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

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Effective Thermal Conductivity of Drift Collapse Material

Presented to:
Nuclear Waste Technical Review Board

Presented by:
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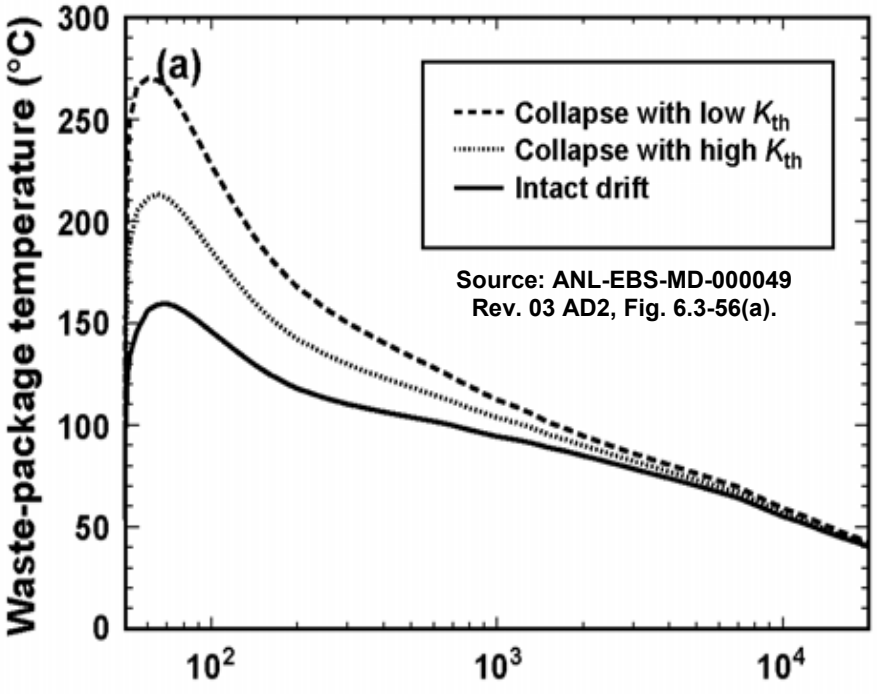
Effective Kth of Drift Collapse Material
Outline

- Drift Collapse Thermal Effects in TSPA
- Predicting Drift Collapse Effective Kth
- Implementation as Model Input
- Experimental Support
  - Test description
  - Results
  - Comparison with TSPA implementation
- Summary

Effective Kth of Drift Collapse Material
Drift Collapse Thermal Effects in TSPA

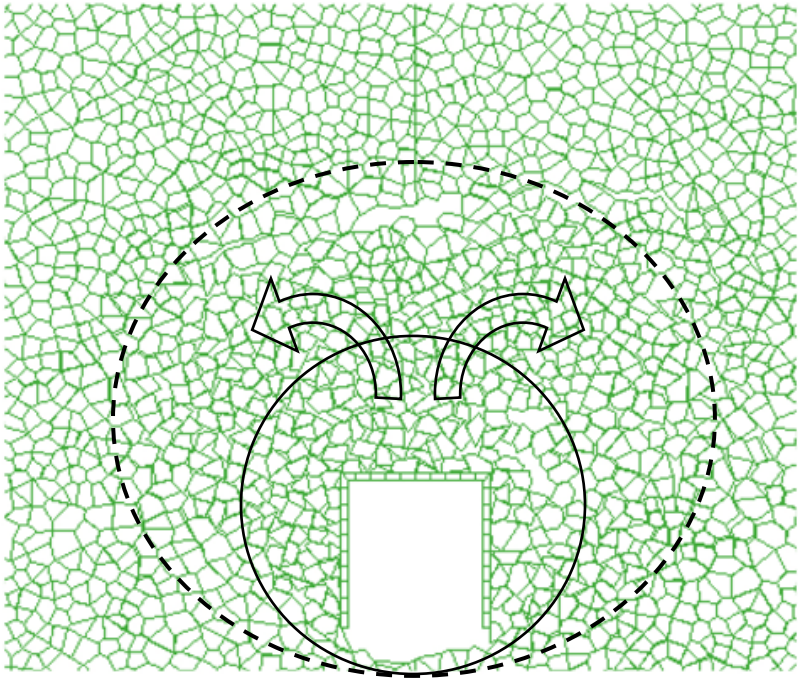
- **Multiscale Model Output Used in TSPA**
  - Seepage
  - Waste package corrosion
  - In-package chemistry
  - Waste form degradation
  - Engineered Barrier System (EBS) transport



- **Multiscale Model**
  - Thermal-hydrologic parameters calculated for intact and fully collapsed conditions
  - Offset calculation method applied at complete collapse
- **Collapse is seismically induced, in lithophysal tuff**

Effective Kth of Drift Collapse Material
Predicting Drift Collapse Effective Kth

- **Literature Review: Packed Beds**
  - **Crane et al. (1977)**
  - **Kunii & Smith (1960)**
- **Conduction + Radiation**
  - **Convection not included**



Source for UDEC graphic: ANL-EBS-MD-0000027 Rev. 03, Fig. 6-127.

