Flexible Siting Criteria and Staff Minimization for Micro-Reactors

NEUP Project #: 20-19042
Schedule: Oct 2020 → Sep 2022 (completed)
Budget: $434k

MIT Energy Initiative

NSE
Nuclear Science and Engineering
science : systems : society

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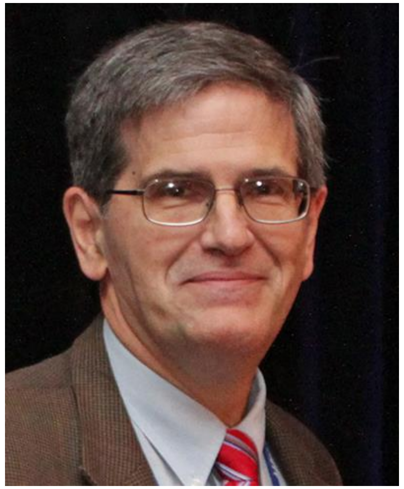

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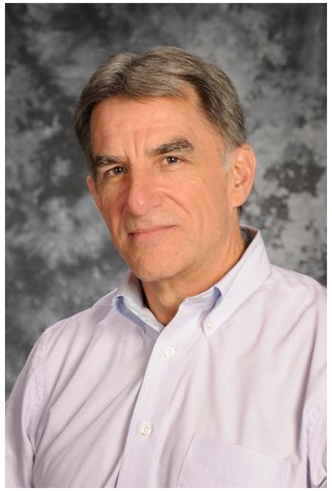

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ECONOMIC IMPERATIVES FOR MICROREACTORS

- To access large markets, microreactors must be licensable for deployment near and within population centers ⇐

- LCOE and LCOH analysis suggests that microreactors can meet the heat and electricity cost targets for large markets, if:

  - Power output is maximized, within microreactor constraints (e.g., truck transportability, passive decay heat removal)
  - Staff is in the 0.5-1.5 FTE/MW range ⇐
  - Enrichment <10% and burnup >20 MWd/kg_U
  - Microreactor fabrication cost (excluding fuel) <5000 $/kW
  - Discount rate <10 %/yr

⇐ focus of this project

PROJECT OBJECTIVES

- Develop siting criteria that are tailored to micro-reactors deployable in densely-populated areas, e.g., urban environments.
- Identify optimal licensing path for micro-reactors in Part 50 and Part 52 framework
- Conceptualize a model of operations and security for micro-reactors that would minimize the staffing requirements, and thus reduce the cost of electricity and heat generated by these systems.
- Develop a new Type B transport cask design for fueled micro-reactors *(ADDED IN YEAR 2)*
- Develop a risk-informed framework for threats and vulnerabilities assessment of micro-reactors *(ADDED IN YEAR 2)*

