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

YUCCA MOUNTAIN PROJECT

Status of the Department of Energy's Igneous Activity Analyses

Presented to:
Nuclear Waste Technical Review Board

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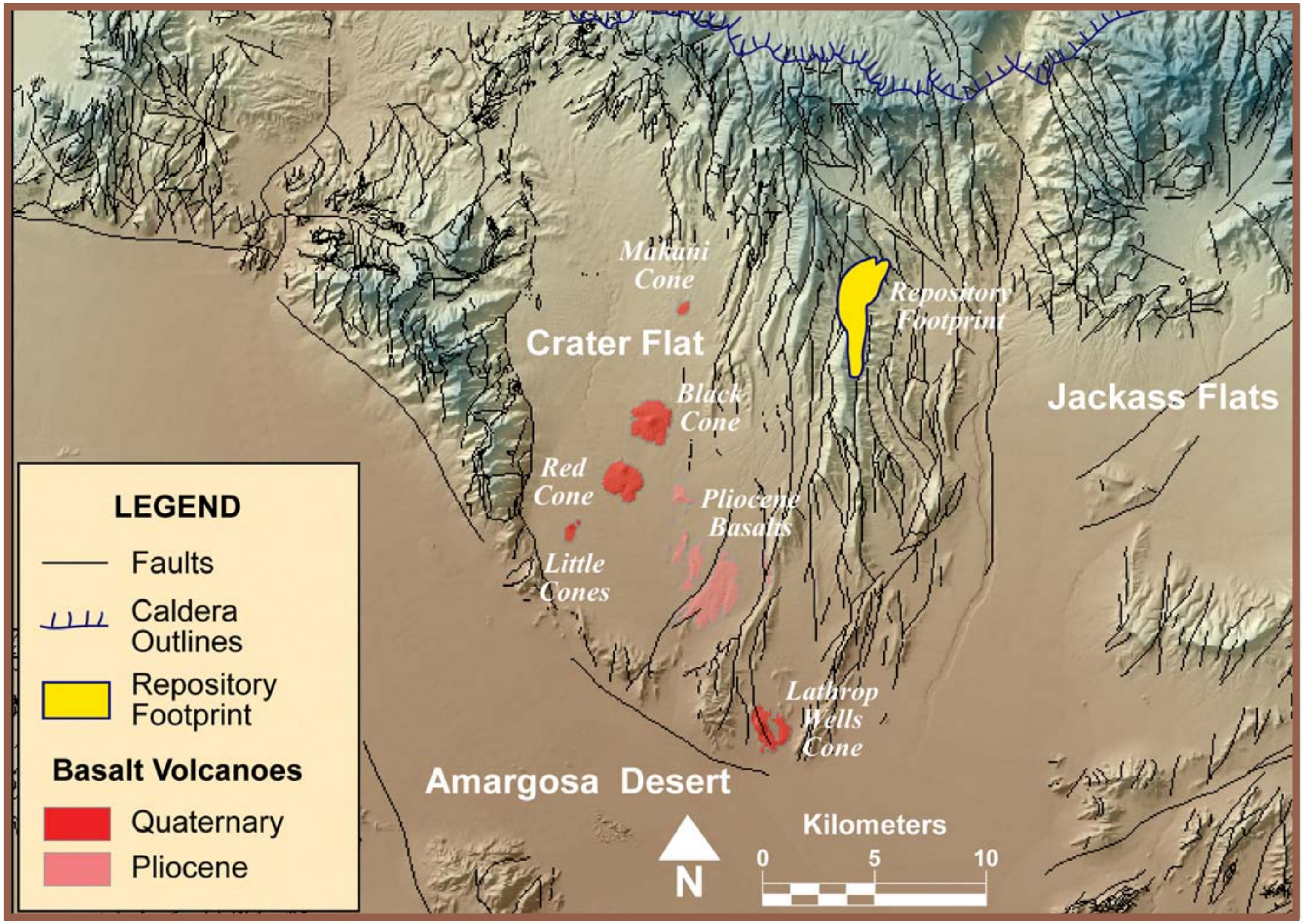
Overview

