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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: GEOMECHANICAL UNCERTAINTIES

PRESENTER: DR. LAURENCE S. COSTIN

PRESENTER'S TITLE AND ORGANIZATION: SUPERVISOR
PERFORMANCE ASSESSMENT APPLICATIONS DIVISION
SANDIA NATIONAL LABORATORIES
ALBUQUERQUE, NEW MEXICO

PRESENTER'S TELEPHONE NUMBER: (505) 844-0397

OCTOBER 8 - 10, 1991

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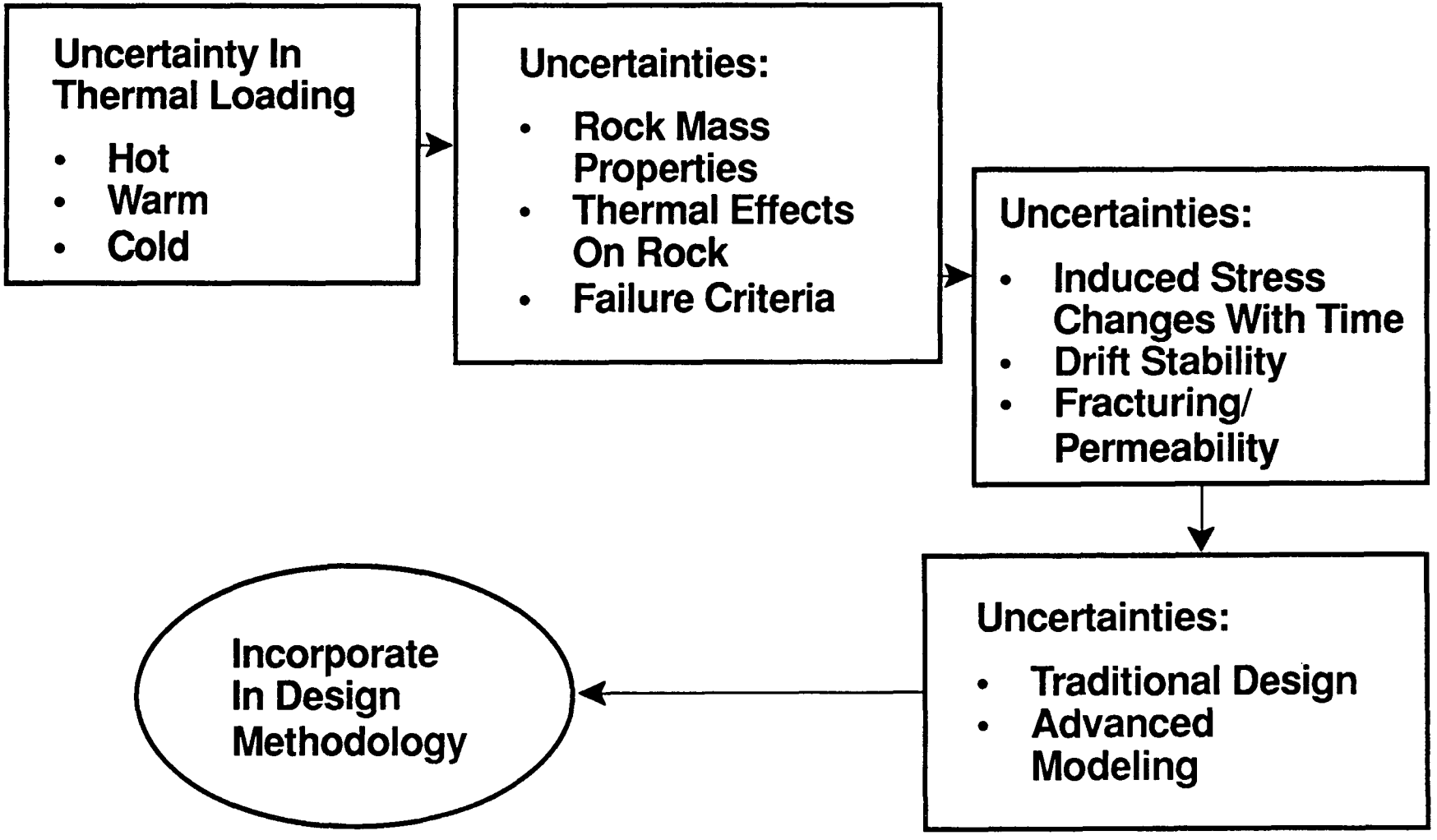
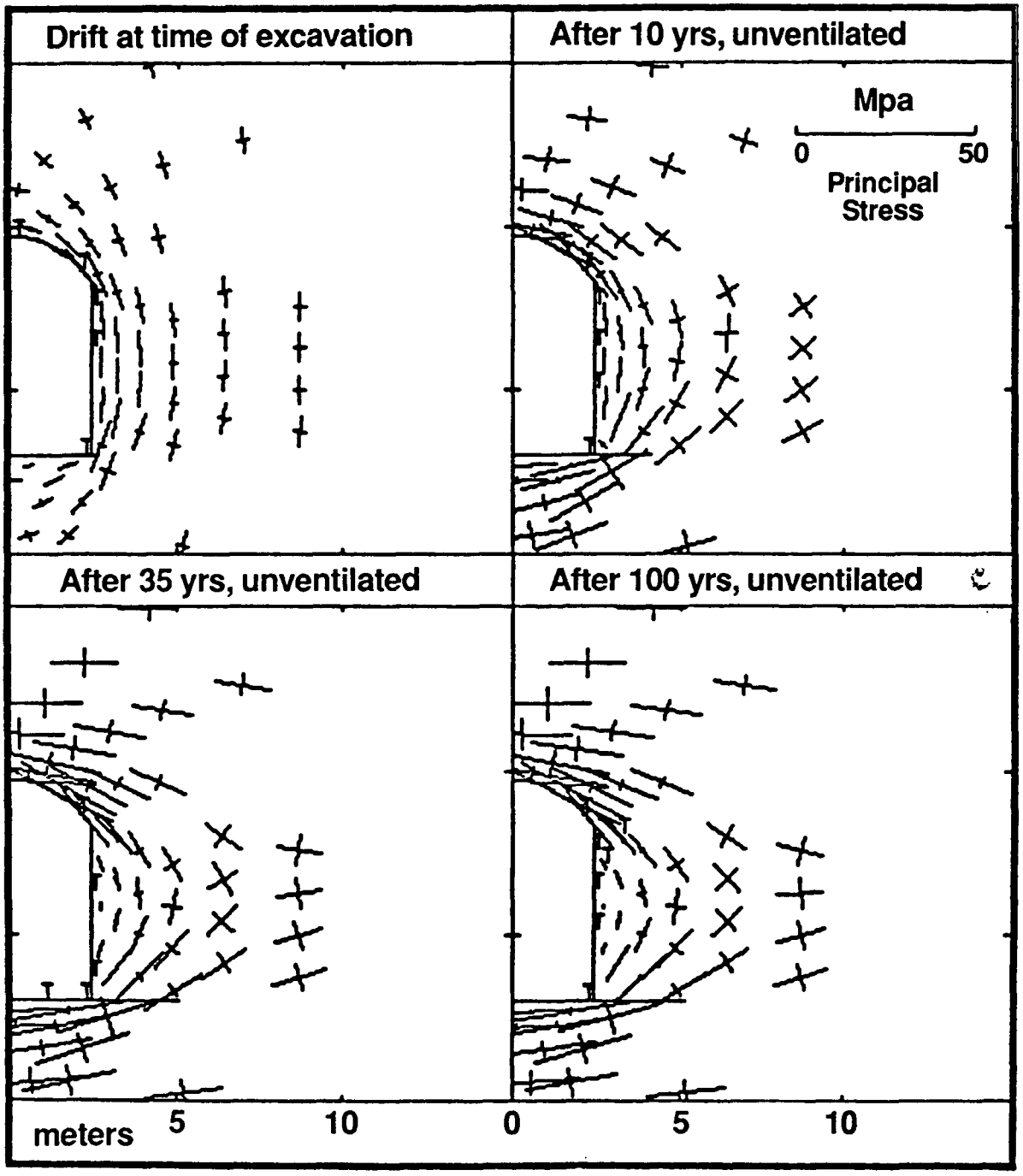
Presentation Topics