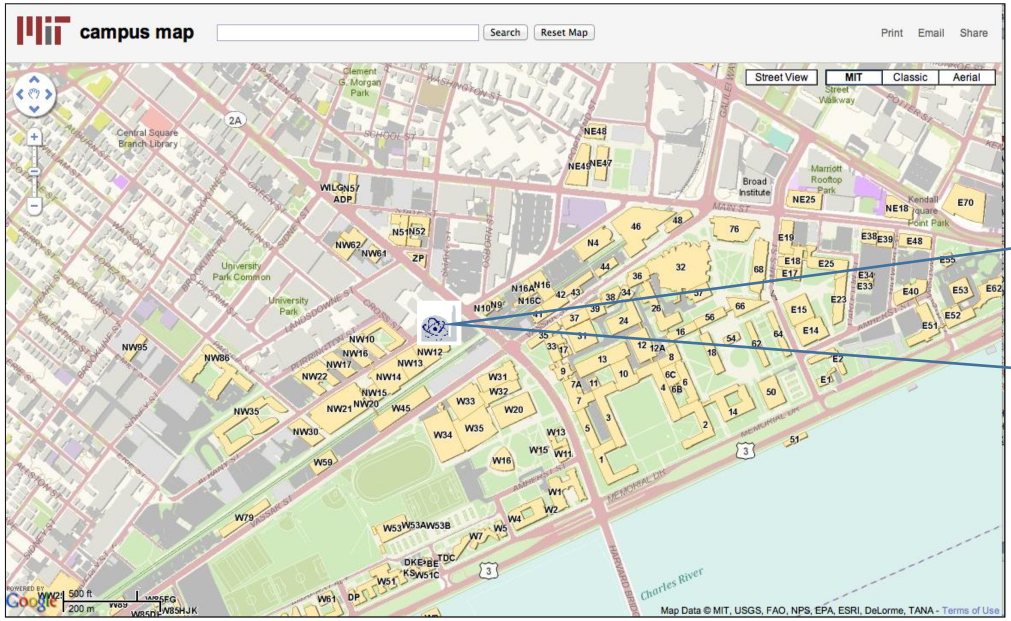
APPROACH

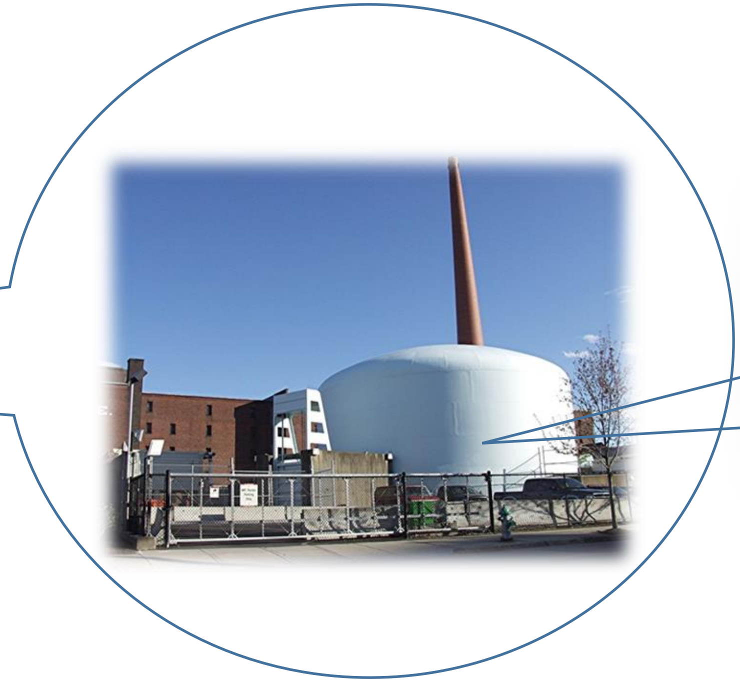
- Compare MIT nuclear reactor (MITR) with leading micro-reactor concepts, and evaluate whether and how the MITR design basis (e.g., inherent safety features, engineered safety systems, source term, emergency planning and emergency operating procedures) and associated regulations may be applicable to micro-reactors.

- Review the MITR experience and requirements, as well as survey the innovations in autonomous control technologies (e.g., machine learning) and monitoring (e.g., advanced sensors, drones, robotics) that may permit a dramatic reduction in staffing at micro-reactor installations.

