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A First Principle Look at the Electromotive Force Generation from Molybdenum and Niobium Alloys

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Changing the World's Energy Future

Idaho National Laboratory

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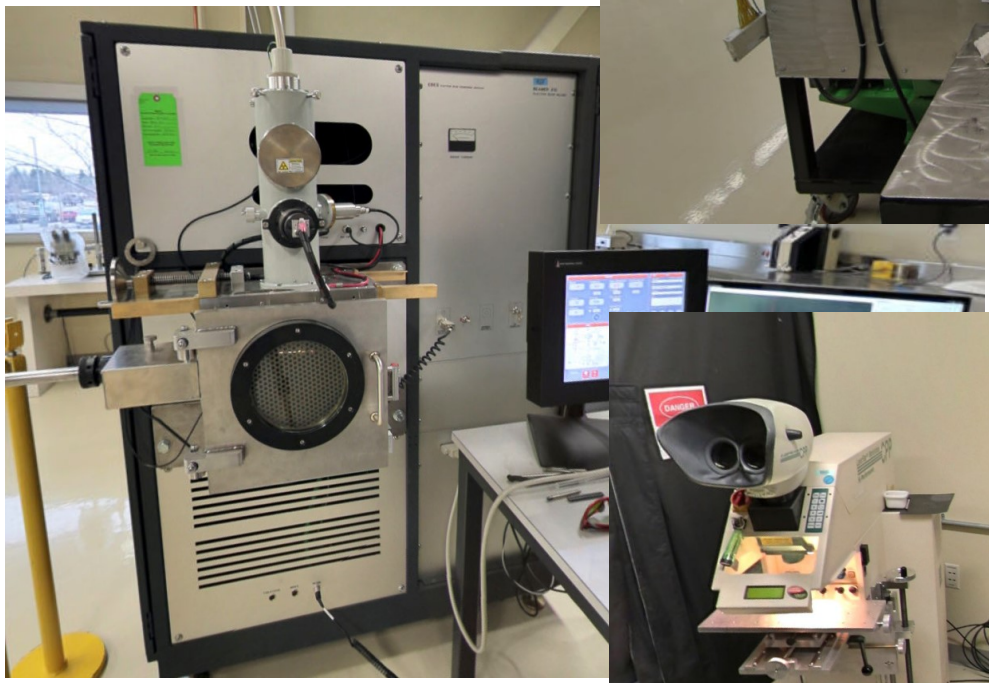
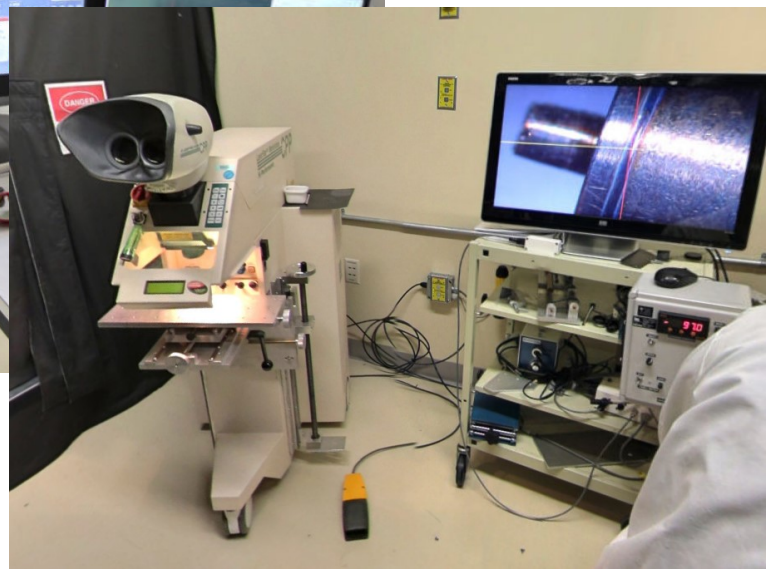
Measurement Science Laboratory

