INL/MIS-24-76695-Revision-0

Sensitivity Analysis of Irradiated Fueled Experiments using the MOOSE Framework

February 2024

Jackson R Harter, Joseph W Nielsen

Changing the World's Energy Future

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

INL/MIS-24-76695-Revision-0

Sensitivity Analysis of Irradiated Fueled Experiments using the MOOSE Framework

Jackson R Harter, Joseph W Nielsen

February 2024

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

February 28, 2024
Jackson R. Harter
Staff Scientist

24P1087-010FP

Sensitivity Analysis of Irradiated Fueled Experiments using the MOOSE Framework

Principal Investigator: Jackson R. Harter

Co-investigator: Joe Nielsen
Program Advisor: Kevan Weaver

INL/MIS-24-76695

Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy

Idaho National Laboratory

Uncertainty quantification applied to irradiated experiments

Compute Stochastic Input
(Re)Compute a matrix of stochastic data, each row in the matrix represents the data for a sub-application (e.g., sample known distributions for uncertain simulation parameters)

1

Transfer stochastic input to sub-applications
Apply each row of stochastic data to the sub-applications, as dictated by the main application

2

Execute sub-applications and compute QoI(s)
Perform simulations (complete or single timestep) and compute the desired quantities of interests (QoIs)

3

Transfer QoIs from sub-applications
Extract QoIs from sub-applications and transfer to the main application and store in distributed vector(s)

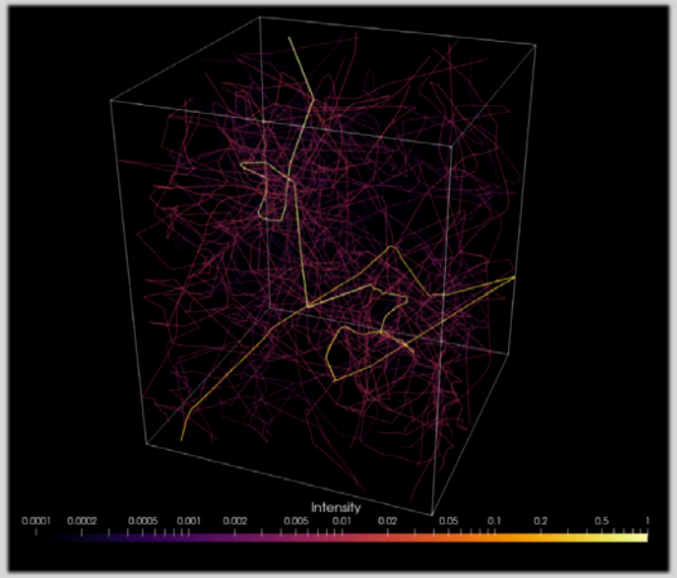
4

Perform analysis of QoIs
Analyze and output the QOIs (e.g., compute statistics or train reduced order model), results obtained here can inform the main application if additional stochastic runs should be computed

5

General pattern of execution for stochastic simulations using the MOOSE-STM

Sub-applications are complete MOOSE simulations (e.g., compute the intensity of a single ray of light as it reflects and refracts within a porous structure), as such the possibilities are limitless and can even include additional sub-application performing multiscale or even other stochastic simulations.



