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Nuclear Safety and DOE Authorization

Jason Andrus, Alison Wells

04/23/2024

Nuclear Safety Overview

Organizational Mission to Assist in the Development and Deployment of Reactor Experiments in a Safe and Compliant Manner

Engage with Reactor Designers to Support Design Interfaces and Develop Safety Basis Documents

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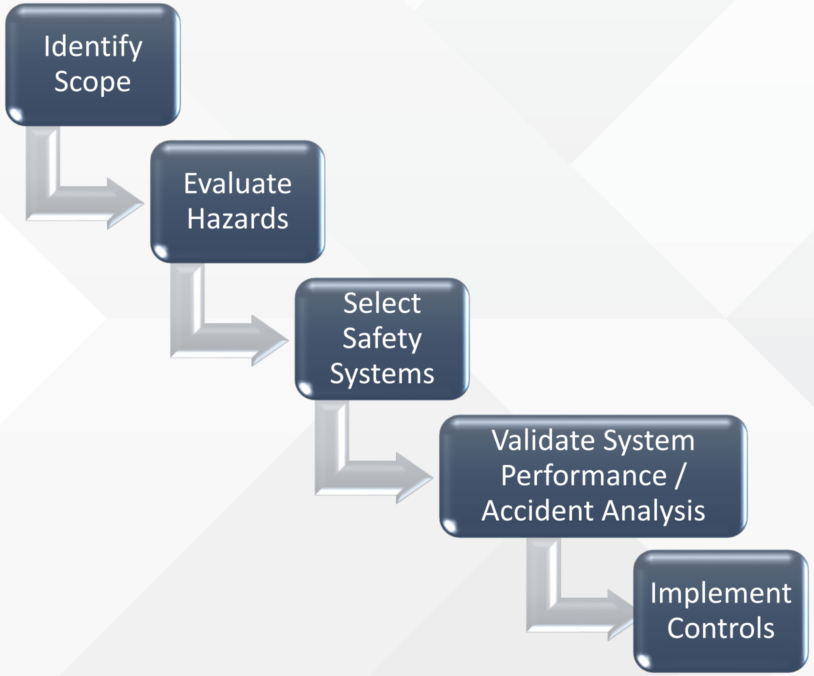
Role of Safety and Authorization

- DOE-STD-1189-2016
  - Process Standard – Stage Gates
  - Establishment of Regulatory Requirements
  - Clarity of Path Forward
  - Integration of Safety and Design
  - Reduce Project Risk by Establishing Regulatory Certainty through formal regulatory approvals.
- Flexibility in risk analysis and presentation methods.
  - ANSI/ANS 15.21, DOE-STD-3009, LMP/TICAP



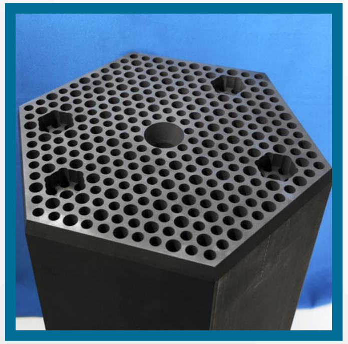
Major Updates

Long Lead Procurement Tailoring

- DOE Letter Allows for Applying a Graded Approach
  - QA Program Implementation
  - DOE Safety Submittals
- MFC-ADM-0200 Provides Details

DOE Guidance on Autonomous Controls

DOE Clarifying Guidance on SSC Classifications



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Best Practices

- Communications and Briefings
- Regular Touch-ups at All Appropriate Levels
- Early Identification and Collaborative Resolution of Challenges
- Clear Definition of Boundaries and Transferal of Roles
- QA Program Implementation

Lessons Learned

- Intentional use of Digital Tools
- Early Identification and Alignment on Specific Technical Challenges and Resolution Pathways
- Level of Maturity for Deliverables
- Establishment of Detailed Schedules and Visibility to All Affected Stakeholders
- Early Alignment and Expectations for Design Phases
- Interface Details Have to be Thought Through and Documented Well

Questions?

