National Nuclear Security Administration (NNSA)

Defense Nuclear Nonproliferation (DNN)

Analysis Methods for Lead Test Assemblies in the Advanced Test Reactor

2022 RERTR International Meeting

Challenges at ATR for Low Enriched Fuel

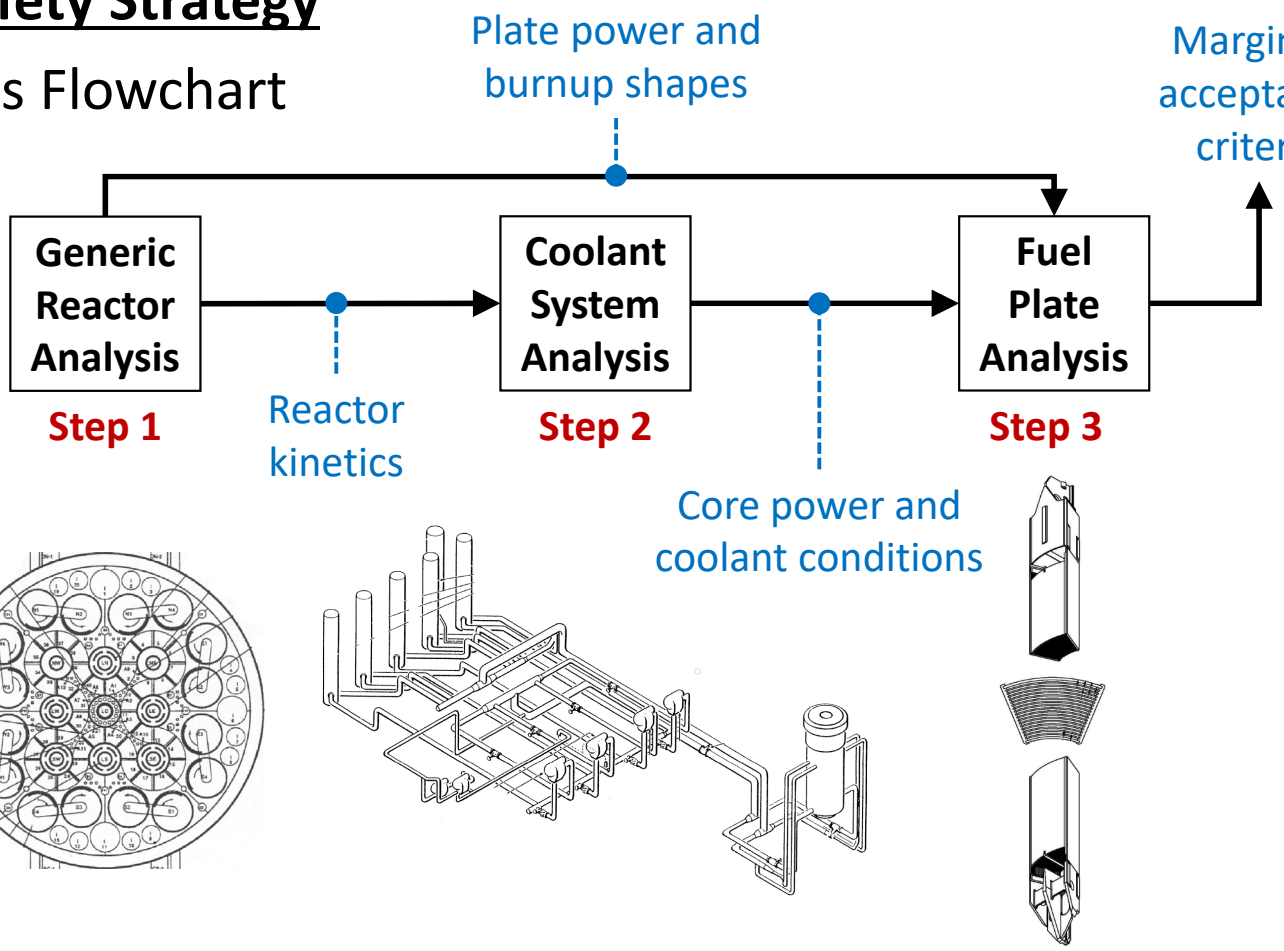
1. Efficiency in performing engineering analyses
   - *Numerous analysis cases*
   - *Evolving input parameters*
   - *Limited engineering staff*