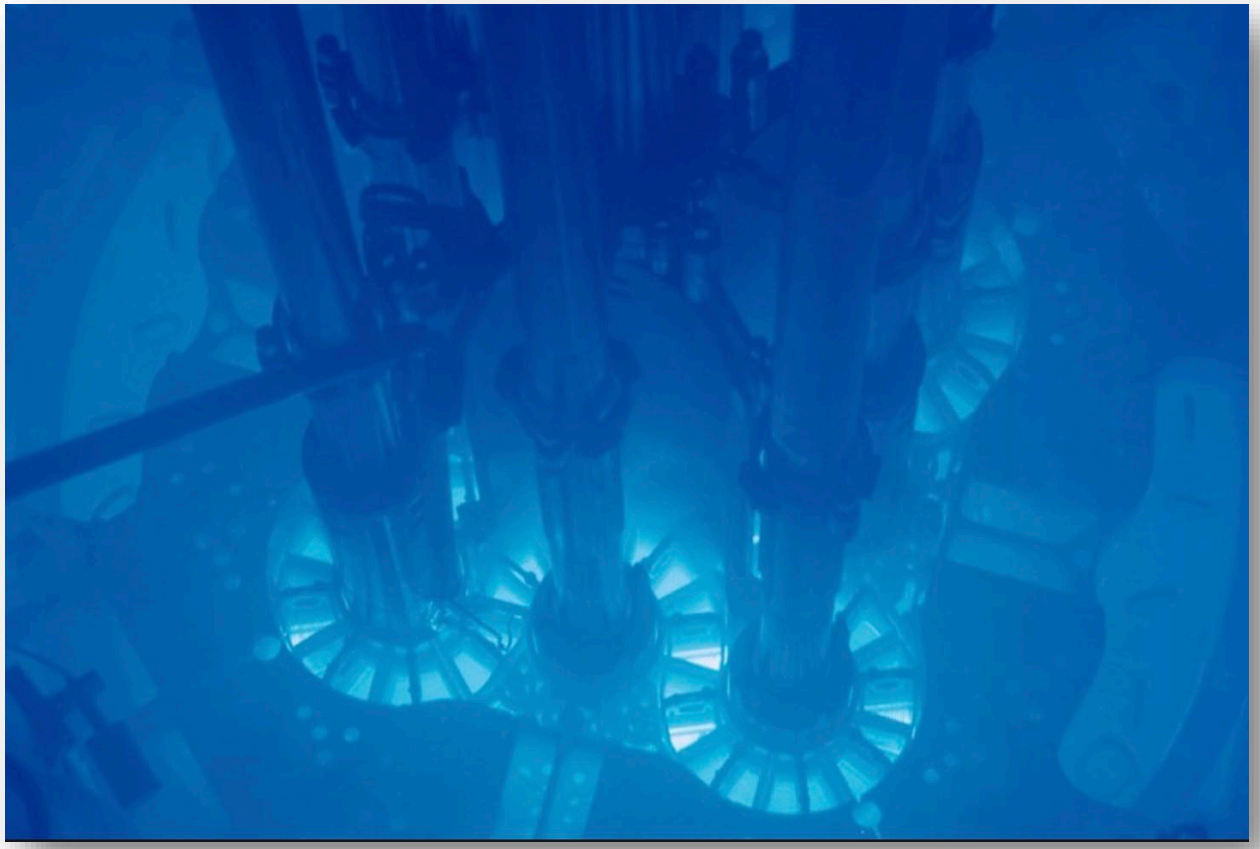
Agenda

- *Customer*
- *Opportunity*
- *Solution*
- *Team*
- *Advantage*
- *Result*
- *Requests/Budget*

Customer driven development

Uncertainty quantification applied to irradiated fuel experiments

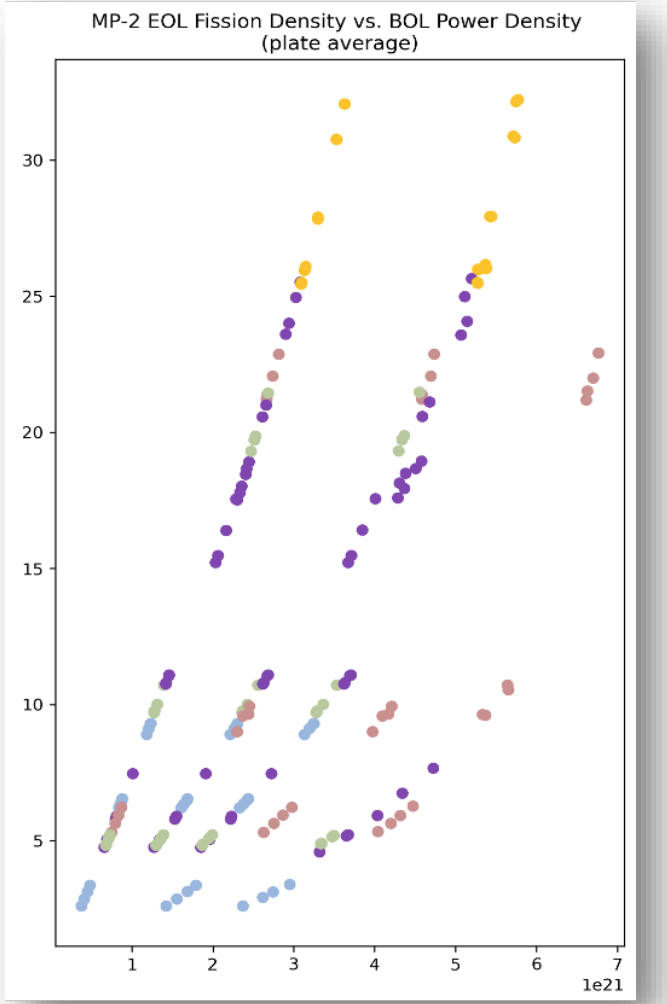
- Sensitivity and uncertainty quantification (SUQ) must be applied to experimental investigations
  - Nuclear Regulatory Commission (NRC) requires this
  - Idaho National Laboratory (INL) is poised to become the lab where in-house software tools are validated against experiment
    - Other national laboratories unable to meet specifications from regulatory bodies
- Intense efforts are employed to understand sensitive parameters in neutronics experiments



