Instrumentation and Sensors - ORNL

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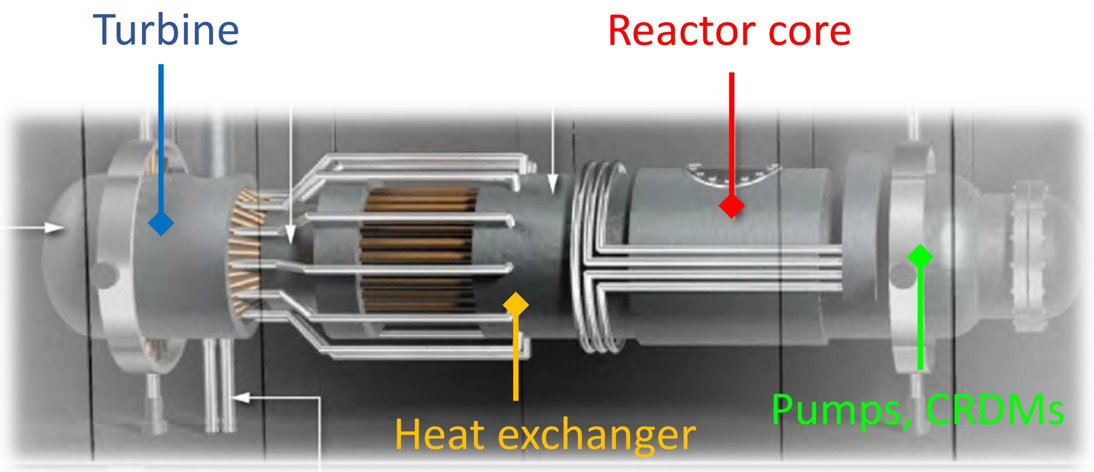
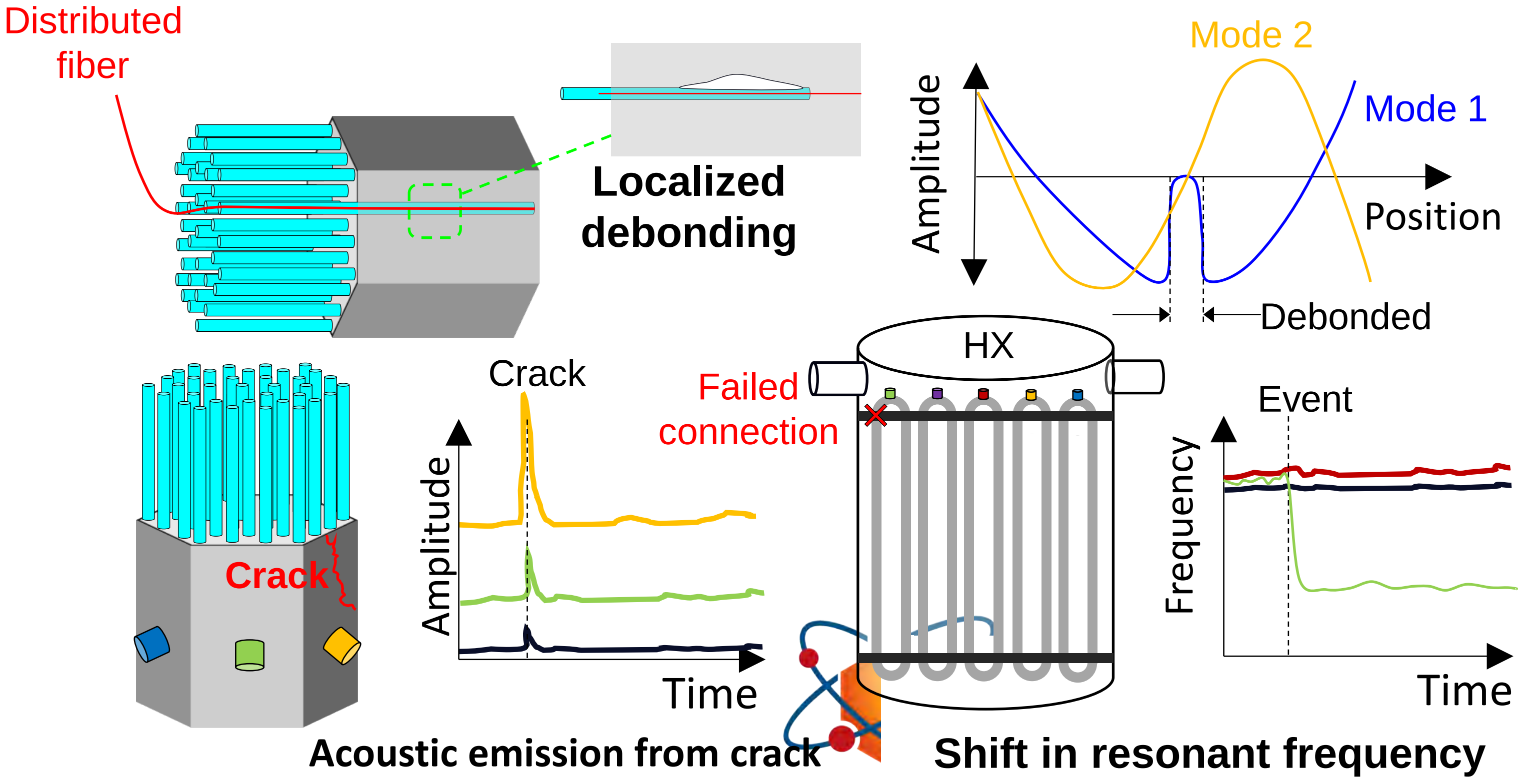
Microreactor applications

