Flexible Siting Criteria and Staff Minimization for Micro-Reactors

MIT Energy Initiative

NSE
Nuclear Science and Engineering
science : systems : society

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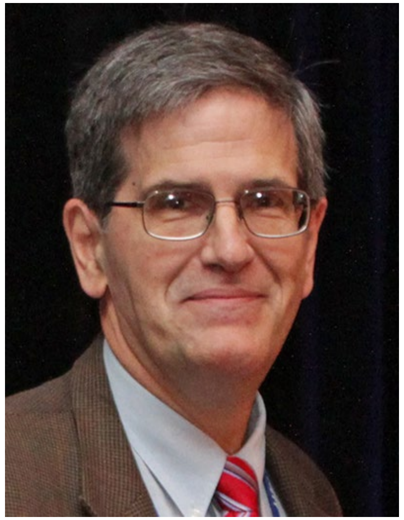

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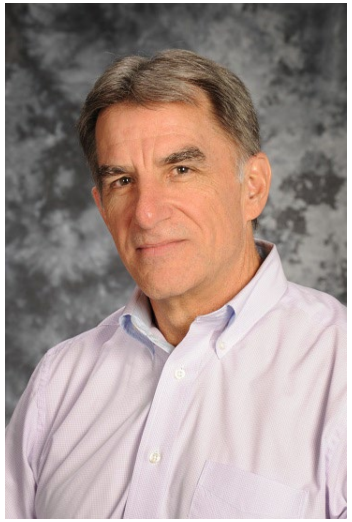

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ECONOMIC IMPERATIVES FOR MICROREACTORS