2. Useful resolution in analysis results
   - *Fuel operating limits*
   - *Critical parameters*
   - *Control element positioning*

3. Flexibility towards multiple fuel designs
   - *Both high and low enriched fuel in reactor*
   - *Heavier weight of low enriched fuel*

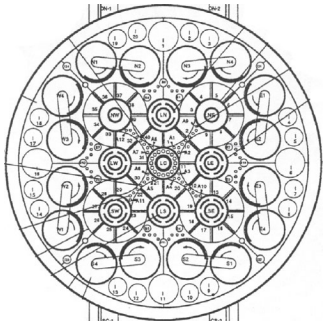
ATR Safety Strategy

Analysis Flowchart



Cycle-Specific Reactor Analysis

Step 4



Step 4 affirms the inputs used in steps 2 and 3

ATR Safety Strategy

Acceptance Criteria

Thermal Criteria

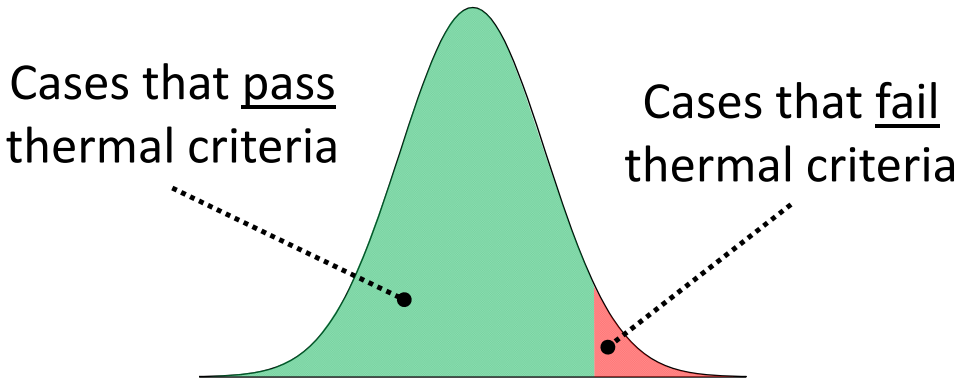
To ensure safety, do not exceed:

- Saturation temperature
- Critical heat flux
- Plate buckling temperature
- Fuel blistering temperature

Statistical Criteria

To accommodate analysis uncertainty:

- 95% of perturbed cases must pass thermal criteria
  (43 parameters are perturbed in each case)
- 95% confidence level needed in case distribution
  (153 perturbed cases are run)

