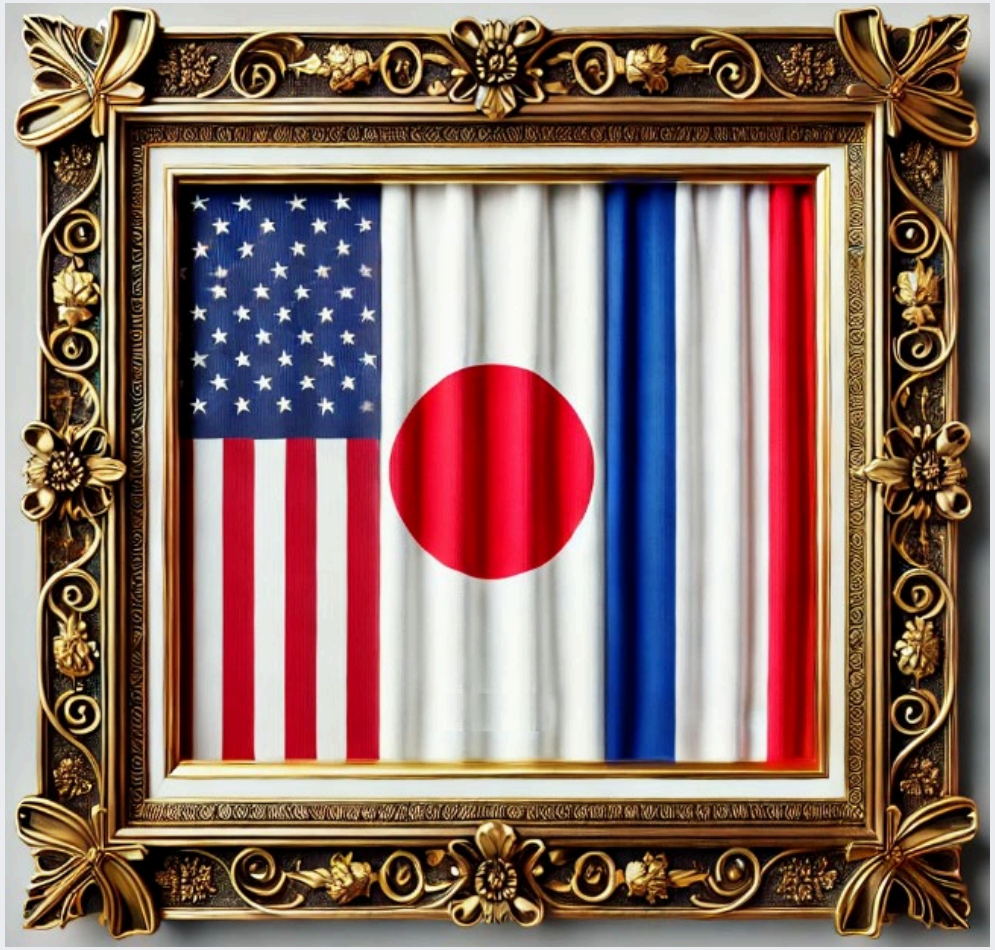
NCSP
NUCLEAR CRITICALITY SAFETY PROGRAM

1FRAME:
1F Fuel Retrieval and Monitoring Experiments

J. Hutchinson, D. Bowen, N. Cannon, A. Chambers, J. Clavel, J. Goda, D. Henzlova, C. Kostelac,
G. McKenzie, W. Monange, J. Moussa, M. Nelson, M. Rising, L. Rolinson, R. Weldon, N. Whitman

1FRAME

- Focus on collaborative research in the area of criticality monitoring for fuel debris removal at Fukushima Daiichi nuclear power station (1F)
- 1FRAME: 1F Fuel Retrieval and Monitoring Experiments
- Work will include blind tests (analysis of unknown data) using existing measured data, simulated data, and new experimental data
- DOE NCSP IE task (IE 35)
- Work is just starting (Oct 24), so more of a background talk



Objectives

- April: Launched the Fukushima Daiichi Decommissioning partnership with TEPCO and U.S. Labs to seek research cooperation for the steady implementation of decommissioning the Fukushima Daiichi Nuclear Power Station, especially for fuel debris retrieval.
- DOE-Nuclear Criticality Safety Program (NCSP) vision statement:
  - Continually improving, adaptable, and transparent program that communicates and **collaborates globally** to incorporate technology, practices, and programs to **be responsive to the essential technical needs of those responsible for developing, implementing, and maintaining nuclear criticality safety**.
- 1F fuel debris removal provides one of the most significant opportunities for international criticality safety technical collaboration today
  - New capabilities/technologies to help with fuel debris removal also align with needs of US applications

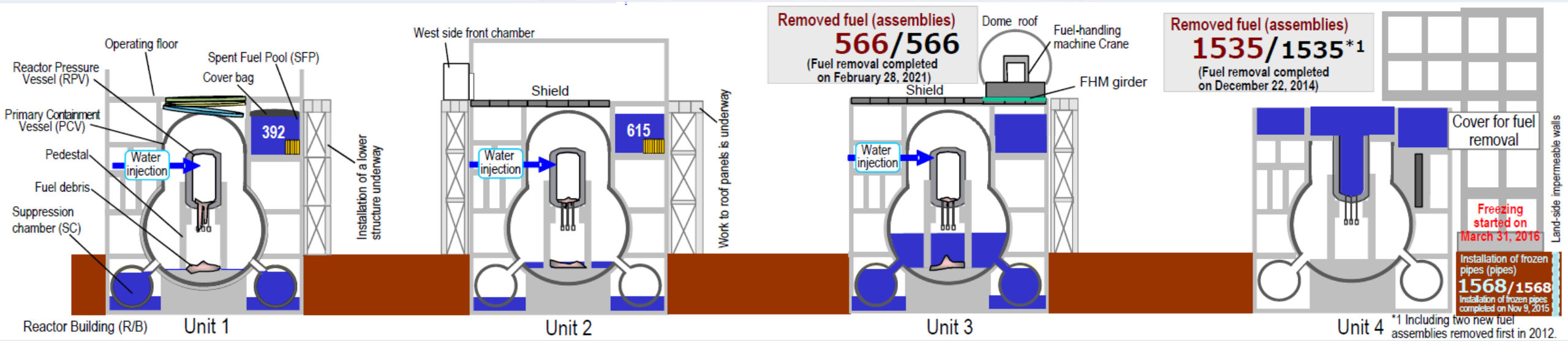
Joint leaders meeting

- In April 2024 Fumio Kishida visited the US White House
- US White House Joint Leaders Statement: https://www.whitehouse.gov/briefing-room/statements-releases/2024/04/10/united-states-japan-joint-leaders-statement/
- US White House Fact Sheet: https://www.whitehouse.gov/briefing-room/statements-releases/2024/04/10/fact-sheet-japan-official-visit-with-state-dinner-to-the-united-states/
- Previously, a meeting has been held in Tokyo in October 2023 with TEPCO-IRSN-LANL to present collaborative work between IRSN and LANL on subcritical experiments and noise technics