- 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 *(NEW)*

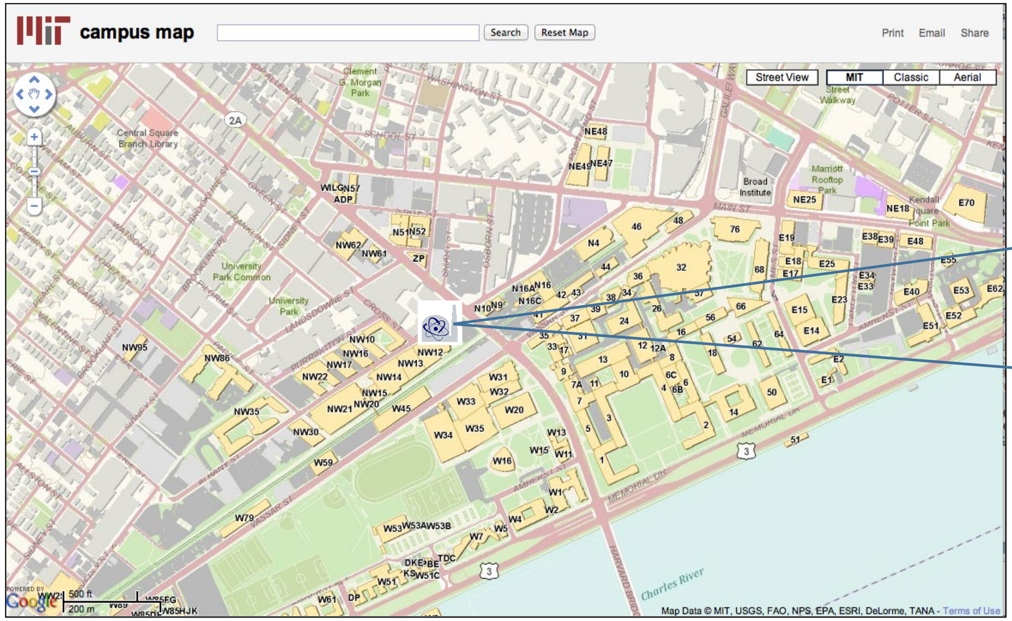
APPROACH

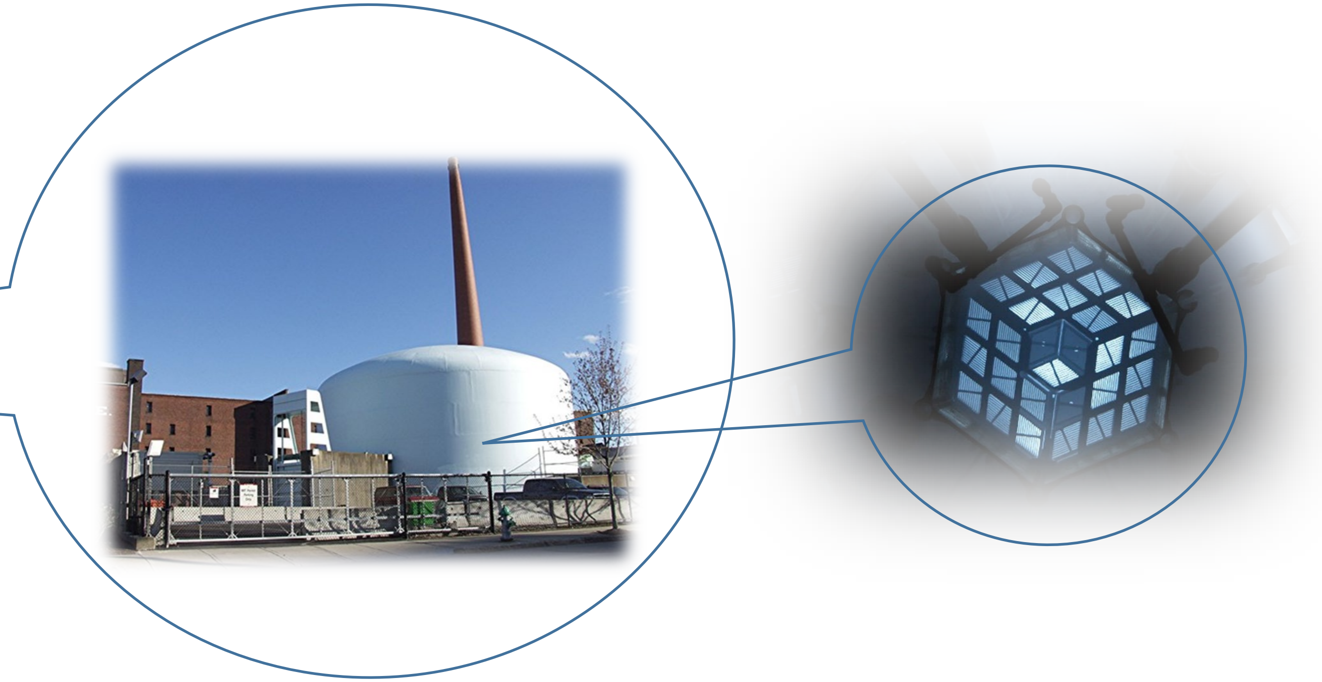
- Compare MIT nuclear reactor (MITR) with leading micro-reactor concepts, and evaluate whether and how the MITR design basis (e.g., inherent safety features, engineered safety systems, source term, emergency planning and emergency operating procedures) and associated regulations may be applicable to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