Effects of Thermal Loading (Preclosure Period)

- Magnitude of stress field changes with time
- Orientation of stress field changes with time
- Thermal effects on rock properties
- Thermal effects on support structure and materials
- Interaction of support structure with rock mass changes with time

Principal Stresses in the Vicinity of a Vertical Emplacement Drift



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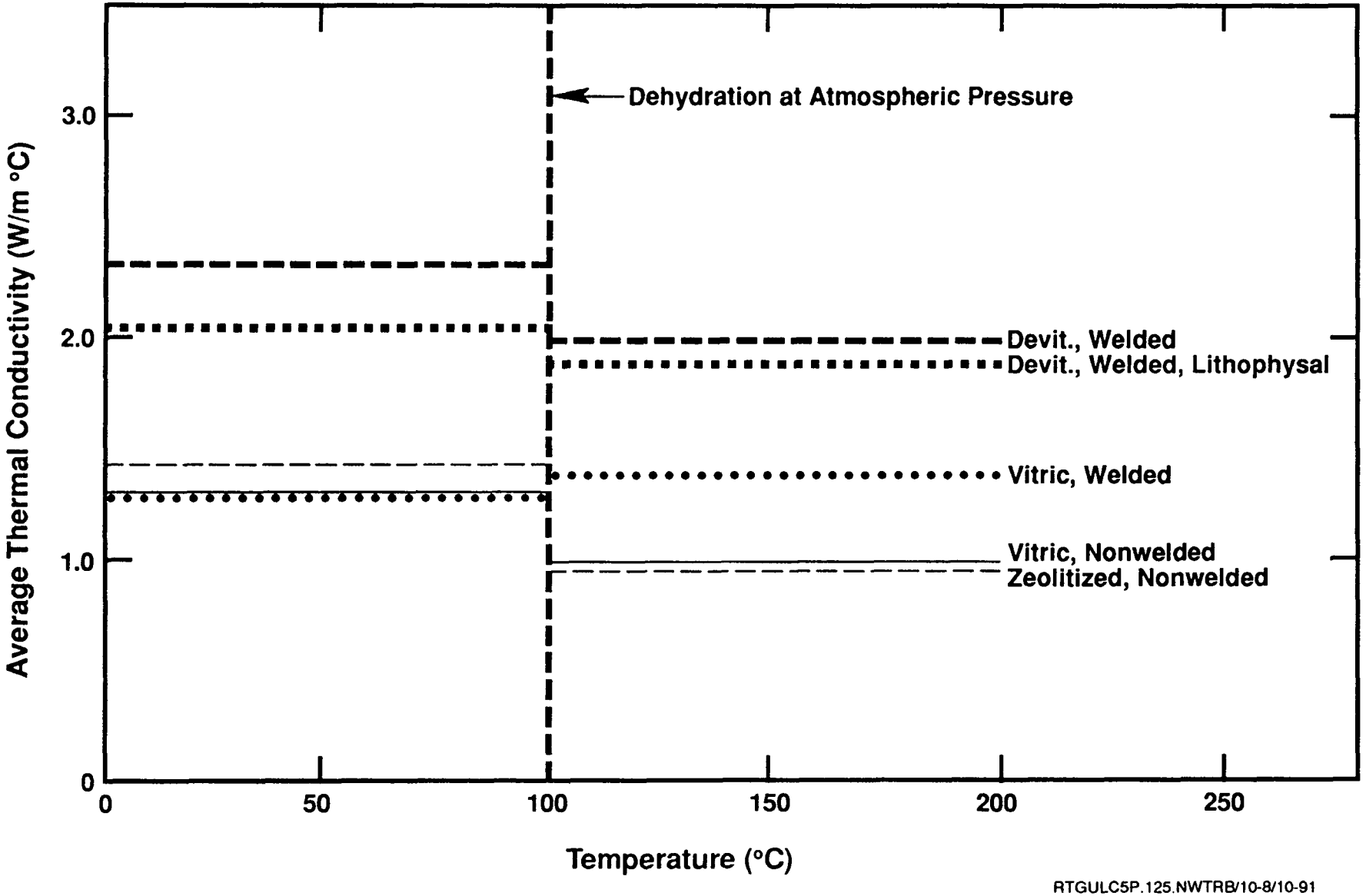
Thermal Effects on Rock Properties

- Thermal Conductivity
- Thermal Expansion
- Modulus
- Failure

Temperature Dependence of Average Thermal Conductivity



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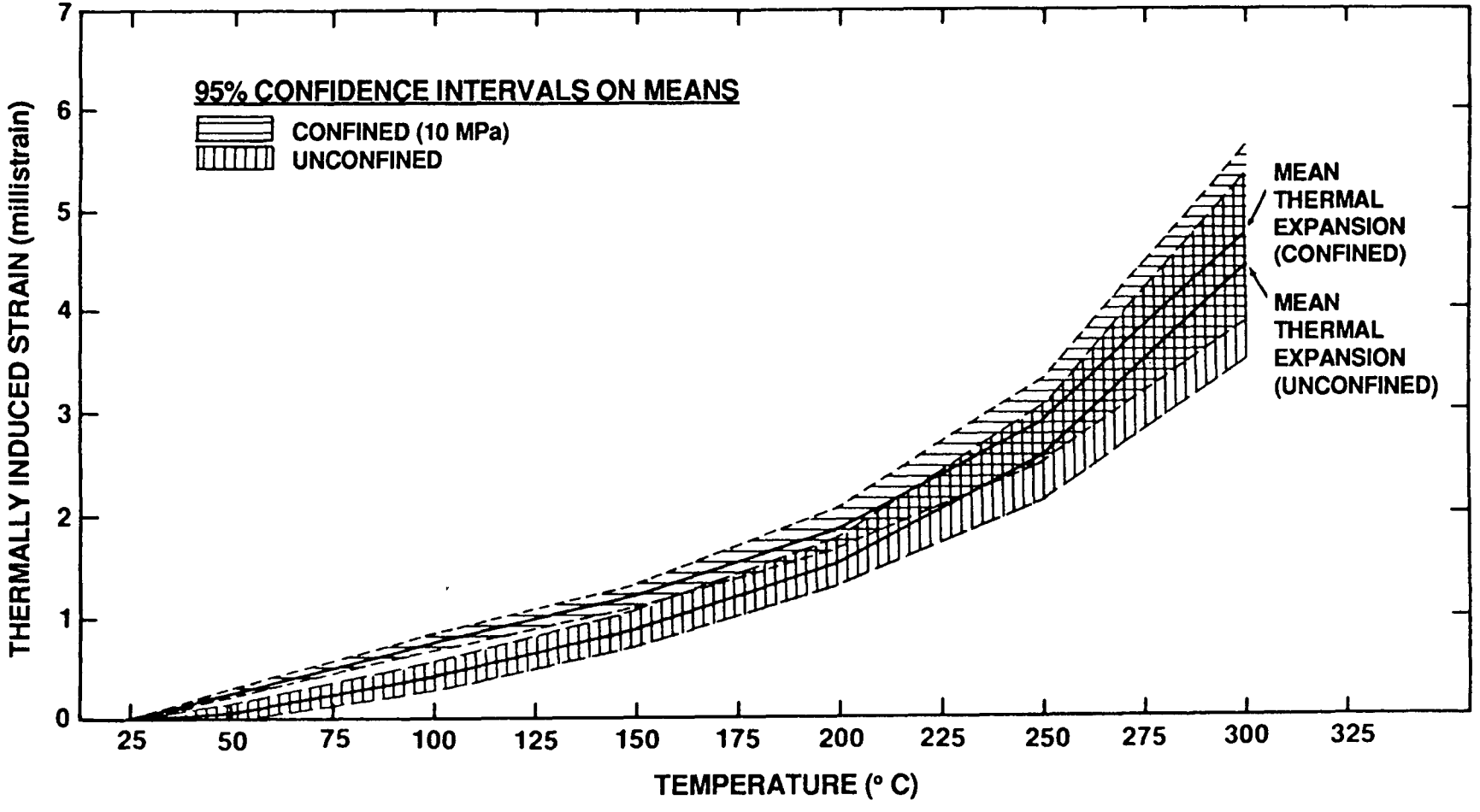
Thermal Expansion Behavior of Confined and Unconfined Samples of Unit TSw2