- Summary of the Igneous Disruption Scenario
- Nuclear Regulatory Commission (NRC) - Department of Energy (DOE) Agreements
  - Alternative Eruptive Pathways and Dike/Drift Interactions
  - Event Probability
  - Magmatic Effects on Waste Packages and Waste Forms
  - Surface Redistribution of Contaminated Ash
- Recommendations of the Igneous Consequences Peer Review Panel
- Observations of the Nuclear Waste Technical Review Board (NWTRB)
- DOE responses and path forward
- Current Status of Igneous Consequence Modeling for the Total System Performance Assessment-License Application (TSPA-LA)

Basaltic Volcanism near Yucca Mountain



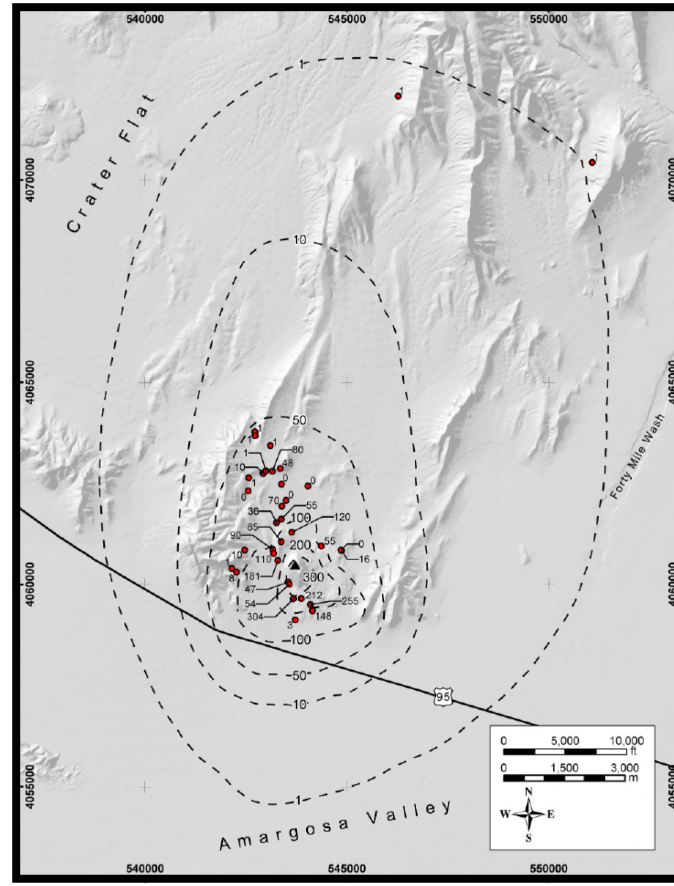
Pliocene basalt in Crater Flat is approximately 3.7 million years old
Quaternary Cones in Crater Flat are approximately 1 million years old
Lathrop Wells Cone is approximately 77 thousand years old

Basaltic Volcanism at Lathrop Wells

Above: Lathrop Wells Cone, viewed from the north. Summit of cone is ~ 140 m above base