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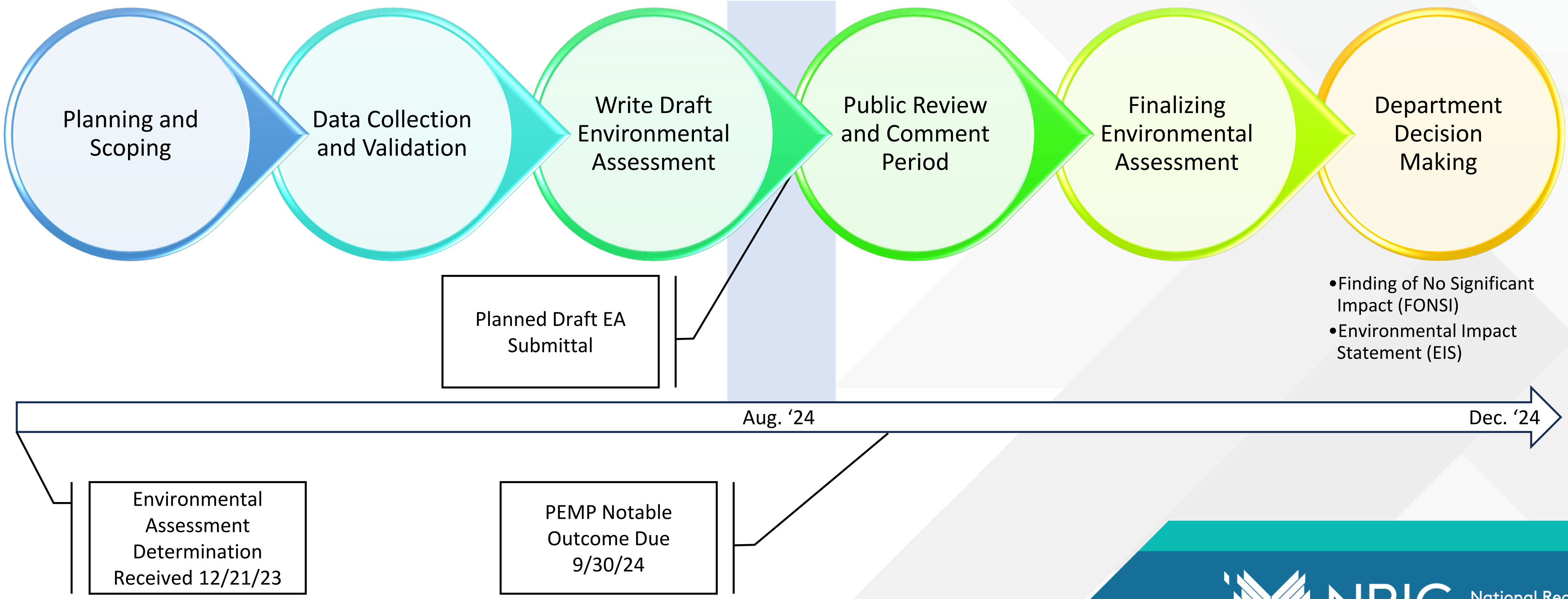
National Environmental Policy Act (NEPA) Evaluation for Demonstration of Microreactor Experiment (DOME) Testbed

Jenifer Nordstrom

4/23/2024

Environmental Assessment Process



Environmental Assessment Process Description

Planning and Scoping

March/April ‘24

- Develop Schedule
- Define EA team
- Modeling, Information, Data Call and Plan
- Draft EA scoping checklist
- Define alternatives
- Internal scoping meeting

Data Collection and Validation

March/April ‘24

- Review Previous Data
- Gather and Validate Historical Data
- Review Existing Environmental Documentation
- Create New Models as Needed

Environmental Assessment Process Description

Write Draft Environmental Assessment

April – August '24

- Final EA Scoping Checklist
- Prepare and Compile Preliminary Draft EA document
- Department of Energy (DOE) Review of Draft EA
- DOE Comment Incorporation
- Release Public Notices
- **DOE Formally Receives Draft EA**

Public Review and Comment Period

September '24

- Release Draft EA
- Public Review and Comment Period
- Evaluate Public Comments and Prepare Response Document

Environmental Assessment Process Description

Finalizing Environmental Assessment

October – November ‘24

- Prepare and Compile Preliminary Final EA
- Review Period
- Comment Incorporation or Resolution
- Release Public Notices
- Release Final EA

