main

Reducing Hydrologic Uncertainties
(Continued)

- Address variability in percolation flux; verify or reduce range
  - Total chloride: Chloride, mass balance and Chloride-36 in ESF main (sidewall borings), niche samples, E-W drift, and new boreholes
  - Other chemical elements: Strontium isotopes, environmental isotopes (Cl-36, Tritium, C-14, C-13, Technetium, Iodine, ESF main, niches, E-W drift, and new boreholes
  - Temperature: Geothermal gradient measuring in boreholes
  - Fracture coatings: Calcite/opal for Uranium disequilibrium samples collected in ESF niches, E-W drift and new boreholes

Preliminary East-West Drift Layout - - Recommended



East-West Cross Drift Critical Schedule Elements

• Launch chamber design (70 days)	6/2/97-9/5/97
• TBM planning, acquisition, rehabilitation and assembly (147 days)	5/19/97-0/31/97
• Excavate launch chamber (66 days) Station 00+00 to 00+90	9/15/97-2/15/97
• Move TBM to face (22 days)	12/16/971/14/98
• Equipment shakedown Station 00+90 to 02+40	1/15/98-1/28/98
• Excavate 2010 meter cross drift	2/5/98-5/1/98
• (62 days) Station 02+40 to 21+00	
• Excavate to Solitario Canyon 200 meters (7 days) Station 21+00 to 23+00	5/4/98-5/12/98

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Scientific Studies Update at Yucca Mountain

Presented to:
Nuclear Waste Technical Review Board

Presented by:
Larry R. Hayes
Site Evaluation Program Operations
Civilian Radioactive Waste Management System
Management & Operating Contractor

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

June 25-26, 1997

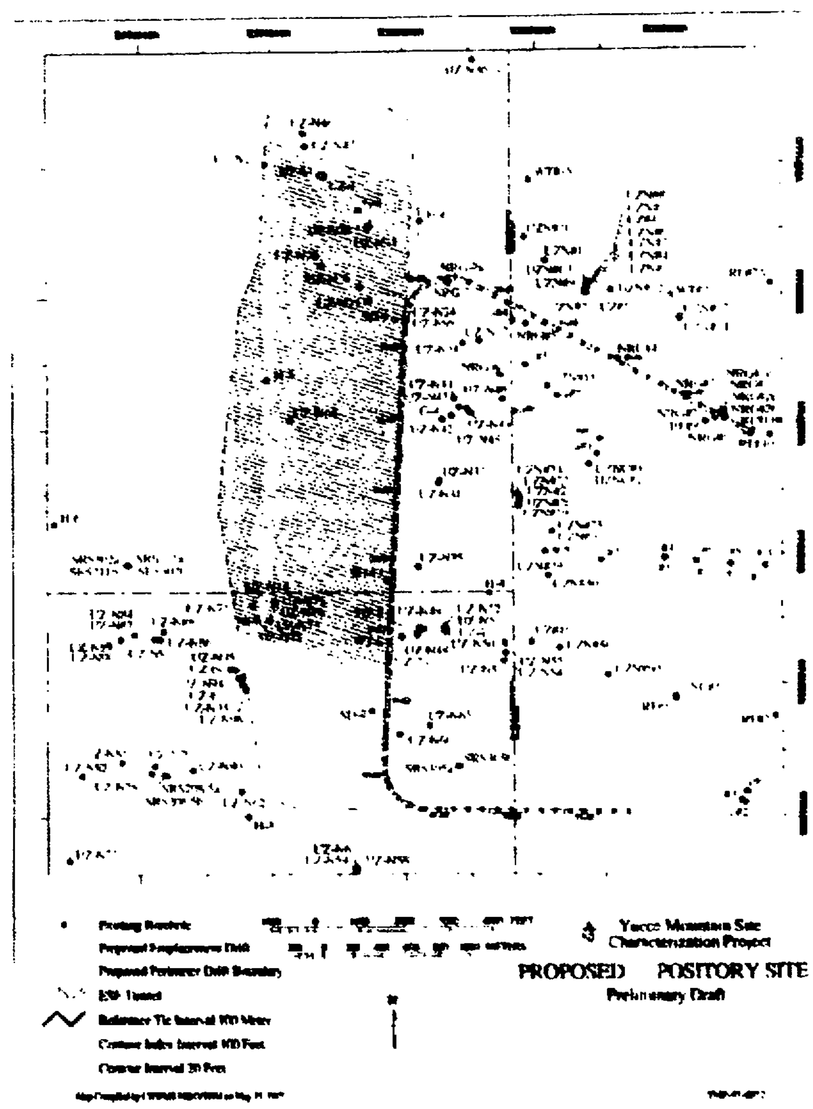
Focus of the Briefing

- Data Collection at Yucca Mountain
- In Situ Thermal Testing
  - Single Heater Test
  - Drift Scale Test
- C-Well Testing
  - Update on Hydrologic Information
  - Update on Transport Information
- ESF Moisture Studies
  - ESF Percolation Study
  - ESF Niche Study