Realizing the potential of in-house software tools

Leveraging INL tools to perform cutting-edge research

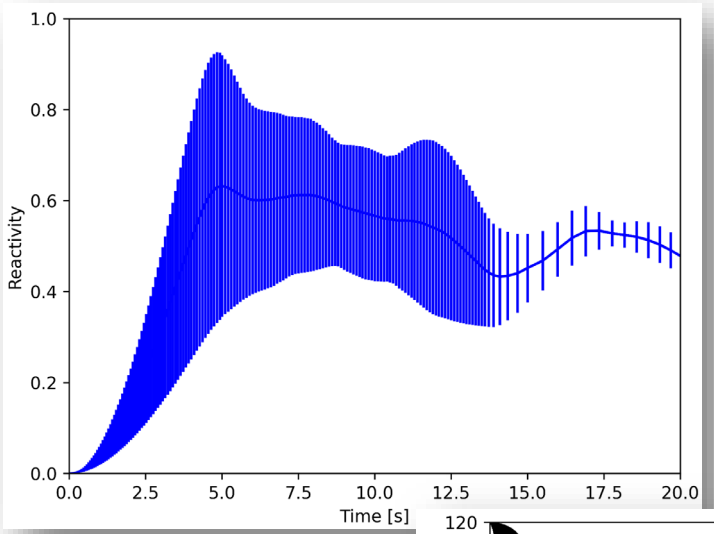
- *We hypothesize that the addition of sensitivity analysis using INL designed software tools will provide opportunity and value to experimental programs*
  - Use in-house SUQ methods to understand critical parameters in experiments destined for irradiation
- *No other research entity connected to NRC can provide this analysis*
- Understand quantities of interest (QoI) in fueled, irradiated experiments such as fission power, burnup, and geometric dimensions

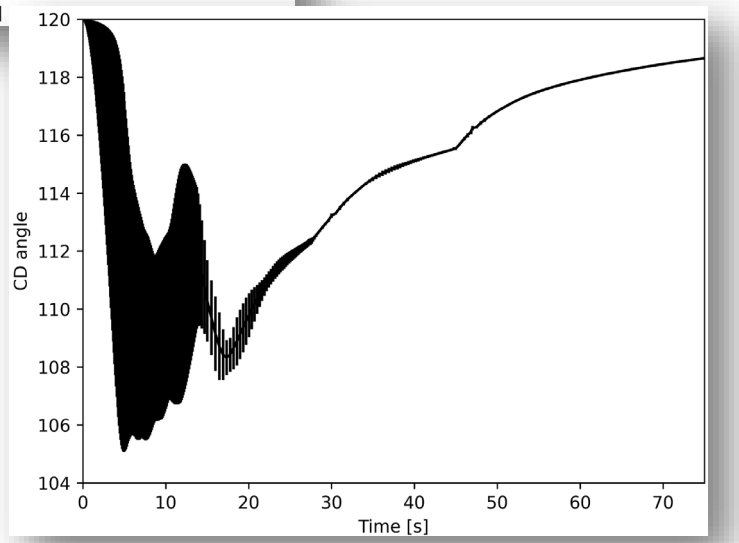


To seize the opportunity, develop unconventional methods

New insight on traditional approaches changes the playing field

- A large gap exists in INL methods and tools to quantify uncertainty in 1) modeling and simulation, and 2) validation of experiments
  - The need for 1) and 2) can be fulfilled by applying the stochastic tools module in MOOSE to neutronic (and heat conduction) simulations of irradiated experiments
- Develop finite element models, implement reduced order, polynomial chaos expansion (PCE) methods using Latin hypercube sampling to quantify uncertainty