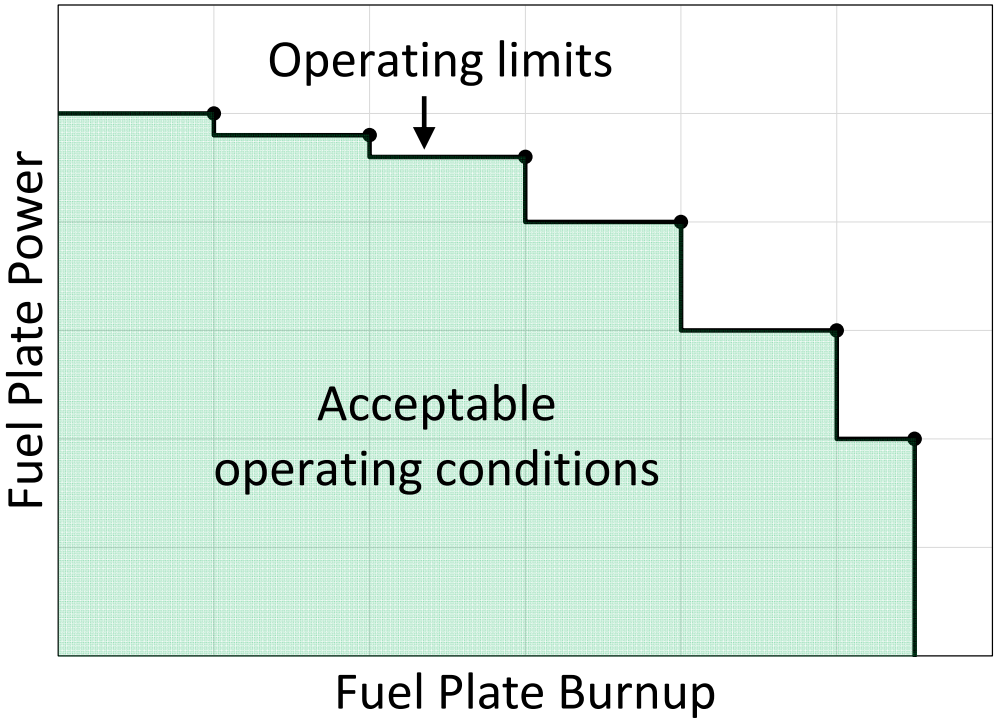


Example distribution of perturbed cases

ATR Safety Strategy

Fuel Operating Limits

- Limits defined by power and burnup
- Different limits for each fuel plate
- Limits ensure margin to acceptance criteria
- Limits identified using numerous cases with varied power and burnup



ATR Safety Strategy

Analysis Case Execution

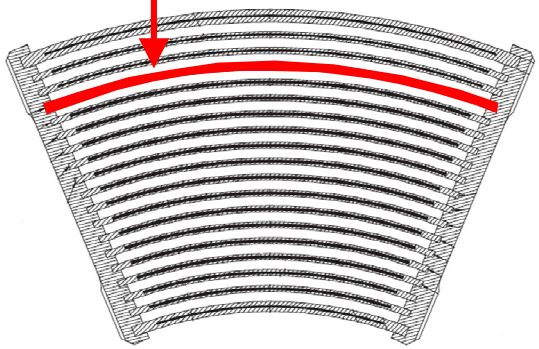
153	×	39	×	19	×	13	=	1,473,849
cases to evaluate uncertainty		*cases to identify operating limits*		fuel plates in a fuel assembly		*accident scenarios*		*fuel plate thermal-hydraulic analysis cases*

- 1.47 million cases took 2 weeks to complete on the INL computer *Sawtooth.*
- Case execution was automated using *Python* programming language.
  - Parallel-computing used to increase speed.
  - Monte Carlo sampling used to perturb inputs.
  - Root finding used to identify operating limits.

ATR Safety Strategy

Fuel Operating Limits

Fuel Plate	Burnup [10^{21} fissions/cm^3]	Power [kW]	Limiting Accident	Margin to Blistering [°F]	Margin to Buckling [°F]
16	1.0	502.6	Large in-pile tube break	157.40	0.04
	2.0	502.0	Large in-pile tube break	81.47	0.02
	3.0	486.8	Large in-pile tube break	1.63	15.49
	4.0	424.4	Large in-pile tube break	0.14	82.47



Maximum permissible power

Accident scenario that limits power

Criterion that limits power

Fuel Cycle Design and Analysis

Particle Transport Modeling

To enable operations with LEU fuel, new reactor analysis tools were deployed.