Data Collection at Yucca Mountain

Data Summary

- A 5-mile underground testing facility with 7 major testing alcoves
- About 350 surface-based boreholes (more than 30 miles of drilling)
- About 200 underground boreholes
- More than 75,000 feet of core
- More than 15,000 samples for geohydrologic analyses
- More than 200 pits and trenches
- More than 500 water and rock samples for age dating and geochemical analyses
- Periodic water level monitoring in about 50 boreholes
- Neutron monitoring in about 90 boreholes
- Continuous pneumatic monitoring in 76 hydrogeologic zones
- About 50 seismic monitoring stations



Generalized Rock and Hydrologic Properties, Unsaturated Zone at Yucca Mountain

Unit	Generalized Rock Properties	Generalized Hydrologic Properties	Derived Flux (averaged) mm/yr		Minimum Observed Water Ages* (years)		Method	Data Source
			Fracture	Rock Matrix	Fracture	Rock Matrix		
TCw	Moderately to densely welded Bulk Density 2.23 Porosity 0.1 Thermal Conductivity 1.39 W/mK Fracture Density 35 frac/m³ About 810 Samples	Saturation about 0.7 Saturated Hydraulic Conductivity about 1 x 10³ mm/yr About 40 Samples	6	1	Modern	Modern	C-14 Tritium Cl-36	RIB Section 1.12a Geologic/Lithologic Stratigraphy & Hydrologic Properties
PTn	Nonwelded Bulk Density 1.39 Porosity 0.4 Thermal Conductivity 0.57 W/mK Fracture Density 1 frac/m³ About 690 Samples	Saturation about 0.5 Saturated Hydraulic Conductivity about 7 x 10⁴ mm/yr About 65 Samples	0	6	Modern Near Faults	2,000 (SD-12) 3,000 (SD-7)	C-14, Tritium	Recent Project Reports and TDB Submittals Baseline. RIB Section 1.12a Geologic/Lithologic Stratigraphy & Hydro-geologic Properties
TSw	Moderately to densely welded. Bulk Density 2.20 Porosity 0.1 Thermal Conductivity 1.23 W/mK Fracture Density 25 frac/m³ About 2100 Samples	Saturation about 0.7 Saturated Hydraulic Conductivity about 1 mm/yr About 285 Samples	4	1	Modern Near Faults	Perched water at basal vitrophyre: 2,100-2,700 (NRG7a) 4,000-5,000 (SD-9) 5,700-6,300 (UZ-14)	C-14, Tritium	Recent Project Reports & TDB Submittals Baseline. RIB Section 1.12a Geologic/Lithologic Stratigraphy & Hydro-geologic Properties
CHn	Nonwelded (vitric and zeolitic) Bulk Density 1.74 Porosity 0.3 Thermal Conductivity 1.20 W/mK Fracture Density 1 frac/m³ About 1300 Samples	Saturation about 0.9 Saturated Hydraulic Conductivity about 1 x 10³ mm/yr (vitric) and 1 mm/yr (zeolitic) About 220 Samples	0 Vitric 2.5 Zeolitic	3 Vitric 0.5 Zeolitic	Modern Near Faults	500 (UZ-14 & SD-9) 3,000 (SD-12 & SD-7)	C-14, Tritium, Cl-36	Recent Project Reports & TDB Submittals Baseline. RIB Section 1.12a Geologic/Lithologic Stratigraphy & Hydro-geologic Properties