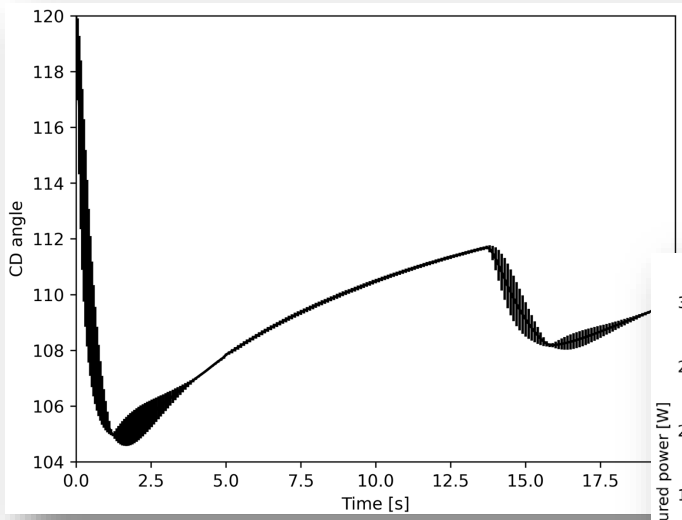
The proper team ensures success

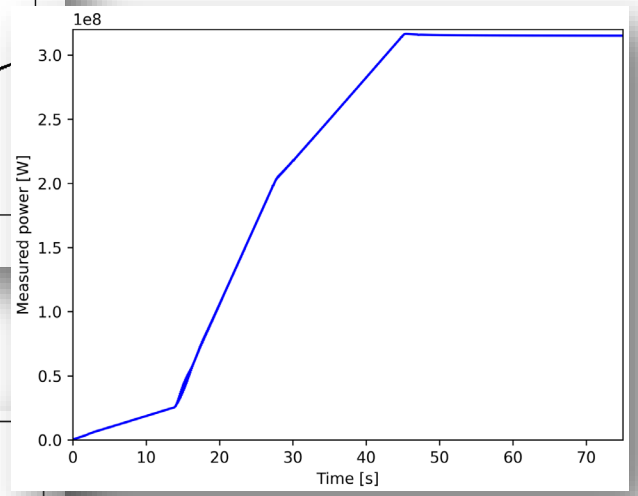
- **Jackson Harter:** Computational scientist, neutronics methods and analysis, UQ methods
- **Joe Nielsen:** Neutronics analysis, irradiation experiment analysis, UQ methods

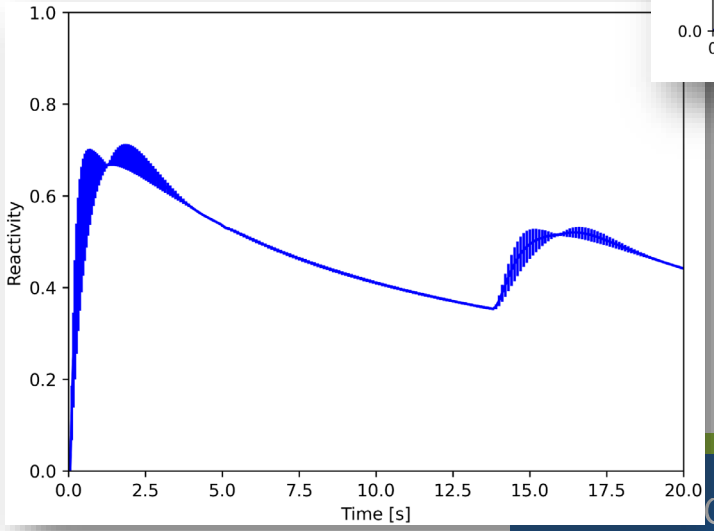
Advanced methods for sensitivity prediction

What sets your solution apart from other alternatives?