Right: Estimated tephra thickness in cm from Lathrop Wells cone

Source: Draft ANL-MGR-GS-000002 Rev 01



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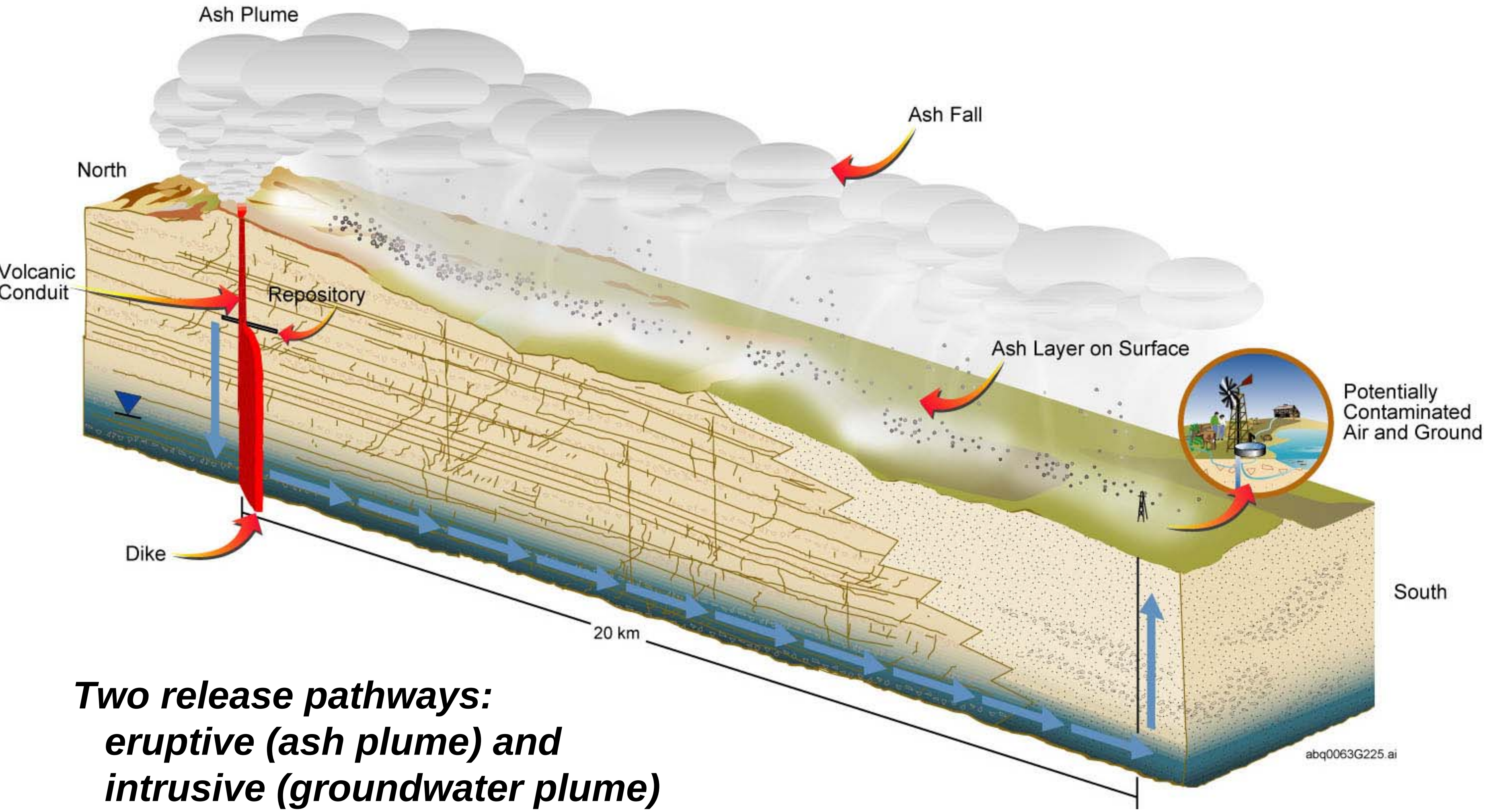
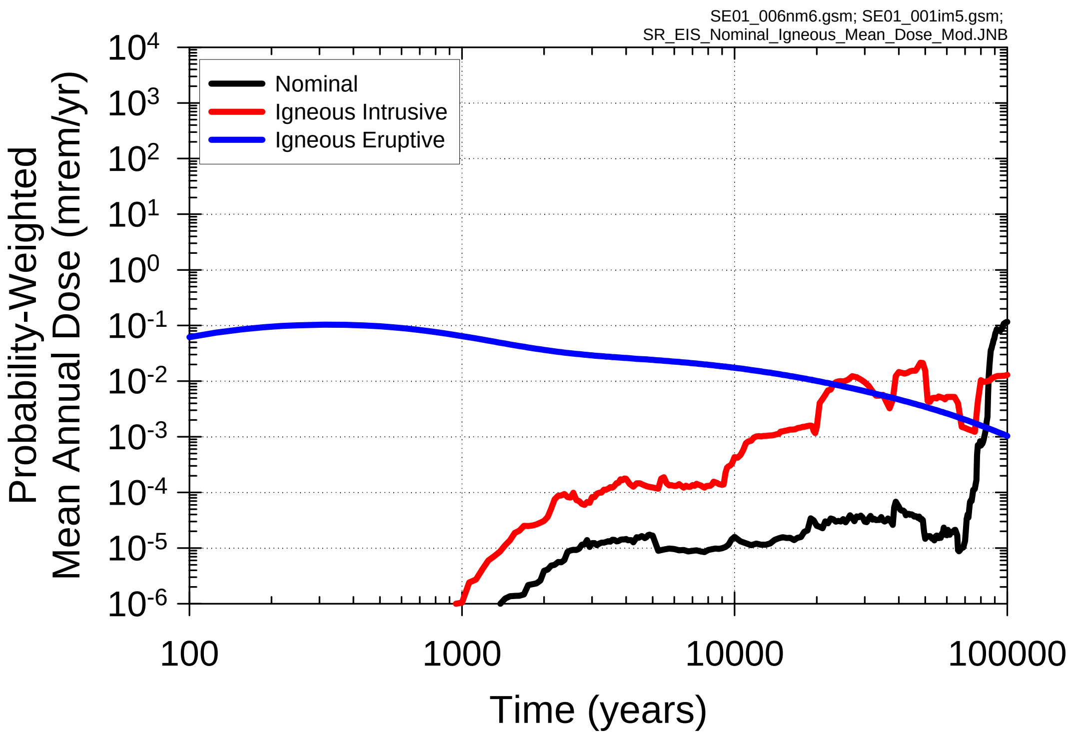
Igneous Disruption Scenario