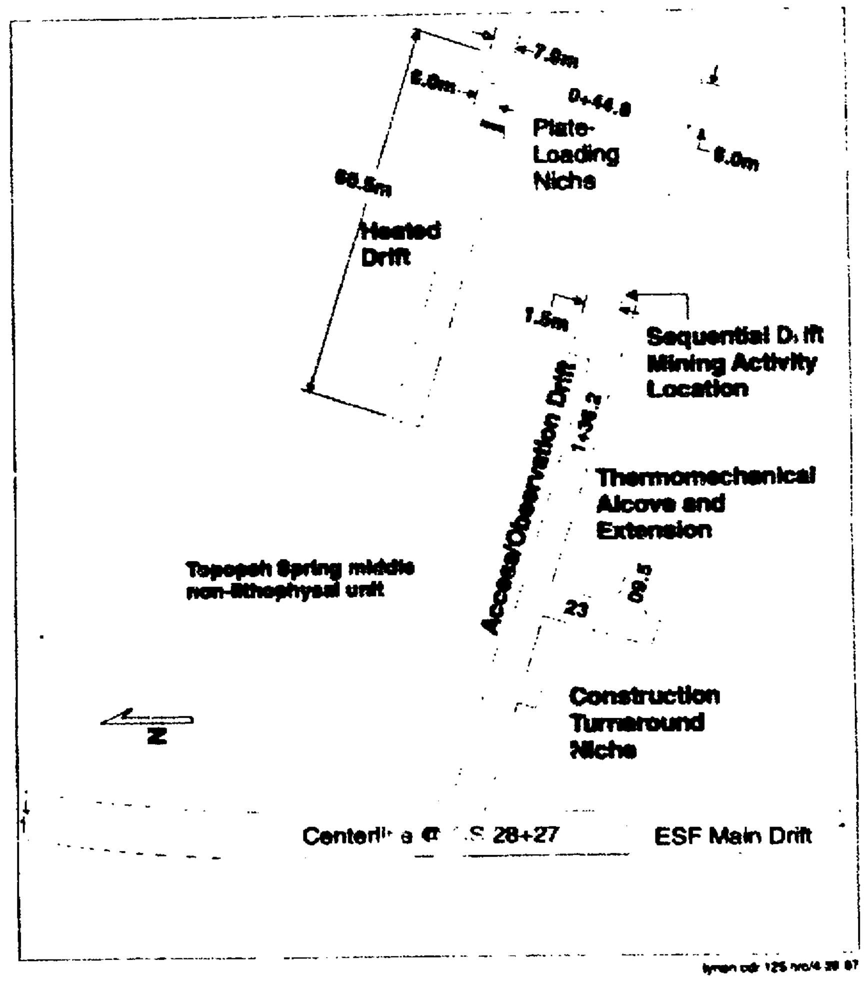
* Maximum inferred ages range from 20,000 to 2 million years

In Situ Thermal Testing

Objectives

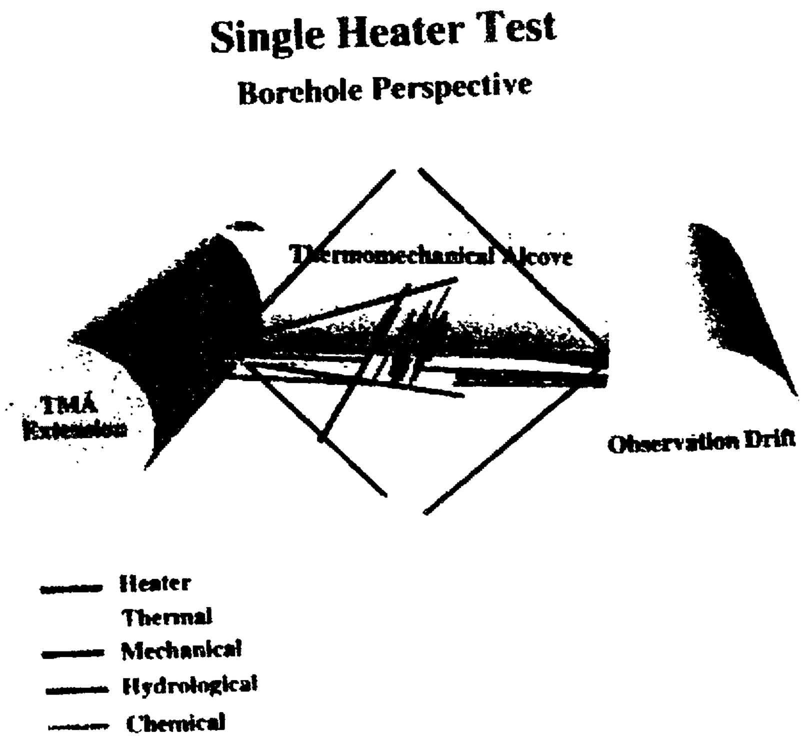
- Estimate temperatures, determine effects of heat on moisture, chemistry, corrosion and rock stresses
- Compare predictions with measurements in small-scale (single heater) test
- Extend small-scale model to drift-scale test to calibrate model at large scale

