

# Robust Heat-Flux Sensors for Coal-Fired Boiler Extreme Environments

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NETL, Crosscutting Research - Sensors and Controls

2021 DOE/FE R&D Project Review Meeting

# Project Objectives

- **Develop robust heat-flux measurement systems** capable of operating in the challenging high-temperature, corrosive environments of the boilers of coal-fired power plants.
- Support the **training of graduate and undergraduate students** in STEM disciplines, preparing them to apply science and engineering principles to solve real-life problems.

# Technical Approach

- Prototyping the wire-wound Schimdt-Boelter-style sensor head
- Prototyping the Transverse Seebeck Effect sensor head
  
- Modeling of the Thermo-Mechanical Properties of the sensor head
  
- System design
- Testing and Calibration

# Project Participants



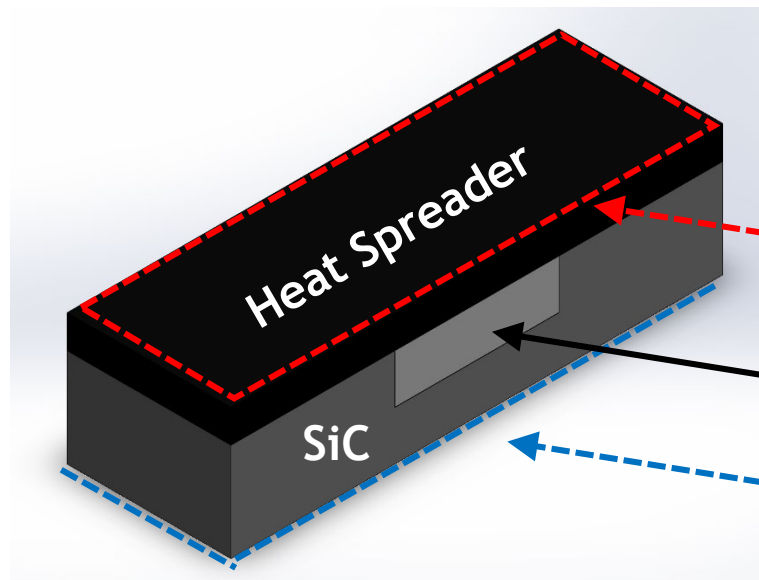
- PI: Oded Rabin, Materials Science and Engineering
- Co-PI: Peter Sunderland, Fire Protection Engineering
- Graduate students
  - K. M., 1<sup>st</sup> year graduate student in Aerospace Engineering
- Undergraduate students
  - A. L., Sophomore in Mechanical Engineering
- Technical staff (PT)
  - Machining and rig construction

# Project Timeline

		Lead Person	FY 2021				FY 2022				FY 2023			
TASKS			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
			1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30	31-33	34-36
1.0	Project Management and Planning	PD												
1.1	Project Management Plan	PD												
1.2	Technology Maturation Plan	PD												
2.0	Prototyping the Wire-Wound Schmidt-Boelter Style Sensor Head	PD												
2.1	Materials Procurement	Staff												
2.2	Ceramic Machining	Staff												
2.3	Thermopile Wire Fabrication	PD				X								
2.4	Sensor Head Assembly	All												
3.0	Prototyping the Transverse Seebeck Effect Sensor Head	PD												
3.1	Materials Procurement	Staff												
3.2	Ceramic Machining	Staff												
3.3	Single Crystal Preparation	PD					X							
3.4	Sensor Head Assembly	All												
4.0	Modeling of the Thermo-Mechanical Properties of the Sensor Heads	co-PI				X								
5.0	System Design	PD						X						
6.0	Testing and Calibration	co-PI												
6.1	Design and Set-Up of Test Facilities	staff												
6.2	Low-Temperature Heat Flux Signal Testing	co-PI												
6.3	High-Temperature Resilience Testing	co-PI									X			
6.4	High-Temperature Heat Flux Signal Testing	co-PI												
6.5	Heat Flux-to-Electrical Signal Transfer-Function Analysis	PD												
6.6	High-Temperature Heat Flux Measurement: Testing against Commercial Sensor	co-PI												X
7.0	Presentations, Intellectual Property, and Partnerships	All	□	□	□	□	□	□	□	□	□	□	□	□

# Thermo-electrical Modeling

- Sensor head consists of thermoelectric unit (voltage generating), blackbody absorber (heat spreader) and ceramic casing.