Two release pathways:
eruptive (ash plume) and
intrusive (groundwater plume)

Probability-Weighted Dose Estimates from Igneous Disruption (Fall 2001)

- **Results from the September 2001 Revised Supplemental TSPA to support the Final Environmental Impact Statement (FEIS) and Site Suitability Evaluation (high-temperature operating mode)**
- **100,000-year probability-weighted mean annual doses for both igneous disruption pathways and nominal performance shown for comparison**
- **Mean annual probability of igneous intrusion is 1.6×10^{-8}**
- **Models and analyses will be updated for the License Application**



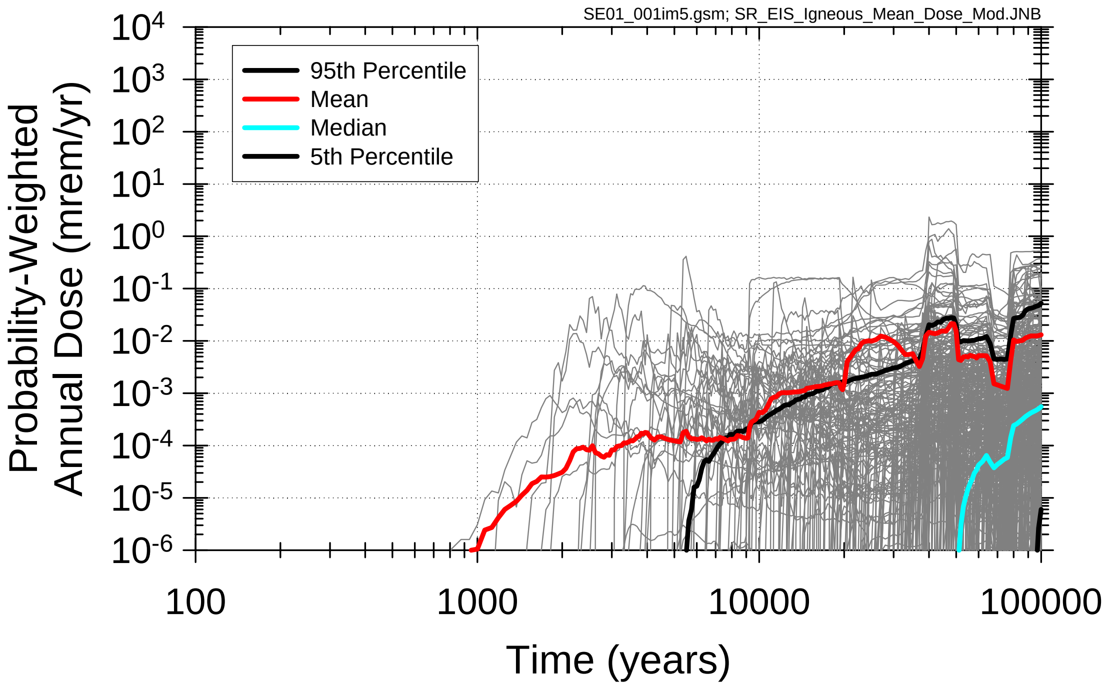
Eruptive doses peak near 300 years and dominate for ~ 20,000 years