DOE Determination

December ‘24

- DOE makes determination
    - FONSI
    - EIS

Plant Parameter Envelope (PPE)

Specific advanced reactor demonstrations are unknown. Idaho National Laboratory (INL) is developing a Plant Parameter Envelope (PPE)

A set of reactor and owner-engineered parameters that set the bounding characteristics of a reactor that may be demonstrated in DOME

PPE values serve as a surrogate design for the Environmental Assessment

Environmental Review Process for Advanced Reactor Demonstrations in DOME

Developer Proposes Demonstration

- Proposed reactor parameters are reviewed by INL NEPA team and compared to the bounding parameters of PPE and environmental impacts evaluated in the DOME EA

If covered by the DOME EA

- Following DOE concurrence, INL issues a NEPA Determination that the demonstration is covered by the DOME EA, concluding the NEPA process

If NOT covered by DOME EA

- Project will need to complete a Supplement Analysis or project specific EA/EIS

Questions?

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Startup Physics Testing of Advanced Reactors

A Survey of Historical Practices

Samuel E. Bays

04/23/2024

Scope

- Document the startup physics testing from initial fuel loading to ascension to full power for historical advanced reactor programs.
  - What was measured?
  - Why was it measured?
  - How was it measured?
  - How well did measurements agree with predictions?

- Provide broad coverage over advanced reactor types:
  - System for Nuclear Auxiliary Power (SNAP10A)
  - Molten Salt Reactor Experiment (MSRE)
  - Ft. St Vrain (FSV)
  - High Temperature engineering Test Reactor (HTTR)
  - Experimental Breeder Reactor – II (EBR-II)
  - Superphénix

What is startup physics testing?

- Startup physics testing is a set of measurements made prior to normal operation of all reactors and is a normal part of reactor commissioning.
- These tests verify that the as-built reactor will operate as it was designed, including important safety and hazard mitigation features.
- Structures, systems, and components (SSC) are tested when the reactor is at a power level sufficiently low that reactor safety is not reliant on the successful demonstration of the SSC to perform its safety function.
- The startup physics test plan is organized into a series of hold points of increasing power, temperature, and pressure.

Startup physics testing satisfies requirements set by regulations

- 10 CFR 50.43(e)(1),
  - the applicant's license will be approved if performance of each safety feature of the design has been demonstrated through either analysis, appropriate **test** programs, experience, or a combination thereof

- 10 CFR 52.47(b)(1),
  - The proposed inspections, **tests**, analyses, and acceptance criteria that are necessary and sufficient to provide reasonable assurance that, … that incorporates the design certification has been constructed and will be operated in conformity with the design certification

- 10 CFR 830.3 [definitions: surveillance requirements],
  - requirements relating to **test**, calibration, or inspection to ensure that the necessary operability and quality of safety SSCs and their support systems required for safe operations are maintained …

Measurements common to all advanced reactors studied

- Inverse multiplication (1/M)
  - Typically going critical at the critical mass.
- Quantification of control rod (or drum) reactivities.
- Reactor power [and distribution] using in-core / ex-core detectors.
- Temperature and power coefficients of reactivity.
- Power and temperature response to changes in coolant flow.