ESF Alcove 5 Thermal Test Facility



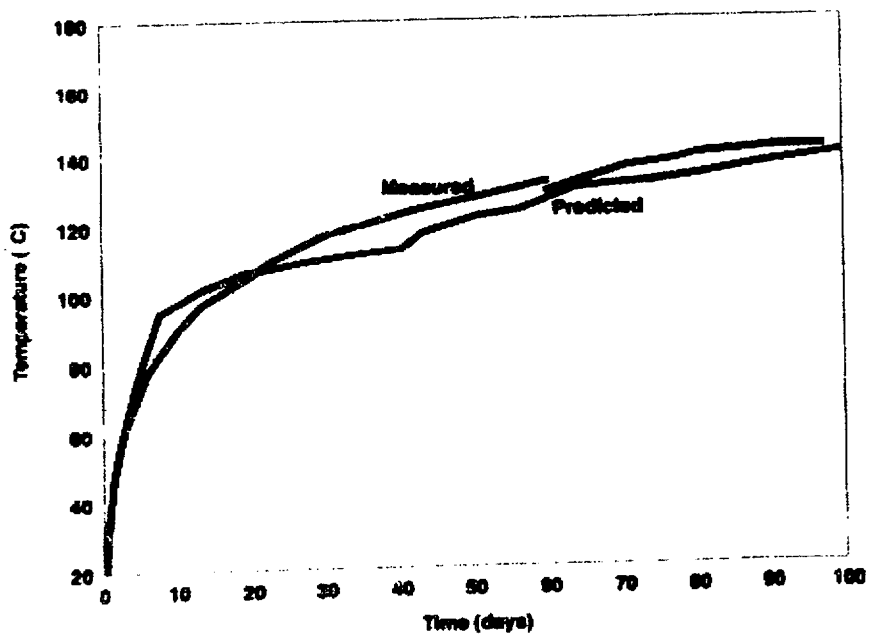
Thermal Testing: Single Heater Test

- One 5 m-long heater, 4 kW
- 530 sensors, 41 holes
- Heated rock volume > 1600 m^3
- Rock heated above 100°C ~ 20 m^3
- Heater started August 26, 1996, and was turned off May 28, 1997, beginning cool-down phase
- Data will be available to support VA

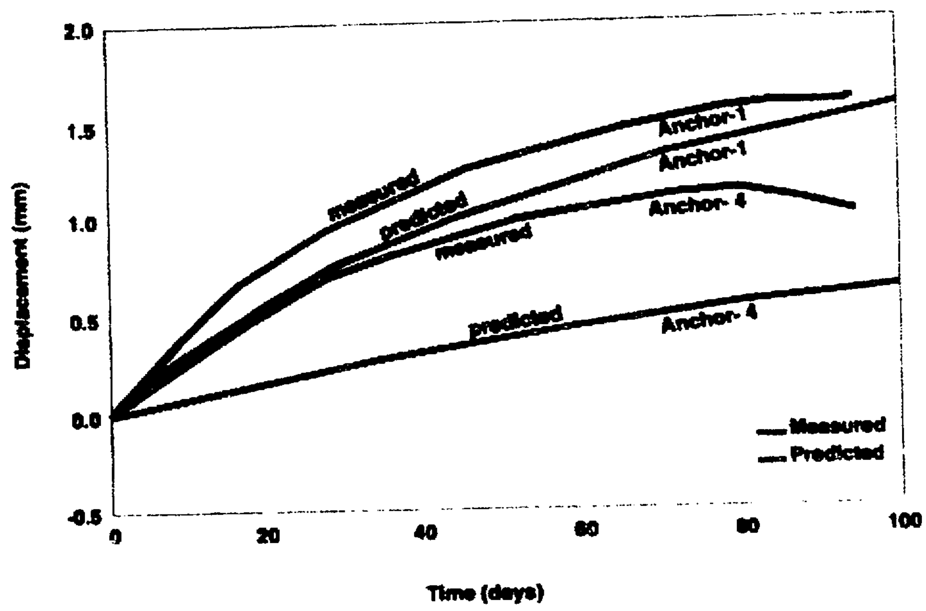


Single Heater Test Key Results

Single Heater Test: Thermal Results



Single Heater Test: Mechanical Results



Single Heater Test: What We Have Learned

- Temperature predictions are consistent with measured temperatures
- Deviations from the predicted T/M were not unanticipated due to recognized limitations in modeling approach (difficult to account for fracture effects); simple elastic model is insufficient
- Water is mobilized by heat (as expected)--fractures play key role in the mobilization
- Near-field gas chemistry under heated conditions is dominated by water vapor and carbon dioxide
- Water-chemistry results are consistent with modeled predictions of near-field chemical evolution