Intrusive groundwater doses peak with 38,000 year full glacial climate

Nominal dose remains below mean igneous dose until ~ 80,000 years

Uncertainty in Probability-Weighted Dose Example Results for Igneous Intrusion

- Monte-Carlo approach used to capture uncertainty in model results based on uncertainty in model inputs
- Results from the September 2001 Revised Supplemental TSPA to support the Final Environmental Impact Statement and Site Suitability Evaluation



- 500 out of 5000 TSPA realizations of annual dose from the igneous intrusion pathway only are shown with 95th, 50th, and 5th percentiles and the mean annual dose

Uncertainty in Probability-Weighted Dose Estimates from Igneous Disruption
(Continued)

- Main contributors to uncertainty in eruptive dose:
  - Event probability
  - Wind speed
  - Number of waste packages intersected
  - Characteristics of the eruption (e.g., conduit diameter, erupted volume, particle size)
  - Biosphere dose conversion factors for inhalation
- Main contributors to uncertainty in groundwater dose from igneous intrusion:
  - Event probability
  - Number of waste packages damaged
  - Groundwater flow and transport

Nuclear Regulatory Commission/Department of Energy Igneous Activity Agreements

- **Formal NRC-DOE agreements address the following four major areas (as well as other more narrowly focused topics)**
  - **Alternative models for consequences of igneous disruption**
    - **DOE will further evaluate possible alternative models for dike/drift interactions (e.g., "dog-leg" eruption pathways)**
  - **Event Probability**
    - **DOE will further evaluate impact of possible buried volcanic centers on event probability**
  - **Magma effects on engineered materials**
    - **DOE will further evaluate effects of magmatic conditions on engineered materials (e.g., enhanced waste package degradation and waste form mobility)**
  - **Redistribution of contaminated ash and sediment**
    - **DOE will evaluate effects of surface redistribution of contaminated ash after deposition of an initial ash layer**

Igneous Consequences Peer Review

- The DOE conducted the Igneous Consequences Peer Review (ICPR) (July 2002 – February 2003) to address specific issues related to consequences of a potential igneous event intersecting the proposed repository
- Major ICPR Comments
  - "The overall conceptual model … [for an igneous event] … is both adequate and reasonable"
  - ICPR recognizes the limitations of scientific understanding and computational capabilities for developing more sophisticated mechanistic models for igneous events, particularly as they relate to
    - Damage to waste packages from magma flowing into drifts
    - Pyroclastic flow past waste packages in an eruptive conduit

Specific Igneous Consequences Peer Review Recommendations

- **Future modeling should focus on developing a 3-D model for dike propagation, dike/drift interaction, and quantifying the dog-leg scenario**
- **More sophisticated software and modeling should address**
  - **Gas/vapor evolution in the rising magma**
  - **Gas/vapor cavity length behind the dike tip**
  - **3-D coupled models for unsteady dike/drift flow**
  - **Gas pressure loss through rock permeability**
- **Approach giving more weight to Plio-Pleistocene igneous events near Yucca Mountain is reasonable; however, additional age dating should be performed**

Additional Igneous Consequences Peer Review Recommendations

- **Consider repository design modifications to minimize impacts of igneous events**
- **Additional work to reduce uncertainties**
  - **Laboratory experiments to**
    - **Address transition between bubbly magma and gas-filled cavity**
    - **Chemical/mechanical effects on waste packages**
  - **Compare ASHPLUME predictions to predictions from other computer models using fixed set of data**

Observations from the Nuclear Waste Technical Review Board

- Consultants to the NWTRB provided observations both before and after the ICPR
- Main recommendations from consultants prior to the ICPR
  - Convene an expert review panel
  - Develop more robust and realistic models of dike/drift interactions
  - Reconsider conservatism of damage to waste packages and waste form

Observations from the Nuclear Waste Technical Review Board

(Continued)

- **Main observations from the NWTRB after completion of the ICPR**
  - **Panel's work is independent and of high technical quality**
  - **The Board recommends that the DOE emphasize**
    - **Updated models of dike/drift interactions, including effects of compressible magma**
    - **Further evaluation of the effects of magma on waste packages and waste form**
    - **Evaluation of aeromagnetic anomalies with drilling and dating**