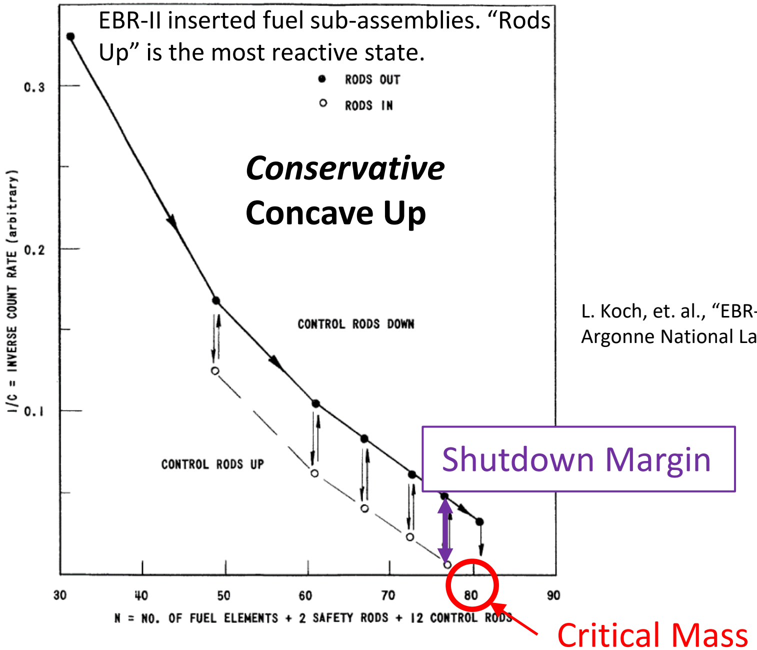
Notable observations

- All reactors studied (except Fort St. Vrain) used the 1/M method to measure critical mass with all control rods removed.
- All reactors used super-critical methods for measuring control rod/drum worths. Augmented by subcritical measurements.
- All reactors evaluated control rod resonance interference.
- All reactors measured flux/power distribution using in-core activation dosimeters or neutron flux detectors.

Initial loading to critical

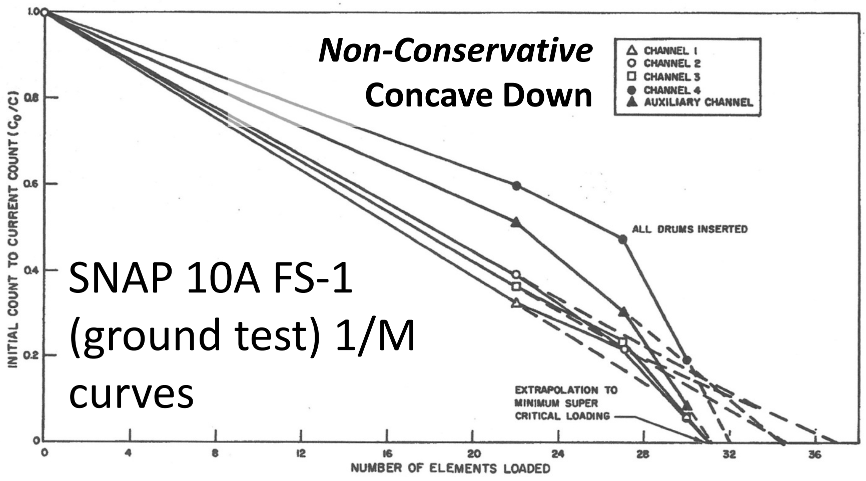
- The 1/M approach to critical process ensures the correctness of: modeling and simulation, the fuels and materials manufacturing, the reactor configuration, and the instrumentation and control (I&C).

- Concave up conservatively predicts critical mass.
- Concave down can result from too large of fuel addition or poor field of view between source and detector.



EBR-II 1/M curves with and without control rods inserted.

L. Koch, et. al., "EBR-II Dry Critical Experiments", Argonne National Laboratory, ANL-6299, (1961)



SNAP 10A FS-1 (ground test) 1/M curves

R. Gimera and R. Johnshon, "SNAP10A Reactor Quarterly Progress Report", Atomics International, NAA-SR-9594, (1964).

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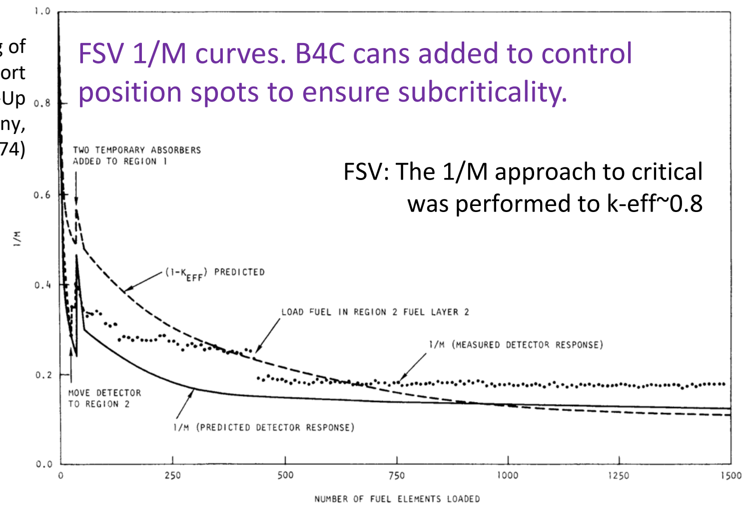
Ex-core detector miscalibration

- FSV: A 2nd 1/M measurement with the core fully loaded was performed. Inverse multiplication measured as a function of control rod position revealed an ex-core detector “de-calibration” effect.
  - Later attributed to the power in outer core fuel columns being suppressed by control rod motion disproportionately to the average reactor power. Most of the flux entering ex-core detectors originates only in outer core fuel columns.