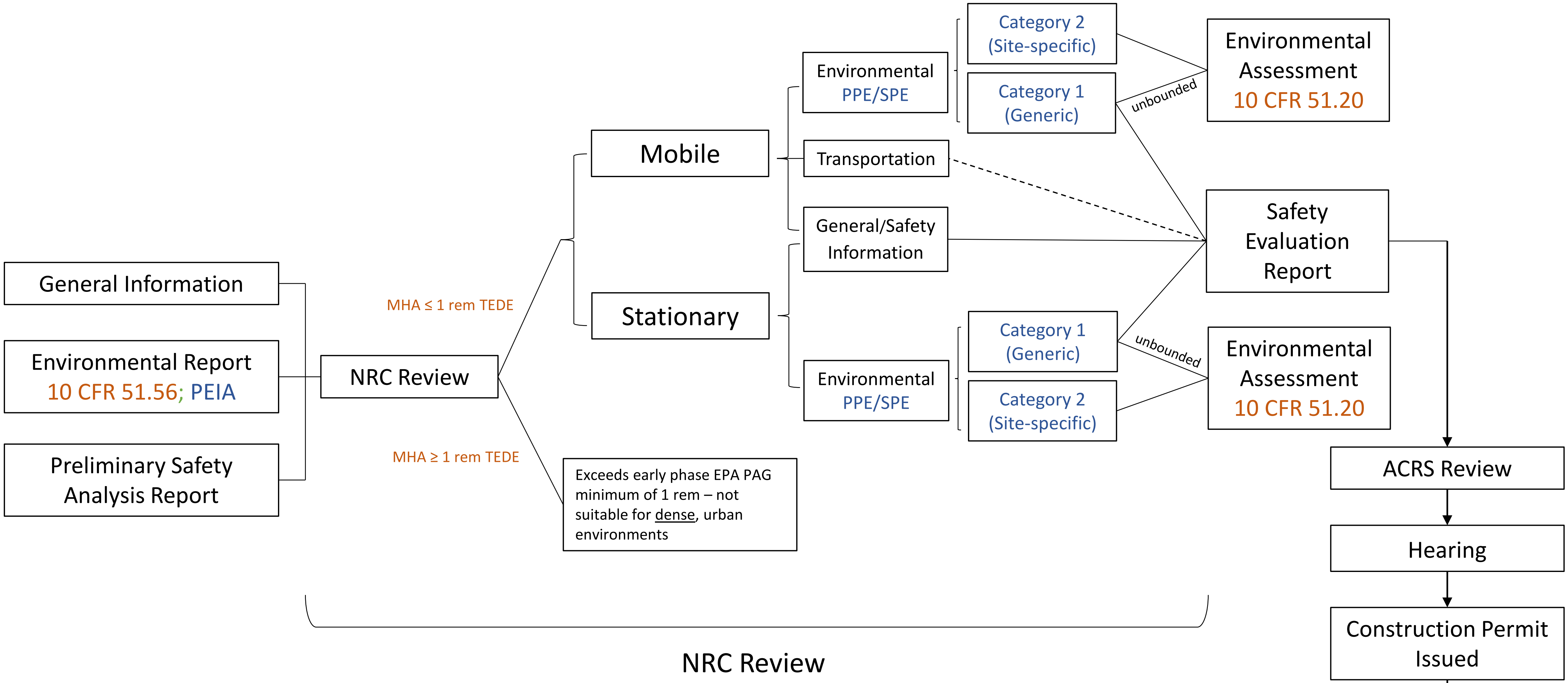
MITR is an urban micro-reactor:
- low power (6 MWt)
- 24/7 ops
- ultra-safe





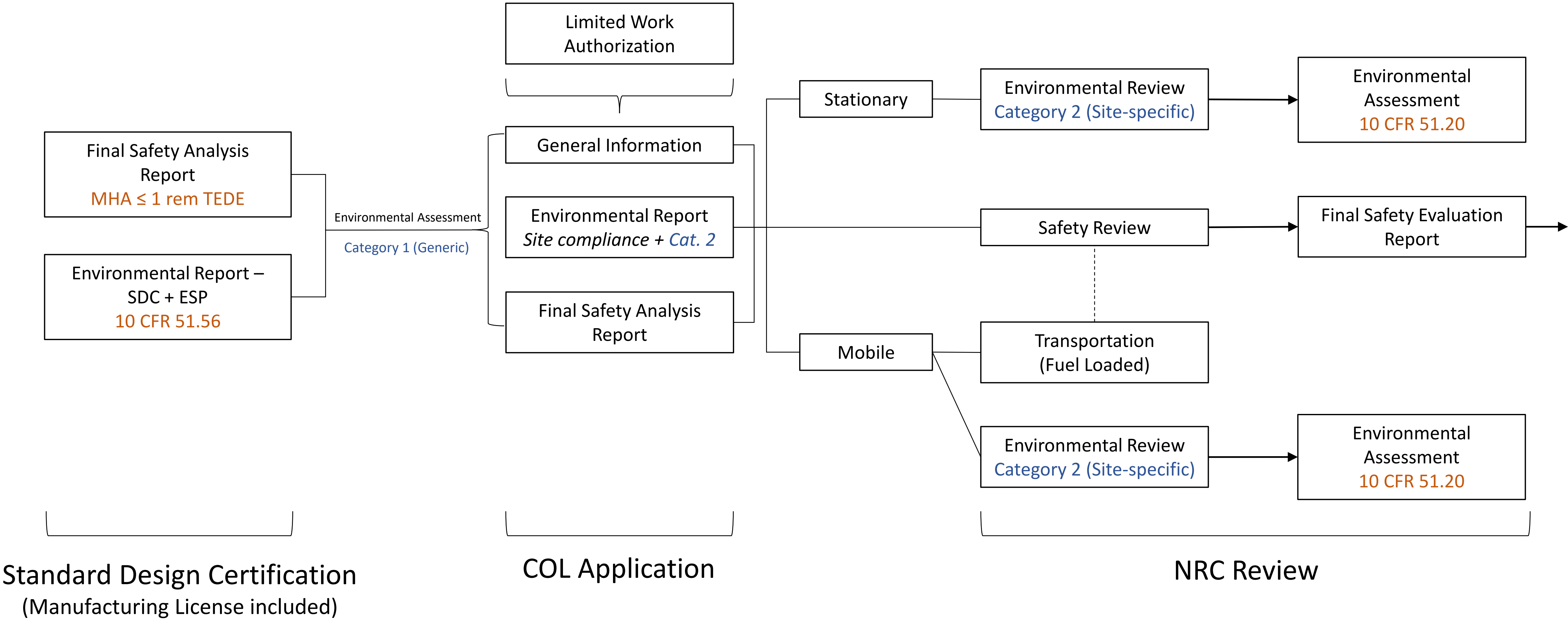
But there are major differences:
- the mission is research (vs. commercial)
- unsuitable for heat utilization and electricity generation (<60°C core outlet temperature)
- frequent refueling (every 10 weeks)
- non-transportable
- large staff (operations + research + admin = 60 FTEs)