Department of Energy Responses and Path Forward

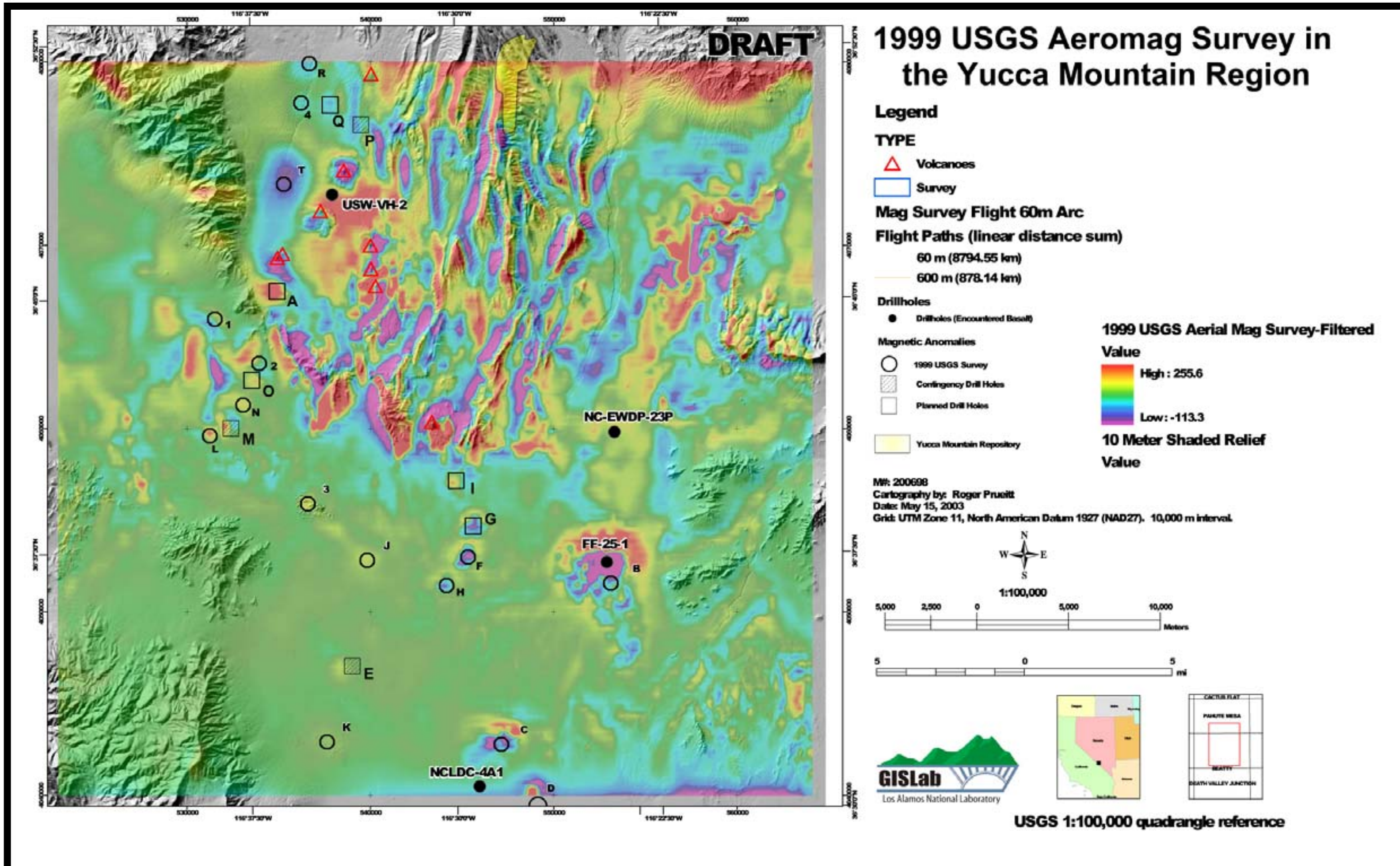
- **Primary emphasis for the igneous consequences model to support the license application will be to address NRC agreements and to develop an appropriate abstraction for TSPA**
- **DOE agrees with the ICPR that the overall conceptual model of dike-drift intersection is adequate and reasonable**
- **Igneous consequences model for TSPA-LA takes ICPR and NWTRB recommendations into account, considering importance to risk**
  - **Enhanced modeling of dike/drift interactions: Recently completed modeling is sufficient to support licensing; dog-leg eruption is not plausible**