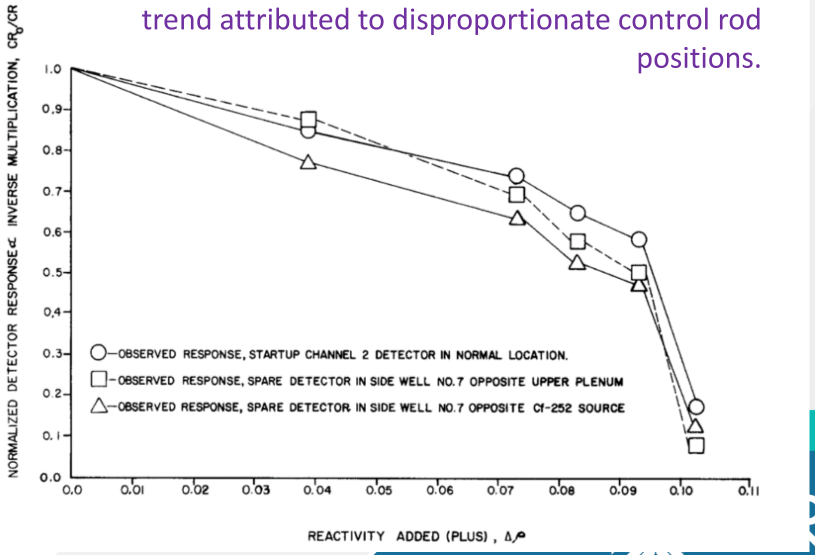
A. Marshal and J. Brown, “Loading of Fuel and Reflector Elements in the Fort St. Vrain Initial Core (Results of Start-Up Test A-1)”, General Atomic Company, GA-A13101, (1974)



FSV 1/M curves. B4C cans added to control position spots to ensure subcriticality.

FSV: The 1/M approach to critical was performed to k-eff~0.8

FSV 1/M curves from a fully loaded core. Concave down trend attributed to disproportionate control rod positions.



H. Olson et. al., “The Fort St. Vrain High Temperature Gas-cooled Reactor: IX. Rise-to-Power Physics Tests”, Nuclear Engineering and Design, vol. 76, pp 71-77, (1983)

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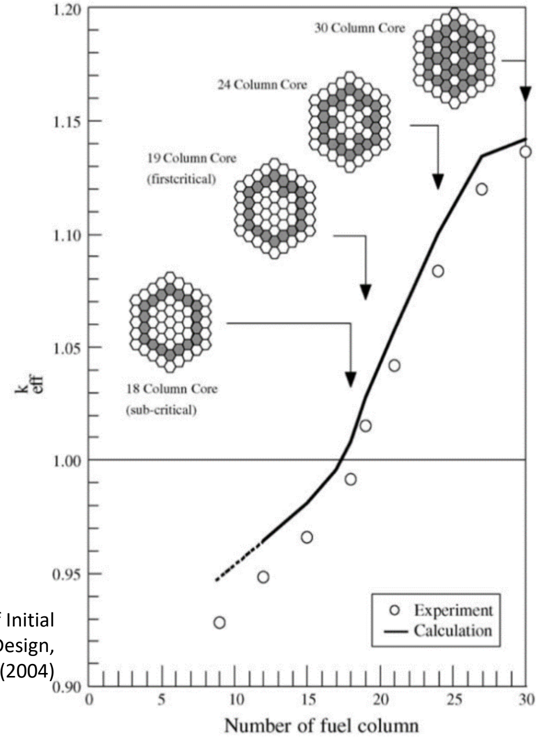
Miss-prediction of critical mass

- HTTR: The 1/M approach to critical revealed a different critical mass than predicted by both nodal diffusion and Monte Carlo codes.
  - Later attributed to poorly characterized nitrogen impurities in the graphite blocks and boron impurities in the graphite dummy blocks.