THE MITR

MITR is an urban micro-reactor:
- low power (6 MWt)
- 24/7 ops
- ultra-safe

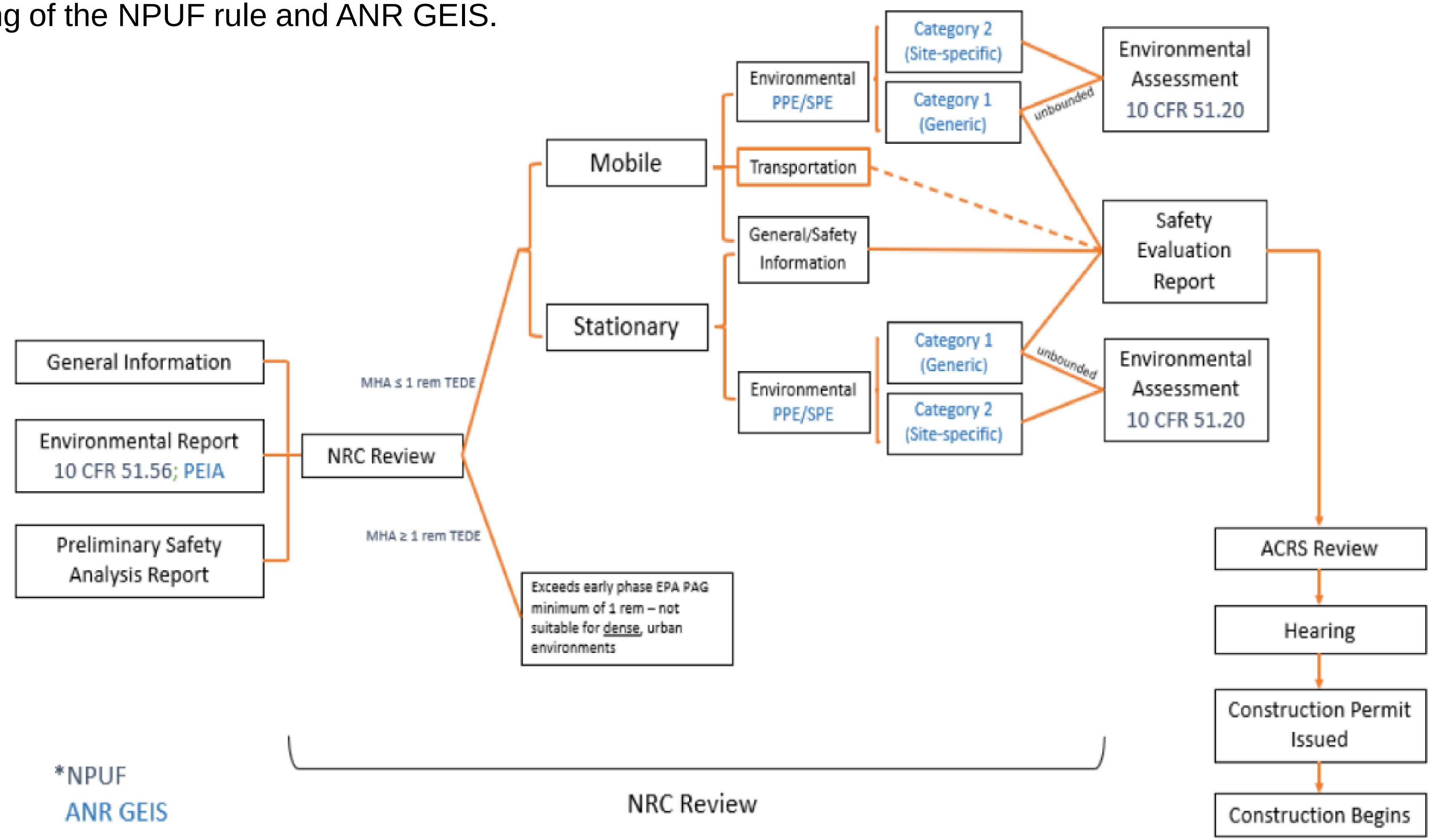




But there are major differences:
- the mission is research (vs. commercial)
- unsuitable for heat utilization and electricity generation (<60°C core outlet temperature)
- frequent refueling (every 10 weeks)
- non-transportable
- large staff (operations + research + admin = 60 FTEs)

MAIN FINDINGS

- Developed scaled micro-reactor siting criteria and requirements to reflect those of research reactors specifically for deployment in densely populated urban environments. In doing so, we found that the main difference between a commercial micro-reactor and a research reactor is simply the end destination of their products, which should not warrant a substantially different regulatory treatment of the two classes of reactors. Thus, adoption of the so-called Non-Power User Facility (NPUF) rule and Advanced Reactor Generic Environmental Impact Statement (ANR GEIS) is recommended.
- Developed an optimal licensing path for micro-reactors under the existing 10 CFR Part 50 and 10 CFR Part 52 frameworks with integration and leveraging of the NPUF rule and ANR GEIS.