standards of safety, security, and safeguards. President Biden commended Japan's safe, responsible, and science-based discharge of Advanced Liquid Processing System treated water at Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Station into the sea. Our two countries plan to launch the Fukushima Daiichi Decommissioning Partnership focusing on research cooperation for fuel debris retrieval.

Our two countries plan to launch the Fukushima Daiichi Decommissioning partnership with Tokyo Electric Power Company and U.S. national laboratories to deepen research cooperation for the steady implementation of decommissioning the Fukushima Daiichi Nuclear Power Station, especially for fuel debris retrieval. Recognizing the important role of nuclear energy to

Background



- 1F has 6 units: 400-1100 MW
  - 3 operational units on 3/11/11
  - Units 1-5 are BWR Mark I
- After 9.1 magnitude earthquake, all 3 units scrammed successfully
  - Tsunami fully flooded backup generators
- Core meltdown in Units 1-3
- Hydrogen explosion in Units 1 and 3

- Japan goal: complete decommissioning of all units
  - Removal of all spent fuel assemblies in all units
  - Removal of fuel debris in Units 1-3
  - Remain subcritical during fuel debris retrieval
  - Will take several decades
  - Decommissioning led by the utility TEPCO

Image from monthly released reports:
https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/index.html#progress_status
https://www.tepco.co.jp/en/hd/decommission/information/committee/index-e.html

Criticality monitoring will be very challenging

- Real-time measurements are needed for data-driven decisions.
- Fuel debris composition is not well known
- Fuel debris location is only partially known
- Very high gamma dose
- Some units are underwater
- Access is a large challenge
- Very different than laboratory measurement conditions

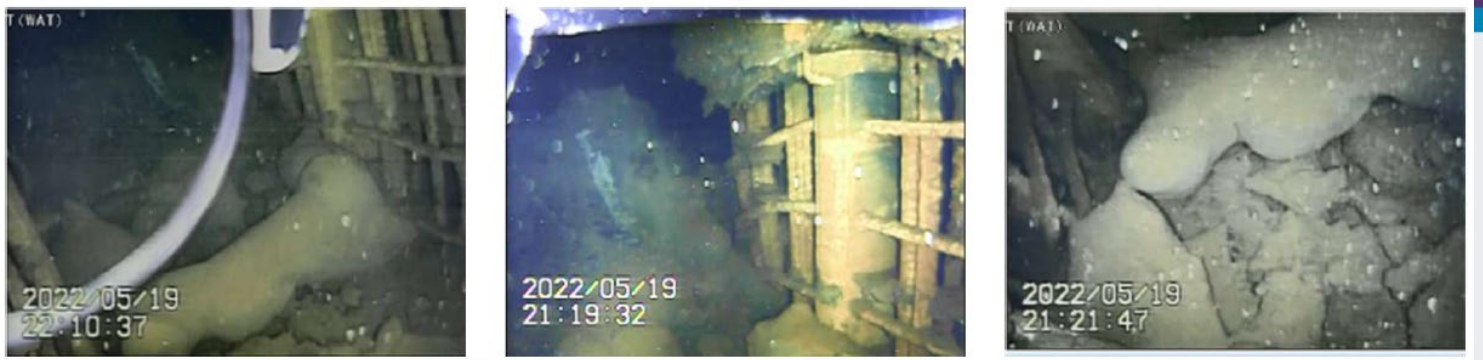


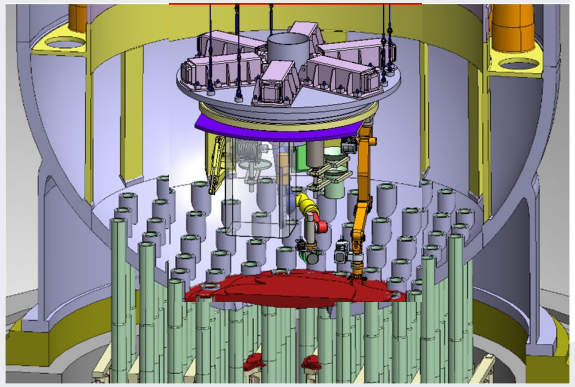
Figure 6. Bulky deposits (around point ① in Figure 5) [3]

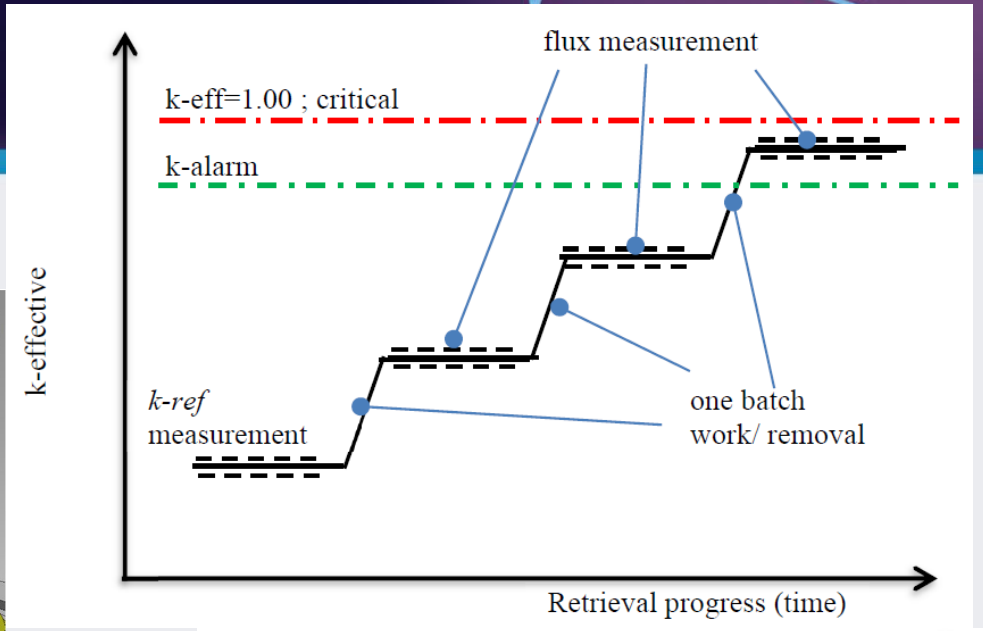
Figure 7. Thread-like deposits (point ② to ④ in Figure 5) [3]