Unconsolidated loose packing of spheres
Mechanistic, geometrical solution
Conduction in pore network, plus void-void radiation
Conduction in solid particles, plus solid-solid radiation

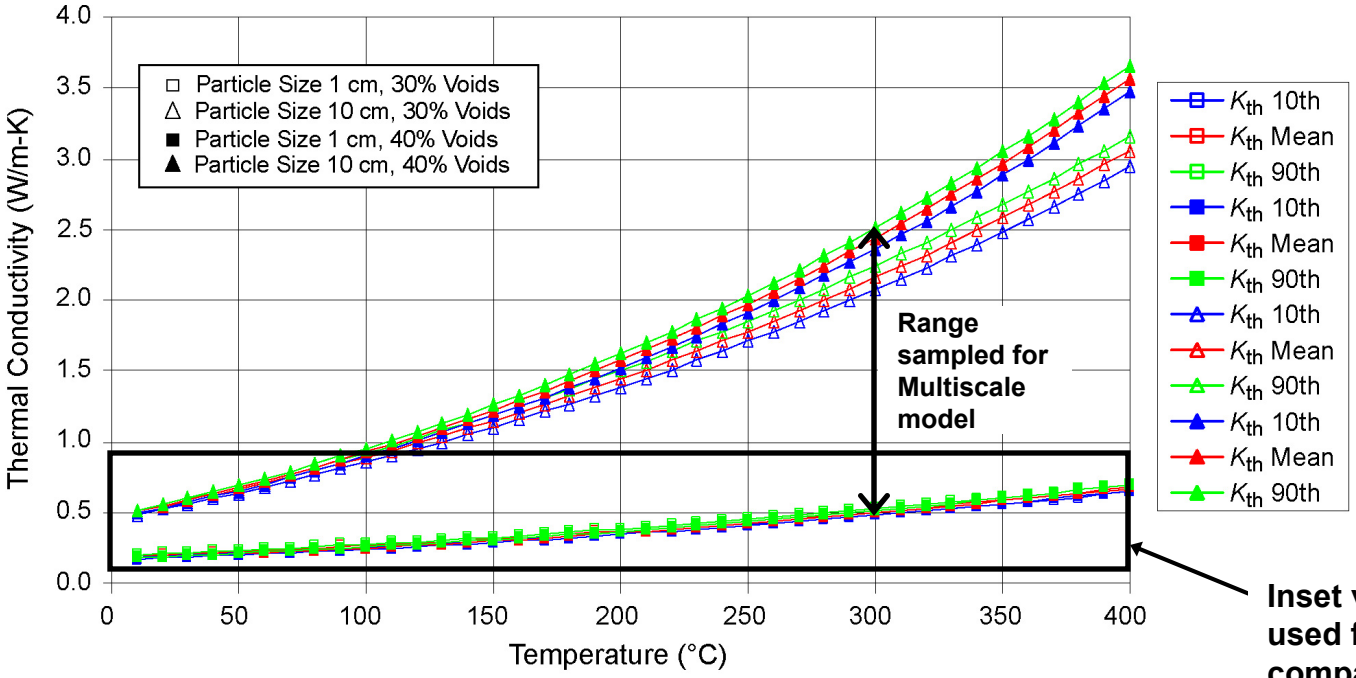
Effective Kth of Drift Collapse Material Implementation

- **Tuff Characteristics**
  - Lithophysal spacing
  - Fine fractures
  - Approx. 20 cm block size
  - Lithophysal porosity (8% to >30%) collapses
- **Kth Temperature Dependence**
  - Large voids >> dominated by radiative coupling
  - Small voids >> dominated by air Kth dependence

Simplification for thermal-hydrology: drifts are either intact or completely collapsed

Sources: ANL-EBS-MD-000049 Rev. 03 AD2, Appendix XI; ANL-EBS-MD-000027 Rev. 03, Section 6.1.4 and Fig. 7-25.

Effective Kth of Drift Collapse Material
Predicting Drift Collapse Effective Kth, cont.



