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U.S. Fast Reactor Research and Development Activities:

Outlook for Monju Collaborations

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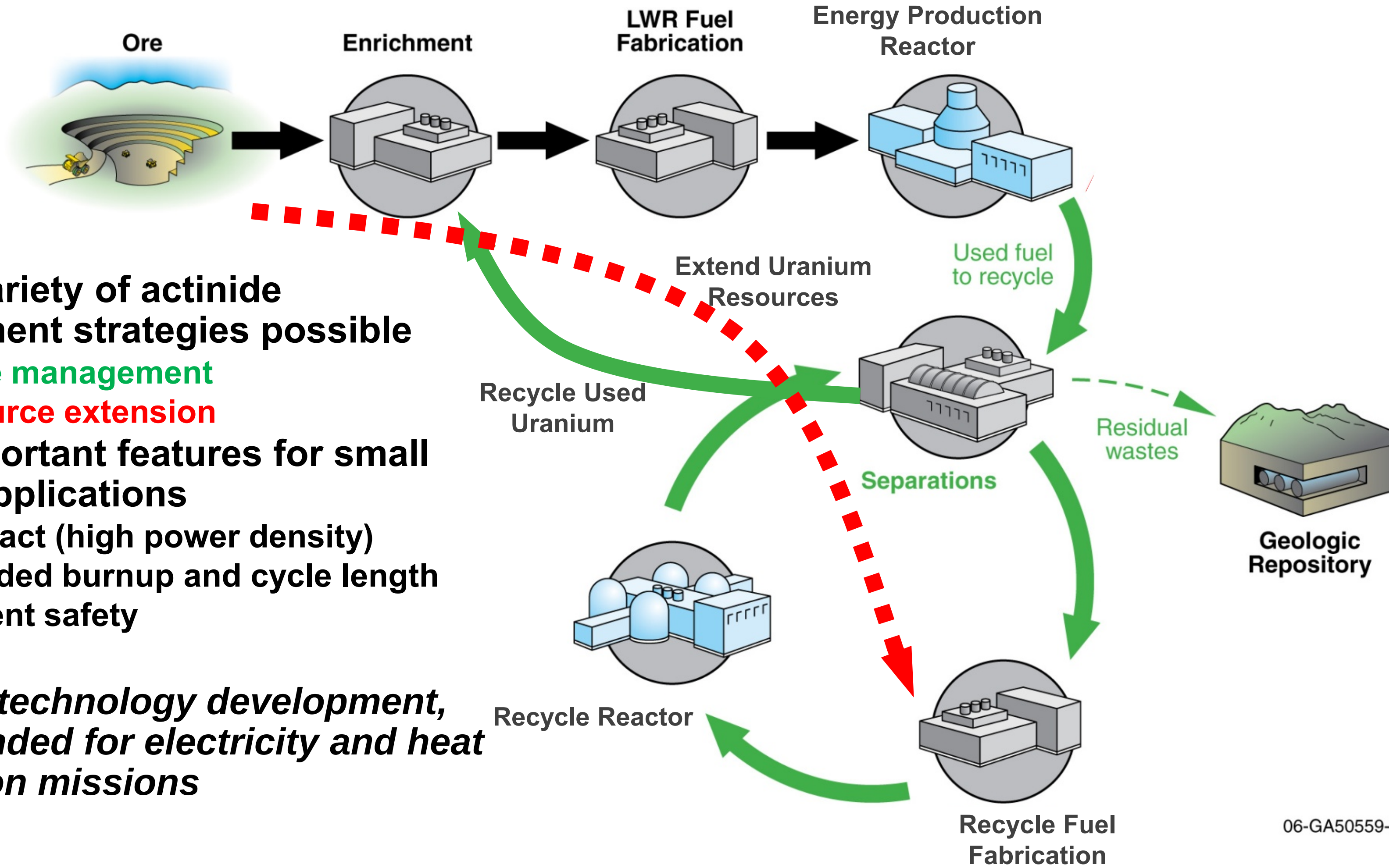
Actinide Management in Fast Reactors

- A wide variety of actinide management strategies possible
  - Waste management
  - Resource extension
- Also, important features for small reactor applications
  - Compact (high power density)
  - Extended burnup and cycle length
  - Inherent safety
- *With key technology development, also intended for electricity and heat production missions*