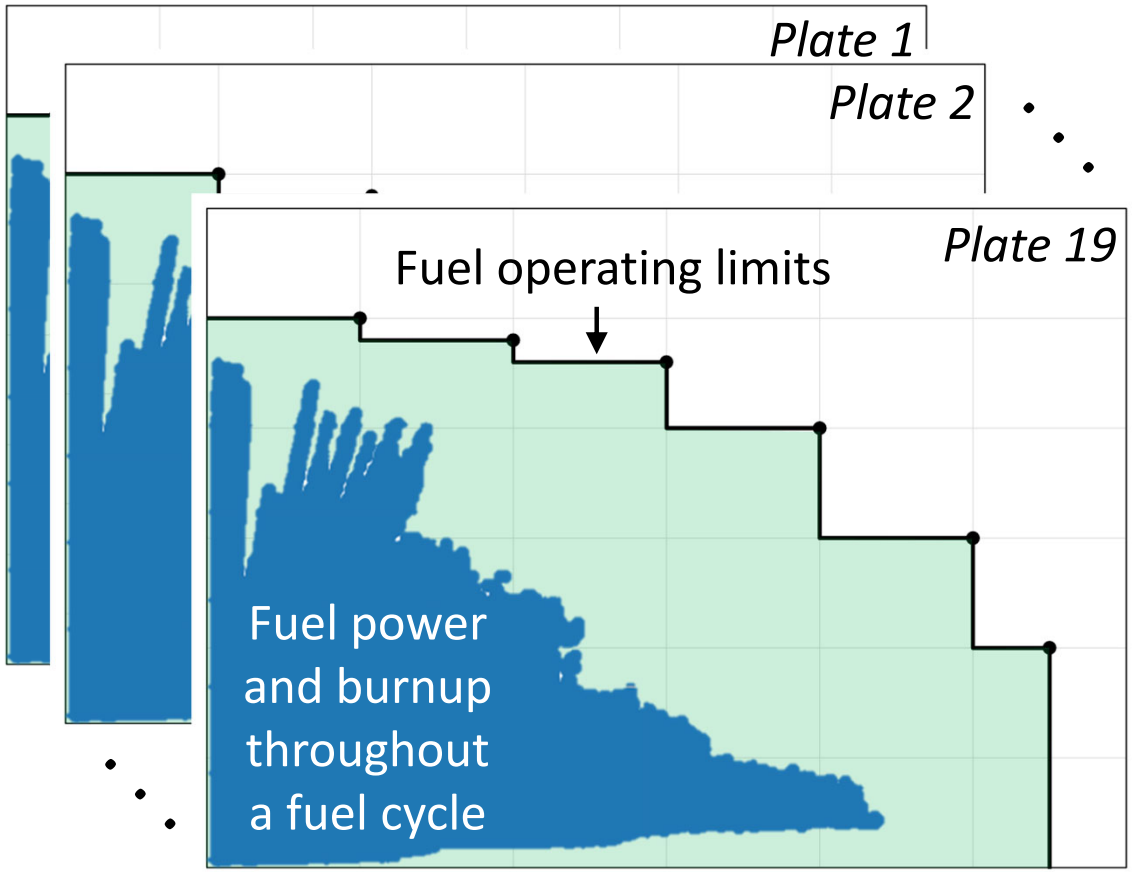
Features	Legacy Analysis Tools	New Analysis Tools
Numerical Solver	2D Modeling	3D Modeling (MC21)
Analysis pre/post processing	Limited functionality	More comprehensive functionality and automation
Flexibility	HEU fuel only	HEU, LEU, or mixed

ATR Safety Strategy

Core Cycle Design

New tools enable:

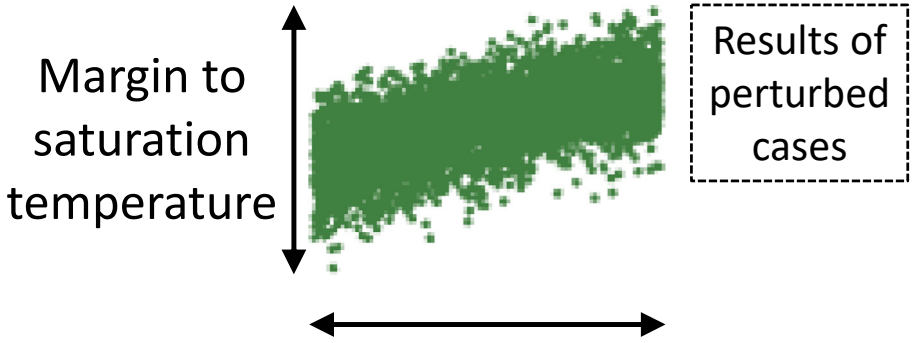
- Clear view of operating conditions
- Clear view of operating limits
- Rapid cycle design process
- Intelligent specification of irradiation conditions for LEU fuel tests



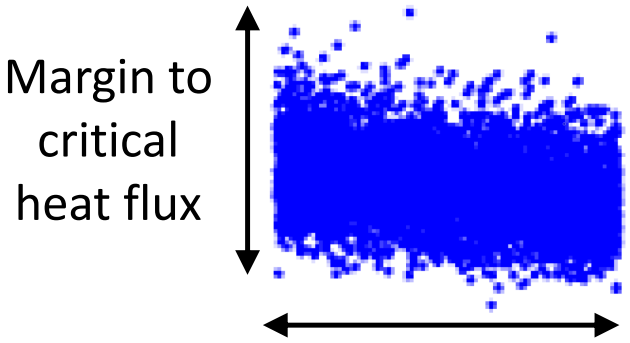
Critical Parameters

- To determine which analysis input parameters are important for safety, the influence of individual parameters on margin to acceptance criteria was evaluated.
- 43 parameters were perturbed in thousands of cases for different accident scenarios.