K. Owada, "Features of Fukushima Daiichi Nuclear Power Plant Accident and Information on Fuel Debris Obtained from PCV Internal Investigations," ICNC 2023.

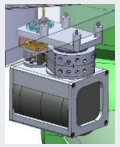
Previous/current R&D efforts

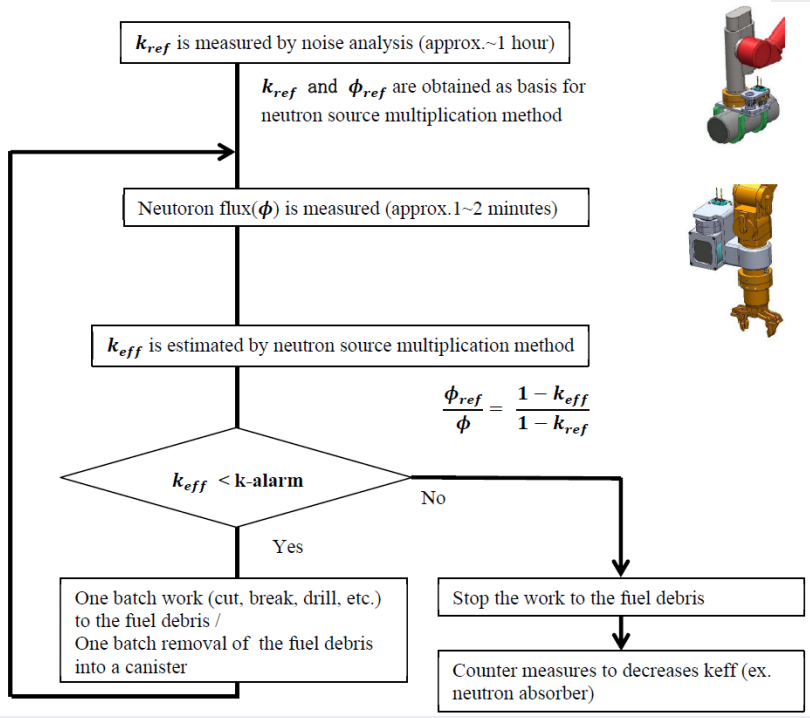
- Goal: detect when/if approaching criticality
- 2 kinds of technologies
  - Neutron detectors
  - Noble gas





- 3 kinds of neutron detectors
  - **Sub-criticality measurement**
    Use neutron noise Feynman-α method to assess k-eff.
    Use at first to estimate k-eff
  - **Source Neutron Multiplication method**
    To decide to suspend of resume work
  - **Continuous neutron flux monitoring**
    To detect unexpected criticality change





Y. Hayashi, "DEVELOPMENT OF CRITICALITY APPROACH MONITORING METHOD USING NEUTRON DETECTORS FOR FUEL DEBRIS RETRIEVAL IN FUKUSHIMA DAI-ICHI NPP," ICNC 2023.

Organizations/Meetings

TEPCO Tokyo Electric Power Company Holdings

METI

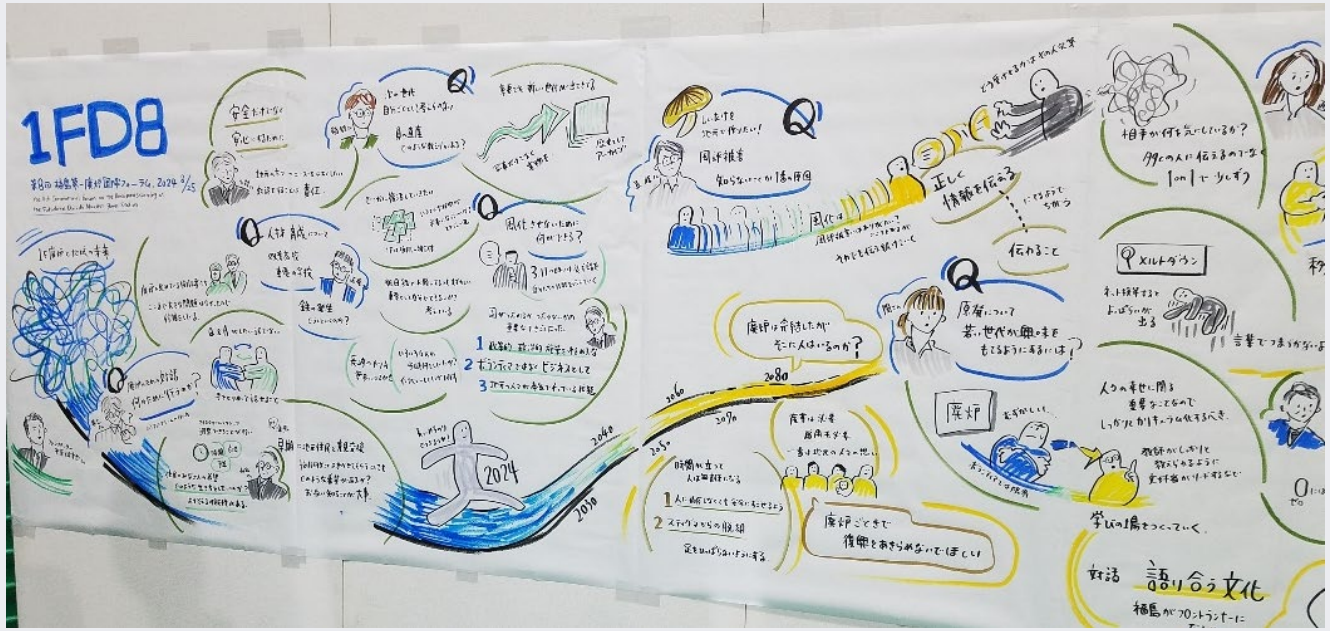
IRID

NRA JAPAN Nuclear Regulation Authority

JAEA

NDF

- Aug 2024 meetings in Japan
  - METI, MOFA, Toshiba, TEPSYS, JAEA
  - Attended 1FD8 forum
- Oct 2024 several of our team members attended FDR 2024