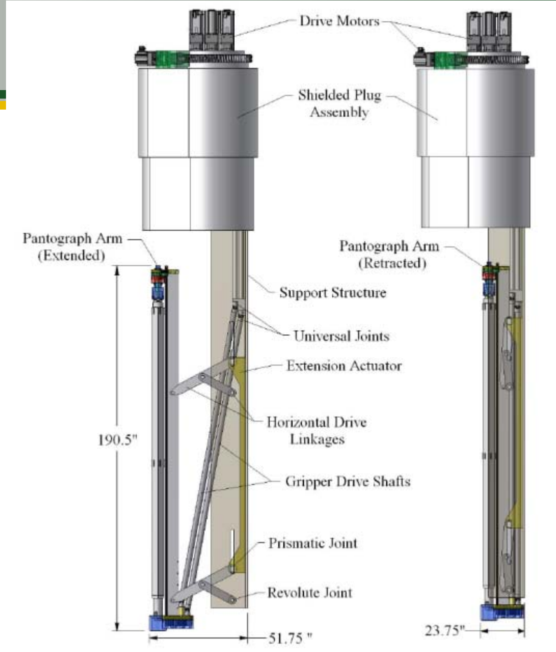
Fast Reactor R&D Priorities

- **Capital investment in reactors is the dominant cost of any nuclear fuel cycle; thus,**
- **The primary <u>research focus is capital cost reduction</u> through application of innovative technology solutions**
  - Concept development studies (improved design approach)
  - Advanced structural materials
  - Supercritical CO_2 Brayton cycle energy conversion
  - Advanced modeling and simulation
- **Other important technology research topics that must be addressed for successful application:**
  - Safety (and licensing)
  - Undersodium viewing (reliability and maintenance)
  - Fuels development (performance and fabrication)

Fast Reactor Advanced Concept Studies (examples)

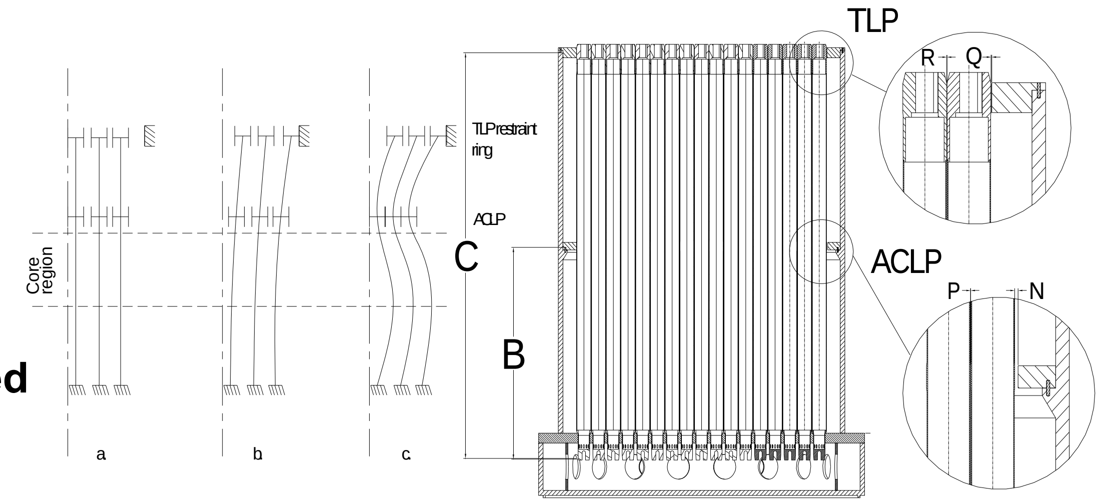
- **<u>FY11 and FY12 work focused on SMR (~100 MWe) concepts:</u> unique features include long-lived core and fuel shuffling strategies**

- **Developed compact fuel handling mechanism:**
  - Single rotating plug configuration
  - Pantograph design
  - Offset from center