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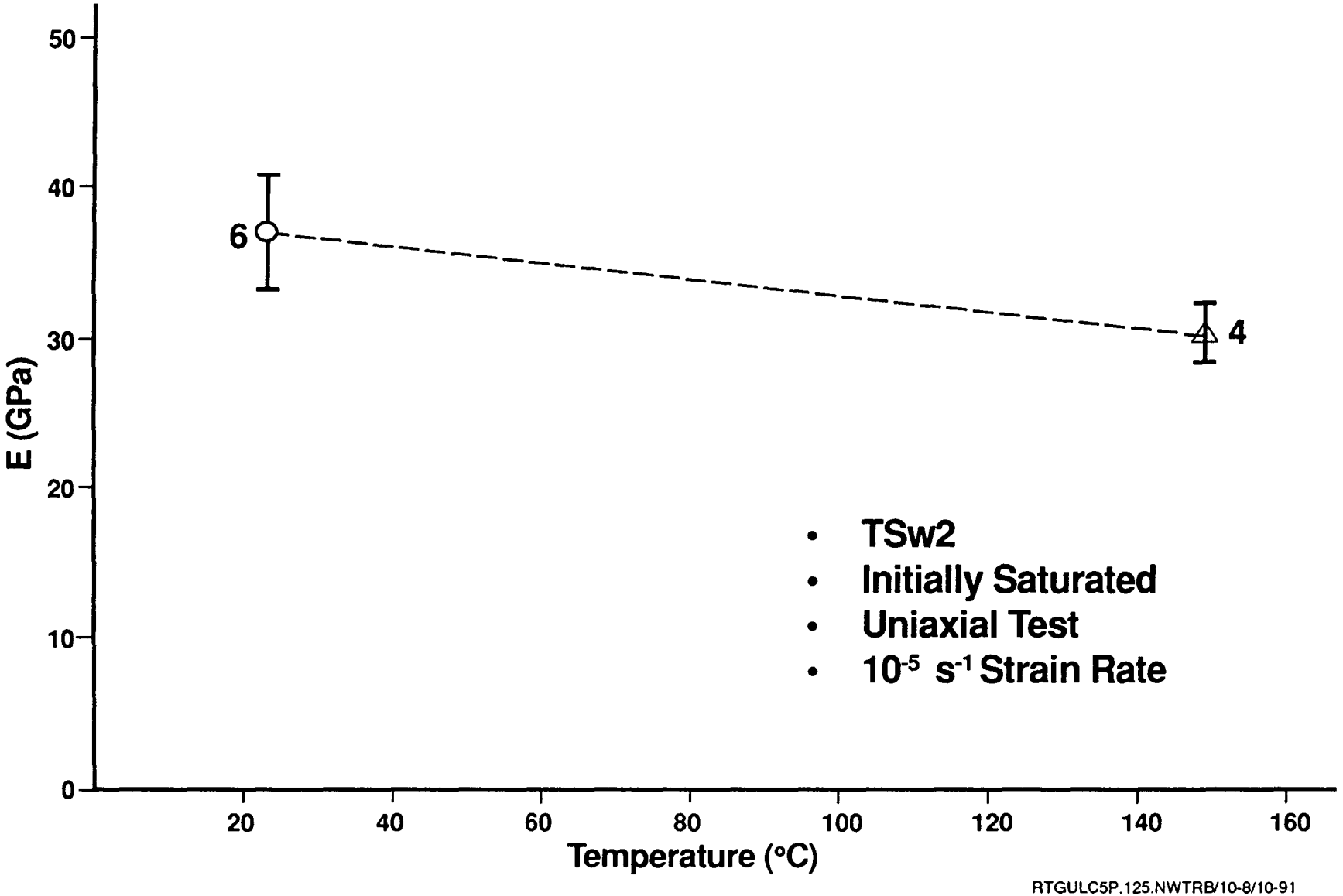
Intact Rock Modulus



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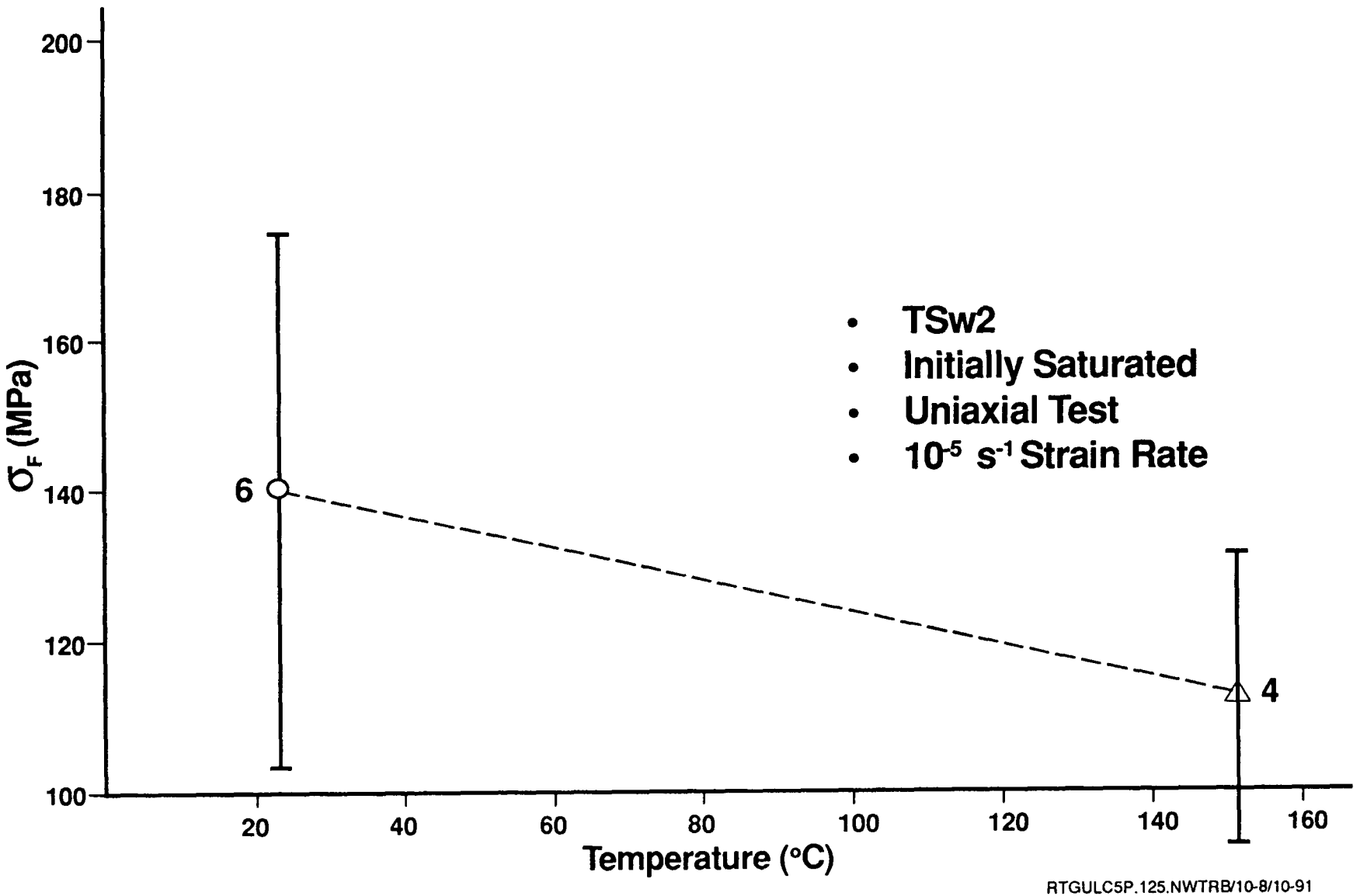
Intact Rock Failure