- Smaller size
- Factory assembled
- Automated or autonomous operation to reduce O&M costs (no economies of scale)
- Components may be located closer to the core in a **harsher environment** with **limited access**
  - Challenging to monitor or inspect, could benefit from advanced monitoring techniques
- Longer refueling cycles, less time for inspections/maintenance
  - **Manual inspections may not be an option**
  - **Online monitoring could enable predictive maintenance**

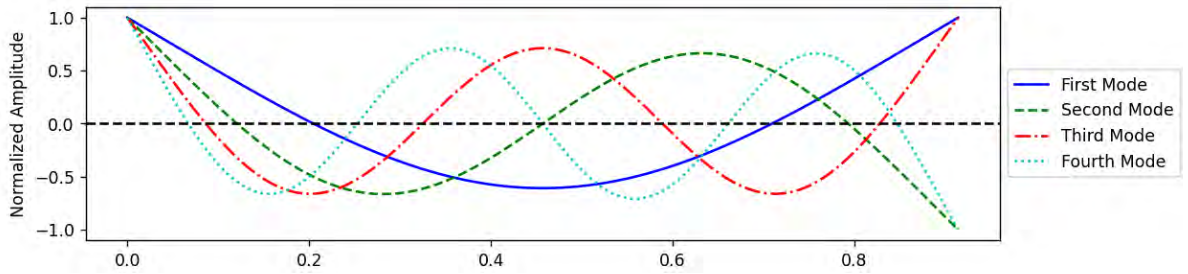


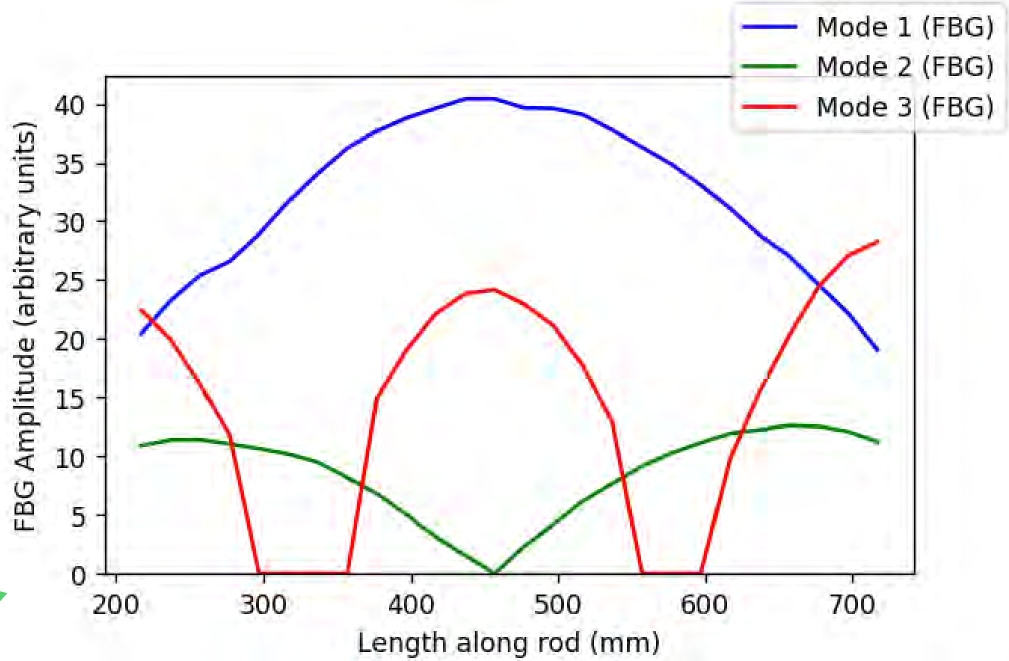


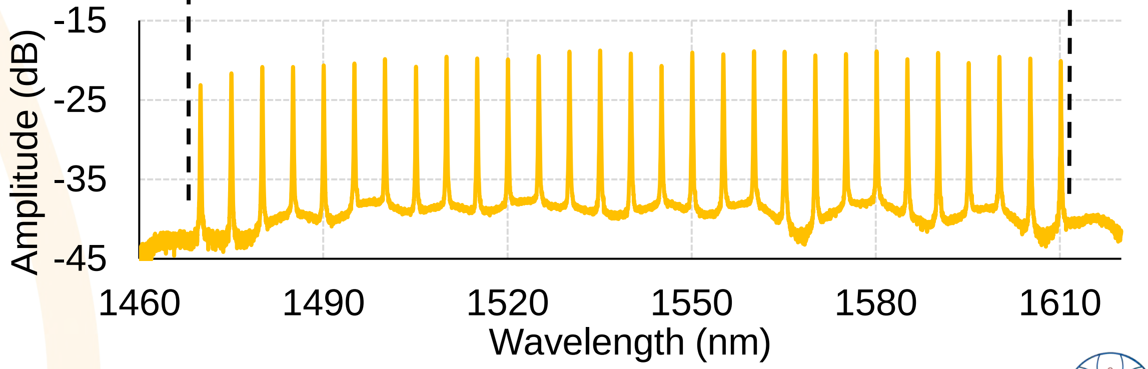
https://inl.gov/trending-topic/microreactors/