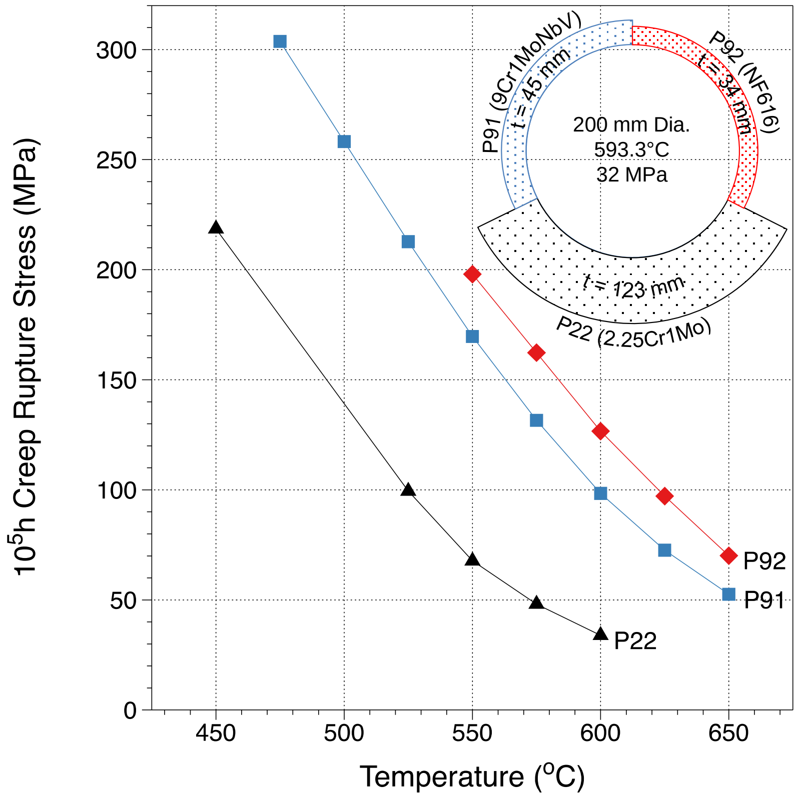
- **Detailed analysis and design options for core restraint**
  - A key feature for inherent safety reactivity feedbacks
  - NUBOW bowing analysis code recovered and refined
  - Limited free bow design

- **AFR-100 safety analyses conducted**
  - Verify inherent safety in double fault transients



Advanced Steels Provide Greater Safety Margin and Design Flexibility

- **Higher strength for constant temperature:**
  - Reduced commodities
  - Greater safety margins
  - Longer lifetimes
- **Higher temperature for constant stress:**
  - Higher plant performance (e.g., thermal efficiency)
  - Reduced commodities
  - Greater safety margins in accident scenarios
- **Combinations of above:**
  - Greater design flexibility



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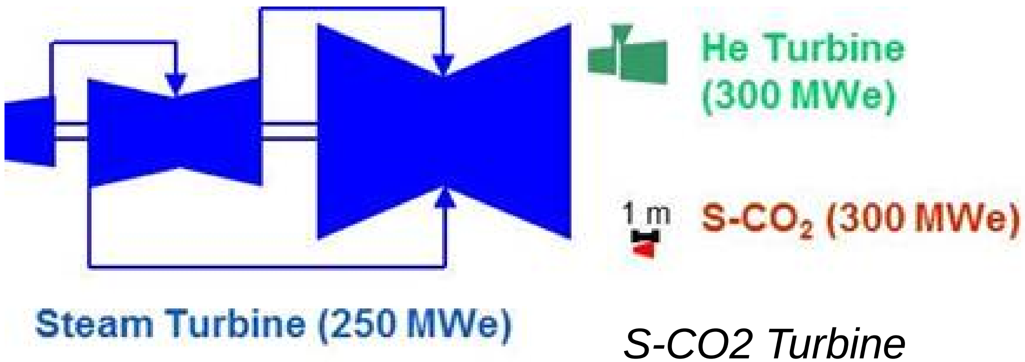
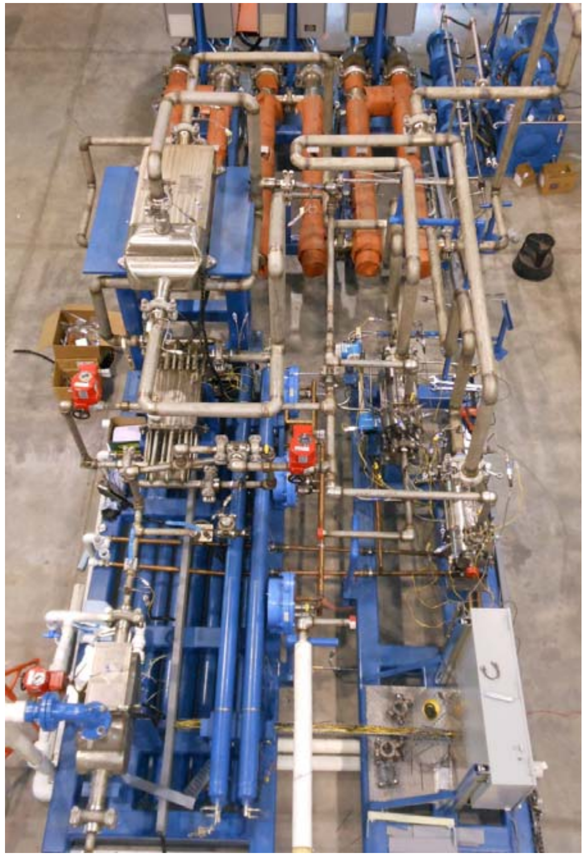
Supercritical CO_2 Brayton Conversion Cycle