- Currently, SUQ augmentation to modeling experiments in INL programs does not exist
  - Classical software approaches (MCNP, ABAQUS, etc) are employed to model experiments with no supporting sensitivity analysis
- MOOSE SUQ methods are mature, robust, and have been used to model neutronic analysis simulations in 3D, full scale simulations
  - NASA --- power, reactivity, control drum angle
- Some improvements are necessary





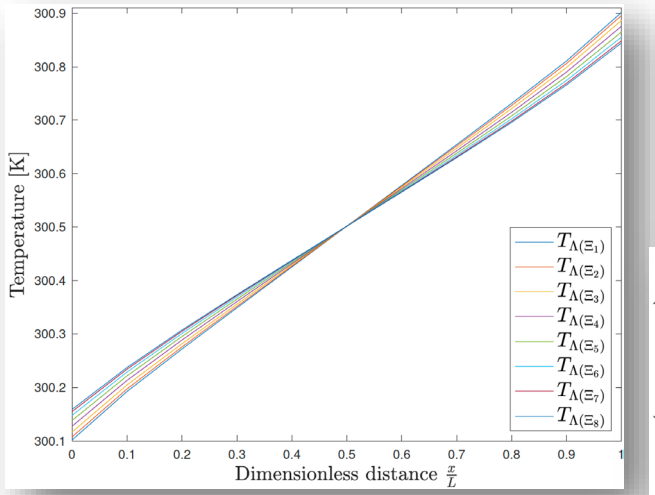


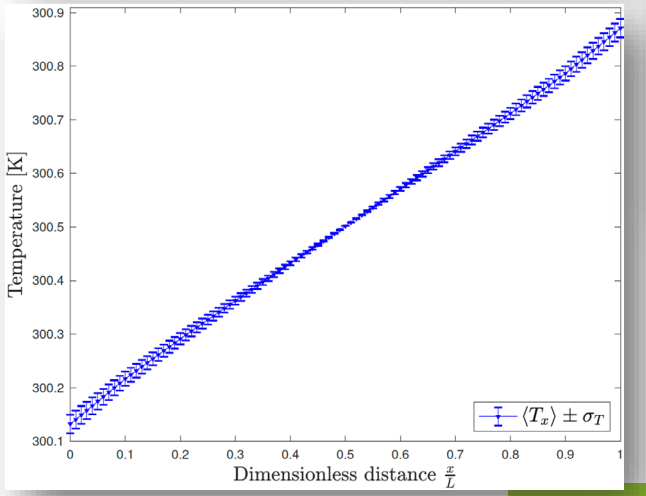
CO★STAR

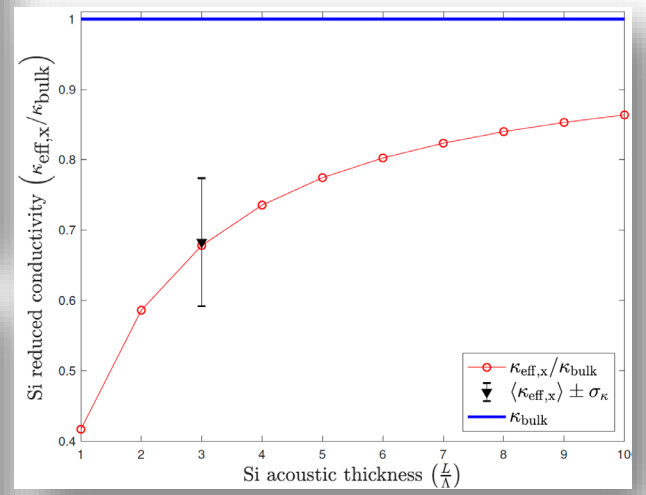
Developing sensitivity and uncertainty analysis protocols

What outcome will be attained through your solution?

- If successful, this effort will augment INL experimental programs to provide an element of sensitivity analysis and uncertainty quantification to modeling and simulation of irradiated experiments
  - Increase margins of safety
  - Reduce simulation time for providing safety analysis
- INL poised to become the only lab to provide sensitivity analysis of irradiated experiments to regulatory bodies







Requests/Budget

A: Research Tasks	FY-24 ($90k)	FY-25 ($60k)	Total ($150k)
Task 1: Develop FE and Serpent2 models of fueled experiment	30	0	30
Task 2: Generate macroscopic cross sections	30	0	30
Task 3: Construct and run Griffin model	30	0	30
Task 4: Apply PCE-SUQ to Griffin model	0	20	20
Task 5: Write publication	0	40	40
Total Task budget	$90k	$60k	$150k
B: Budget by researcher	FY-24 ($90k)	FY-25 ($60k)	Total ($150k)
Harter, Jackson	85	55	140
Nielsen, Joe	5	5	10
Total INL labor	$90k	$60k	$150k
C: Non-labor	FY-24 ($0k)	FY-25 ($0k)	Total ($0k)
Total non-labor	$0	$0	$0
Total Budget Request (B +C)	$90k	$60k	$150k

Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.