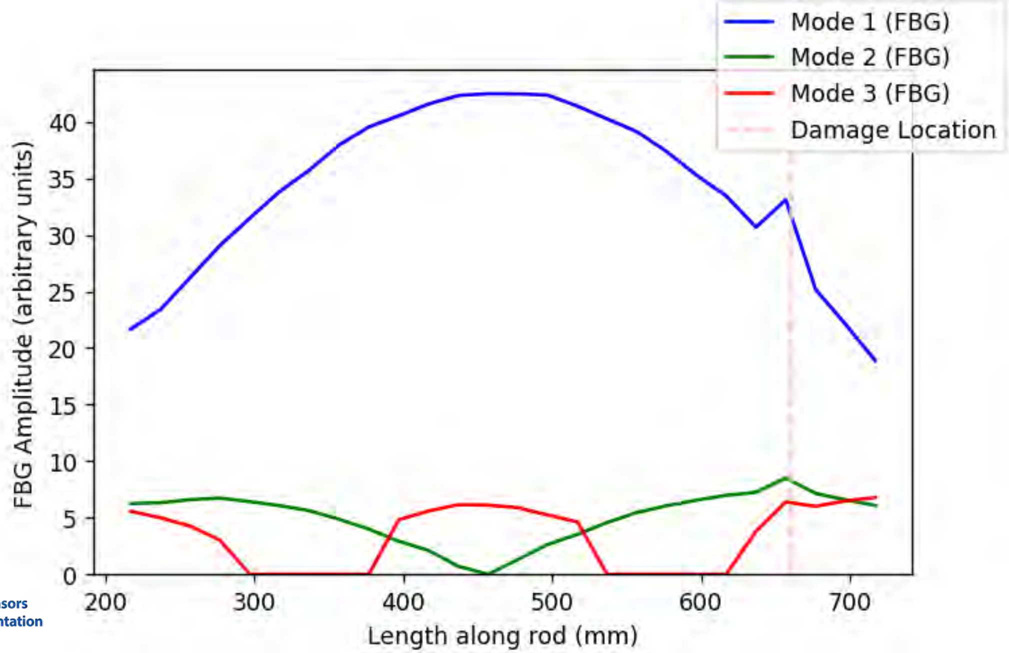
FY24 recap: Distributed fiber optic acoustic sensors for localized damage detection in metals

Theoretical vibrational modes









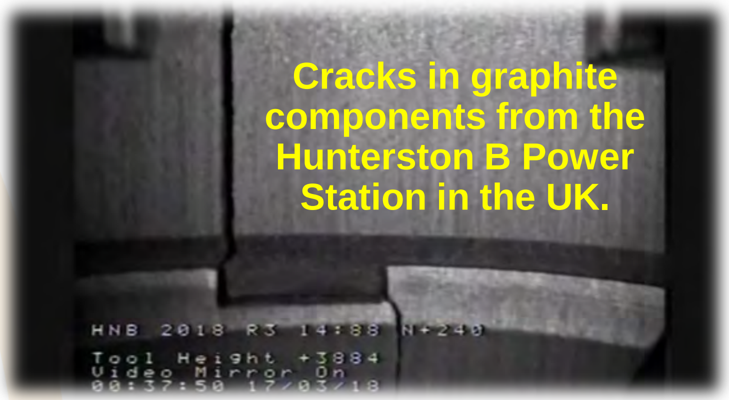
Graphics courtesy of T. Birri (ORNL)

FY25

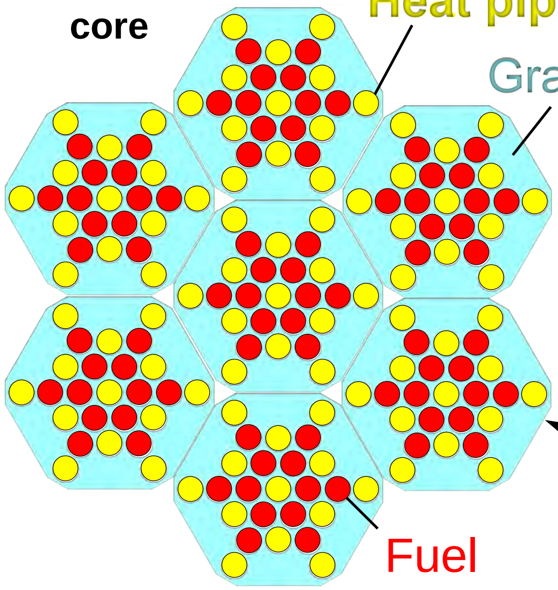
ASI Advanced Sensors and Instrumentation

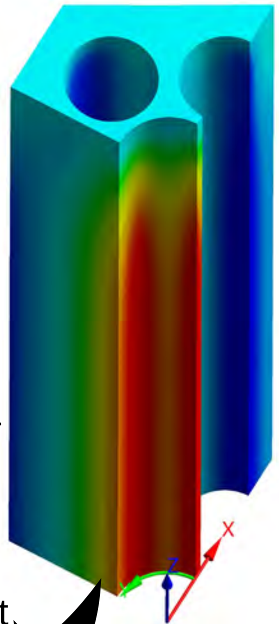
FY25: Focus on graphite in-core components