- **R&D has demonstrated this system's capability at the lab level (1MW).**
- **DOE's Sun Shot program is funding ramp up to the 10MW level.**
- **U.S. industry has shown interest in this technology.**



S-CO2 Turbine	*1 M*
He Turbine	*3 M*
Steam Turbine	*22 M*



Sandia National Lab
Brayton Cycle Test Loop

Advanced Simulation Goals and Strategy

- **Goal: Apply modern, high-performance computing techniques to nuclear reactor modeling**
  - Use advanced simulation tools to improve accuracy allowing reduced conservative margins, and improved safety assurance
  - Provide local data needed to enable predictive fuel performance simulations, allowing exploration of broad range of reactor features
  - Understand and reduce uncertainty of computational models
  - Develop user and code interfaces to facilitate design integration and promote optimization of advanced reactors

- **Strategy: Develop flexible, mission-agile toolbox for construction of virtual reactor models**
  - Adopt multi-scale strategy to enable application to problems relevant to industry using a wide range of computing platforms
  - Utilize modular architecture to enable component-wise use by most advanced users or integrated user interface driven application by less advanced users.
  - Develop collaborations with customers to define near term applications/demonstrations

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Fuel Irradiation: Irradiation Testing Program in ATR

	AFC-1	AFC-2	AFC-3	SET-1
Test Strategy	Scoping – Many compositions	Scoping – Focused compositions	Focused compositions	Generic
	Nominal conditions	Nominal conditions	Nominal conditions	Variable conditions
Capsule Type	Drop-in	Drop-in	Drop-in	Instrumented lead
Fuel Types	Metallic Nitrides	Metallic (2 A&B) Oxides (2 C&D)	Advanced Metallic Concepts	Generic
Key Features	Baseline + MA	Baseline + MA + RE	FP control, annular fuel, FCCI barriers, ultra-high burnup	Temperature control/measure-ment; deploy advanced sensors
Time Frame	FY 2003 – FY 2008	FY 2008 – FY 2012	FY 2011 – FY 2017 +	FY 2014 – ?

Past test series (grey) | Test series in progress (white) | Future test series (yellow)

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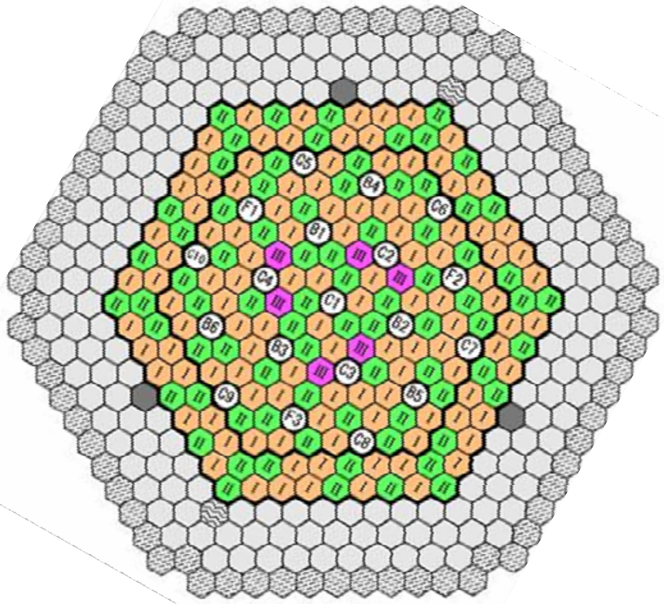
MONJU R&D Collaborations: System Startup Tests

- **The main objective is to obtain unrestricted Monju startup tests data valuable for validating advanced reactor simulation tools**
  - Large amount of americium (~1,5% on the core average) accumulated during the long-term reactor shutdown is valuable addition to existing database
  - The initial startup test data (1994-1995) for clean core is essential
  - Detailed operational response data of plant and equipment in reactor, primary/secondary cooling systems