- Critical number of fuel columns was initially predicted to be 16±1 by both deterministic and Monte Carlo codes.

- The actual number of columns needed for criticality was 19.

N. Nojiri, et. al., "Characteristic Test of Initial HTTR Core", Nuclear Engineering and Design, vol. 233, pp 283-290, (2004)



- Reevaluation of the nitrogen content of the graphite, the boron impurity in the graphite dummy blocks, the nuclear data library, and coated fuel particle heterogeneity treatment in the design codes resulted in an updated predicted value of 18 ± 1 columns.

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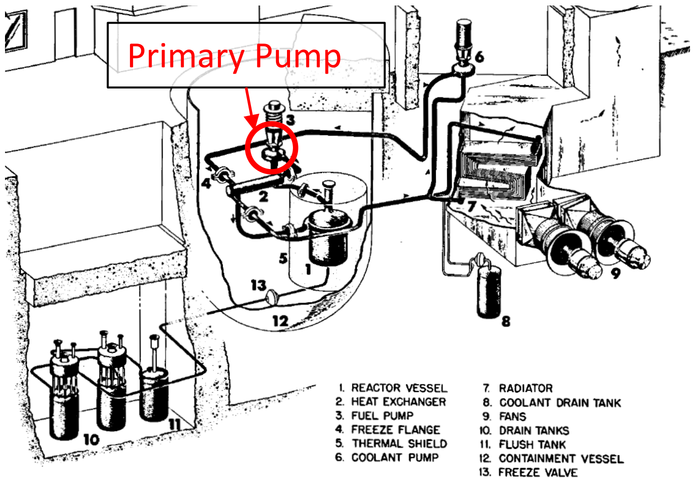
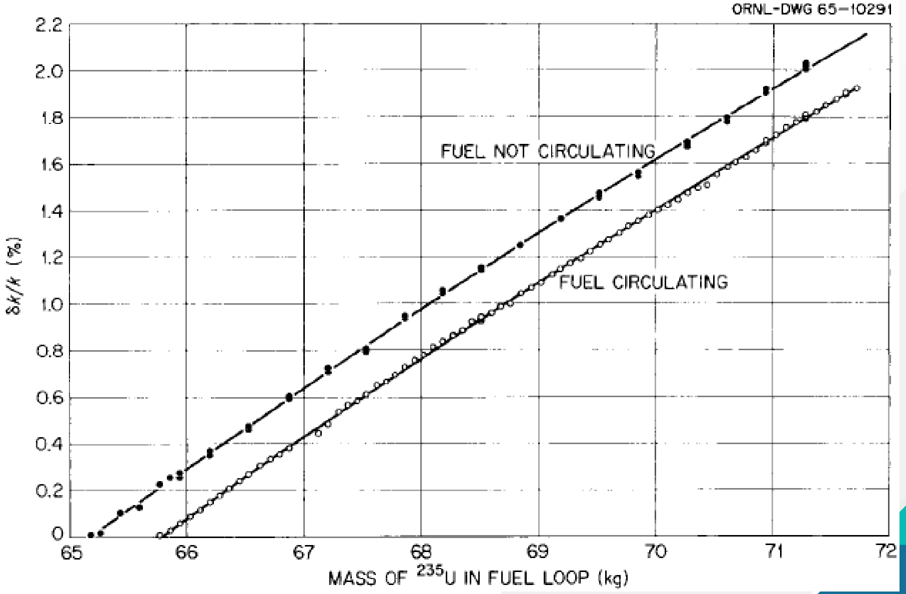
The role of delayed neutron precursors in molten salt reactors

- The MSRE critical control rod position was measured with the pump on and off after every 4th fuel capsule addition.
- The difference in core reactivity is due to the delayed neutron precursors, which would normally contribute to buffering prompt neutron changes in the core, decay outside of the core as the fuel salt carries them through the primary coolant piping.