Thermal Testing: Drift Scale Test

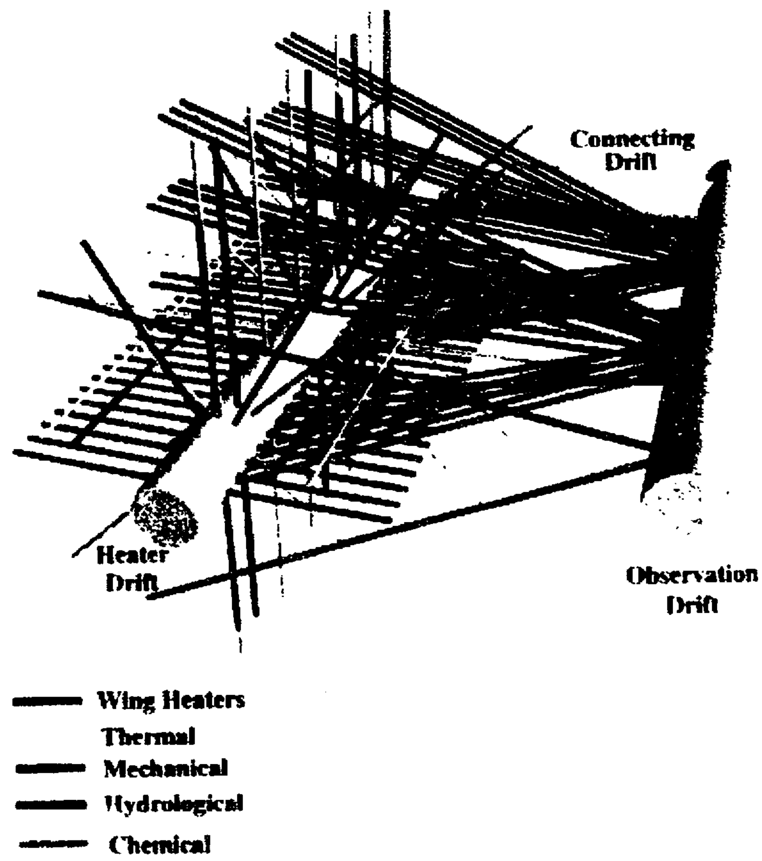
Induce Accelerated Near-Field Processes

- Heated Drift: 47.5 m long, 5 m diameter
- 147 holes, total length: 3,300 m
- 9 canister heaters: 7.5 kW each
- 50 wing heaters: Inner Segments 1150 watts ea
  Outer Segments 1720 watts ea
- Heating duration: up to 4 yrs
- Rock heated volume: >200,000 m^3
- Rock heated above 100° C:>10,000 m^3
- Total sensors: 3,500
- Data collection system: approx 5,000 channels
- Limited data will be available to support VA, but LA and performance confirmation are the primary customers

	Upper Lith	Middle Non-Lith	Lower Lith
Porosity	0.15	0.11	0.13
Initial Saturation	0.8	0.9	0.8
Thermal Conductivity w(m°k)	1.7(wet) 1.2(dry)	2.0(wet) 1.7(dry)	2.3(wet) 1.6(dry)
Permeability (Darcies)	0.02D	0.01D	0.005D

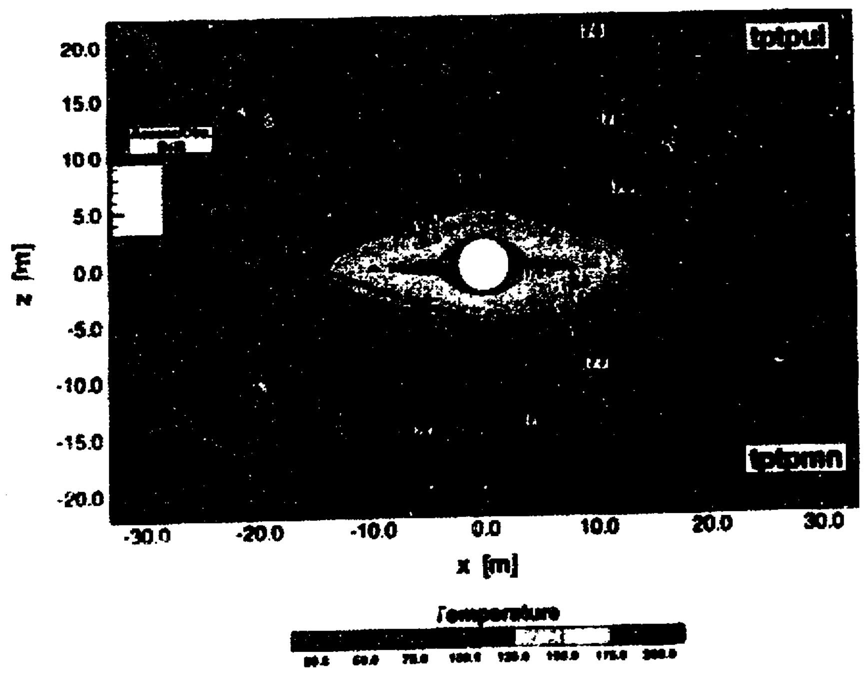
Drift Scale Test

Borehole Perspective



Thermal Testing: Drift Scale Test Near-Field Performance Predictions

Thermal - Hydrological Situation after 4 Years of Heating
(3.6 mm/yr infiltration, 100%/50% heating schedule,
ECM, uniform heat input along drift wall)