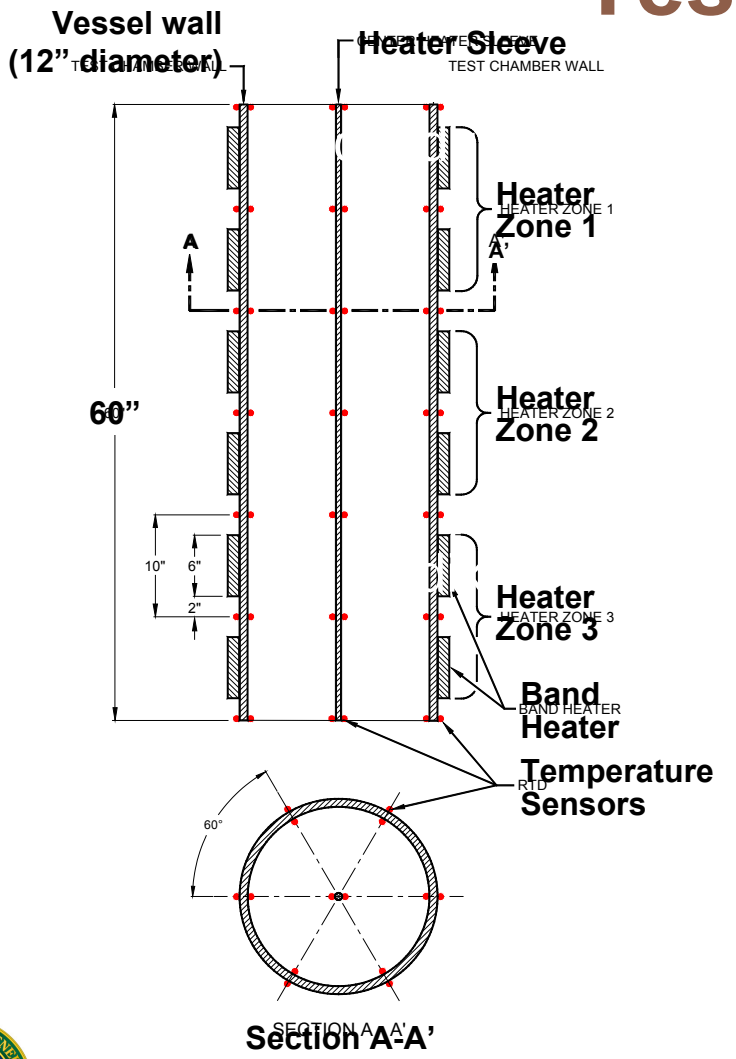
Inset view used for comparing to measurements

	Rock Unit: Lower Lithophysal (tsw35)		
Particle Size (cm)	**Intact Rock Mass K_{th} Dry (W/m·K)**		**Intergranular Void Fraction**
1	**10th percentile:**	**1.071**	**0.3 / 0.4**
	Mean:	**1.240**	**0.3 / 0.4**
	90th percentile:	**1.414**	**0.3 / 0.4**
10	**10th percentile:**	**1.071**	**0.3 / 0.4**
	Mean:	**1.240**	**0.3 / 0.4**
	90th percentile:	**1.414**	**0.3 / 0.4**

Based on Kunii and Smith (1960), Equation 8

Source:
ANL-EBS-MD-000049 Rev. 03 AD2, Appendix XI[a]

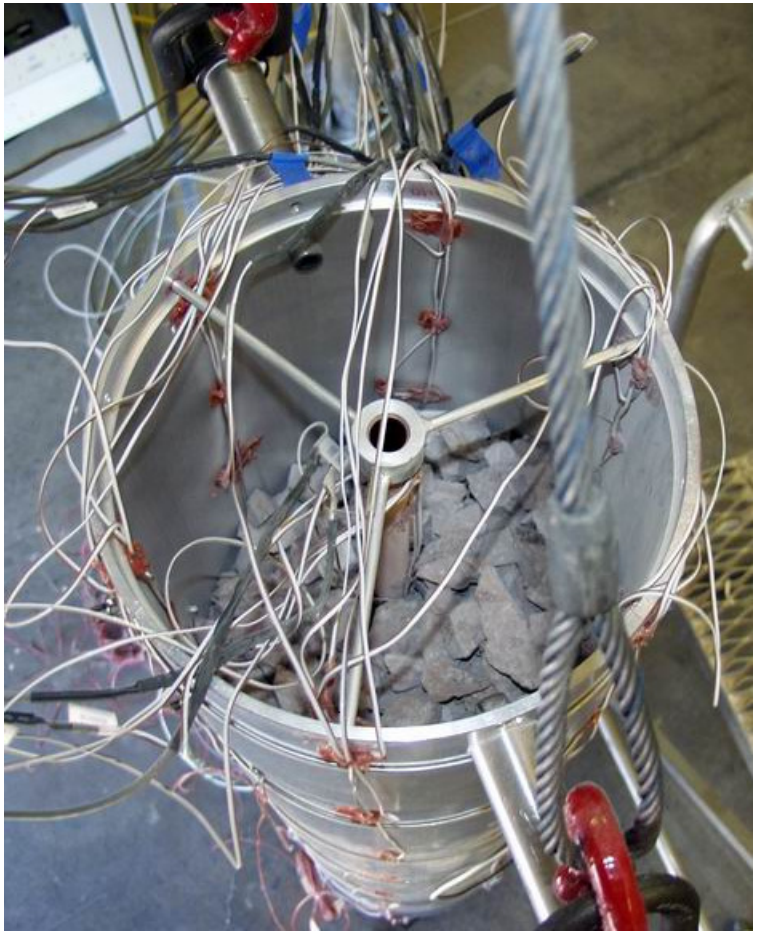
Effective Kth of Drift Collapse Material
Experimental Verification Test Design