Fuel Debris Monitoring Collaboration and Experiences in Criticality Monitoring

NCSP

J. Hutchinson[1], D. Bowen[3], J. Clavel[2], J. Goda[1], C. Kostelac[1], J. Miller[4], G. McKenzie[1], W. Monange[2], M. Nelson[1], S. Pignet[2], R. Weldon[1], N. Whitman[1], A. Chambers[5]
[1]Los Alamos National Laboratory, [2]IRSN France, [3]Oak Ridge National Laboratory, [4]Sandia National Laboratories, [5]DOE-NCSP

Abstract
Fukushima Daiichi fuel debris removal provides technical challenges and opportunities for the international criticality safety community. The US DOE-NCSP (Nuclear Criticality Safety Program) and France (IRSN) will support 1F fuel debris efforts through collaboration on real-time criticality monitoring.

1. Introduction
Neutron monitoring of neutron multiplication (or degree of subcriticality) is required to help inform fuel debris removal activities and reduce the risk of re-criticality during the removal process. The upcoming Japan/US/France collaboration will focus on research and development associated with criticality monitoring. The US work is funded by the DOE-NCSP and the work in France will be performed by IRSN.

2. Previous work
The DOE Nuclear Criticality Safety Program has funded Research and Development efforts associated with subcritical neutron noise methods for over 10 years. This has included 5 International Criticality Safety Benchmark Evaluation Project (ICSBEP) benchmarks, which have included collaboration with IRSN. In addition, two measurement campaigns on thermal reactor systems have been performed: one at the Reactor Critical Facility (RCF) at the Rensselaer Polytechnic Institute (RPI) (2017) and one at the Sandia National Laboratories 7uPCX (2022). The former experiments included placing 30 ^{3}He under approximately 10 feet of water (inside custom water-proof covers, not in dry-wells). For this measurement campaign, roughly 100 hours of continuous real-time streaming data were acquired.
In addition to benchmark measurements, our team has experience in measuring unknown systems under field conditions. Last, we perform approach-to-critical operations for several new critical experiments each year. We will share this experience to assist in real-time criticality monitoring.

3. Conclusion
The US and France are excited to start collaborating on criticality monitoring associated with 1F fuel debris removal efforts. Work will begin later this year with a focus on neutron analysis, radiation detection, radiation transport simulations, and culminate in a capability demonstration.

Real-time neutron data acquisition with 30 submerged ^{3}He tubes at the RPI research reactor.

Comparison of measured and simulated data for several subcritical benchmarks.

Subcritical measurements at the National Criticality Experiments Research Center.

"Our two countries plan to launch the Fukushima Daiichi Decommissioning Partnership focusing on research cooperation for fuel debris retrieval."

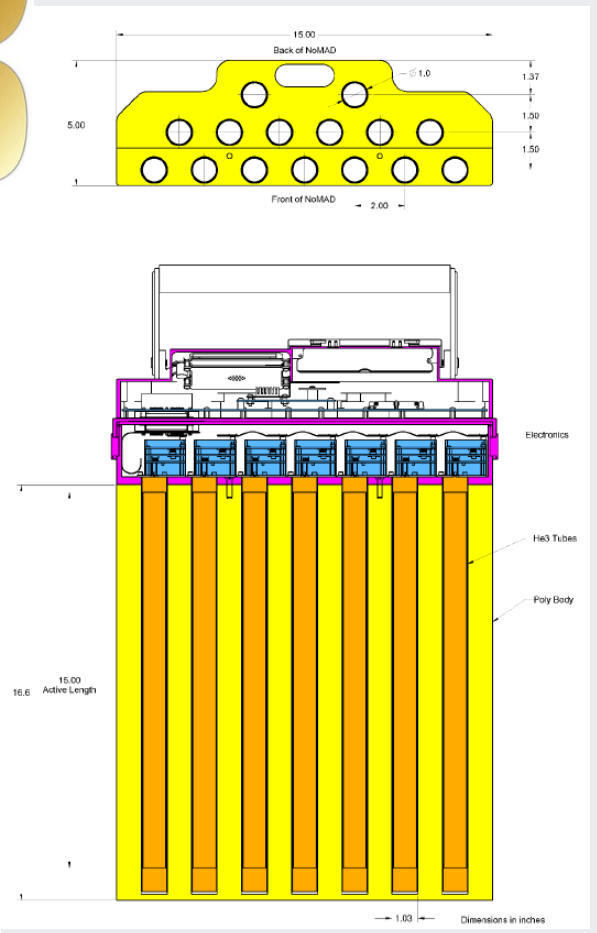
Joint Statement by Prime Minister KISHIDA Fumio and President Joseph R. Biden, Jr. - April 10, 2024
https://www.whitehouse.gov/briefing-room/statements-releases/2024/04/10/united-states-japan-joint-leaders-statement/