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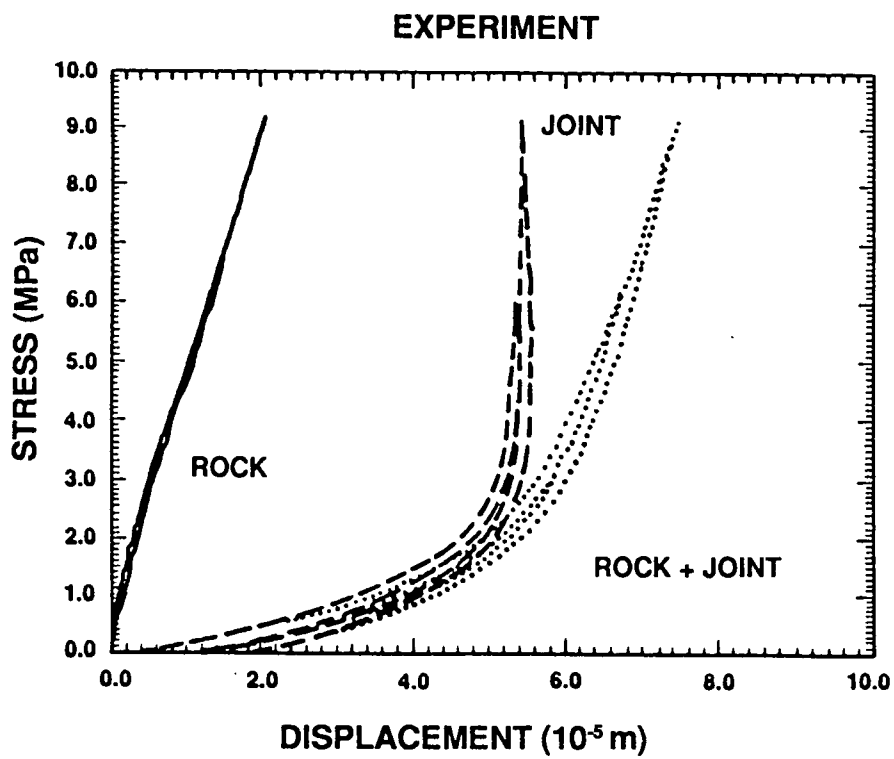
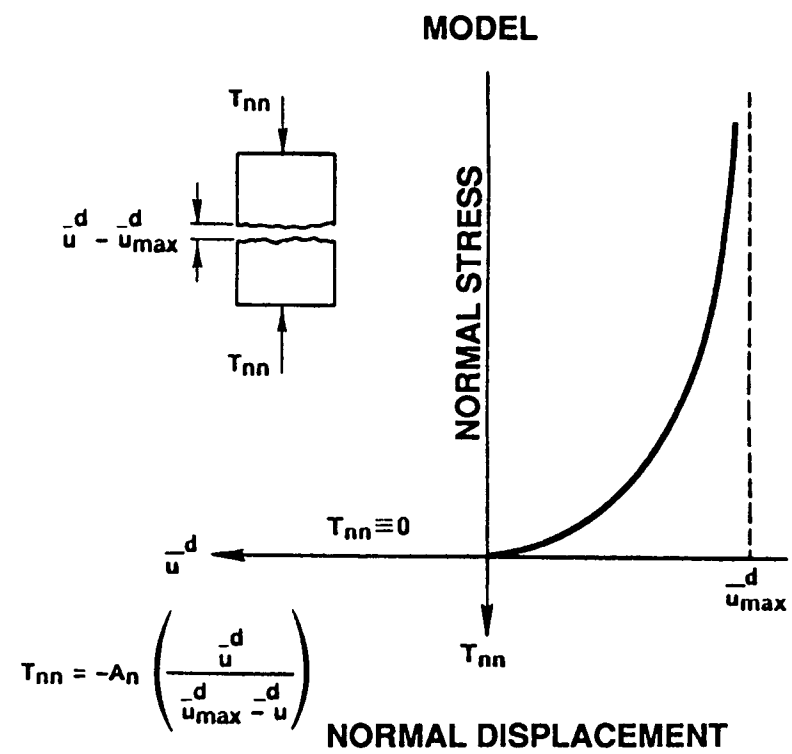
Thermal Effects on Rock Mass

- Jointed rock mass leads to coupling between thermal expansion and rock mass modulus
- Thermal expansion tends to increase modulus (non-linear)
- Rock mass stresses tend to increase (non-linear)
- Fracture permeability tends to decrease (non-linear)

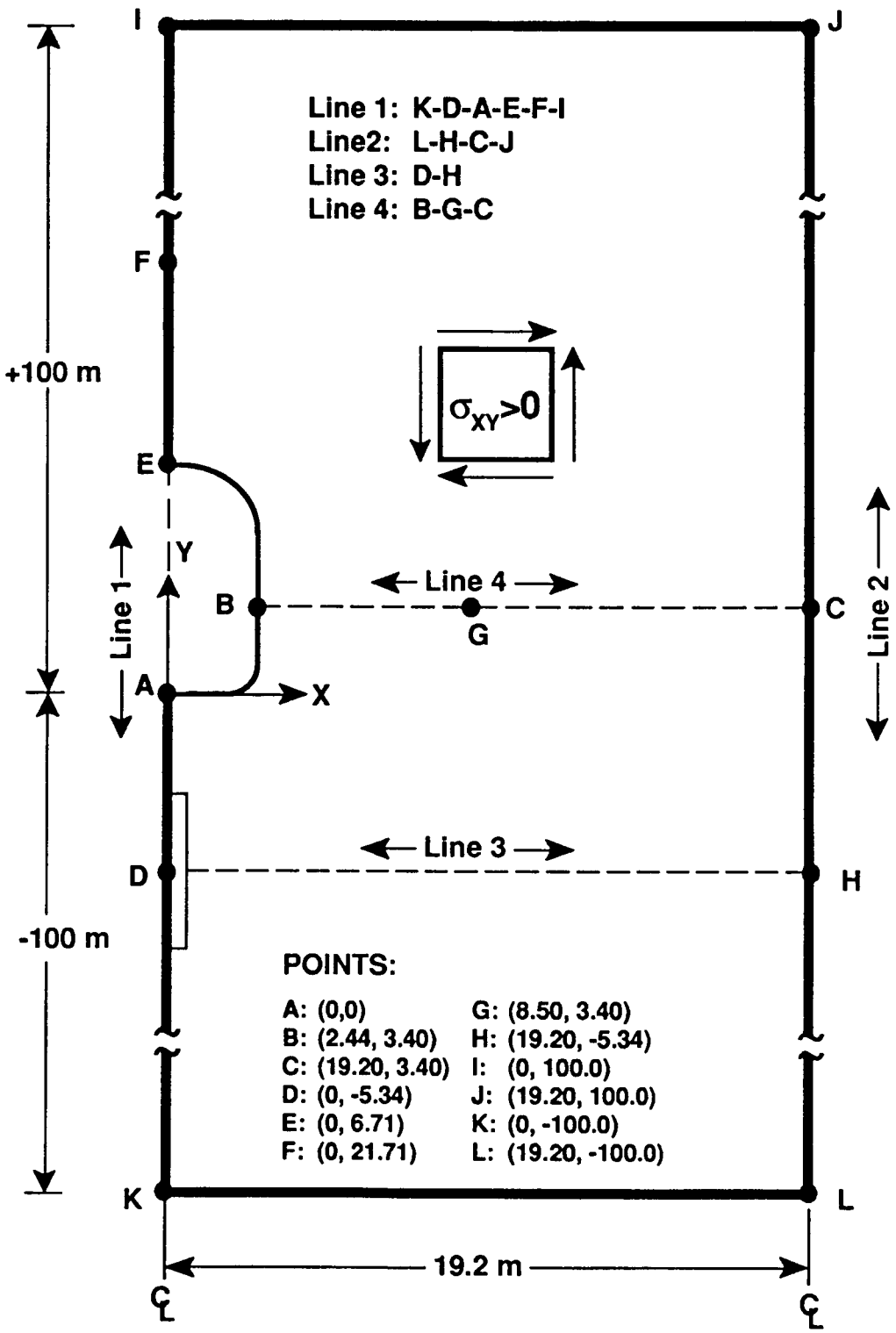
Nonlinear Elastic Normal Joint Behavior



(from W. Olsson)