- Test of 0.875” to 1.25” tuff aggregate
- Vertical orientation
- 3 inch-thick insulating blanket
- Temperature sensors
- Set up for inner and/or outer heaters
- Use outer heaters to control bulk temperature
- Apply step-function changes in power (inner) or temp. (outer)

Effective Kth of Drift Collapse Material Test Design (cont.)

- 6 external band heaters, total capacity of 7200 W
- Central 1-in. diameter copper sleeve contains rod heater
- Temperature sensors
  - 98 resistance-temperature devices (RTDs) installed to all surfaces of the test vessel and sleeve



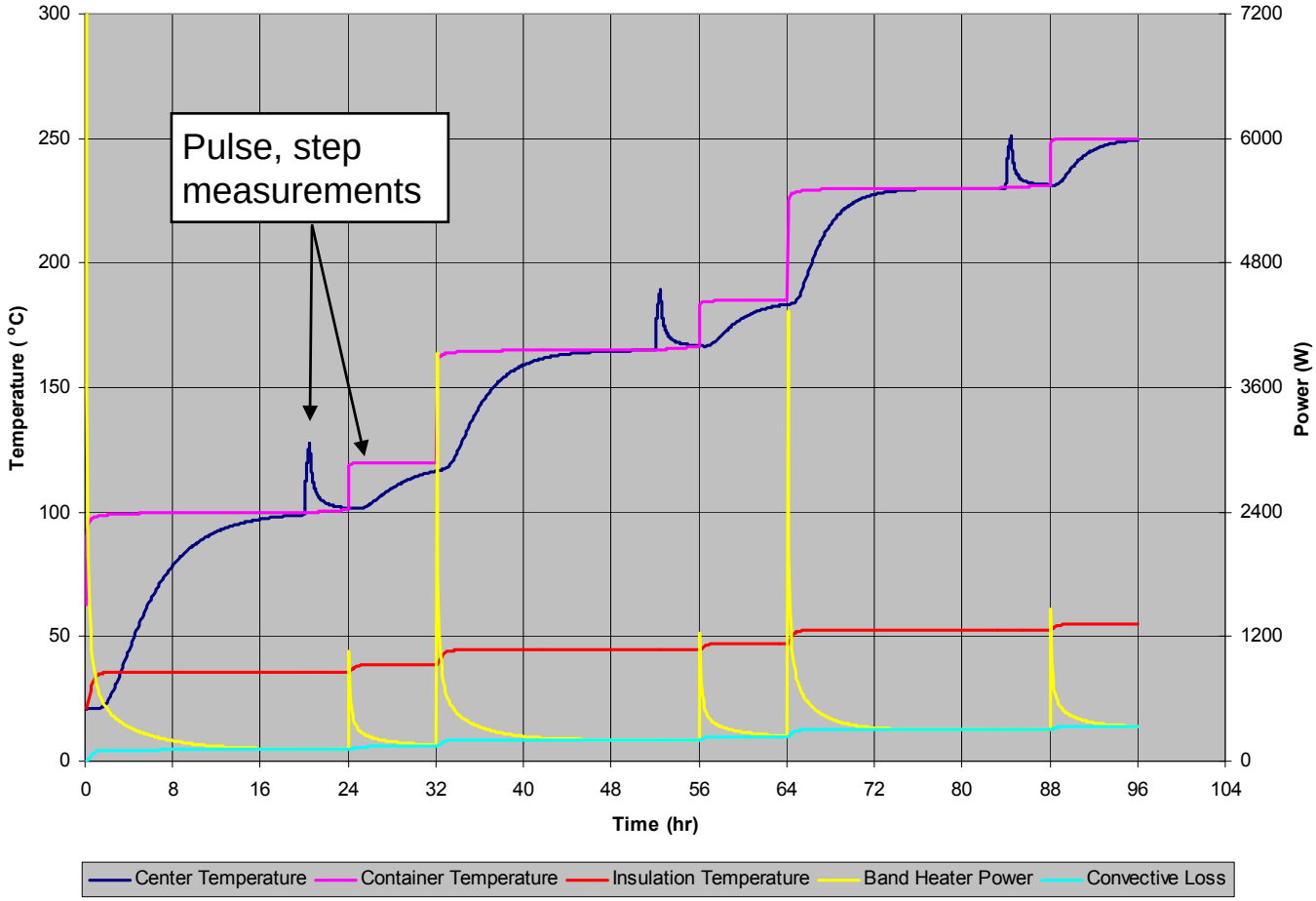
Effective Kth of Drift Collapse Material
Welded Tuff Aggregate Material