FEA MODEL

Cross-sectional view of sensor head

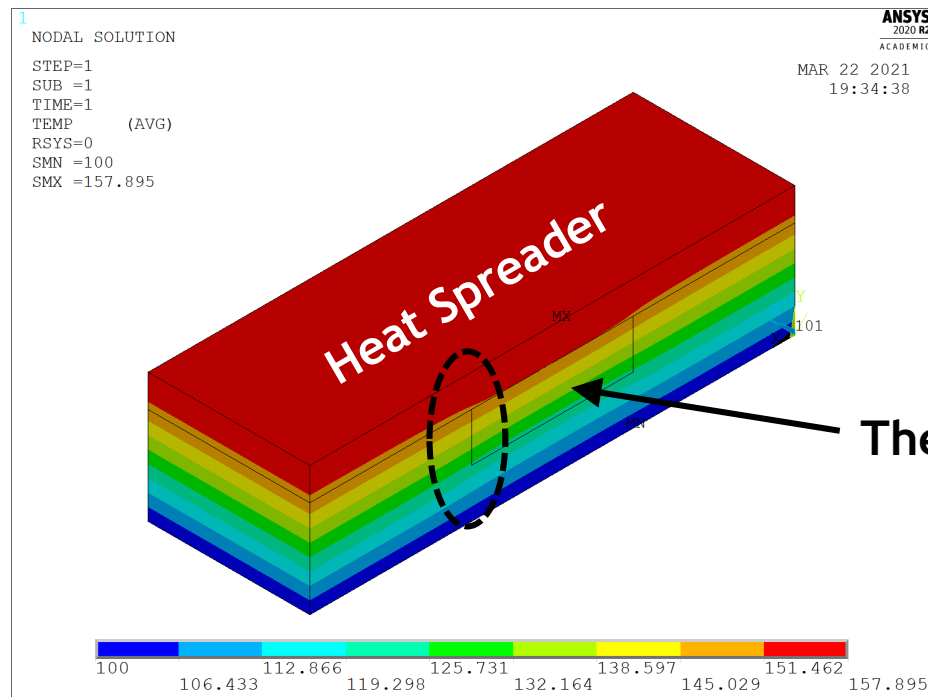
*Constant Heat Flux boundary plane*

Thermoelectric Element

*Constant Temperature boundary plane*

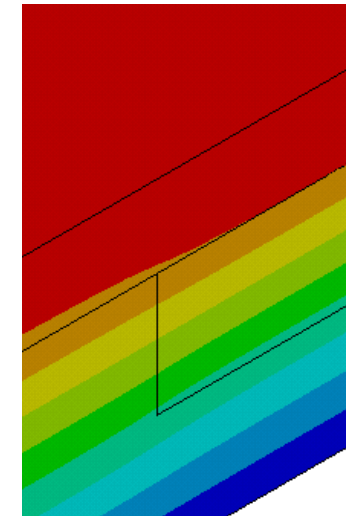
# Thermo-electrical Modeling

- A one dimensional heat flow through the thermoelectric element is desired for the most linear sensor response.



## FEA RESULTS

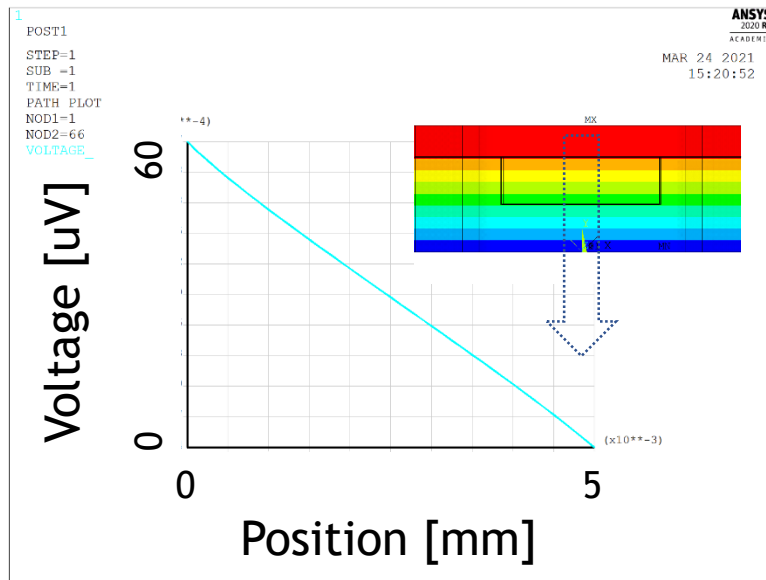
### Temperature Distribution in Sensor Head



# Thermo-electrical Modeling

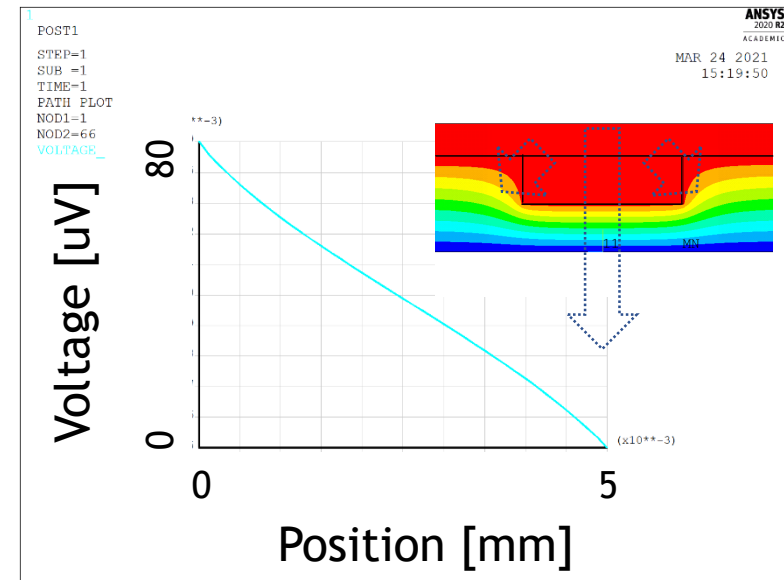
- Voltage profile in thermoelectric element

## One-dimensional Heat Flow



Linear voltage profile (constant  $\frac{\partial V}{\partial x}$ )

## Three-dimensional Heat Flow



Deviations from constant  $\frac{\partial V}{\partial x}$  at the edges of the sample



# Conclusions

- One dimensional heat flow through the thermoelectric sensor produces a linear voltage response to heat flux. Deviations from a one-dimensional heat flow reduce linearity and complicate deployment.
- The thermo-electrical FEA simulations helped us determine the range of acceptable values of materials parameters, for materials selection and system design.

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