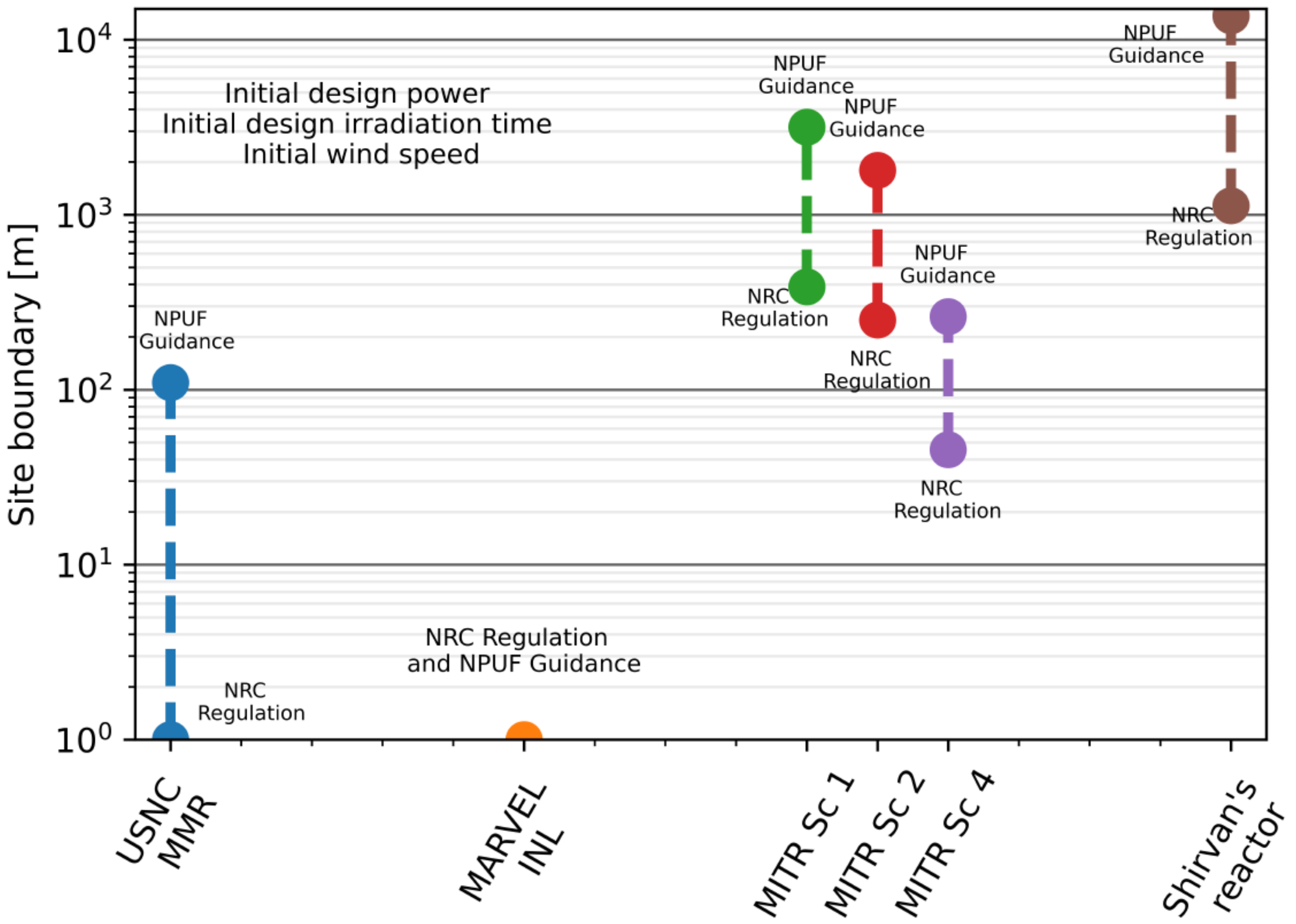
MAIN FINDINGS (cont.)