Department of Energy Responses and Path Forward

(Continued)

- Design alternatives: Modification to backfill in access mains to impede magma flow between drifts being evaluated for inclusion in the design
- Laboratory studies of waste package and waste form behavior in magma are not currently planned; TSPA-LA model will remain conservative
- ASHPLUME validation by additional natural analog comparisons
- New aeromagnetic and drilling data will be obtained and impacts on event probability will be evaluated

Igneous Event Probability and Aeromagnetic Survey Data



Sensitivity of Event Probability to Buried Anomalies

- 1996 Probabilistic Volcanic Hazard Analysis (PVHA) considered eight buried anomalies as possible volcanoes
- 2002 sensitivity analyses considered 20-24 buried anomalies as possible volcanoes, recalculated event probabilities using PVHA experts' individual models
  - Assuming 24 additional volcanic centers increases PVHA mean event probability at Yucca Mountain approximately 1.4×
- 2003 sensitivity analyses (in progress) consider possibility of undetected centers closer to Yucca Mountain
  - Adding 9 hypothetical buried volcanoes in western Jackass Flats and 5 in Crater Flat increases PVHA mean event probability approximately 5×

Path Forward for Igneous Event Probability

- DOE is implementing additional activities to identify and characterize potential buried volcanic centers and to evaluate their impact on event probability
  – Low altitude, high resolution aeromagnetic/electromagnetic (EM) survey
  – Phased drilling, with age and chemistry of samples
  – Data analysis and documentation
  – Update to PVHA based on new information

Schedule for Event Probability Activities

- Fiscal Year 2003
  - Document sensitivity analyses
  - Plan aeromagnetic/EM survey and drilling program
- Fiscal Year 2004
  - Initiate drilling
  - Complete aeromagnetic/EM survey
- Fiscal Year 2005
  - Continue drilling contingent on results of aeromagnetic/EM survey
  - Conduct PVHA update
- Fiscal Year 2006
  - Document analyses and PVHA update

Current Status of Total System Performance Assessment-License Application modeling

- **TSPA-LA model for igneous consequences is currently in development, and no model results are available**
- **Underlying technical basis (assumptions, models, and input parameters) is essentially complete**
- **Information provided here regarding TSPA-LA is draft: documents are not in final form**

Magmatic Effects on Repository

- Numbers of waste packages entrained in eruptions and damaged by intrusions are being re-evaluated based on modified repository footprint
- Damage to waste packages and waste form during eruption is similar to TSPA-FEIS
  - All waste packages in the direct path of the eruption are fully compromised and the waste is fully fragmented
- Damage to drip shield in both eruptive and intrusive events is unchanged from TSPA-FEIS
  - All drip shields in all intruded drifts are fully compromised

Magmatic Effects on Repository
(Continued)

- **Damage to waste packages and waste form in portions of intruded drifts away from the path of eruption will be extensively modified for LA**
  - **Analyses indicate that waste packages throughout intruded drifts will be damaged by magmatic heat and elevated static pressures**
    - **New models will assume that all waste packages in all drifts intersected by magma will be sufficiently damaged to provide no further protection**
    - **Waste forms in intruded drifts will be exposed to seepage consistent with degraded drift conditions, with water chemistry consistent with passage through basalt**
    - **Possible barrier effects provided by the damaged packages and chilled magma have not been quantified, and will not be modeled**
  - **Analyses indicate that effects of heat and gas flow into drifts that have not been intruded will be minor, and waste packages in those drifts will be assumed to evolve as modeled for nominal performance**

Surface Redistribution of Ash

- Redistribution of contaminated ash by surface processes following ashfall deposition will be included as a new model
  - Field investigations of the Fortymile Wash alluvial fan and analog studies at Lathrop Wells provide technical basis for modeling approach
  - TSPA model will include approximation of consequences from transport of contaminated ash by sedimentary processes
  - TSPA model will also include removal of contaminated ash, consistent with erosion on major geomorphic landform types
- Wind direction will not be assumed to be fixed toward the location of the reasonably maximally exposed individual
  - This assumption was used in previous TSPAs to compensate for the lack of a model for surface redistribution effects