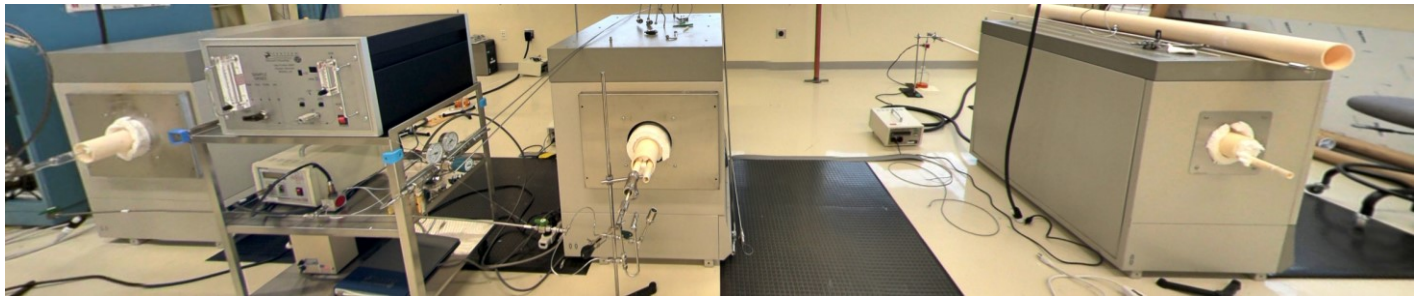
Idaho National Laboratory

Measurement Science Laboratory

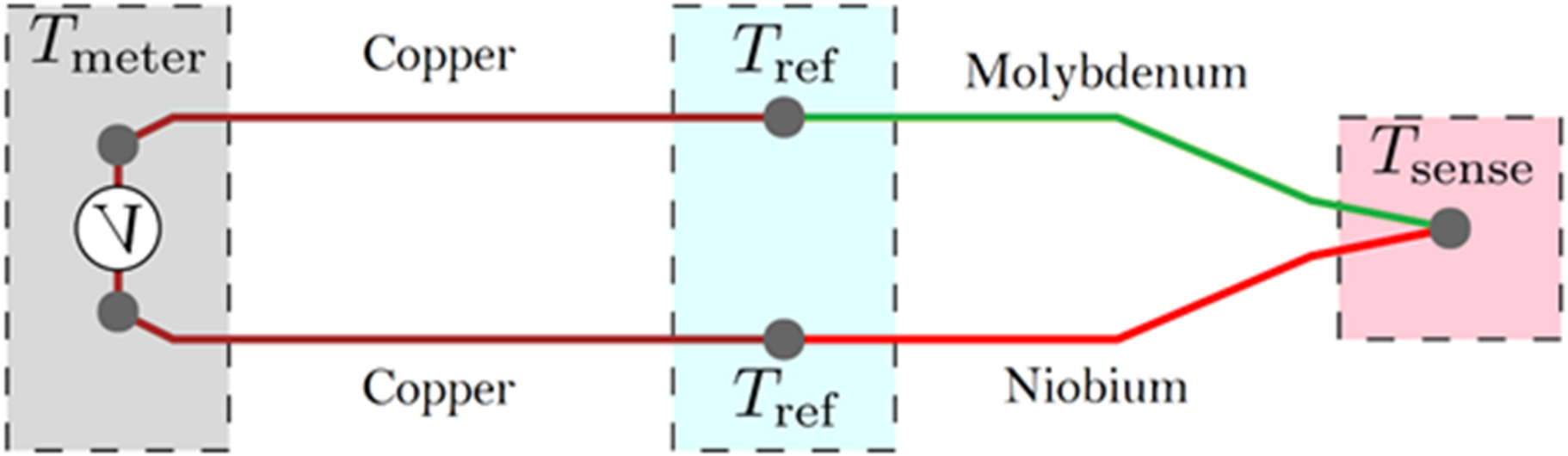
- https://inl.gov/360-tour/high-temperature-test-laboratory







The Electromotive Force (EMF)