NNSA NCSP Los Alamos NATIONAL LABORATORY IRSN NCERC

Poster at 1FD8 forum

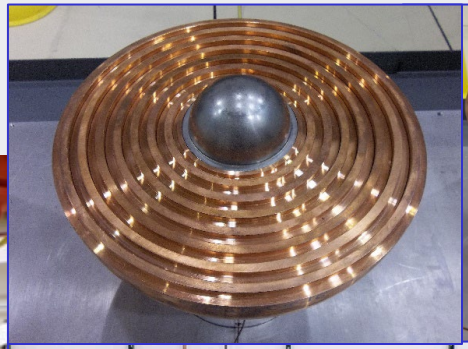
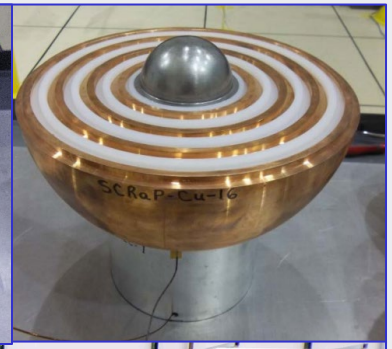
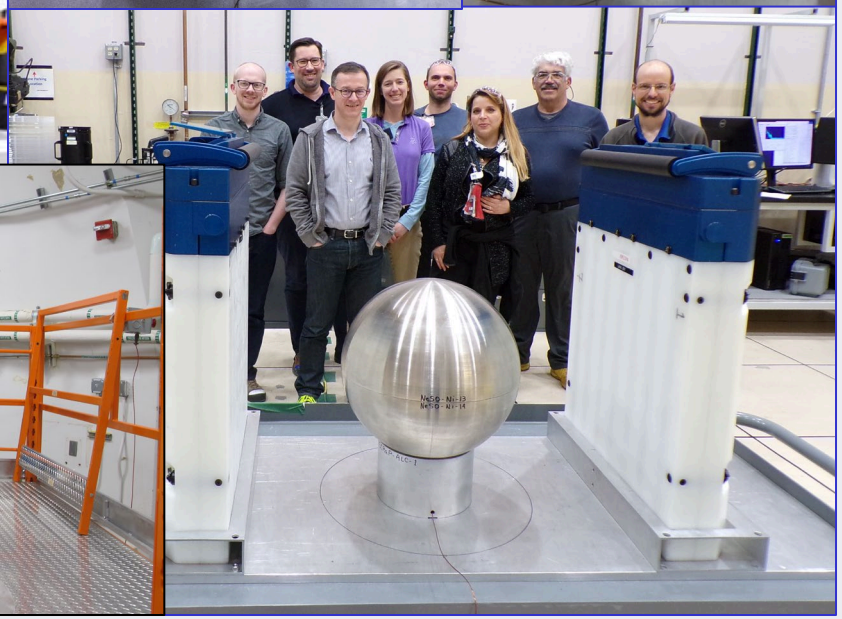
Experience with Measurement Systems and Noise Analysis

- We have experience in many types of radiation detectors.
- The MC-15 system (15 Helium 3 tubes in poly) has been used for many subcritical benchmarks (next slide) and was designed to measure unknown systems.
  - Nuclear nonproliferation and nuclear emergency response.
  - Benchmarks for the Nuclear Criticality Safety Program (NCSP)
- Used routinely for
  - Measurement campaigns at the National Criticality Experiments Research Center (NCERC).
  - Measurement campaigns at other nuclear facilities.
  - Field measurements.
- Very robust system built for field conditions.
- Acquired real-time measurements underwater.

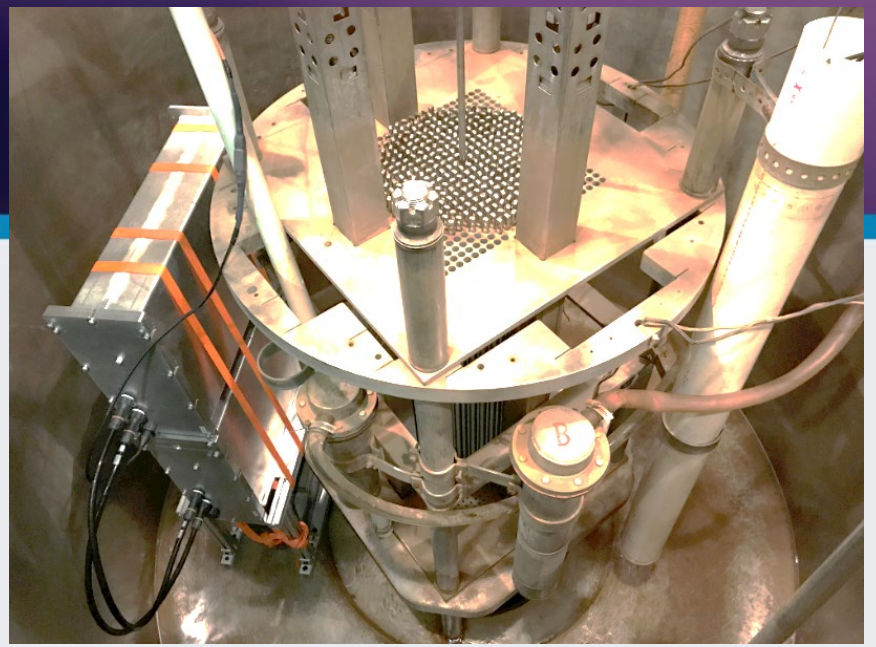


NCSP Subcritical Experiments

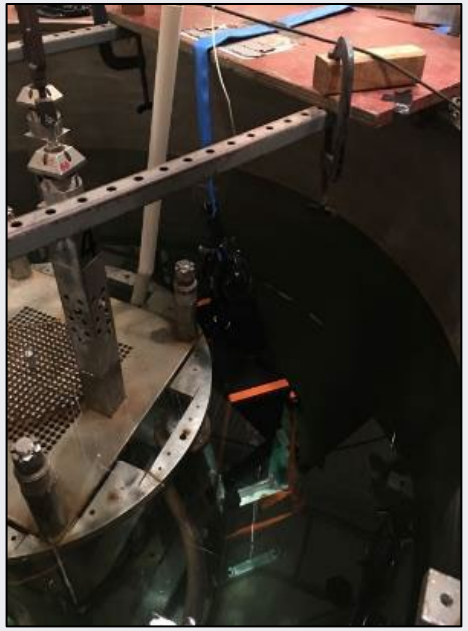
- Growing dataset of neutron multiplication benchmarks experiments/evaluations
  - Many years of sub-critical experiment research
  - Validate nuclear data and computational methods
- BeRP-Ni (2014)
- BeRP-W (2016)
- SCRαP (2019)
- NeSO (2019)
- MUSiC (2021)
- 7uPCX at Sandia (2022)
- Experiment design, simulations, data analysis, and uncertainty quantification