- Quantified the staffing needs for operations and maintenance for four classes of micro-reactors and compared them with various non-nuclear power facilities (i.e., small aero-derivative gas turbines, and transportable supercritical CO2 power units). The analysis shows that with proper use of automation and remote monitoring, the staffing required onsite can be kept at a fairly low level, e.g., order of 1 FTE, but significant offsite staffing is still required for monitoring and servicing the micro-reactors.

Category	Description	MIT research reactor	Gas V16 2.4 MWe	Gas aero-derivative 1.5 MWe	sCO2 power unit	eVinci	Holos	Aurora	MMR
Maintenance – total	Total h of maintenance per year [h]	738	195	92	277	367	388	552	613
Maintenance – onsite, nuclear specific	Total h of onsite nuclear maintenance per year * FTEs [h]	557	0	0	0	118	143	118	143
Maintenance – onsite, non-specific	Total h of onsite non-specific maintenance per year * FTEs [h]	559	354	100	277	506	501	689	729
Maintenance – offsite, nuclear specific	Total h of offsite nuclear maintenance per year * FTEs [h]	0	0	0	0	44	46	44	46
Maintenance – offsite, non-specific	Total h of onsite non-specific maintenance per year * FTEs [h]	0	18	44	0	44	44	0	0
Maintenance – total	Average FTEs for maintenance during 1 year	0.35	0.23	0.09	0.17	0.44	0.46	0.53	0.57
Operation	Average FTEs for operations during 1 year	16	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Total	TOTAL	16.35	0.86	0.71	0.80	1.07	1.08	1.16	1.20
Total	Per MWe	-	0.36	0.48		0.21	0.08	0.77	0.24

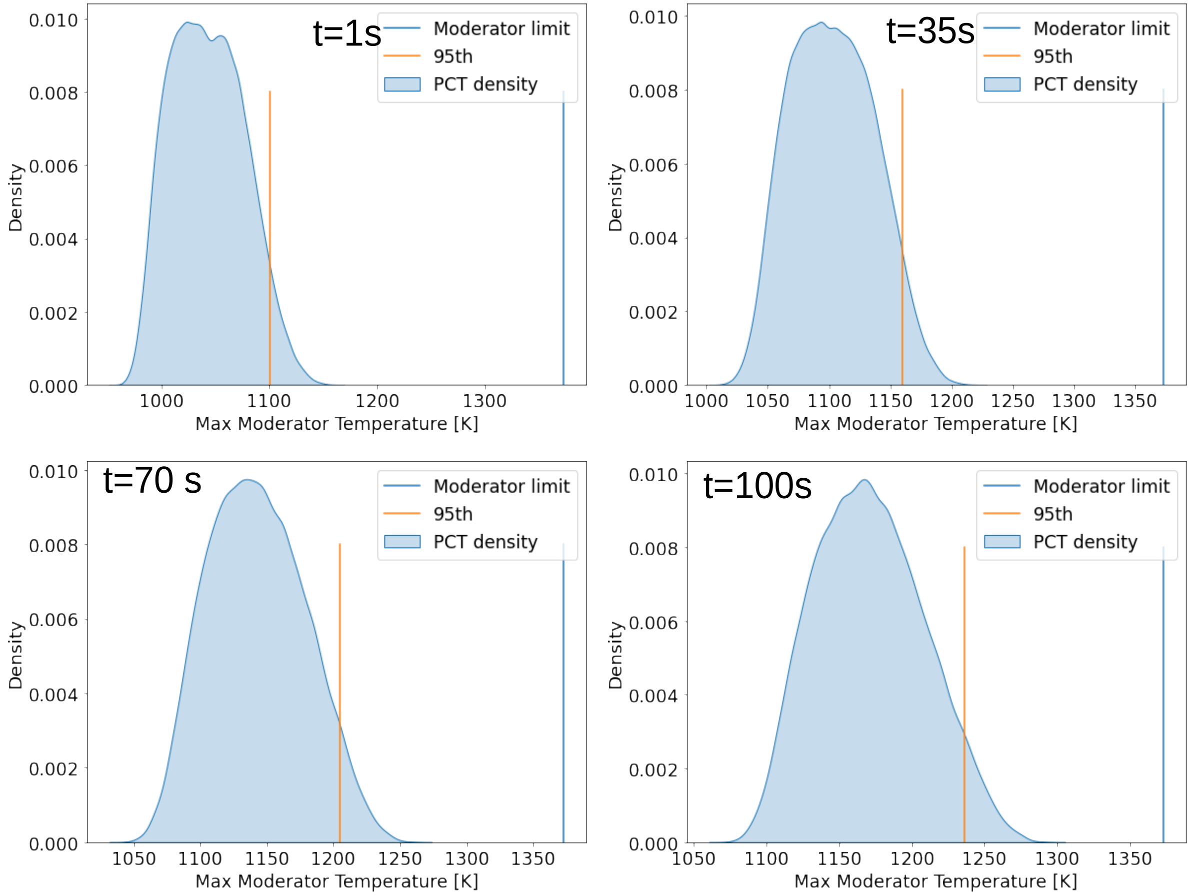
MAIN FINDINGS (cont.)