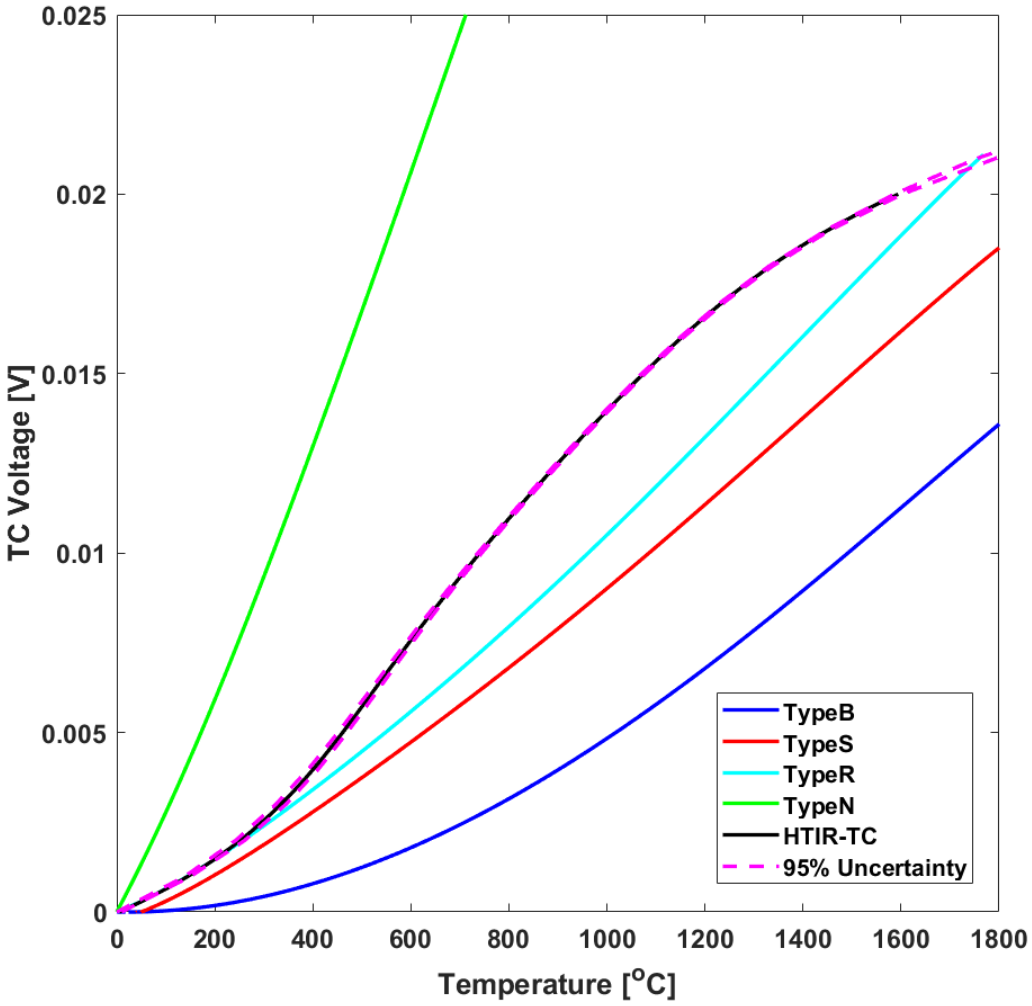
EMF generated along the length of cable:

$$EMF = \int_0^L S_1 \frac{dT}{dx} dx - \int_0^L S_2 \frac{dT}{dx} dx$$

EMF generated along the temperature gradient (assuming homogeneous wires):