- **Participation of international experts would be beneficial to both experiment design and analysis**
  - Minimize the biases due to specific simulation tool and physics data to assure more robust experimental results and uncertainty evaluations

MONJU R&D Collaborations: Main Irradiation Challenge

For an effective irradiation facility to support reactor and fuel cycle R&D programs:

What is required:

Stable, well characterized, test spaces, capable of testing fuels & materials from coupon size up to assembly sizes in a neutron environment, characteristic of thermal or fast spectrum nuclear reactors

Key High Level Considerations:

- **Flux Spectrum - model both thermal and fast spectrum reactors**
- **Fuel Pin Coolant environment - water, sodium/lead, gas, molten salt**
- **Flexibility of fuels to be tested - homogeneous/heterogeneous, LEU, plutonium/thorium bearing**
- **Instrumentation – capable of characterizing fuel, clad, coolant temperatures**

Technical Irradiation Requirements:

"Useful to NE Advanced Development Needs"

- **Test Volume:**
  - coupon size up to 100 liters
  - well characterized test space
- **Irradiation Temperature - e.g. ambient up to 300 C – 1000 C**
- **Neutron Energy - thermal to 14 MeV – maximum**
- **Neutron Flux range - peak value of up to 5×10^{15} neutrons s^{-1} cm^{-2}**
- **Displacement per Atom range - few dpa up to 50 dpa per year**

Associated post irradiation examination or international shipping capabilities must also be planned

Summary

- **U.S. Fast reactor R&D is focused on key technologies innovations for performance improvement (cost reduction)**
  - Design Improvements
  - Advanced Structural Materials
  - Advanced Energy Conversion
  - Advanced Modeling and Simulation

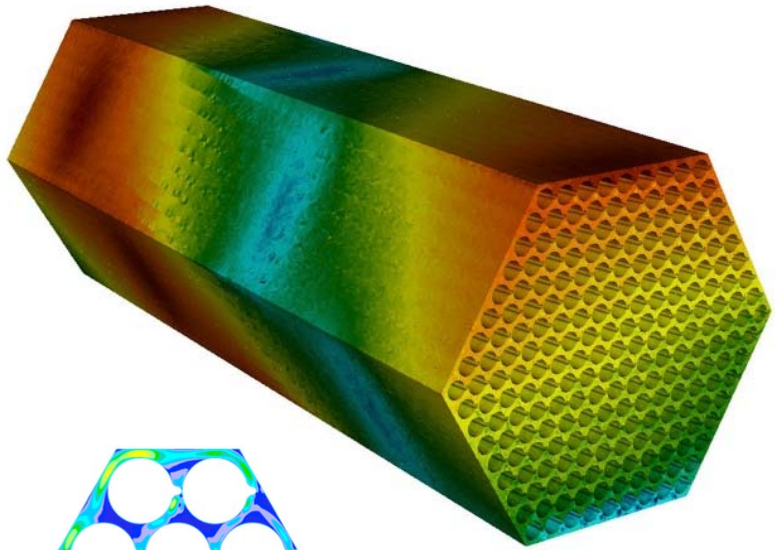
- **Fuel Cycle R&D is also working on fast reactor fuels**
  - Metal alloy fuel irradiation testing

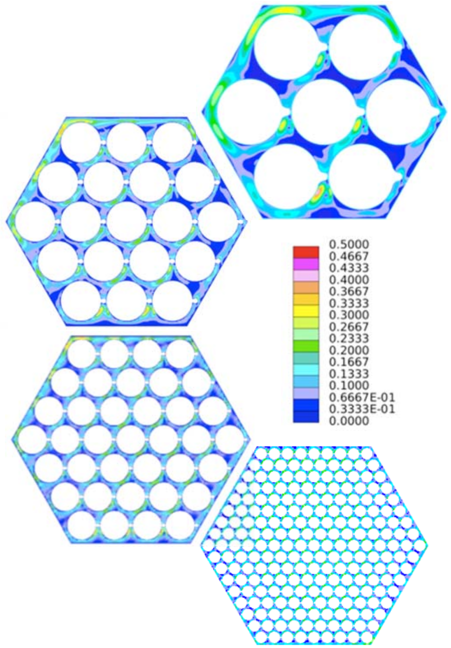
- **Collaboration using Monju can support these R&D activities**
  - Participation in startup testing – generation of validation data
    - *Requires resolution of export control for data sharing*
  - Demonstration of plutonium utilization
  - Well characterized fuels and materials irradiation locations