Geometry for Benchmark Calculation



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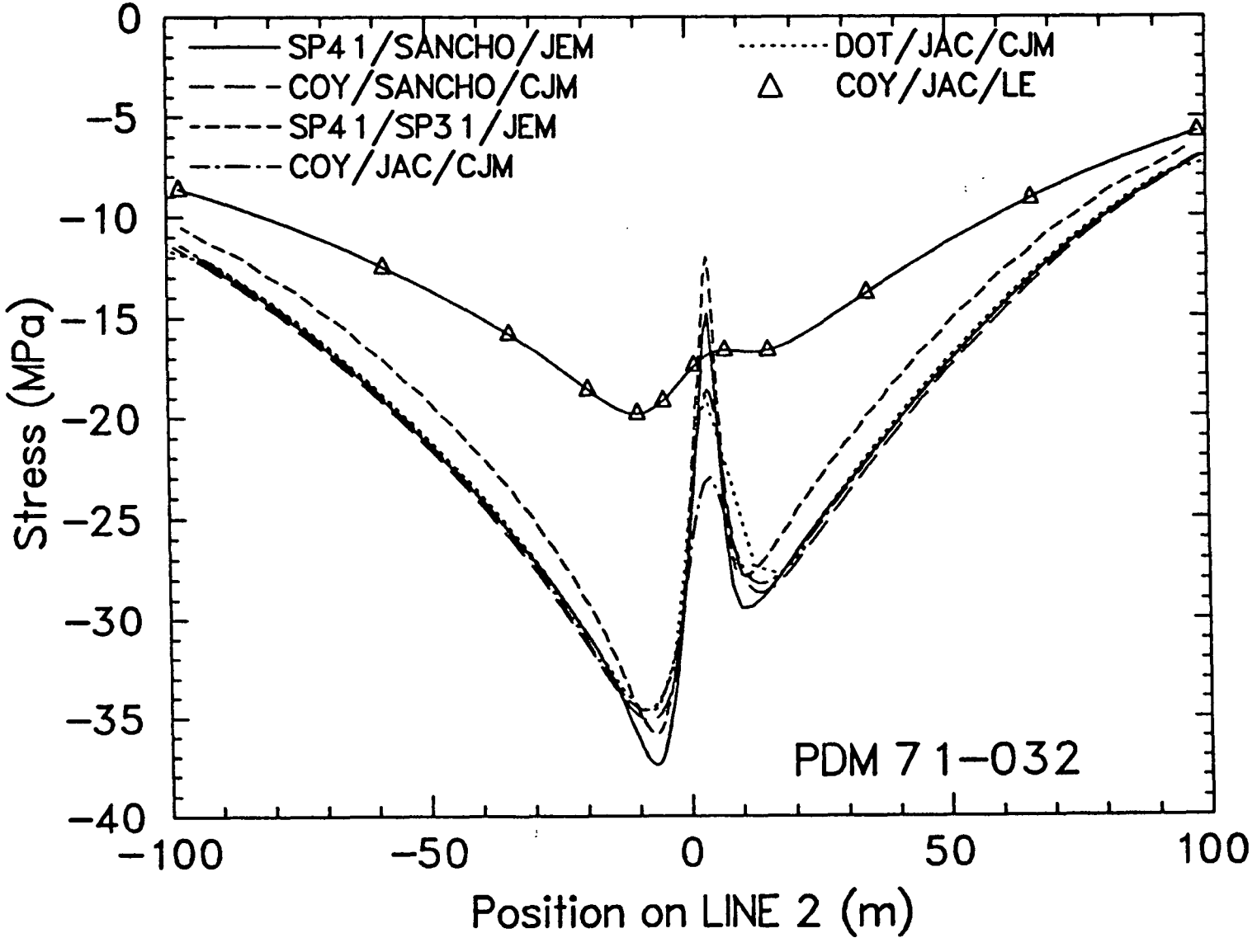
Horizontal Stress Along Line 2 at 101 Years



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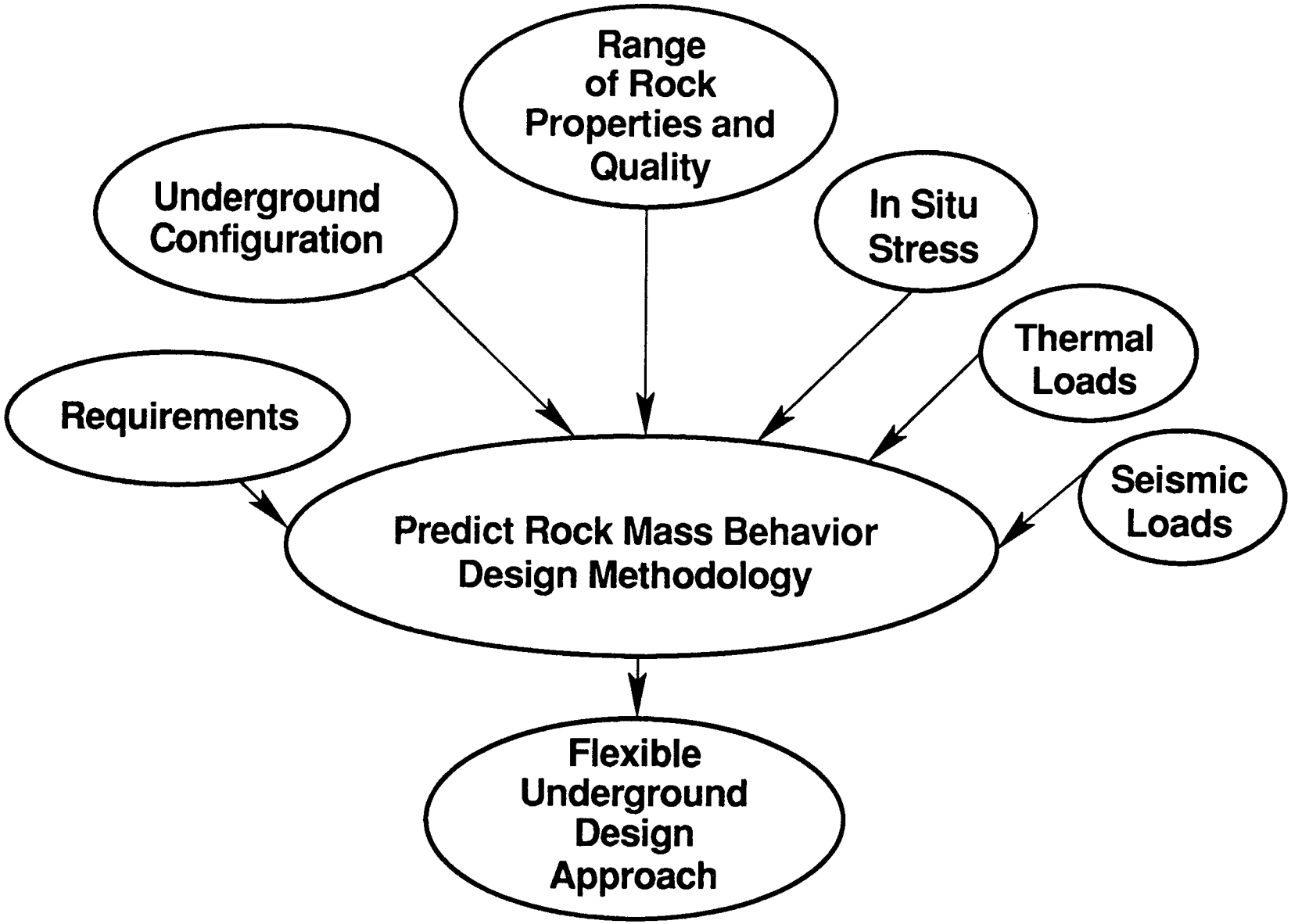
Uncertainty in Design