$$EMF = \int_{T_L}^{T_H} (S_1 - S_2) dT$$

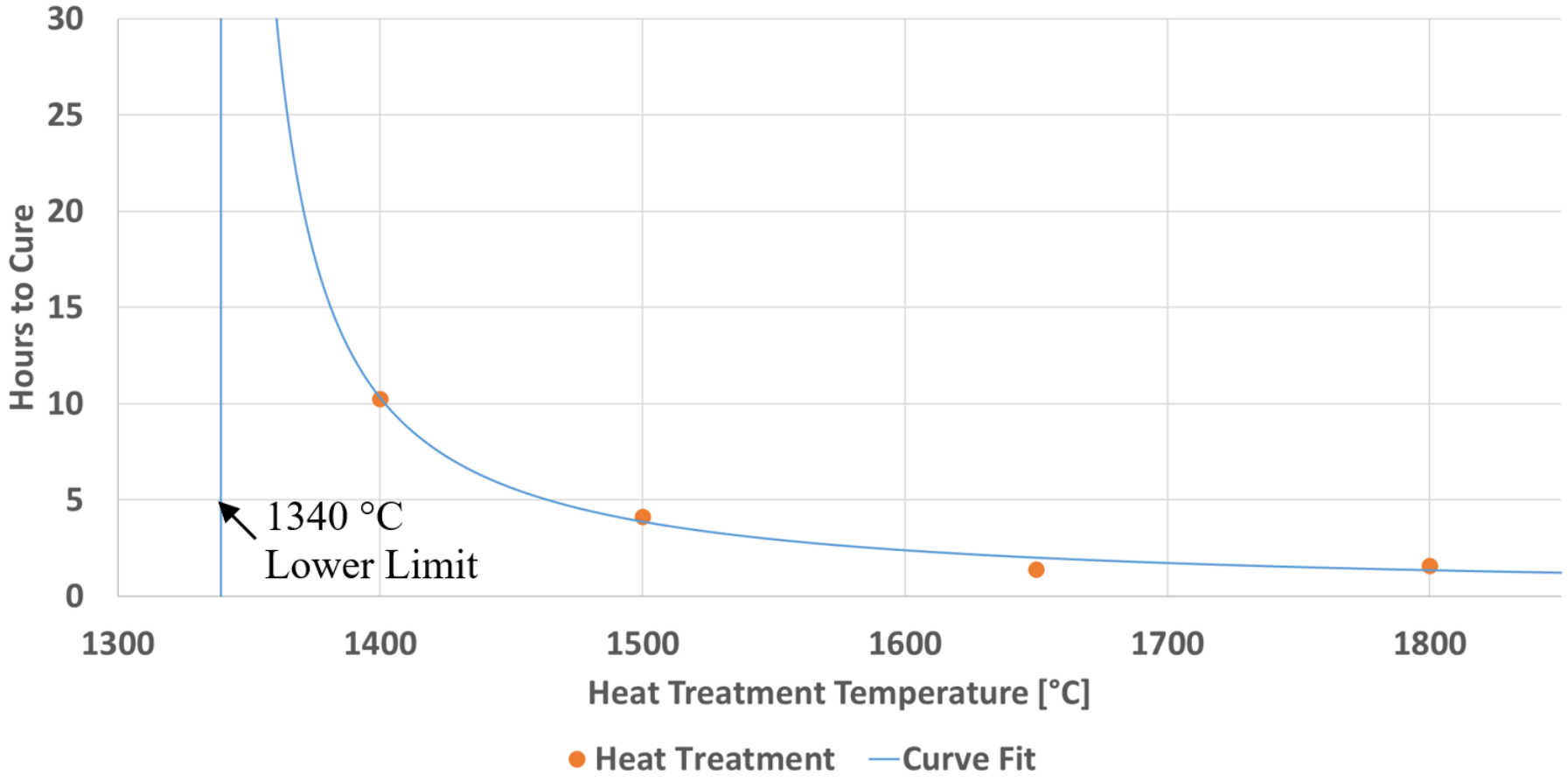
The Temperature Calibration



- Calibration fit using both low and high temperature ranges
- 5^{th} order polynomial works best
- Comparable output to other commercially available TCs
- Linear region between 700 °C and 1500 °C

Avoiding Heterogeneous Cables…

- Heat treatment necessary for stable calibration
- Time and temperature dependent with a 1/x law
- Must reach higher than ~1340 °C to take effect
- Minimum timeframe at around 2.5 hours