Reactivity insertion accident



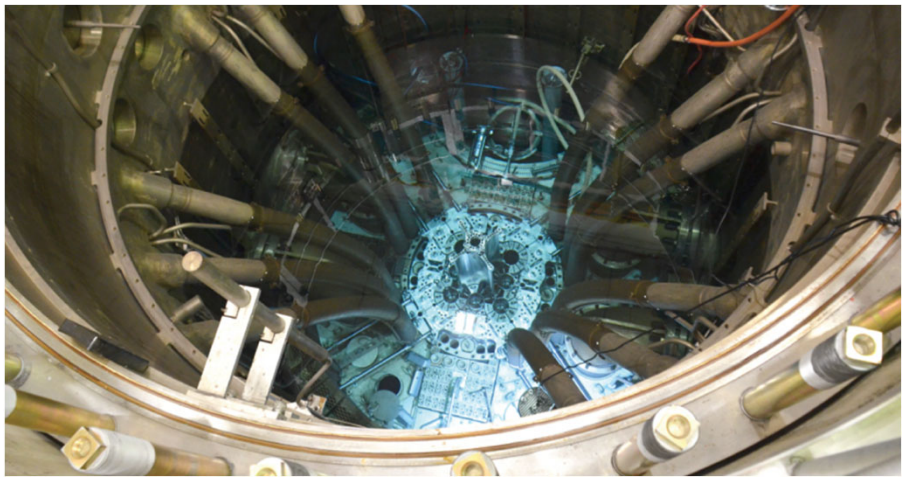
Loss of coolant accident



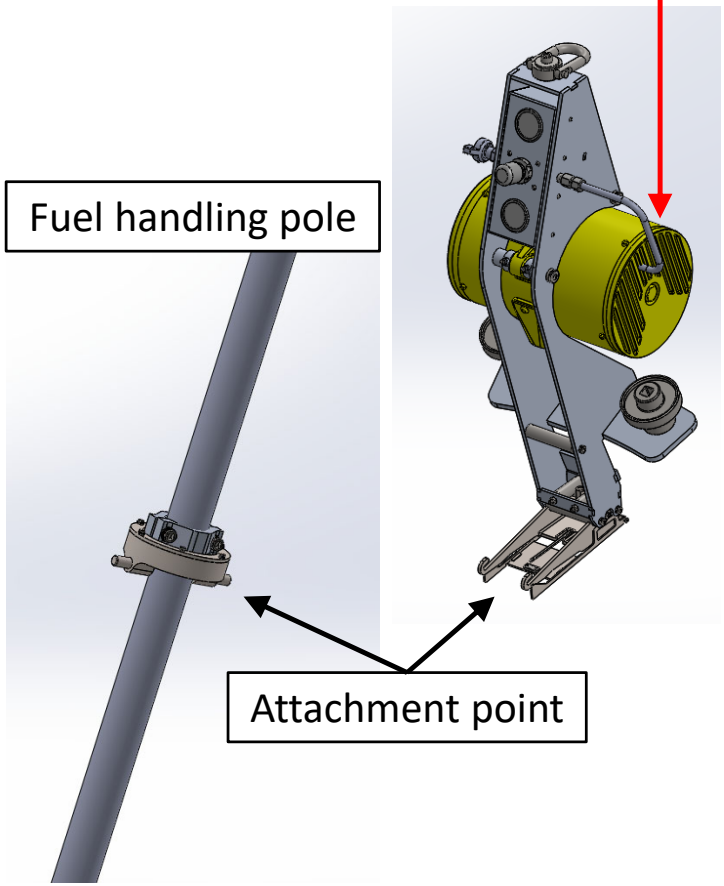
Fuel Handling Tools

Lift Assist for Low Enriched Fuel Assemblies

- New handling tools are being developed to accommodate increased weight of LEU fuel.
- Compressed air in a pneumatic balancer will aid operators with lifting elements.
- Prototype handling tools were tested in the ATR in August 2022.
- Operator feedback on prototype is being leveraged for next design iteration.



Fuel Handling Tools



Pneumatic balancer

Primary take-aways

Due to low enriched fuel efforts at the ATR:

- Engineering analysis processes have been improved
  - *Less labor intensive*
  - *More informative*
  - *More flexibility*
  - *Reduced risk of error*

  } ATR reactor engineering staff have provided positive feedback

- Fuel handling tools are being improved
  - *Ongoing effort, but initial designs show promise*
- ATR facility will be ready to perform lead test assembly insertions of low enriched fuel