Modified Part 50 for Microreactors as NPUFs



NPUF = Non-power Production or Utilization Facility
ANR GEIS = Advanced Nuclear Reactor Generic Environmental Impact Statement
PPE / SPE = Plant Parameter Envelope / Site Parameter Envelope
PEIA = Preliminary Environmental Impact Assessment

Modified Part 52 for Microreactors as NPUFs



*NPUF
ANR GEIS

DC: 12 months   NRC Review: <12 months

BOTTOM-UP EVALUATION OF O&M STAFFING NEEDS

Goal: to demonstrate the minimum staffing level achievable with no technological and regulative constraints

For each planned O&M task, we evaluated:

- frequency, # FTEs involved, task duration

- possible automation technology

MITR planned maintenance tasks - example

Task name	Brief description	Frequency [#/year]	# FTEs involved	Duration [h]	FTE time per year (C*D*E) [h/year]	Possible automation technology
Emergency Cooling System test	Test of the ECCS to make sure adequate flow rate	1	4	4	16	Out of scope: task not needed for MR
Reactor Building Leak Rate	Test to make sure containment is air-tight	0,5	20	24	240	Smart sensors

Worst case

~7 FTEs onsite

Assumptions

Staffing needs in FTEs/year are divided into five categories:

- Planned Maintenance – derived analytically from the study of their systems
- Unplanned Maintenance – hypothesis: 25% of planned maintenance
- Operation – hypothesis: 1 person, 24/7 (equivalent to 5 FTEs), simultaneously monitoring 8 MR
- Administrative – hypothesis: 1 FTE in charge of 8 MR (1 FTE works on 1 daily shift only, not 24/7)
- Engineering – hypothesis: 10% of maintenance

Staffing needs comparison - FTEs/year

	MITR	Gas V16 2.4 MWe	Aero-derived 1.5 MWe	Aurora
Maintenance - nuclear specific	0,3	N/A	N/A	0,1
Maintenance - total	0,7	0,2	0,1	0,4
Operation	10,0	0,6	0,6	0,6
Administrative*	10,0	0,1	0,1	0,1
Engineering*	4,0	0,0	0,0	0,0
Total - nuclear specific	14,3	N/A	N/A	0,8
Total FTEs/year	**24,7***	**1,0**	**0,9**	**1,2**