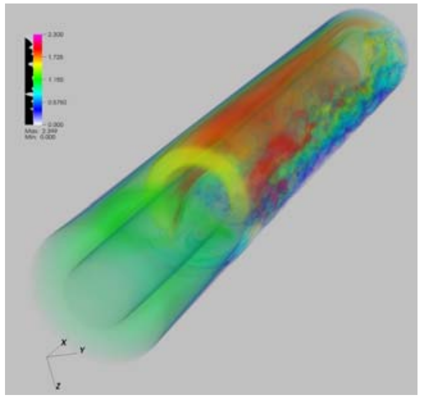
Backup

Major Innovations of NEAMS ToolKit (example)

- **Enables application of high-fidelity CFD tools to large reactor problems**
  - More accurate predictions of temperature and flow effects
  - Reduced reliance on engineering correlations with limited applicability
  - Capability for benchmarking or calibrating lower-fidelity methods
  - Improved understanding of pin bundle flow and heat transfer phenomena







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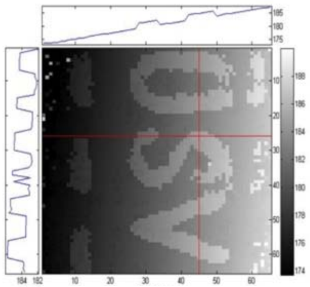
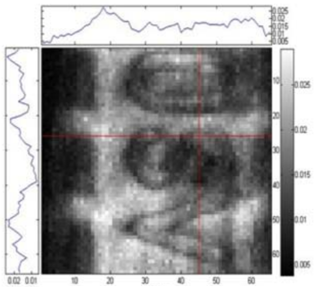
USV Ongoing and Future Works

2nd Generation of USV Test Facility

- *Linear UWT Array*
  - *Fabricate and evaluate linear UWT array*
  - *Develop signal and image processing software*
  - *Demonstrate crack detection/loose-part identification capabilities*
- *Develop brush-type linear UWT Array*
  - *Construct a brush-type waveguide for side-view imaging application*
  - *Develop dry-coupling technique for linear UWT array application*
  - *Develop the imaging algorithm applicable to the linear UWT array*
- *Sodium Test*
  - *Complete new USV test facility for in-sodium tests of linear UWT array (ANL) and phased array transducer (PNNL)*
  - *Demonstrate crack detection/loose-part identification capabilities in sodium*
- *US-Japan Collaboration*