Eruptive Processes and Biosphere

- **ASHPLUME model modified to allow improved treatment of eruptive column**
  - **Column height calculated from mass discharge rate**
  - **Input parameters updated: e.g., wind speed**
- **Biosphere dose conversion factors updated, consistent with NRC comments on inhalation mechanisms, other information**

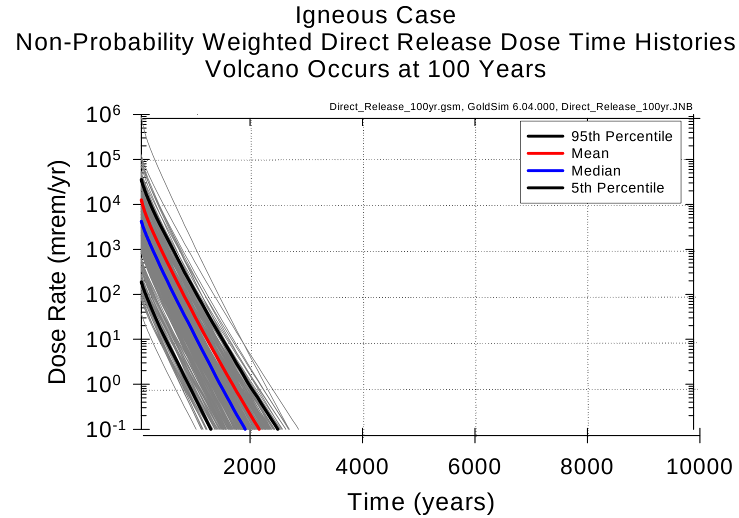
Summary

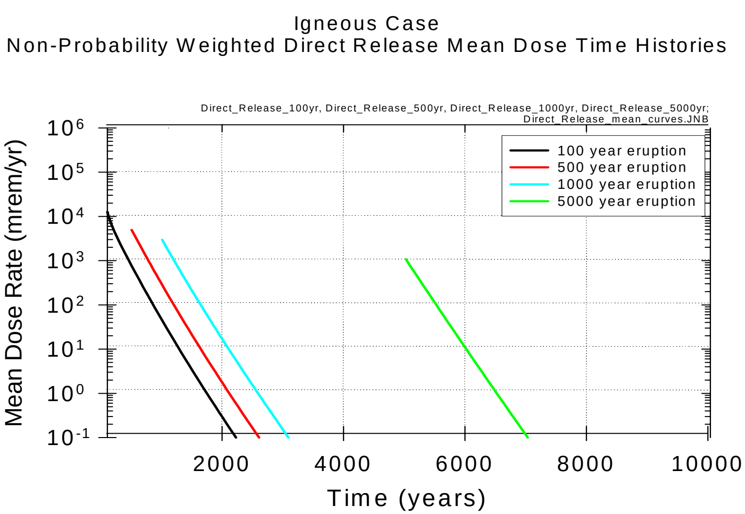
- Consequences of Igneous Activity will be included in the TSPA-LA using updated models
  - Changes in models from previous TSPAs are consistent with results of ongoing work conducted in the last two years, and take into account agreements with the NRC and comments from the Igneous Consequences Peer Review and the NWTRB
- Models for the LA are believed to be reasonable and appropriate to support a licensing decision
  - Conservative assumptions have been used where information to support realistic models remains unavailable, but overall intent is to provide a reasonable estimate of possible consequences, consistent with NRC regulations and guidance

Backup

Analyses for Igneous Activity Scenarios

TSPA-Site Recommendation (SR) Eruptive Dose without Probability-Weighting





- **TSPA-SR models and inputs**
- **Results assume eruption probability = 1 (actual probability ~ 1.6 × 10^{-8}/yr)**
- **Spread in distribution of peak due to uncertainty in**
  - **ASHPLUME inputs: e.g., wind speed, conduit diameter**
  - **Biosphere Dose Conversion Factors (BDCFs)**
- **Drop in "first-year" peak dose at different times due entirely to radioactive decay/ingrowth**
- **Slope of curves determined by soil removal and radioactive decay (dominated by soil removal)**
- **Dose dominated by inhalation pathway, Am, Pu**

Calculating a Probability-Weighted Mean Volcanic Dose