*Majority of MITR staff work is related to set up and management of experiments

Best case

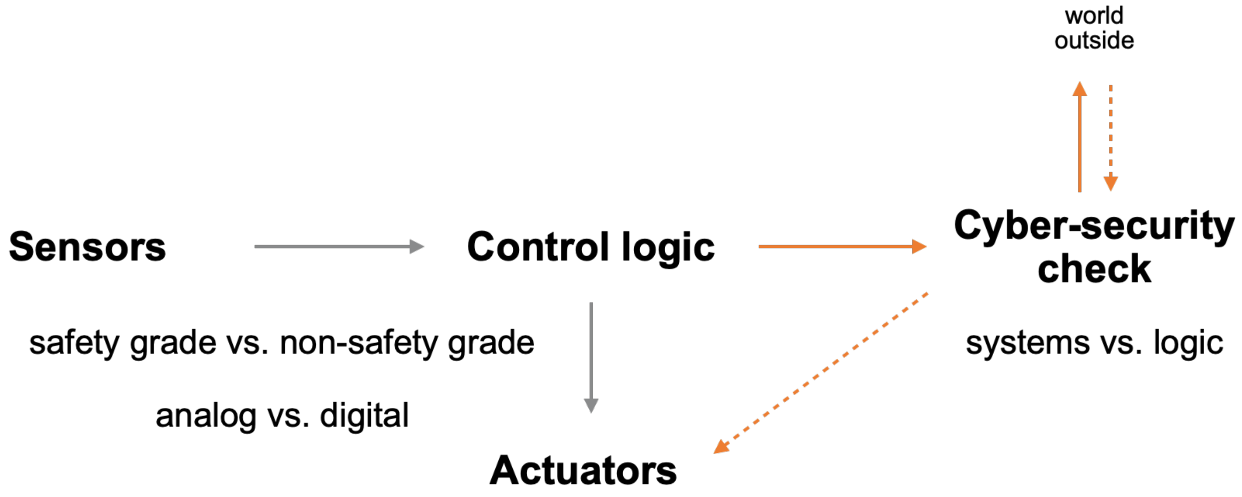
~ 1 FTE mostly offsite

INSTRUMENTATION AND CONTROL FOR MRs

Goal: to determine a fully comprehensive set of I&C that allows to operate at the minimum staffing level

Sensors listed by

- Position: e.g., reactor core, BOP, site boundary
- Scope: e.g., power measurement, structural health monitoring, intrusion detection
- Parameter measured: e.g., n flux, temperature, vibration spectrum
- Type: e.g., self-powered n detectors, thermocouples, fiber optics
- Goal: safety, autonomous operation, predictive maintenance, DT data feed
- Included in: demonstration units, FOAK, commercial fleet
- I/O: analog, digital
- Other features: e.g., TRL, expected lifetime, maintenance/replacement needs



Next steps

- Business case: is it cheaper to operate with more operators onsite and less technology or the opposite?
- Scenarios evaluation: which scenario is more recommendable for the first units? Which for the fleet? Which are the regulatory constraints?

ADVANCED SAFETY ASSESSMENT OF MICROREACTORS

Goal: Develop a general framework to investigate microreactors threats and vulnerabilities, and assess the risk quantitatively

MRs: relatively novel design

Unknown threats

Advanced safety assessment

Design improvement

MRs design analysis and characterization

- Design analysis
- Similar concept analysis
- Review of data and information
- ...

Threats identification

- Known threats of LWRs
- Threats specific to the novel design

Safety functions and safety systems

- Analysis of safety functions and corresponding safety systems according to the novel design

Data and information

- Similar design and concept data
- Data from prototypes
- Data from reports

Model

Scenarios
Transients
Safety parameters
Safety thresholds
Influencing factors

Integrated Deterministic and Probabilistic Safety Assessment (IDPSA)

- Safety margins
- Failure probability

MRs modelling and simulation

- Transient and accidental scenarios modelling and simulations

Dynamic PRA

Techniques:

Advanced MC simulation techniques
Advanced Bayesian modelling
Dynamic Event Tree
...

ADVANCED SAFETY ASSESSMENT OF MICROREACTORS

Main steps and ongoing work

Step	Brief description	Expected output	Status
Qualitative safety evaluation	MRs design analysis and identification of threats, hazards and accidental scenarios of interest.	Characterization of traditional LWR threats/hazards to consider for the MRs, and novel threats/hazards proper of the MRs	A preliminary analysis has been performed and an initial set of accidental scenarios of interest have been identified
Simulation model development	Development of a Best Estimate (BE) simulation model	BE simulation model allows investigating the behavior of MRs during accidental scenarios, and considering the parameters uncertainty in the model	A preliminary simulation model has been developed
Quantitative safety assessment	Development of a safety framework that embeds the BE simulation model and the systematic PRA framework to assess the risk quantitatively	Systematic risk insights such as: *a*) probabilistic safety margins; *b*) components failure probabilities; *c*) analysis of interactions and dependencies among systems, structures and components.	Ongoing