- Uncertainties associated with in situ conditions and rock quality

- Empirical methods
  - Validated by extensive case history
  - Little experience with thermal stresses

- Numerical methods
  - Can incorporate thermal component easily
  - Validation requires new test results from ESF
  - Are becoming an integral part of mining and civil engineering projects



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Requirements

Flow-Down

Regulations
Requirements
Performance Measures

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SCP Goals

↓

Impacts on Design

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Design Criteria

Example

- Retrievability
- Limit Rock Movement

↓

- Closure Rates
- Allowable Rock Fall

↓

Conservative
Ground Support

↓

Spacing & Type of Support
as Function of Ground
Conditions, Loads

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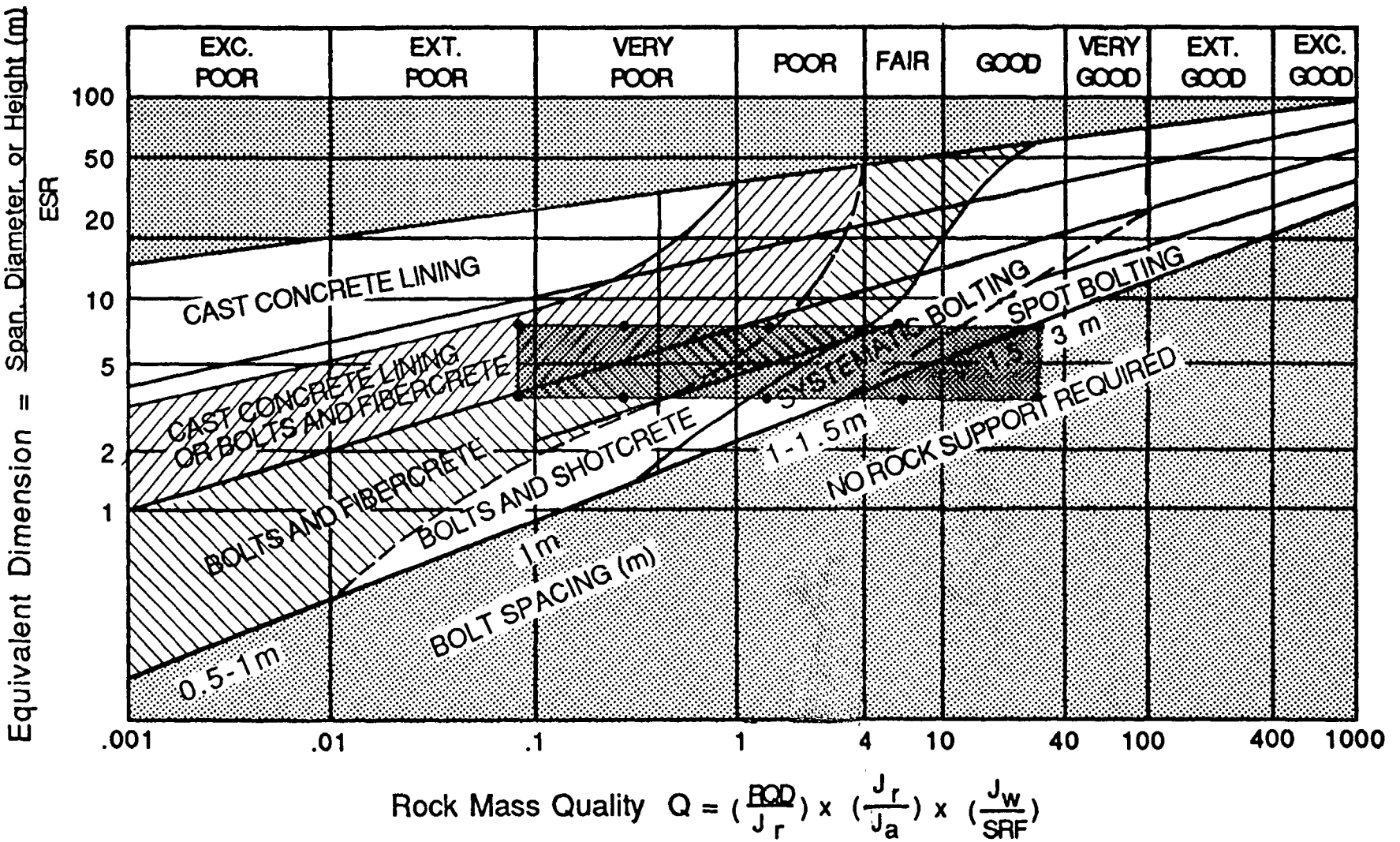
Uncertain In Situ Conditions: Rock Quality

Classification Parameters

CLASSIFICATION SYSTEM	PARAMETER	DESCRIPTION
NGI-Q System	RQD	Rock Quality Designation
	J_N	Joint Set Number
	J_R	Joint Roughness Number
	J_A	Joint Alteration Number
	J_W	Joint Water Reduction Factor
	SRF	Stress Reduction Factor
	Q	Rock Mass Quality
RMR System	C	Intact Core Strength Rating
	F_{RQD}	Rock Quality Designation Rating
	JF	Joint Spacing Rating
	JC	Joint Condition Rating
	JW	Groundwater Rating
	AJO	Adjustment for Joint Orientation
	RMR	Rock Mass Rating

Estimated Support Requirements



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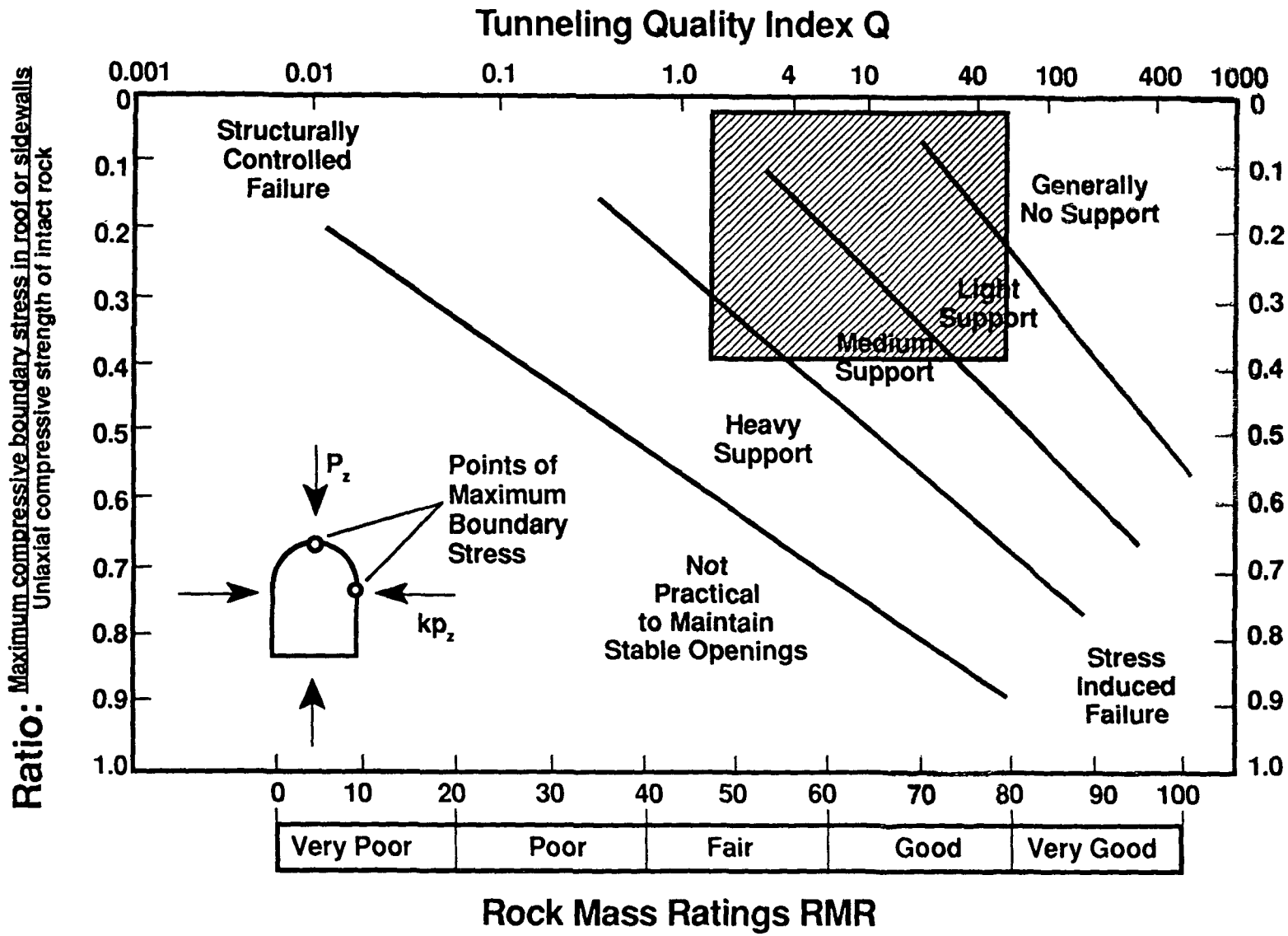
Estimated Support Requirement