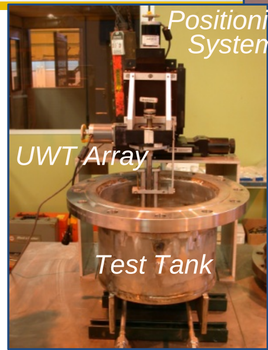


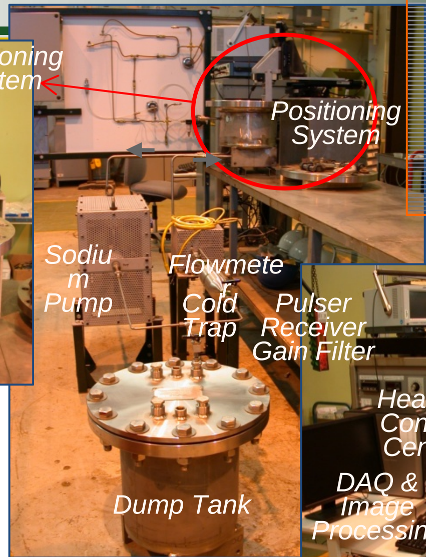
Time-of-Flight

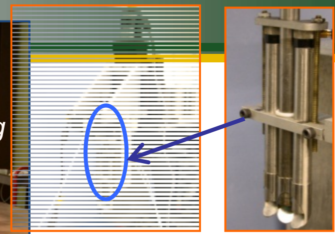


Intensity

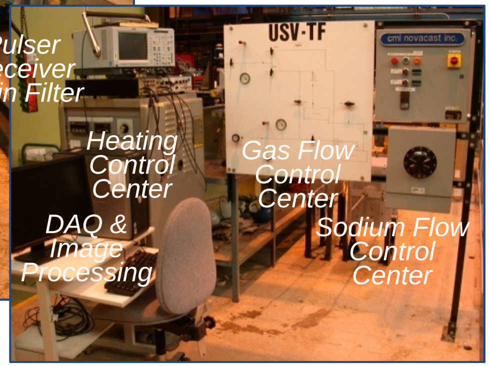
Brush-type Linear UWT Array







UWT Linear Array

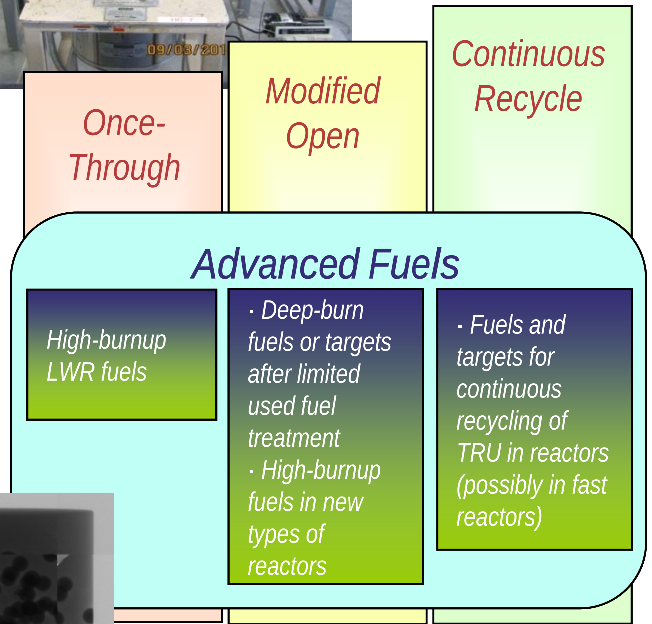


Advantages:

- *Larger opening and tank for linear array*
- *Larger Testing Components/Targets*
- *Easier target and transducer setup and replacement*
- *Add an EM pump (5G/min) and cold trap to circulate and clean sodium*
- *Better temperature control and Higher Operation Temperature (650^{o}C)*
- *Closed-loop design for Safer operation*

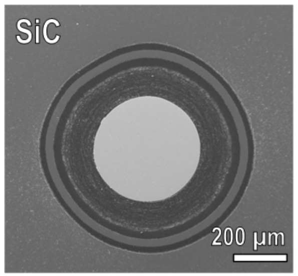
Advanced Fuels and Accident Tolerant LWR Fuels – example of an activity needing significant irradiation related support

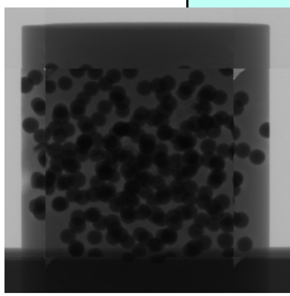
- **Innovative LWR Fuels and Cladding**
  - Better safety performance (e.g. during normal operation, design basis accidents and beyond design basis accidents)
  - Reliability and fuel configurations similar to current fleet
  - Acceptable economics
  - Favorable neutronics and licensing characteristics



- **Advanced fuels in support of closed or partially closed fuel cycles**

- **Advanced fuel fabrication methods with a low degree of losses**





PIE of Legacy Fuels from FFTF & EBR-II

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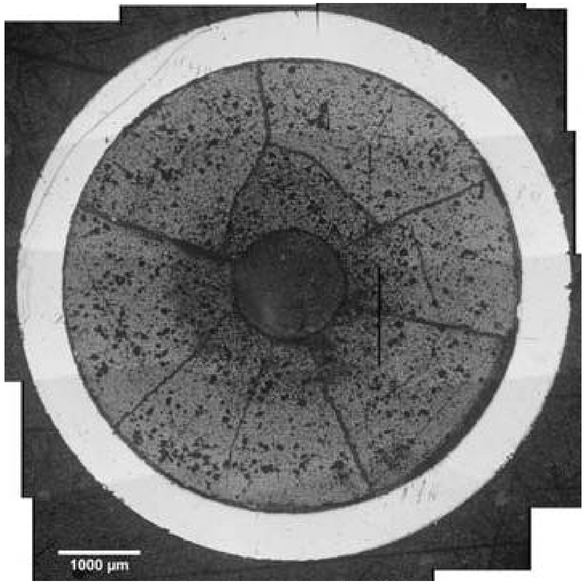
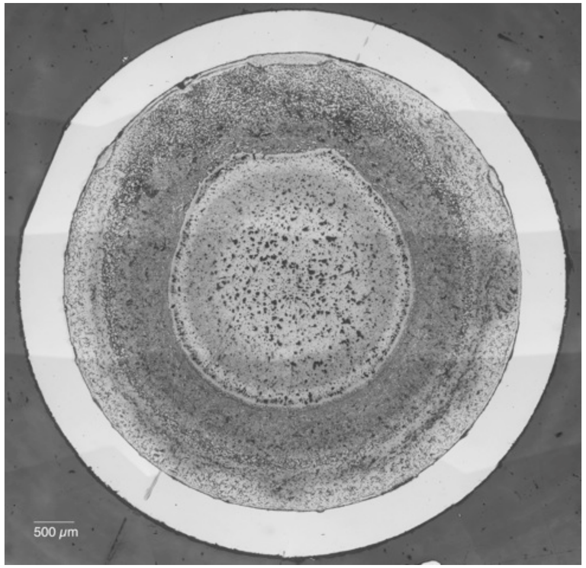
PIE underway on fuel pins from FFTF/EBR-II with <u>relevance</u> to current transmutation mission