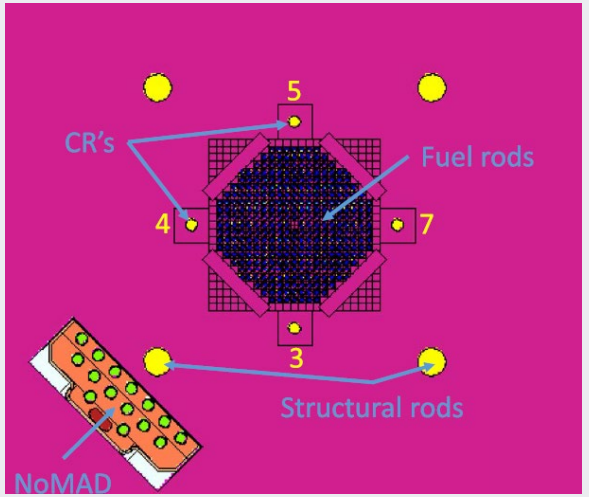





Research reactor measurements



- In 2016 and 2017, two measurement campaigns were performed at the RPI Reactor Critical Facility (RCF) in collaboration with IRSN.
- Configurations ranged from deeply subcritical to critical.
- A water-tight housing was designed to ensure the detection system could operate underwater.





communications physics

ARTICLE

Check for updates

https://doi.org/10.1038/s42005-021-00654-9 OPEN

Patchy nuclear chain reactions

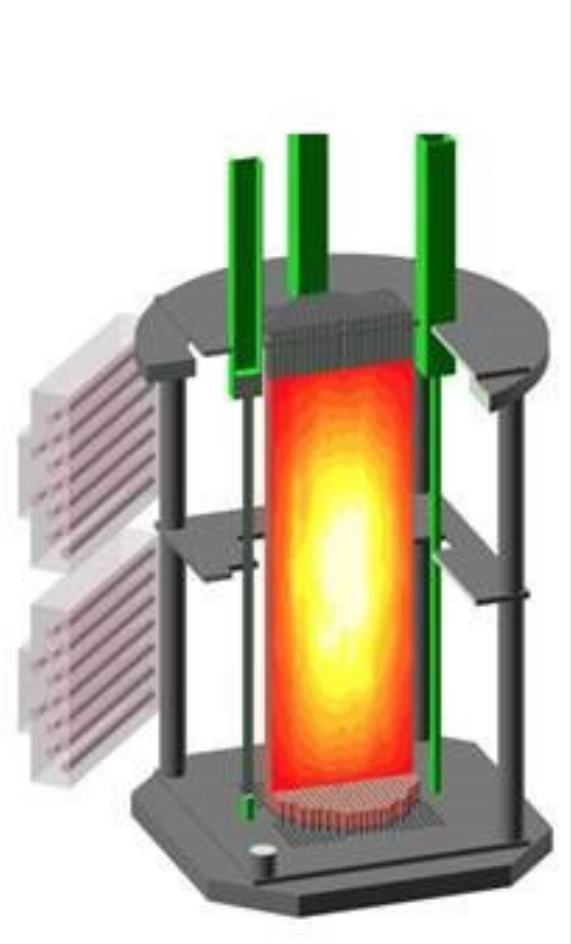
Eric Dumonteil[1,4✉], Rian Bahran[2], Theresa Cutler[2], Benjamin Dechenaux[1], Travis Grove[2], Jesson Hutchinson[2], George McKenzie[2], Alexander McSpaden[2], Wilfried Monange[1], Mark Nelson[2], Nicholas Thompson[2] & Andrea Zoia[3]

NCSP
NUCLEAR CRITICALITY SAFETY PROGRAM

IRSN simulation experience

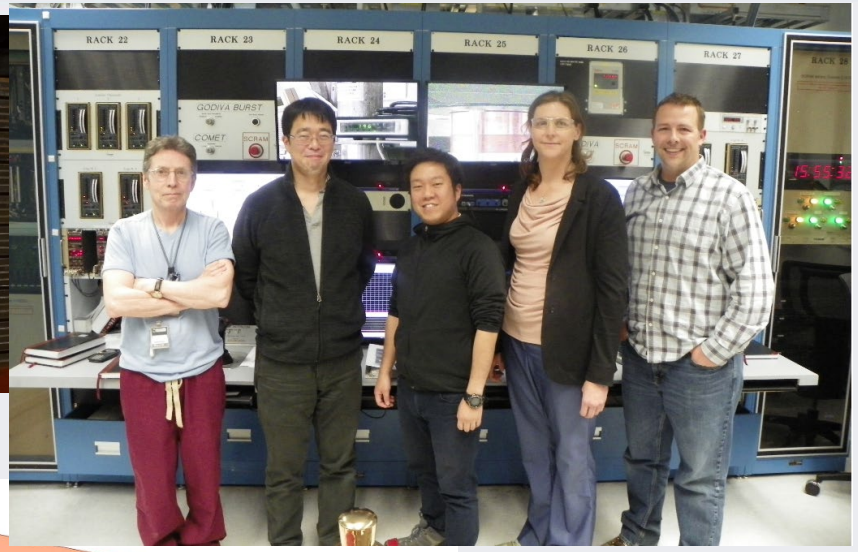
- MORET6 : Analog calculation in fixed source mode (Neutron noise experiments interpretation)