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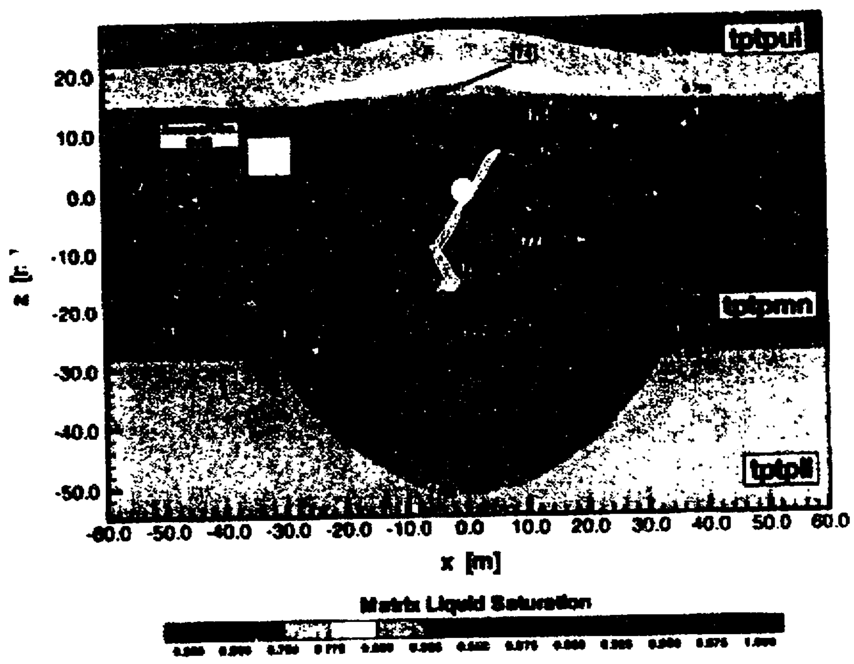
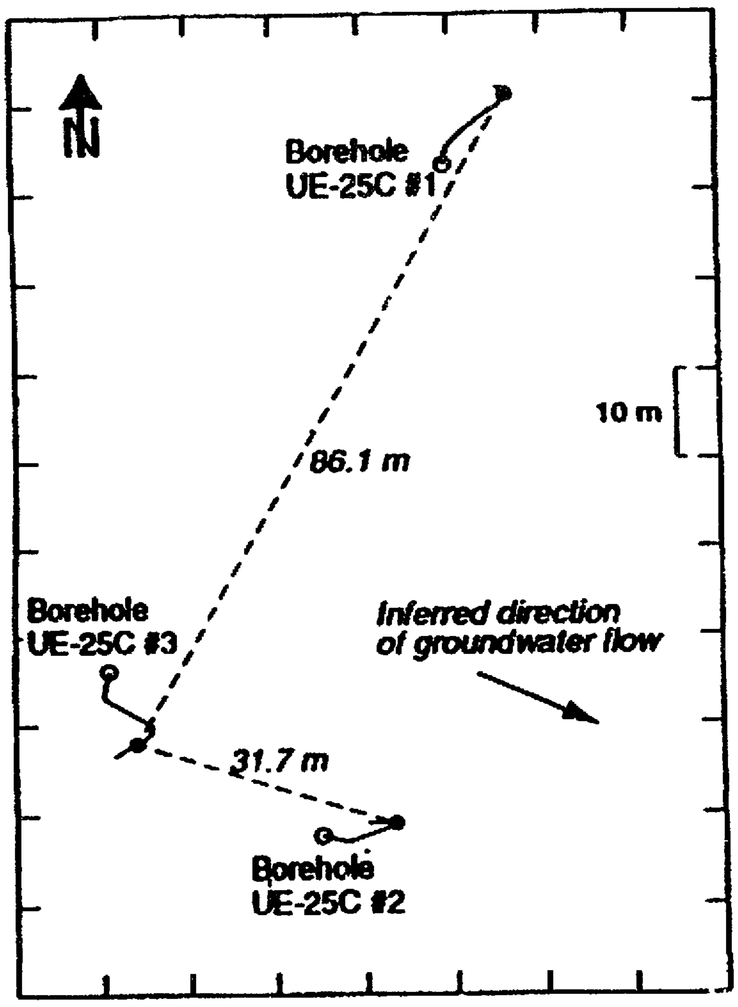