- Identified the worst-case radiological consequences of a situation in which a hostile force gains control of a micro-reactor facility and deliberately damages it. This consequence-based security analysis allowed to quantify the size of the site boundary that is required to meet the radiation dose limits for various micro-reactors.



MAIN FINDINGS (cont.)

- Developed a risk-informed methodology that embeds (i) System-Theoretic Accident Model and Processes (STAMP) principles to guide a qualitative exploration of the system threats and hazards, (ii) Modeling and Simulation (M&S) to investigate the system dynamic behavior during accidental scenarios, and (iii) the Goal-Tree Success-Tree Master Logic Diagram framework to assess risk quantitatively. The integration of these three elements allows for a systematic identification of the risks and a dynamic (time-dependent) assessment of the risk profile.
- Demonstrated this methodology for a micro-reactor design with heat pipes, showing the ability to quantify the time-dependent probability density function for key safety variables (e.g., peak cladding temperature, moderator temperature) and their margin to postulated limits.



FINDING DISSEMINATION

Papers:

- F. Antonello, J. Buongiorno, E. Zio, “Insights in the Safety Analysis of an Early Microreactor Design”, *Nuc Eng Des*, Vol. 4, 112203, Apr 2023.
- F. Antonello, J. Buongiorno, E. Zio, “A Methodology to Perform Dynamic Risk Assessment Using System Theory and Modeling and Simulation”, *Reliability Engineering & System Safety*, 228, 108769, 2022.
- E. Garcia, L. Nester, J. Buongiorno, “Scaling Siting Criteria and Alternative Licensing Pathways for Micro-Reactors”, *Proc. of ANS Meeting*, June 12-16, Anaheim CA, 2022.
- I. Naranjo de Candido, J. Buongiorno, “Staffing minimization for micro-reactors”, *Proc. of ANS Meeting*, June 12-16, Anaheim CA, 2022.
- E. Gateau, N. Todreas, J. Buongiorno, “Consequence-based security for microreactors”, *Proc. ICAPP 2023*, Gyeongju, South Korea, April 23-27, 2023.
- I. Naranjo De Candido, J. Buongiorno, S. Cetiner, “Onsite staffing for micro-reactors: models, needs and business case”, in preparation, *journal TBD*, 2023.
- 1 journal paper in preparation based on E. Garcia’s work.

FINDING DISSEMINATION (cont.)

Thesis dissertations:

- E. Garcia, “Scaling siting criteria and identifying alternative licensing pathways for micro-reactors within the existing regulatory framework”, M.S. Thesis, October 2022
- I. Naranjo de Candido, “Staff minimization strategy for micro-reactors”, M.S. Thesis, November 2022
- E. Gateau, “Consequence-based Security for Micro-Reactors”, M.S. Thesis, August 2022
- L. Galanek, “Physical Security Requirements for Micro-Reactors”, B.S. Thesis, May 2021

Briefings to:

- Micro-reactor program leadership at INL, August 2022
- Micro-reactor principals at the NRC, August 2022
- Micro-reactor group at NEI, August 2022
- eVinci group at Westinghouse Electric Company, August 2022