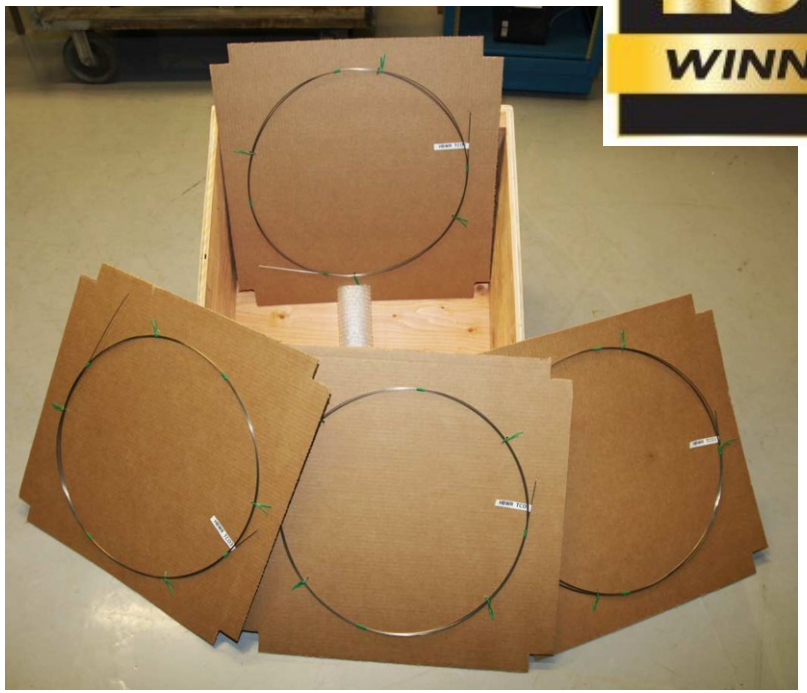


$$EMF = \int_0^L S_1 \frac{dT}{dx} dx - \int_0^L S_2 \frac{dT}{dx} dx \Rightarrow EMF = \int_{T_L}^{T_H} (S_1 - S_2) dT$$

The High Temperature Irradiation Resistant Thermocouple

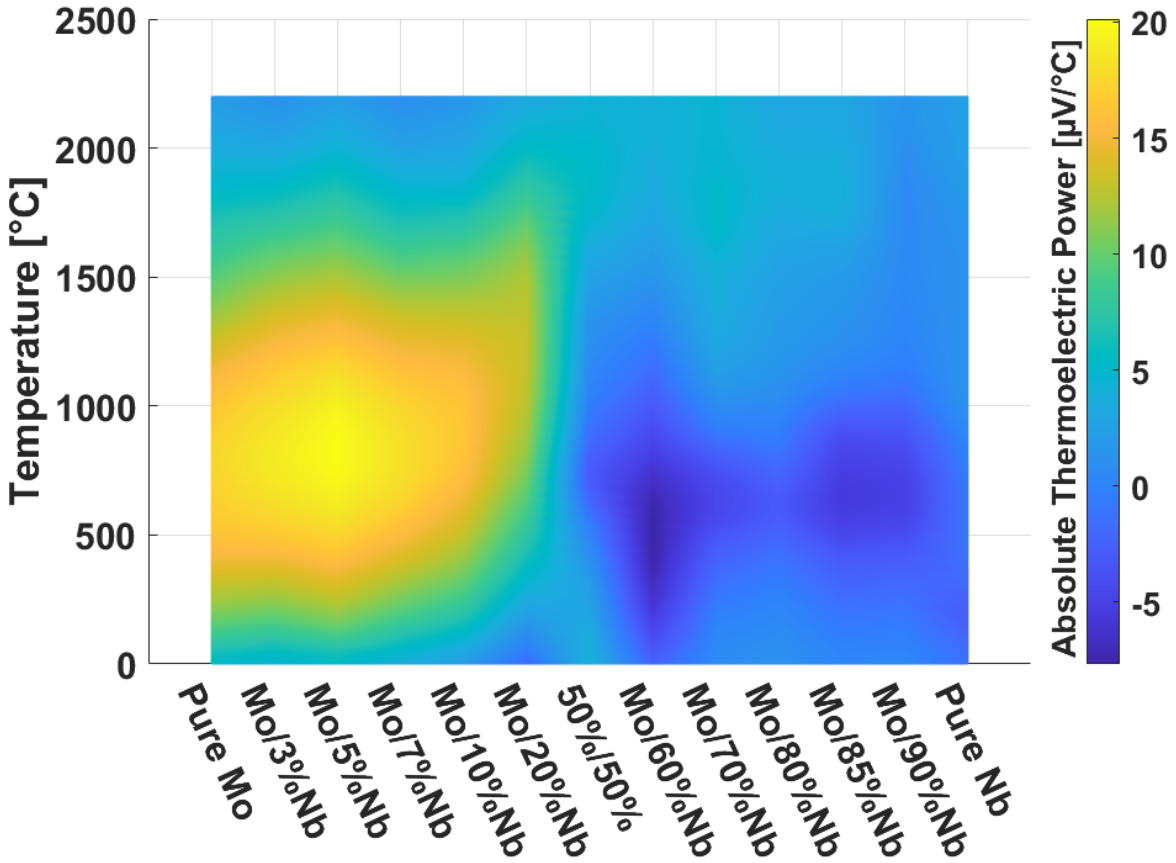
Table 1: Summary of performance parameters for the HTIR-TC