- **Samples collected from core remnants, Exploratory Studies Facility (ESF) boreholes, lower lithophysal zone**
- **800 lbs of coarse-sieved (0.875" to 1.25”) welded tuff aggregate, oven dried**

Effective Kth of Drift Collapse Material
Conducting the Test

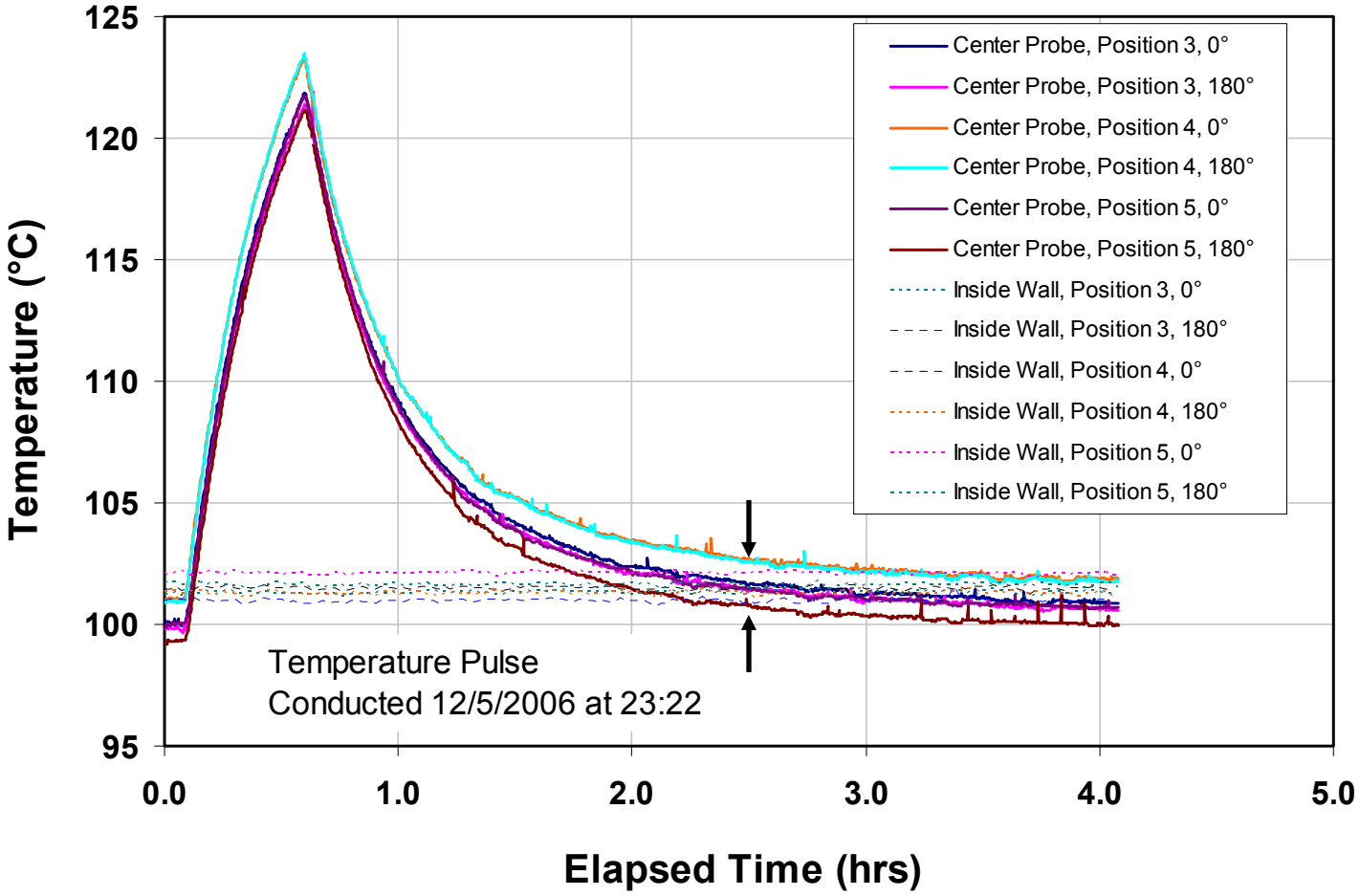
- **Measurements initiated at three temperature levels: 100, 165, and 230°C**
- **Step Tests**
  - **Monitor internal temperature after step-increase of outer wall temperature**
- **Pulse Tests**
  - **After achieving uniform temperature, apply a constant-power pulse to the central heater**
  - **Monitor heater-sheath and internal temperatures**