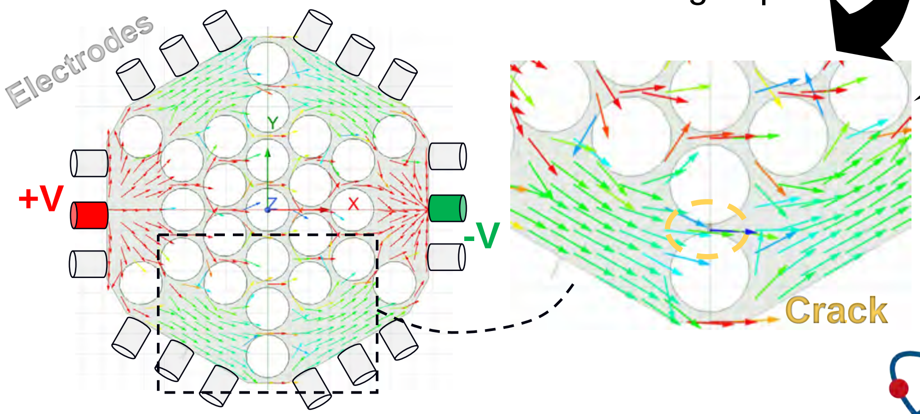
- **Goal:** Utilize electrical impedance tomography (EIT) to localize cracking or other damage in graphite microreactor components
  - Leverages semiconducting properties: conductive, but not *too* conductive (we hope…)



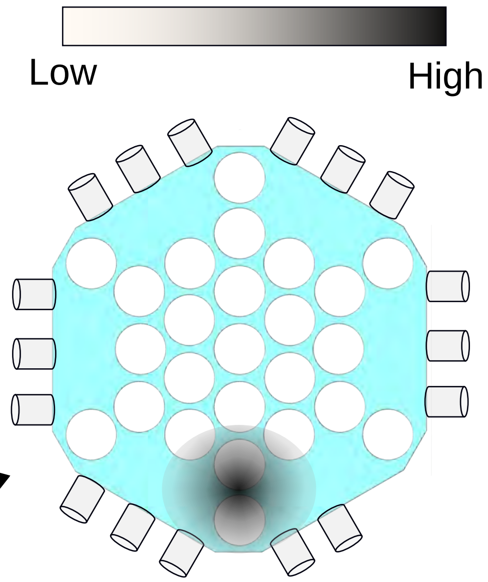
https://ichef.bbci.co.uk/news/1024/cpsprodpb/62E2/production/_105941352_hunterston1.jpg.webp







Current paths during measurements of impedances between electrode pairs



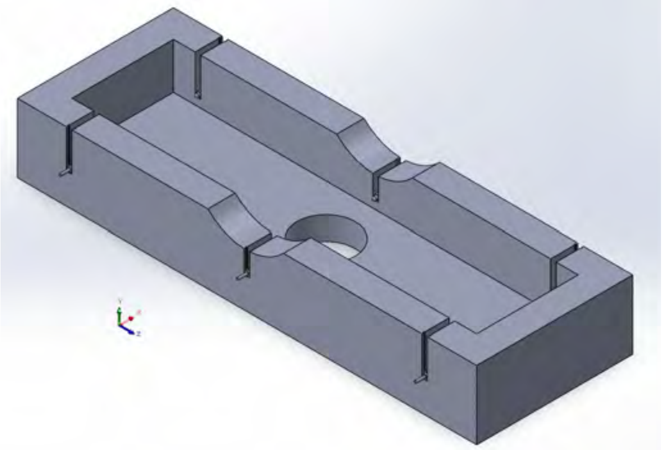
Finite element model solves inverse problem to identify damaged location based on measured impedances

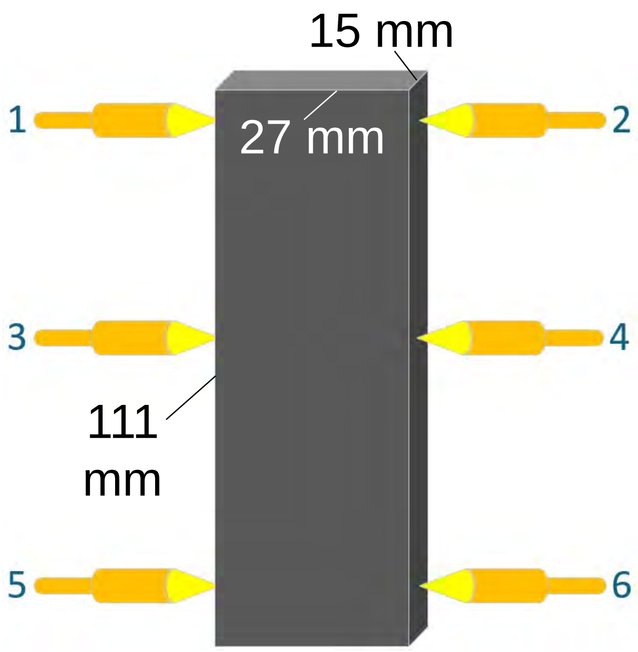
- Informs automated control system or digital twin to evaluate impact on reactor