Range of Conditions for Emplacement Drifts

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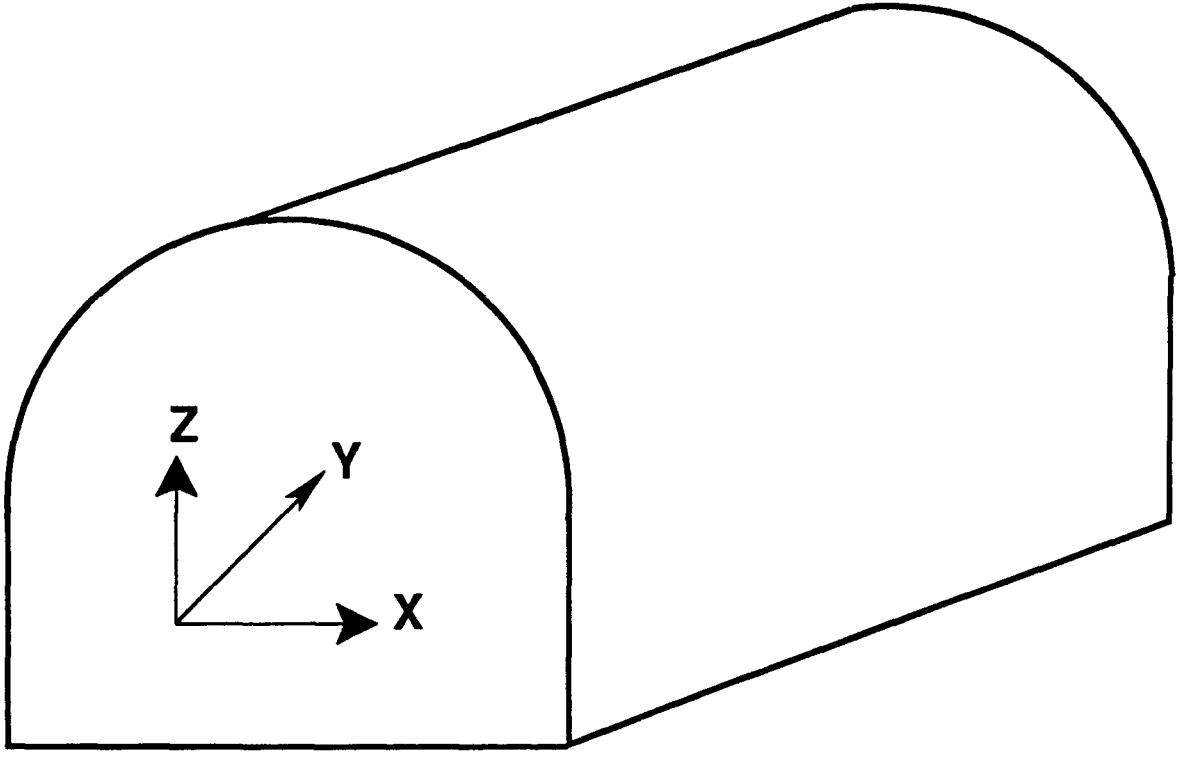
Numerical Design Analysis

- Linear combinations of loads
- Calculate stresses at drift location
  - Stresses depend on time, rock quality (properties), location of drift
- Determine impact on drift excavation and support

3-D Coordinate System



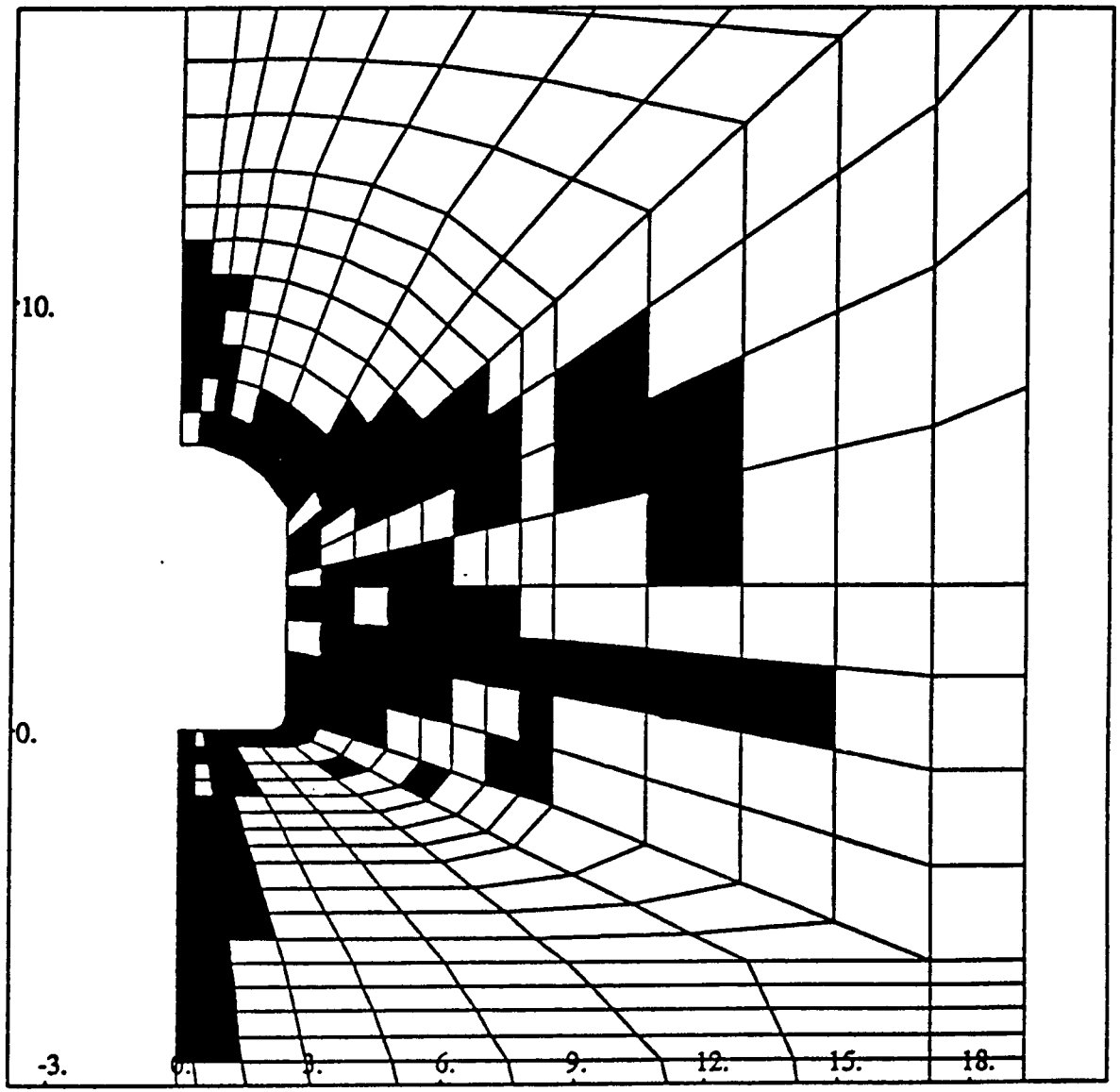
Combined Loads (in MPa) for Midpanel Access Drift at 100 Years