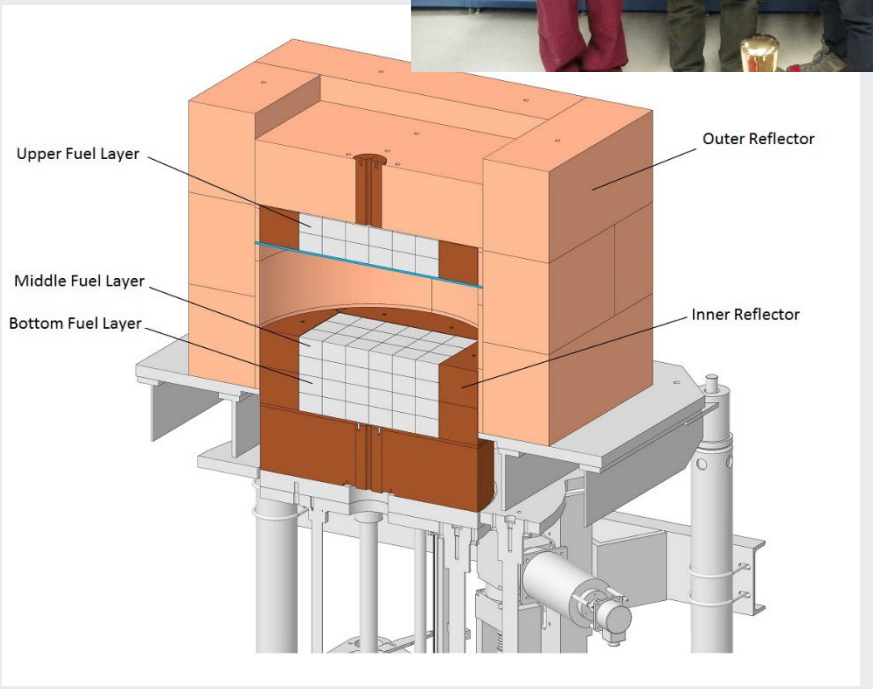
  → *PHYSOR 2022 : New capabilities of the MORET 6 Monte-Carlo neutron transport code,*
  Wilfried Monange, Aurélie Bardelay (IRSN, FRANCE)



JAEA collaborations to support ADS

- Experiments performed in collaboration with JAEA and supported by the NA-232 Office of Nuclear Material Removal.
  - DOE-NCSP provided support for benchmark evaluations
- Accelerated shipping schedule returned HEU and Pu fuel from FCA to US under Remove Program.
- Lead void measurements are important for regulatory approval of system with lead-bismuth coolant.
- HEU, LEU, and Pu experiments performed.
- 5 year program: 2015-2020.



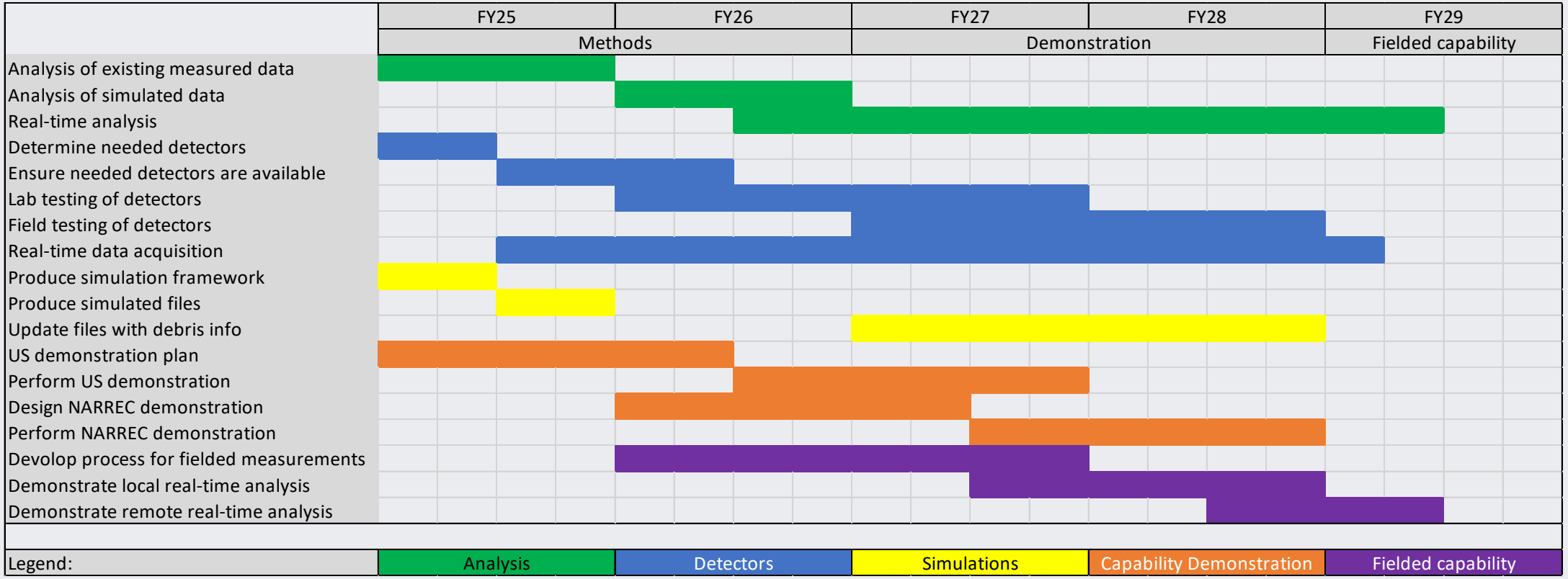


Milestones

- 5-year collaborative project focused on criticality monitoring

Focus areas:

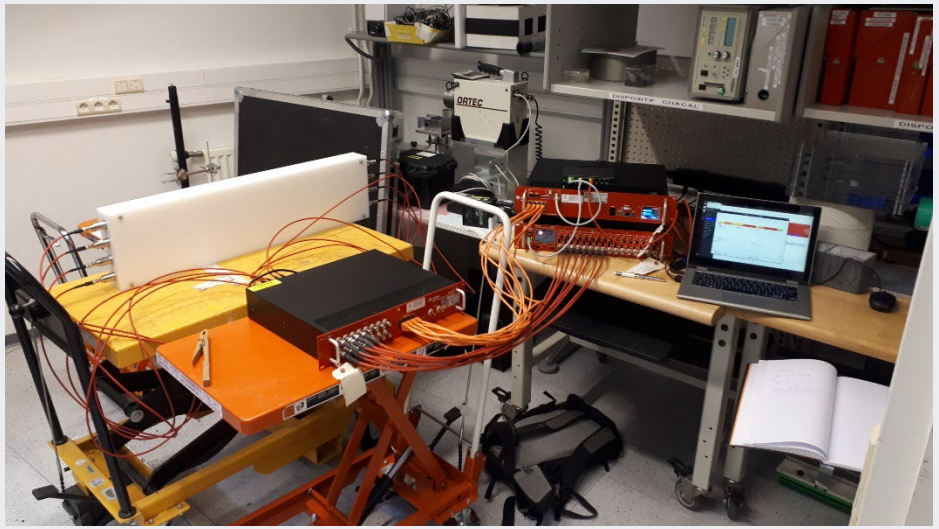
- Analysis
- Radiation detectors
- Simulations
- Capability demonstration
- Fielded capability
- Collaboration