Performance Parameter	Performance Requirement Fuel Test Application	Performance Requirement Stand-Alone Application
Temperature Range	**Room Temperature - 1600°C**	**Room Temperature - 1600°C**
Accuracy	Not Specified	±1%
Drift	**-3% for 4.5×10^{21} nvt (thermal)**	**-3% for 4.5×10^{21} nvt (thermal)**
Life	**4.5×10^{21} nvt (thermal), or 10 thermal shocks (room temperature to 1600°C)**	**18 months or 4.5×10^{21} nvt (thermal)**
Mechanical Ruggedness:		
Rugged Junction	Rugged mechanical junction design	Rugged mechanical junction design
Bend Radius	Minimum of 2 feet	Minimum of 2 feet
Thermal Shock	5 sudden startups and 5 sudden shutdowns—each causing a thermal shock on the order of room temperature up to 1600°C	100°C/hr
Response Time	<0.5 seconds	<0.5 seconds



2019 R&D 100 WINNER

EMF from Molybdenum/Niobium Alloys

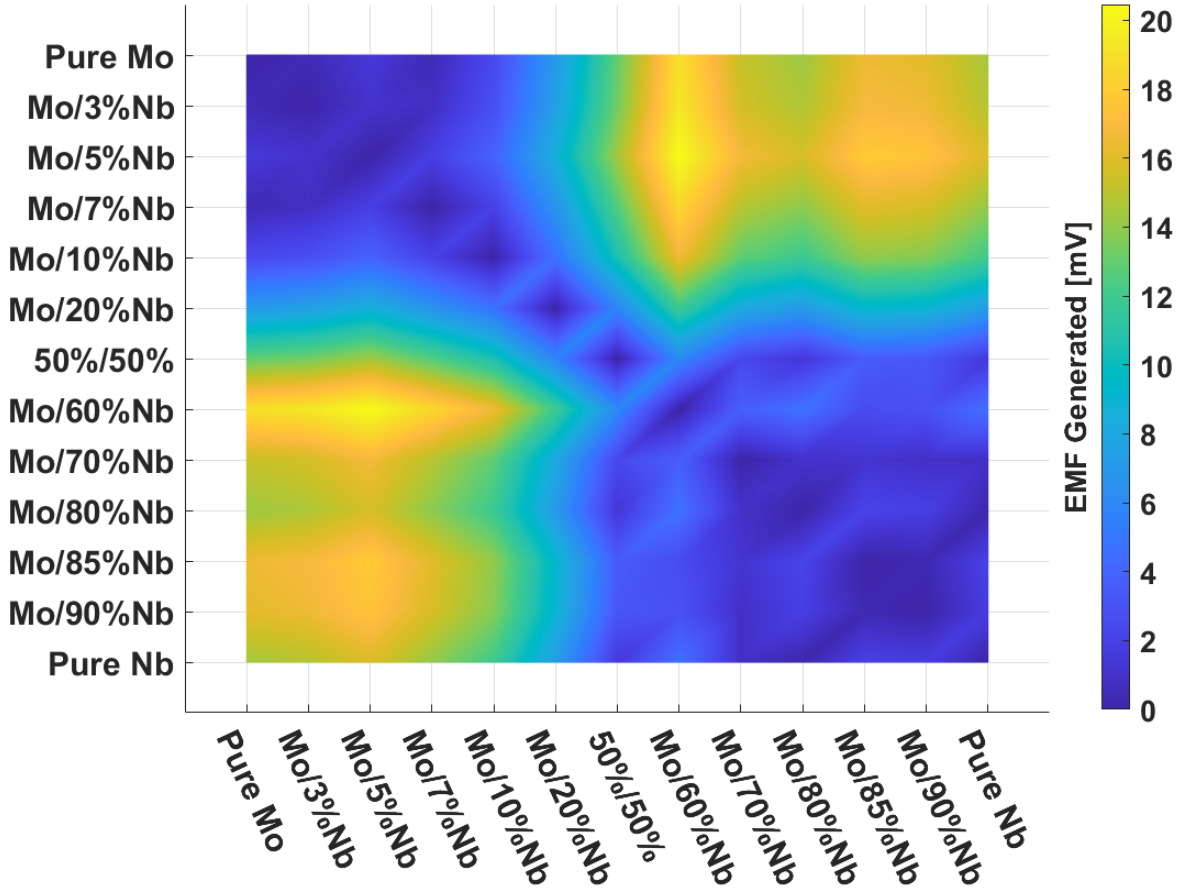


- Data raised from R. Schley, G. Metauer, “Thermocouples for Measurements Under Conditions of High Temperature and Nuclear Radiation,” in Temperature: Its Measurement and Control in Science and Industry. **5**, Part 2, J. F. Schooley, ed., American Institute of Physics, New York, NY, pp. 1109-1113, (1982)
- EMF from temperature gradient, ΔT, shown between 0 and 2200 °C.

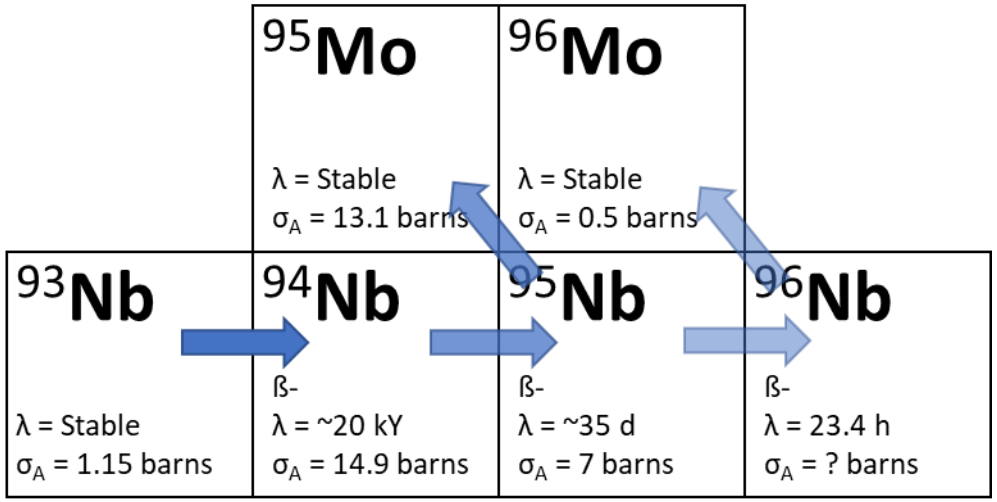
$$EMF = \int_0^L S_1 \frac{dT}{dx} dx - \int_0^L S_2 \frac{dT}{dx} dx \Rightarrow EMF = \int_{T_L}^{T_H} (S_1 - S_2) dT$$