Effective Kth of Drift Collapse Material
Conducting the Test (cont.)

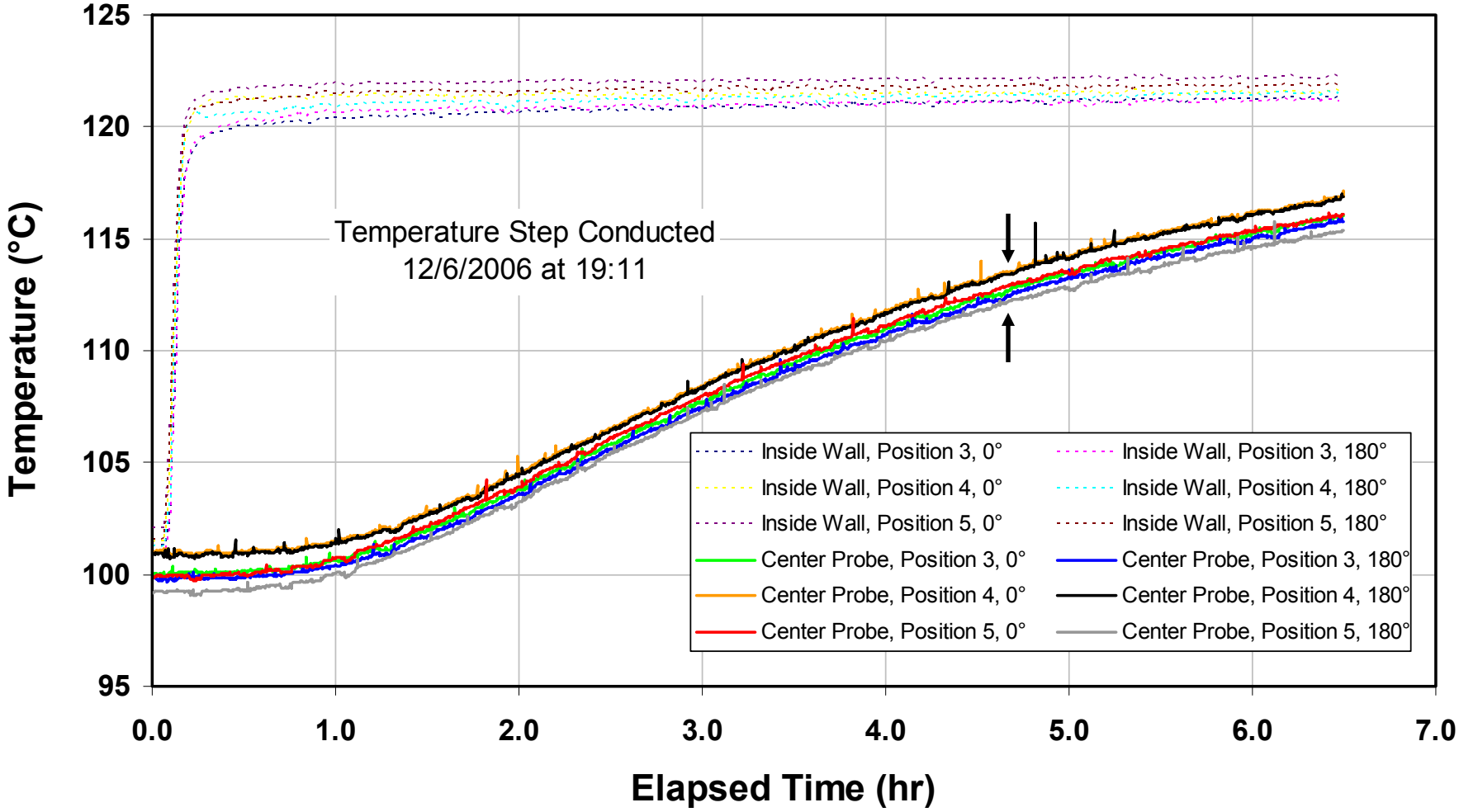


Continuous heating maintained dried state of tuff particles.