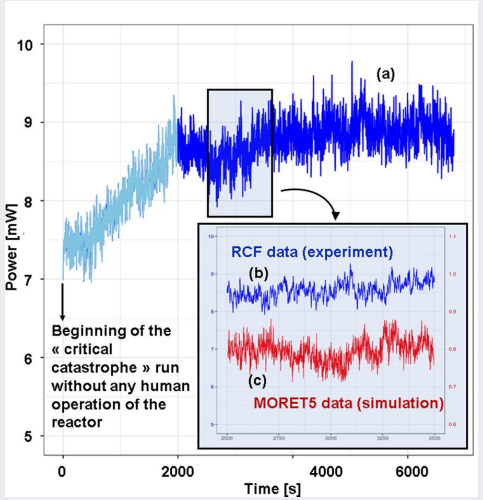
IRSN work FY25

Work for 2025:

- Simulation of current state of the reactors
  - Corium composition
  - Fuel debris position
  - Radioactivity
  - Comparison with measurements from F1S
- Evaluation of neutron noise technics for reactivity assessment in a representative environment of F1S
- Testing / validating the IRSN neutron detector system in experimental reactors
- Evaluate the possibility of using other types of detectors and methods

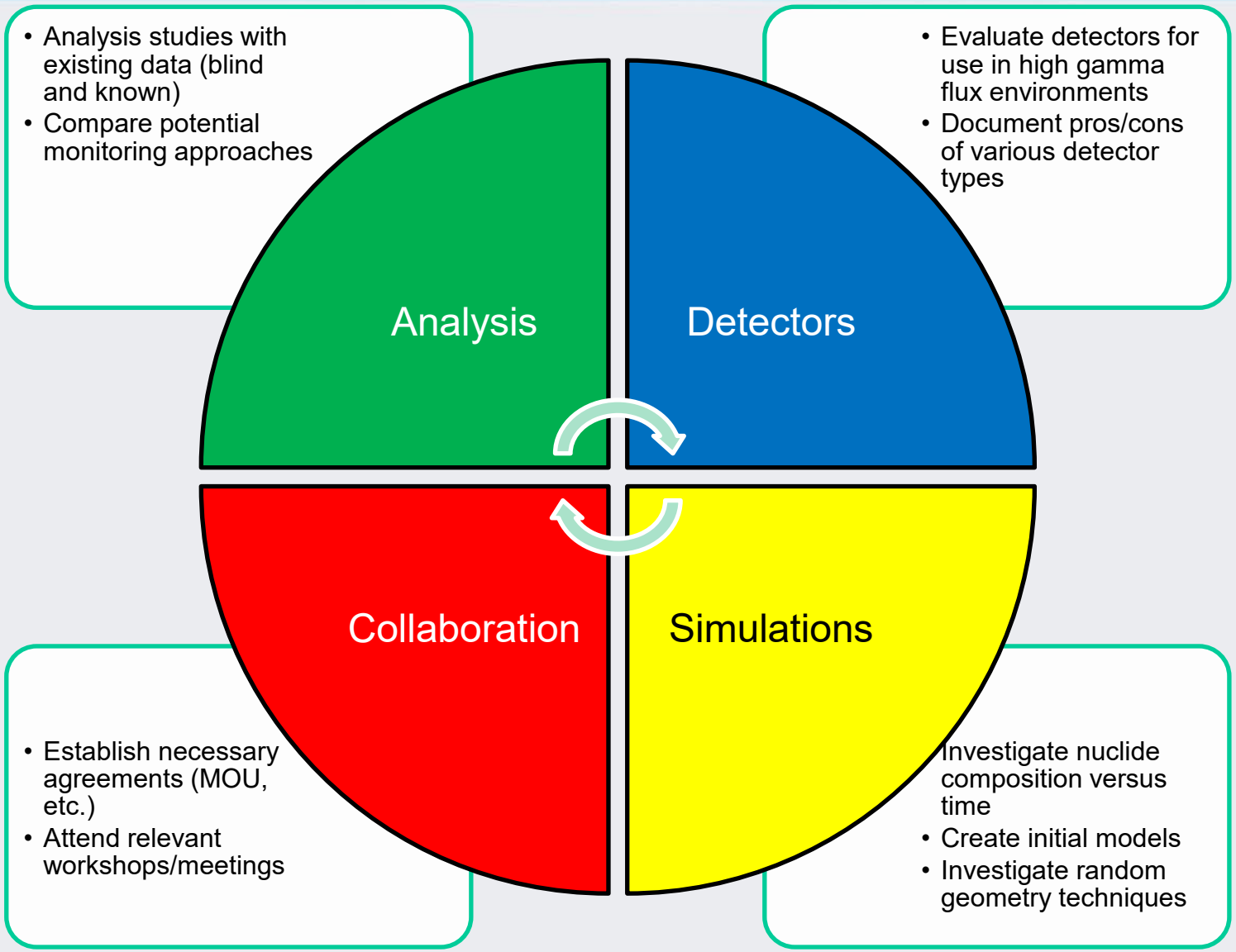


IRSN neutron noise detector



Simulation of the RCF experiment

LANL work FY25



Conclusions and future work

- Work is just starting and we are excited for this challenging opportunity
- Previously funded work (by NCSP and other NNSA sponsors) helps by providing access to
  - Detection equipment
  - Datasets
  - Models
- R&D advancements needed for this application will benefit US missions (criticality safety, nonproliferation, DOE-NE, etc.)

Acknowledgements

- This work was supported by the DOE Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy.
- Los Alamos National Laboratory is operated by Triad National Security, LLC, for the National Nuclear Security Administration of the US Department of Energy under Contract No. 89233218CNA000001.