C-Well Testing

Objectives

- Obtain hydraulic properties of the volcanic aquifer through aquifer testing
- Estimate flow and transport parameters from field tests
- Confirm transport parameters measured in the laboratory

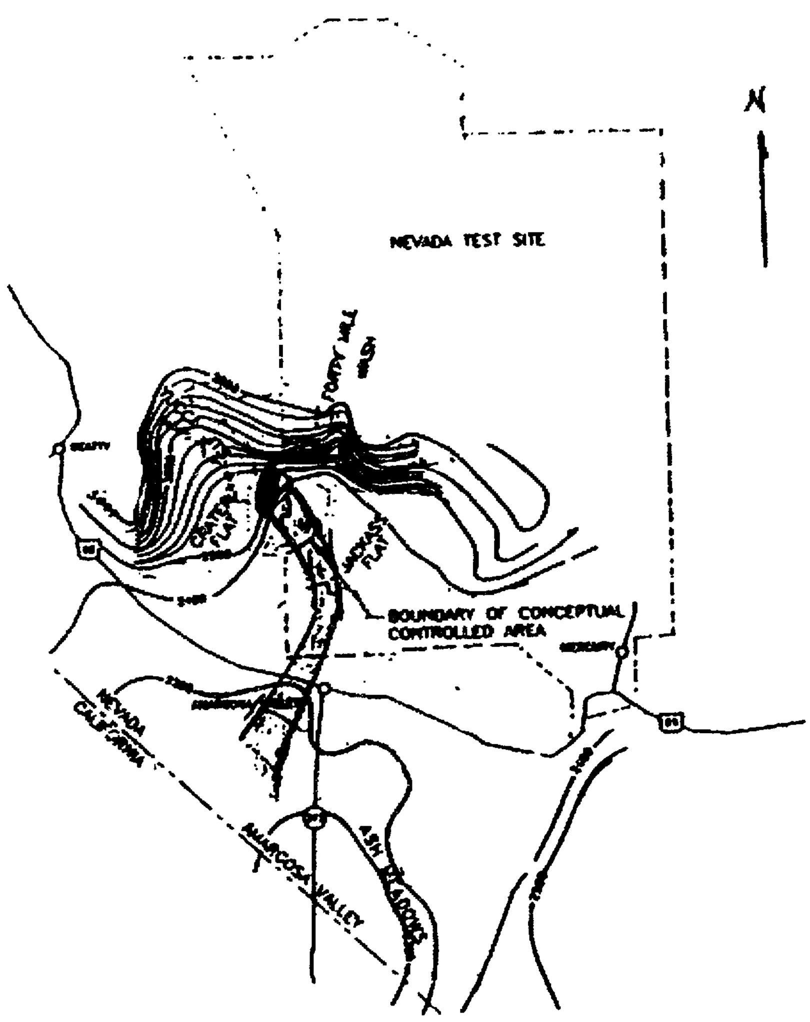


o Borehole location at land surface
• Average borehole location in test interval

C-Well Testing: What We Have Learned

- Range of derived transmissivities is 100 ft^2/day (Calico Hills) to 20,000 ft^2/day (Lower Bullfrog)
- Hydrologic units at this location display anisotropy and lateral heterogeneity
- Measured dispersivity is about 2 m, consistent with measurements at other sites at this scale
- Transport is complex due to heterogeneity; suggests likely important dilution and dispersion effects at larger scale
- Tracers display strong matrix diffusion; suggests radionuclide travel times will be greater than groundwater travel times, and concentrations will be reduced