Effective Kth of Drift Collapse Material
Test Response – Pulse Tests

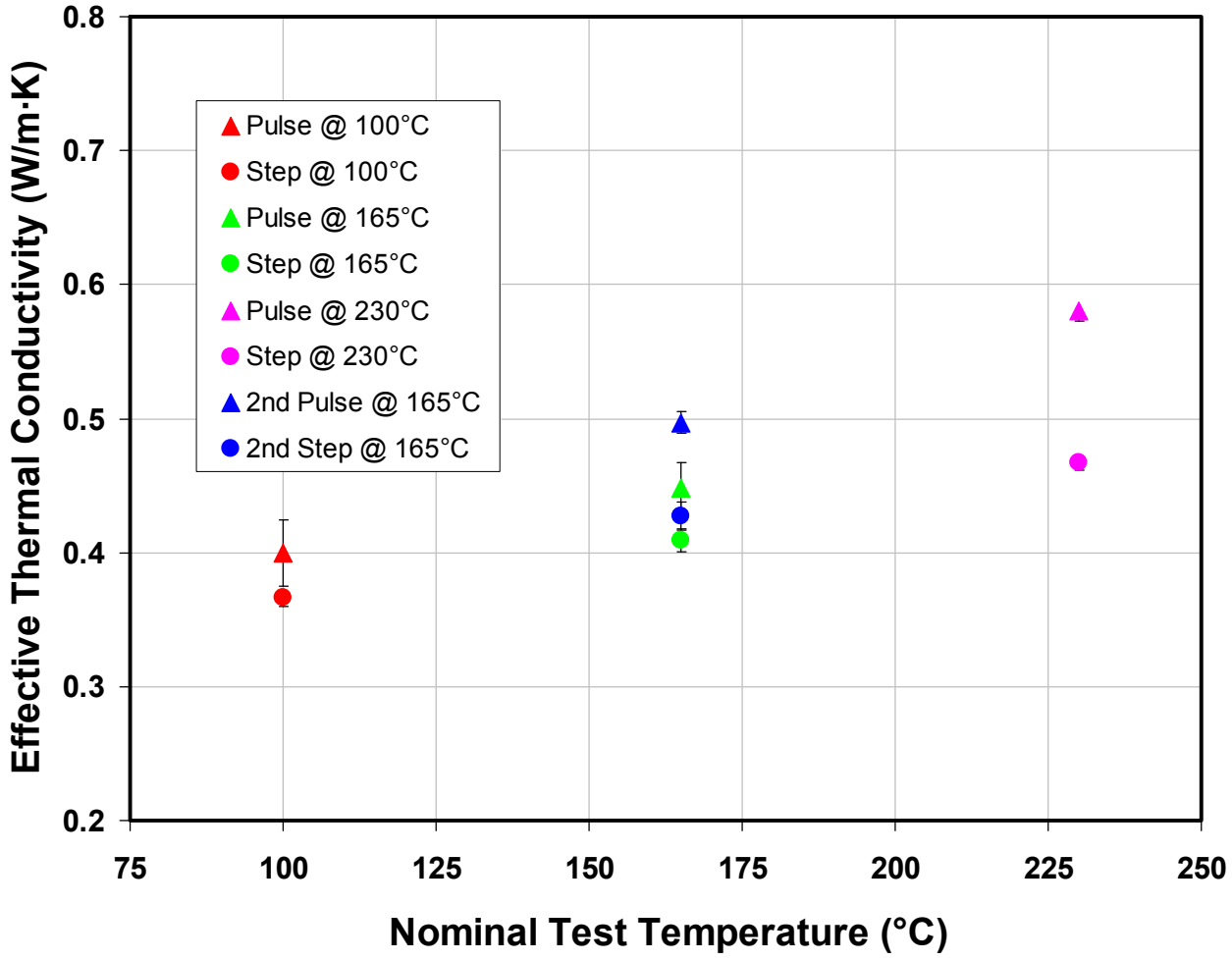


Effective Kth of Drift Collapse Material
Test Response – Step Tests

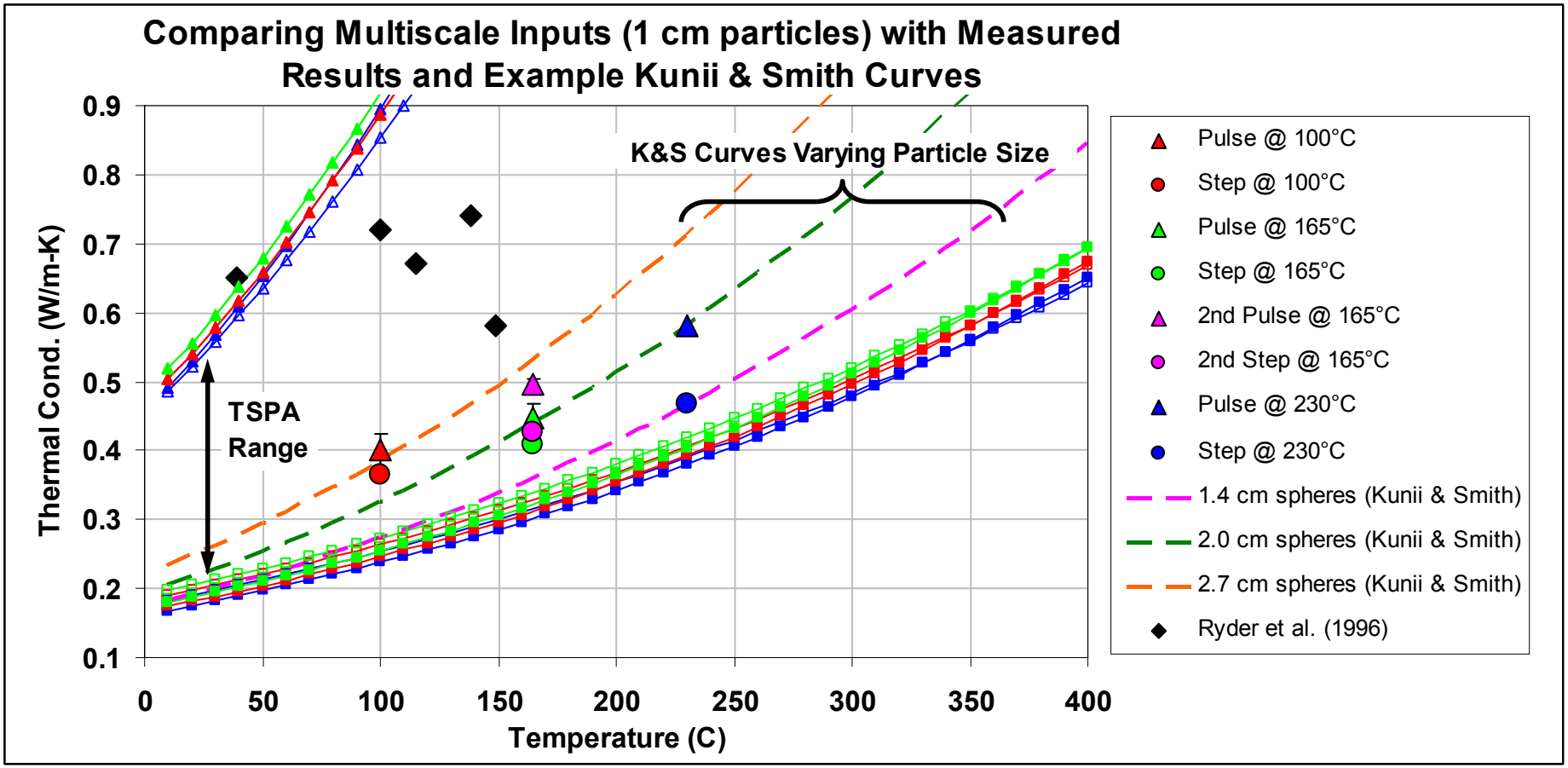


Effective Kth of Drift Collapse Material
Effective Kth Results

Analyzed using least-squares fitting of analytical solutions for radial heat flow; using temperature averages



Effective Kth of Drift Collapse Material
Experimental Verification



NOTES:
1. Pulse and step tests: 0.875 to 1.25" particles, 44.5% porosity (DTN: MO0812ESETCCDB.000).
2. Ryder et al. (1996): 0.5 to 1.5" particles, 48% porosity (SAND94-2320).
3. Multiscale (MSTHM) low and high Kth ranges: ANL-EBS-MD-000049 Rev. 03 AD2, Fig. XI-1[a].
4. Kunii, D. and Smith, J.M. 1960. "Heat Transfer Characteristics of Porous Rocks." *American Institute of Chemical Engineers Journal*, 6, (1), 71-78.

Effective Kth of Drift Collapse Material Summary

- **Effective Kth for tuff aggregate increases with temperature**
  - **Air Kth dominates dependence for small particles**
  - **Radiative transfer dominates for larger particles and higher temperatures**
- **For drift collapse debris**
  - **Particle (void) size uncertainty >> temperature dependence**
  - **Particle size depends on rock fabric, stratification, filtration**
- **Kth range used for the Multiscale model**
  - **Spans conductive vs. radiative dominated behaviors**
  - **Does not include convective heat transfer**