- **ACO-3**: ultra-high burnup (>20%), annular MOX fuels from FFTF
- **MFF-3,5**: U-10Zr fuels from FFTF with HT9 cladding (PICT > 600° C)
- **X496**: U-10Zr fuels from EBR-II with low smear density (56%)



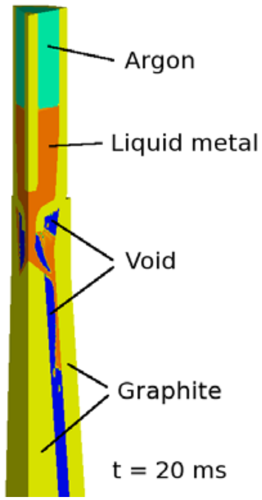
High Burnup MOX Fuel from ACO-3 Experiment in FFTF.

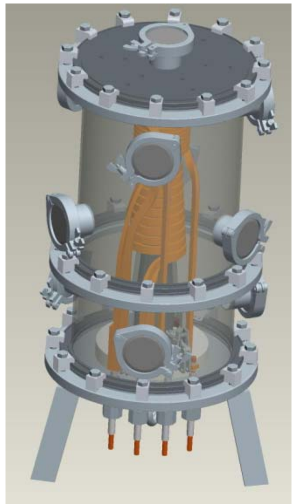


Metallic Fuel with HT9 Cladding Operated at High Temperature from MFF-3 Experiment in FFTF.

Fuel Fabrication Development Challenges

- Minimize/eliminate process losses
- Minimize/eliminate waste streams
- Maximize throughput
- Reduce cost
- Use M/S for development
- Scalable and remote operation
- Flexibility and adaptability
- Meet fuel specification





Motivations for Collaboration on MONJU Startup Test Analyses

- **U.S. and Japan have their own suite of simulation tools for sodium-cooled fast reactor design and analysis, and continues to develop advanced capabilities to reduce prediction biases and uncertainties**
  – All the modeling and simulation tools should be well verified and validated against experiments, in particular to generate information for the regulatory arena, where the ability to accurately and convincingly predict behavior is important
- **MONJU startup tests will provide valuable data for validating the advanced simulation tools which are being developed in U.S. and Japan**
  – In particular, the physics test data of the initial core with relatively large amount of americium (~1.5% on the core average) accumulated during the long-term reactor shutdown will be valuable addition to the existing database
- **Participation of U.S. with U.S. suite of codes would be beneficial to experiment design and analysis**
  – Minimize the biases due to the specific simulation tools and physics data used in processing the raw measurement data

GENIV SFR - GACID Overview

Testing TRU Oxide Fuel Compositions for Monju licensing

- **Step 1: Limited MA bearing fuel preparatory irradiation test in JOYO**
- **Step 2: Pin-scale Cm bearing fuel irradiation test in JOYO and then Monju**
- **Step-3: Bundle-scale MA bearing fuel irradiation demonstration in Monju (removed from current agreement)**

Monju Driver Fuel Assembly

- Monju Core Fuel Assembly:
  Pin Diameter : 6.5 mm
  Pellet Diameter : 5.4 mm
  Number of Pins : 169/Assbly
  Core Height : 930 mm
  Upper Blanket : 300 mm
  Lower Blanket : 350mm

- MA irradiation test:
  MAs (especially Np & Am) can be mixed with MOX fuel pellet, which enables engineering-scale demonstration of MA burning (transmutation) in the fast neutron power plant.
  Some modifications of the fuel design might be necessary due to the mixed MA.