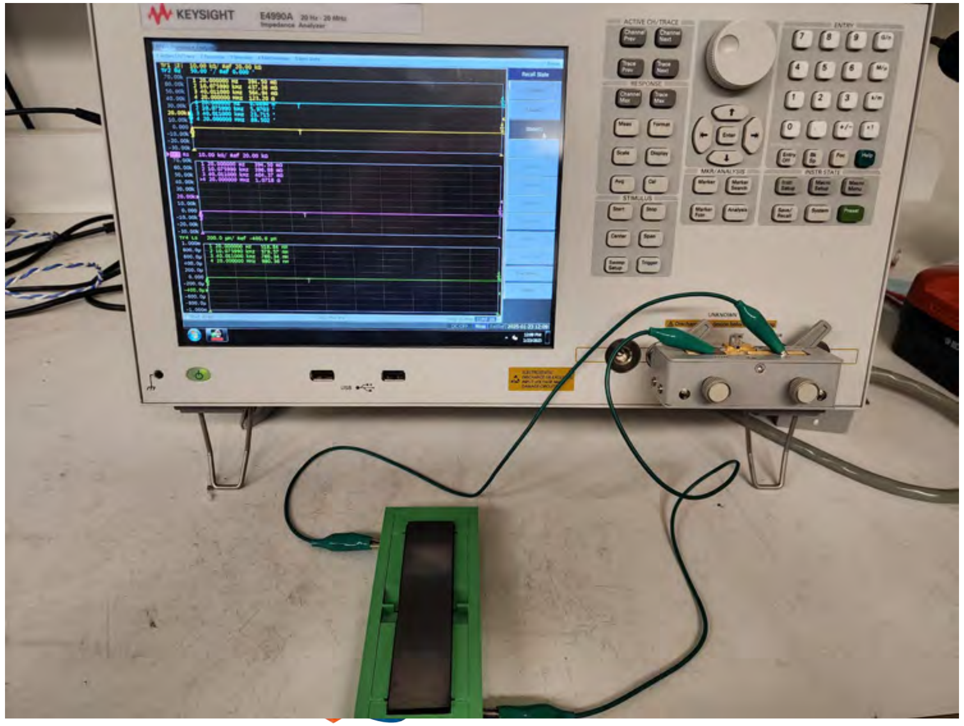
MRP Microreactor Program

Experimental challenge: Reliably measure small changes in impedance across many electrodes

- Multiplexer required to measure impedance between multiple electrode pairs
- DAQM904A
  - Sparse documentation, may not allow switchable common output
- ADG1406
  - Lengthy development time for custom printed circuit board
- Initial testing conducted with block sample and spring-loaded pogo pin contacts
  - May need more reliable connection method to resolve small impedances
- Low expected impedance (tens of mΩ)
  - Needs sensitive, repeatable measurements