Rock Mass Quality Category	In Situ Stress			Seismic Stress			Thermal Stress			Combined In Situ, Thermal and Seismic		
	σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}
1	4.2	3.5	7.0	0.7	0.3	0.8	2.6	1.7	-0.6	7.5	5.5	7.2
2	4.2	3.5	7.0	1.3	0.6	1.4	4.6	3.0	-1.0	10.1	7.1	7.4
3	4.2	3.5	7.0	2.7	1.2	2.9	9.6	6.3	-2.2	16.5	11.0	7.7
4	4.2	3.5	7.0	6.1	2.8	6.7	21.6	14.3	-5.0	31.9	20.6	8.7
5	4.2	3.5	7.0	6.2	2.8	6.7	21.8	14.4	-5.0	32.2	20.7	8.7

Midway Drift Stress Combinations

Time After Waste Emplacement (Years)	Temp. (° C)	Thermal Stress (MPa)			In Situ+ Thermal (MPa) (MPa)			In Situ + Thermal + Seismic (MPa)			In Situ - Seismic		
		σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}
0	24	0	0	0	4.2	3.5	7.0	6.9	4.7	9.9	1.5	2.3	4.1
10	24	0	0	0	4.2	3.5	7.0	6.9	4.7	9.9			
35	32	4.2	0.8	-3.1	8.4	4.3	3.9	11.1	5.5	6.8			
50	47	6.8	2.7	-3.6	11.0	6.2	3.4	13.7	7.4	6.3			
100	74	9.4	6.2	-2.2	13.6	9.7	4.8	16.3	10.9	7.7			
100	80kW/ ACRE	13.2	8.7	-3.1	17.4	12.2	3.9	20.1	13.4	6.8			

Zones of Joint Slip at 100 Years (Benchmark Calculation)



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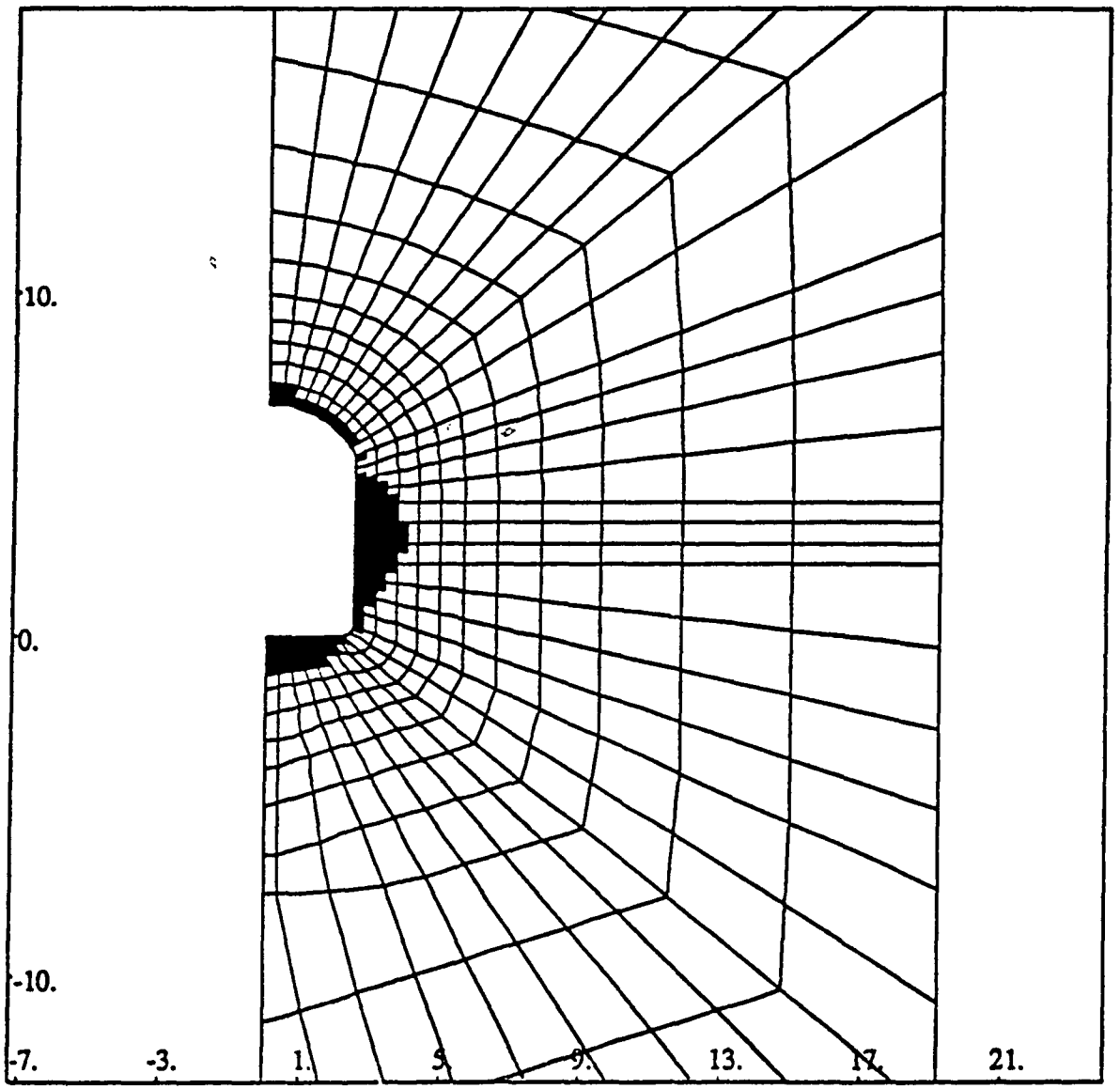
Zones of Failure (Drucker - Prager) at 100 Years



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Impacts of Thermal Loads on the Underground Design

- Thermal load component can be incorporated into the design through analysis methods; jointed rock models are necessary
- Greater thermal loads (increased stress) may result in additional support or some areas being avoided
  - May enhance stability of some drifts
- Thermal loads may facilitate ground control in some areas when considering possible seismic loads
- Degree of impact depends on local rock conditions

Summary Of Geomechanical Uncertainties

There are some advantages to both higher or lower thermal loading

- Lower thermal loads reduce the complexity of the design analysis and confirmation testing
- In better quality rock, higher thermal loads may facilitate ground control, especially when possible seismic loads are considered
- Higher thermal loads may result in a decrease in fracture permeability due to aperture closure

Summary of Geomechanical Uncertainties

(Continued)

Some problems become more significant as thermal load increases

- In lower quality rock, greater thermal loads may result in additional support or some areas being avoided
- Joint slip and fracture propagation around openings increases
- Higher thermal stresses adds some uncertainty and complexity to the design problem
- Potential effects of changes in stress magnitude and direction are not completely understood. The degree of impact depends on local rock conditions
- High thermal loading would require more extensive modeling, model validation, and confirmation testing

Summary of Geomechanical Uncertainties

(Continued)

Resolution of Problems

- Thermal loads can be incorporated into the design through analysis methods
- Design methodology is independent of degree of thermal load
- Sufficient experience in underground excavations with stress magnitudes comparable to those expected at Yucca Mountain suggest that opening can be supported for the required lifetime, but validation is necessary
- Joint slip or fracture propagation is not expected to extend beyond the drift near-field