Thermocouples from Mo/Nb Alloys

- Temperature gradient, ΔT, held constant between 0 °C and 1600 °C
- Symmetrical about the diagonal axis
- Greatest coupling with Mo/5%Nb vs. Mo/60%Nb
- Could be further incremented via advanced manufacturing methods



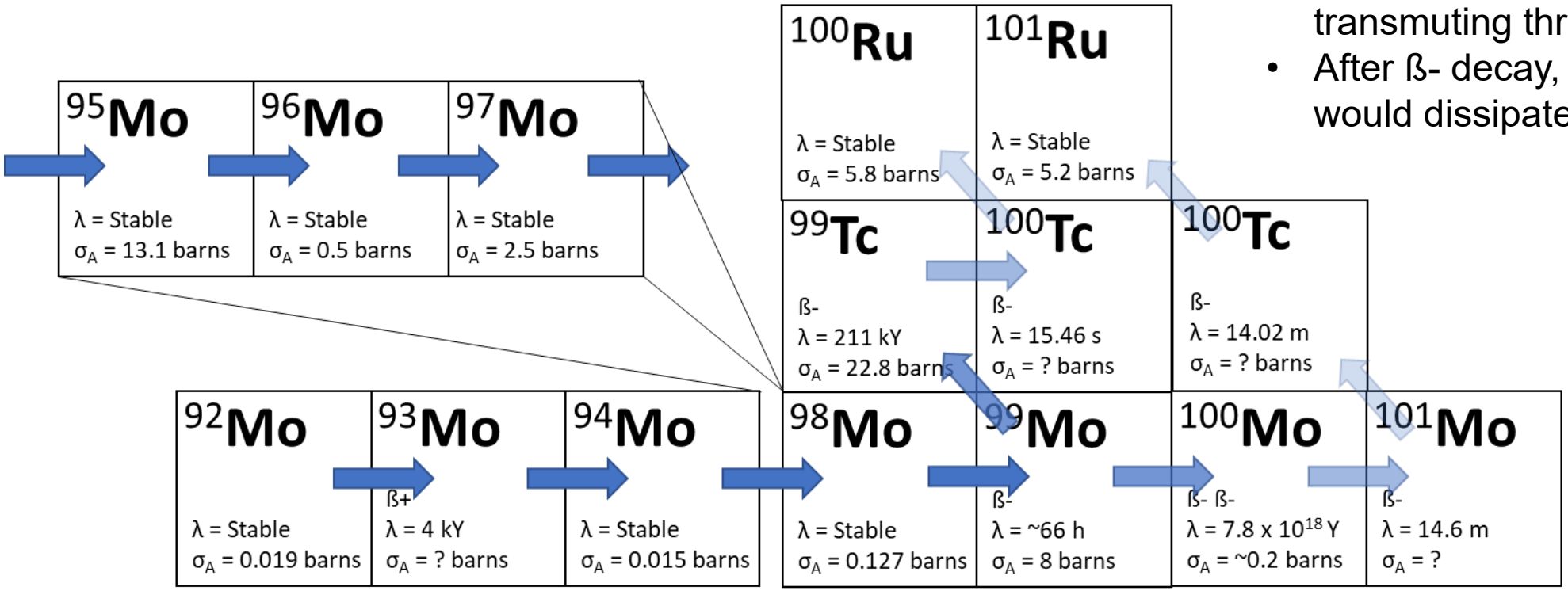
The Path of Transmutation for Niobium (Nb)



- Niobium begins with 100% stable ^{93}Nb
- After neutron bombardment niobium has the potential of transmuting through ß- decay
- After ß- decay, this begins the long process of stable Mo isotopes

The Path of Transmutation for Molybdenum (Mo)

- Molybdenum has various stable isotopes to being with.
- After neutron bombardment molybdenum has the potential of transmuting through ß- decay
- After ß- decay, the transmutation would dissipate to stable ruthenium



Conclusion

- HTIR-TC is a long-lasting nuclear TC up to temperatures of 1600°C
- Alloying Moly/Nb would increase EMF signal
- Alloying Moly/Nb may increase lifetime of TC thermoelements through controlled transmutations

Questions?

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