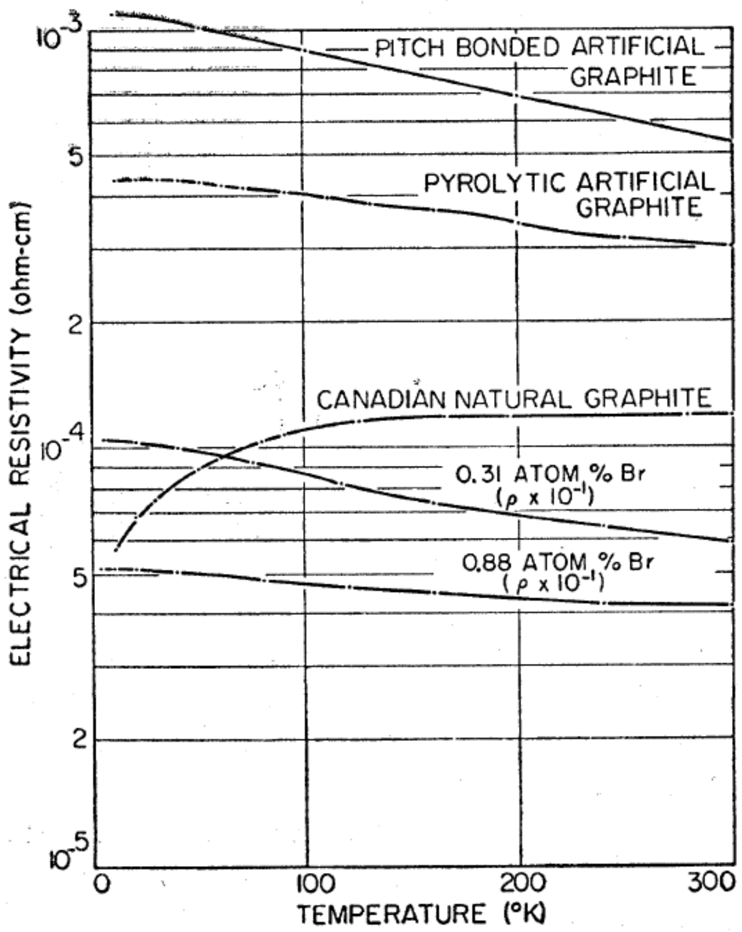




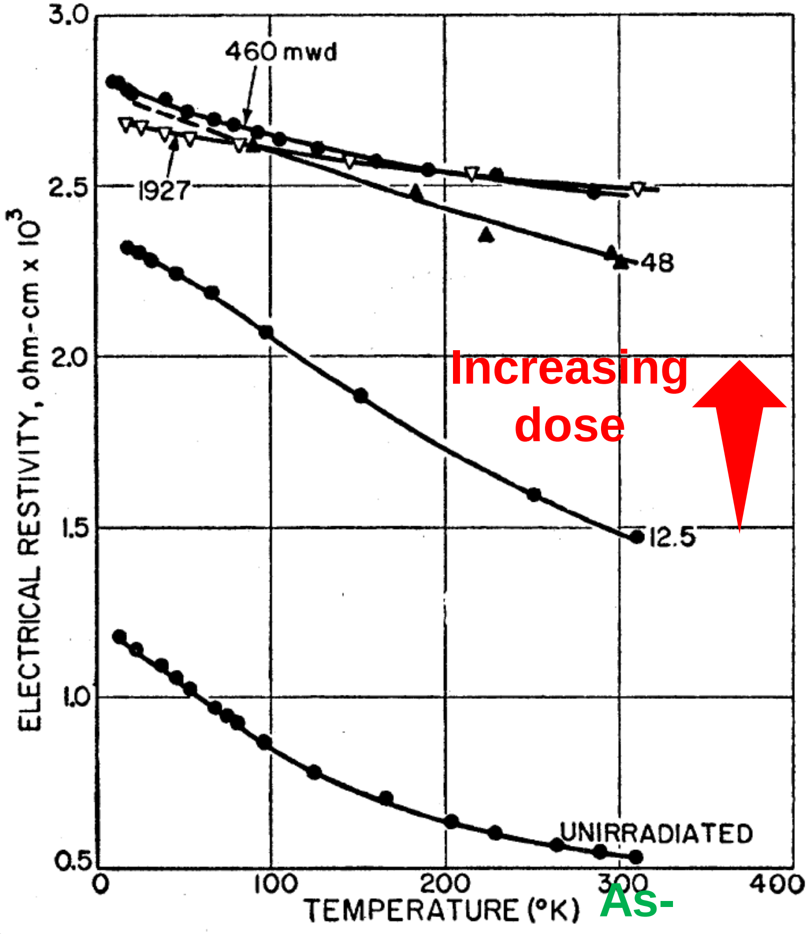


Additional challenge: Electrical impedance of graphite varies considerably

- As-fabricated resistivity of graphite can vary by **more than an order of magnitude**
- Can change by **2–3X under irradiation**
- Currently using POCO AXF-5Q fine-grain (~5 µm) graphite



As-fabricated variations in electrical resistivity



Evolution in electrical resistivity under neutron irradiation

A.W. Smith and N.S. Rasor, "Observed dependence of the low-temperature thermal and electrical conductivity of graphite on temperature, type, neutron irradiation, and bromination." *Physical Review* **104.4** (1956) 885.

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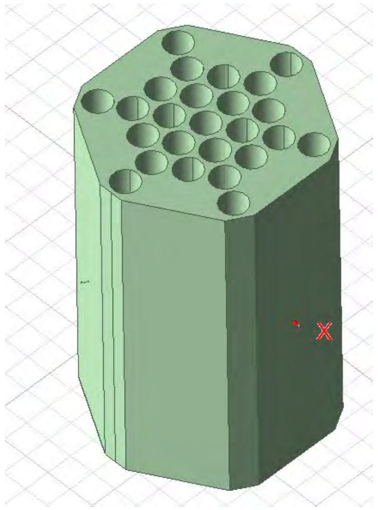
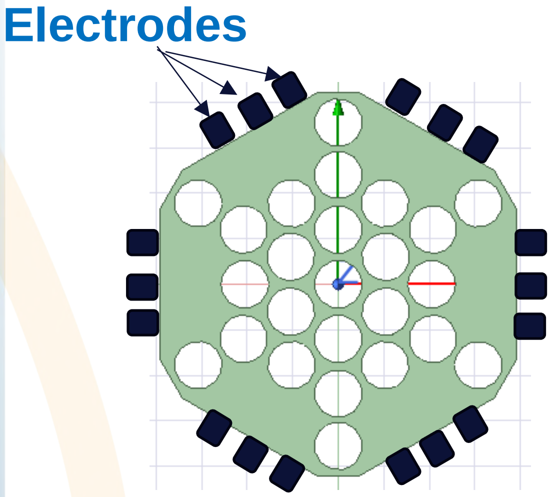
Finite element model + measurements to solve for impedance distribution

Conductivity or impedance distribution

$$\nabla \cdot \left(\sigma \nabla \varphi(\sigma)\right) = 0$$

Potential distribution





ANSYS finite element model

Forward Problem (known impedance)

Input: Known geometry and impedance distribution (σ)
Input: Current applied across specific pairs of electrodes

Output: Voltages across all pairs of electrodes (ϕ)

Inverse Problem (unknown impedance)

Input: Measured voltages with known current applied across each pair of electrodes (ϕ)
Input: Known geometry

Output: Impedance distribution (σ)

