SAND2021-13942PE

ADVANCED REACTOR SAFEGUARDS

Sabotage Targets for Advanced Reactors

Focus on Micro-Reactors

PRESENTED BY

Vincent A. Mousseau

November 9, 2021

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

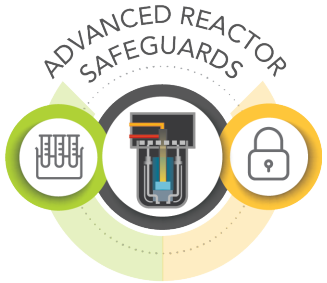
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia National Laboratories | U.S. DEPARTMENT OF ENERGY

Overview of the Work

- The goal is to analyze sabotage threats for advanced reactors and determine:
  - which could fall within DBT capabilities
  - timeline progression
  - if existing modeling tools are adequate
- This work will feed into the physical protection analysis for advanced reactors

Why is this important?



- In the US alone we have approximately 4000 reactor years (100 reactors for 40 years) experience with large LWR reactors.
- That’s about 2500 fuel cycles producing electricity and making a profit.
- Current advanced SMRs designs have limited or no operating experience and no experience with producing a profit since they are based on test reactors that did not need to produce a profit.
- The cost of safety, security, and safeguards has a large uncertainty due to the lack of data.
- Providing knowledge now, that will be filled in later by experiments and operating experience, reduces the risk to investors.

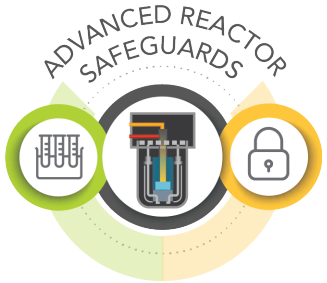
Passively Safe Heat Pipes

- Because there are no moving parts the reliability of heat pipes is very high.
- In addition, microreactor designs often include a large amount of redundancy.
- For steady state microreactor safety this is a very good design.
- In the microreactor, the heat pipes serves as the equivalent of the primary cooling loop.
- Similar to a BWR, the coolant boils and condenses and transports between these two points.
- Transient response of heat pipes, requires very similar physics modeling to a BWR primary.

Heat Pipe Transient Response

- Safety and security is all about timing
  - Safety – How long is “heat in” greater than “heat out”
  - Security – How long before someone can successfully sabotage the reactor relative to how long before responders arrive,
- Capturing how a heat pipe responds (or bounding its behavior) is key.
- Simple response surfaces can be made from a transient heat pipe model.
- Steady state heat pipe models do not model the transient and therefor cannot bound the calculation.

Heat Pipe As the Initiating Event

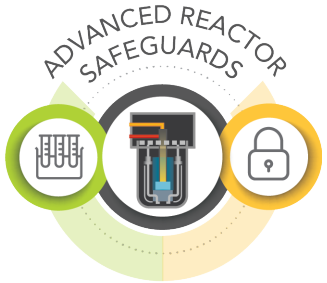


- There are characteristics of heat pipe that make them a potential sabotage target.
- The exploitation of these characteristics require the saboteur to get access to the reactor internals.
- Harder to defend, is if the heat pipe transient response is a secondary effect of an attack on a different target.
- These all require transient heat pipe analysis to analyze or bound the heat pipe response.

Operating Experience

- Although Micro-reactors are a new design, heat pipes are an old technology that have many applications.
- The unique operating experience to fill in is the transient behavior caused by Doppler feedback.
- An increase in the evaporator temperature will cause a decrease in the local reactor power.
- Conversely, a decrease in the evaporator temperature will cause a increase in local reactor power.
- Understanding the feedback between reactor power and evaporator temperature is unique to microreactors where the heat pipe plays the role of the primary coolant loop.

Validation Experiments



- The nonlinear feedback between the local reactor power and the evaporator temperature can be captured by the control system on the power of the experiment.
- The relationship between transient temperature in the condenser and transient temperature in the heat pipe needs to be measured.
- Details about the geometry and properties of the wick (permeability, porosity, wetting) are required to allow the transient heat pipe model to match the experimental transients.
- The transient heat pipe model is needed to design transient validation experiments.

Future Work in FY22

- Focus on Micro-Reactors (with heat pipes) and Sodium Fact Reactors.
- The work will be generic (will apply to more than one reactor design).
- Target sabotage vulnerabilities specific to heat pipes.
- Target sabotage vulnerabilities specific to sodium.
- This will allow vulnerabilities to be designed out of the reactor or minimized by operating procedures.
- This results in cost savings over back-fitting ways to minimize the vulnerability.