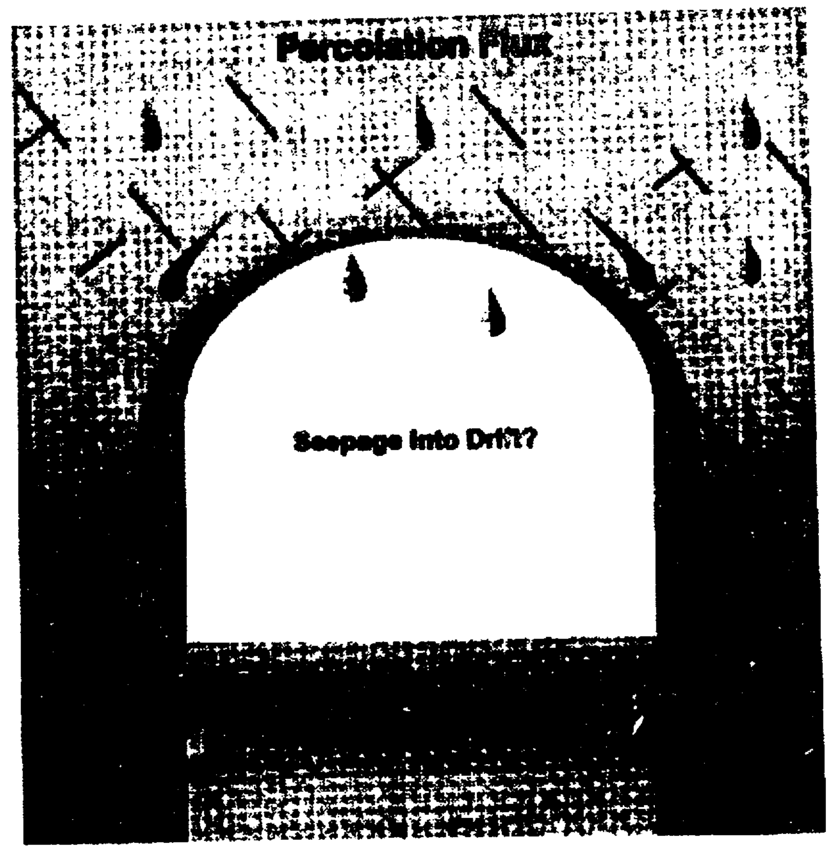
Implications for Radionuclide Transport



- From lab results confirmed at the c-wells:
  - Mechanical dispersion and matrix diffusion will reduce concentrations at this site
  - Flow and transport data adequate for design and performance assessment
- From the regional flow model:
  - General direction and magnitude of flow known
  - Closed basin; no transport to major population areas

Niche Moisture Studies

- Niche studies focus on seepage into drifts and will
  - Examine fracture/matrix interaction and effective wetted area of fractures
  - Determine threshold flux conditions associated with seepage into drifts
  - Provide data to test models of processes affecting seepage (e.g., capillarity, effects of heterogeneity, dynamic effects)
- Limited data will be available to support VA, with full analyses being available for VA



Niche study determines seepage into drifts

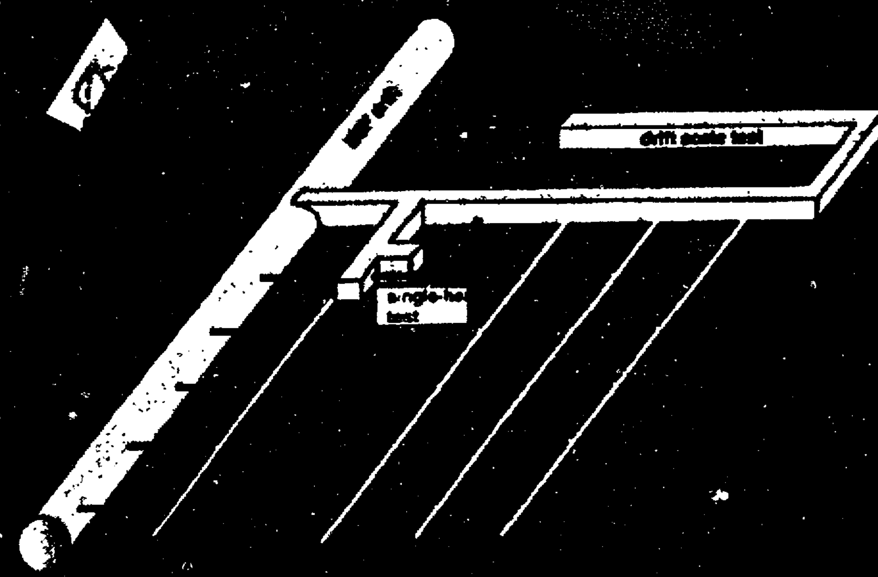
- (infiltration ≠ percolation ≠ seepage)

- Diversion of liquid release above the crown minimizes drips
- Isolation from main drift provides post-emplacement high humidity conditions

- Local fracture network and heterogeneity determine the flow paths to the drift
- Niche monitoring captures potential fast-flow pulses
- Niche alcove and drift-drift studies lead to better representation of multi-drift repository

Percolation study areally determines available water to feed seepage and contact wastes (infiltration ≠ percolation ≠ seepage)

- Long borehole arrays to have large areal coverage (~100 m^2)
- Test-site selection integrates all UZ knowledge at repository level
- Rock sampling systematically confirms understanding of matrix and fracture properties



- Large-scale measurements of temperature, saturation, moisture potential and fast-flow signals determine percolation flux through UZ model
- Testing and monitoring confirm and improve long-term verification and confirmation of UZ barriers.

Focusing the Science Program