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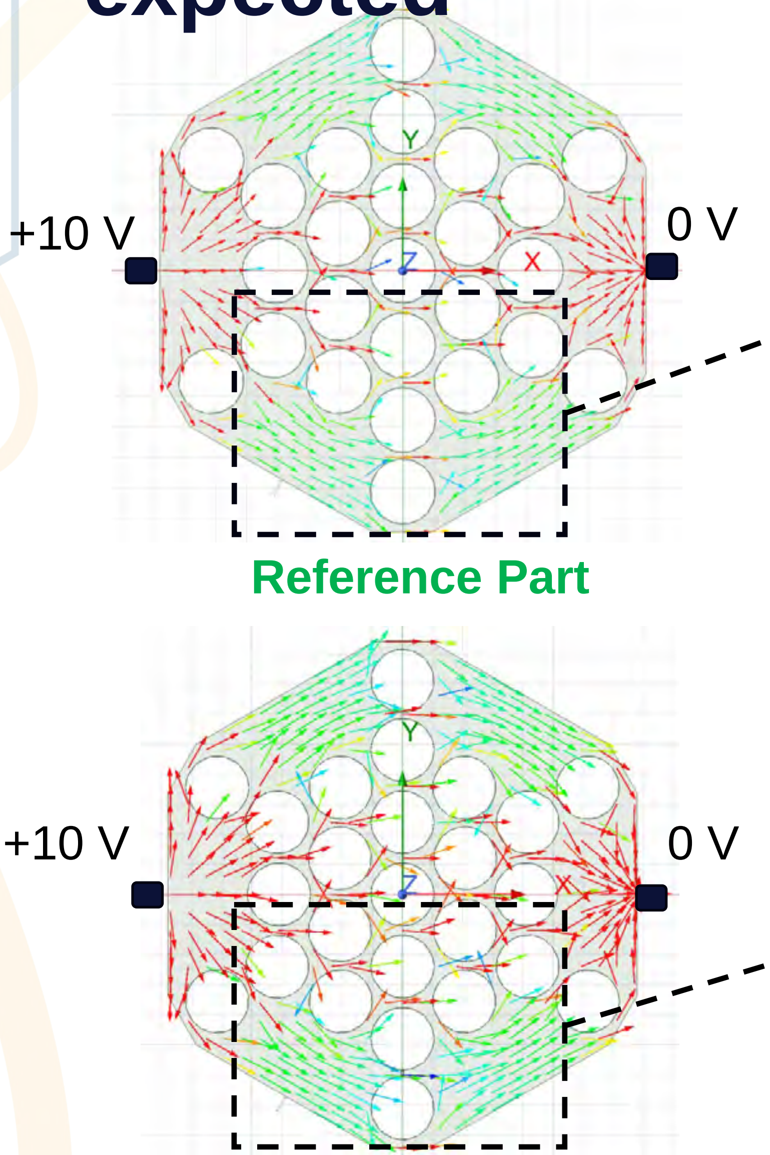
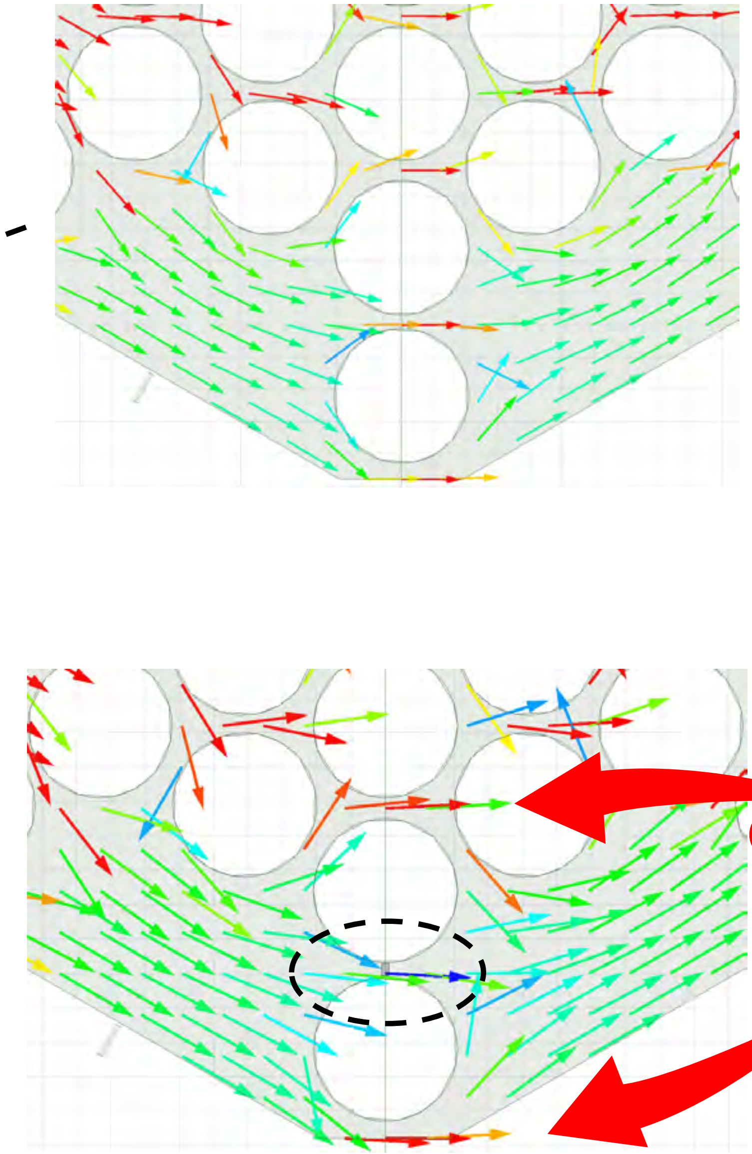
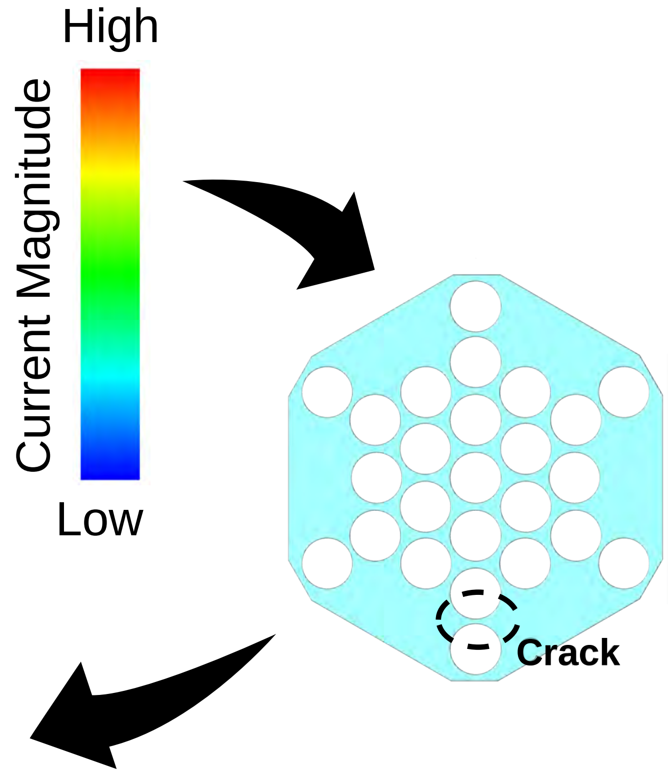
Introducing a crack qualitatively behaves as expected



Reference Part

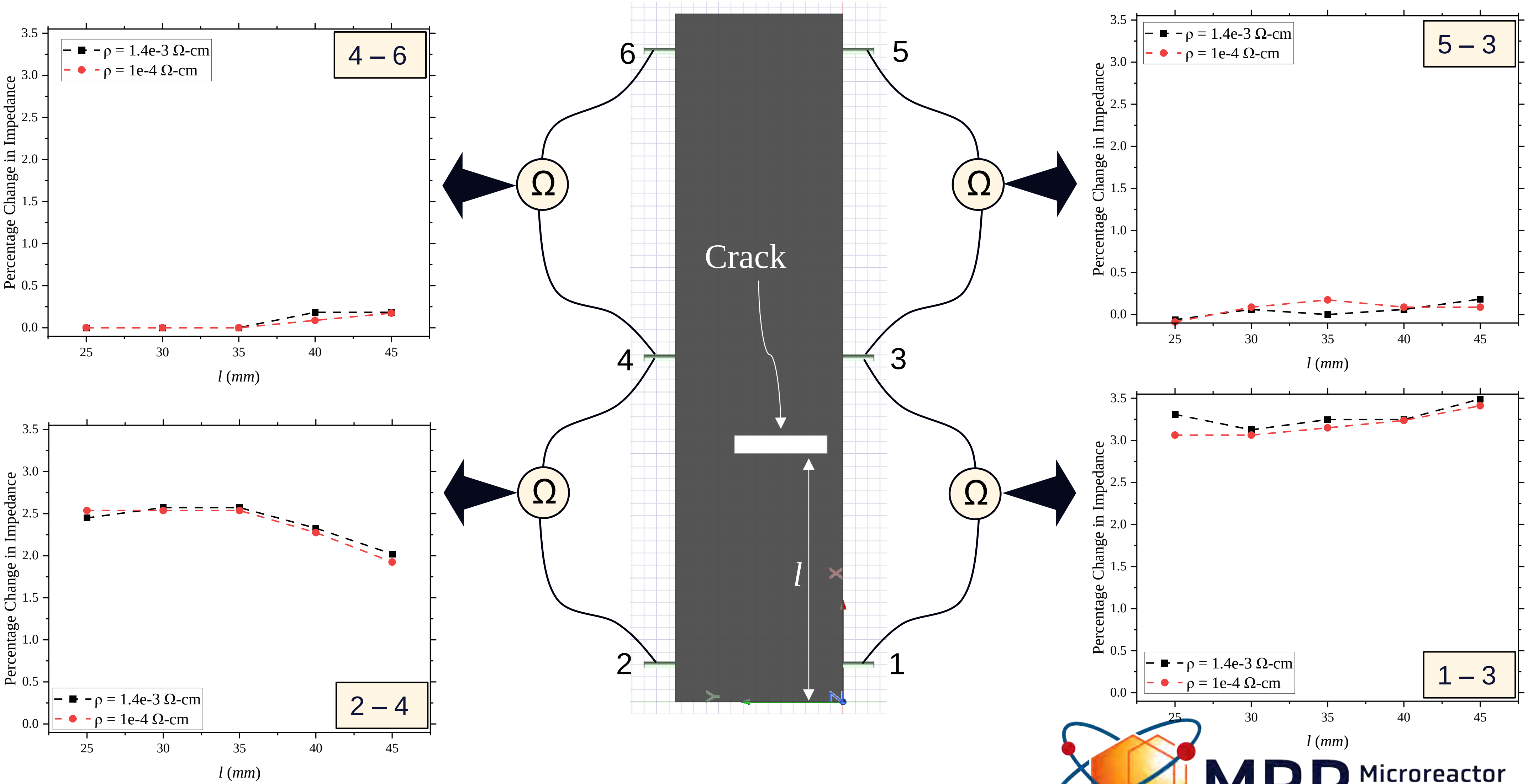
Damaged Part





Crack redirects the current through adjacent paths

Analyzing and isolating a localized crack



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Milestones and future work

- M4: Update status of EIT feasibility evaluation
  - Slides: Due 3/28/2025
  - Satisfied by an updated version of this presentation
- M3: Complete feasibility assessment of using electrical impedance tomography (EIT) for damage localization in graphite microreactor components
  - Report: Due 8/29/2025