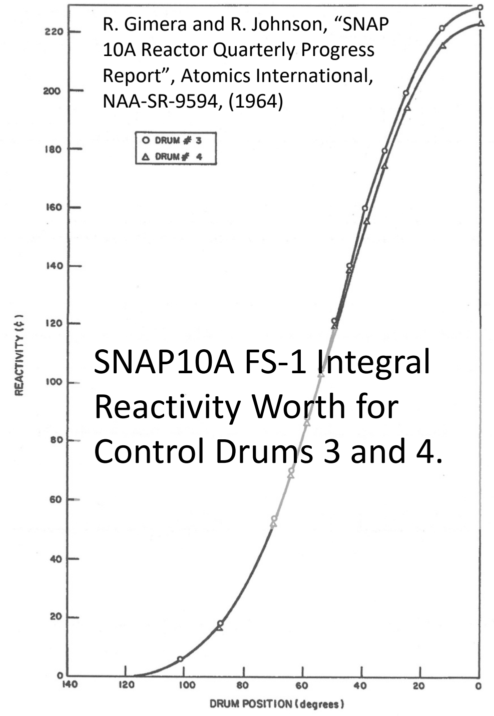




B. Prince, et. al., "Zero-Power Physics Experiments on the Molten-Salt Reactor Experiment", Oak Ridge National Laboratory, ORNL-4233, (1968)

Control element worth

- These measured worths are typically used in routine plant operation rather than the calculated worth curves.
- All reactors measured worth starting from a critical configuration and inserting control rod/drum in step increments to make the reactor super-critical.
  - Step insertions of control rod create a stable period that then can be converted to a reactivity using the in-hour equation.
    - i.e, the rod bump method.
  - Accurate values for prompt neutron lifetime and delayed neutron fractions needs to be available. The FSV measured these parameters at low power.



R. Gimera and R. Johnson, "SNAP 10A Reactor Quarterly Progress Report", Atomics International, NAA-SR-9594, (1964)

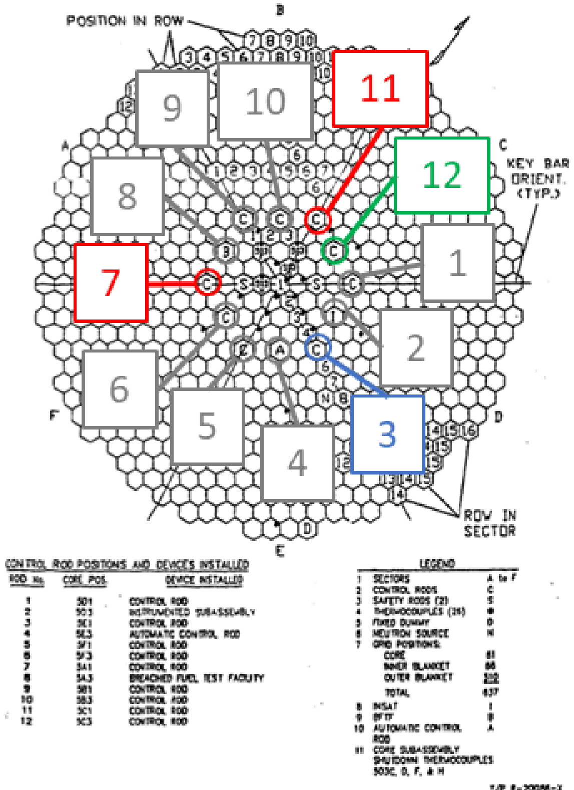
SNAP10A FS-1 Integral Reactivity Worth for Control Drums 3 and 4.

$$\rho = \frac{l^*}{T_P} + \sum_{i=1}^{6} \frac{\beta_i}{1 + \lambda_i T_P}$$

Where ρ is reactivity, l* is the mean neutron generation time. Tp is the stable period. βi is the ith delayed neutron fraction, λi is the decay constant for the ith delayed neutron precursor group.

Control rod interference effects

- Rod-shadowing can change the reactivity of the control rod. Shadowing effects are brought on by the flux depression and/or neutron spectrum influence of neighboring control rods.



REACTOR SUBASSEMBLY ARRANGEMENT

ROD SHADOWING EFFECT

Rod Positions (in.)			Count Rates (counts/min)	Δk (Ih)
No. 12	No. 7	No. 11		
0	14	14	Critical	0
0	0	14	6924	128
0	14	0	7338	120

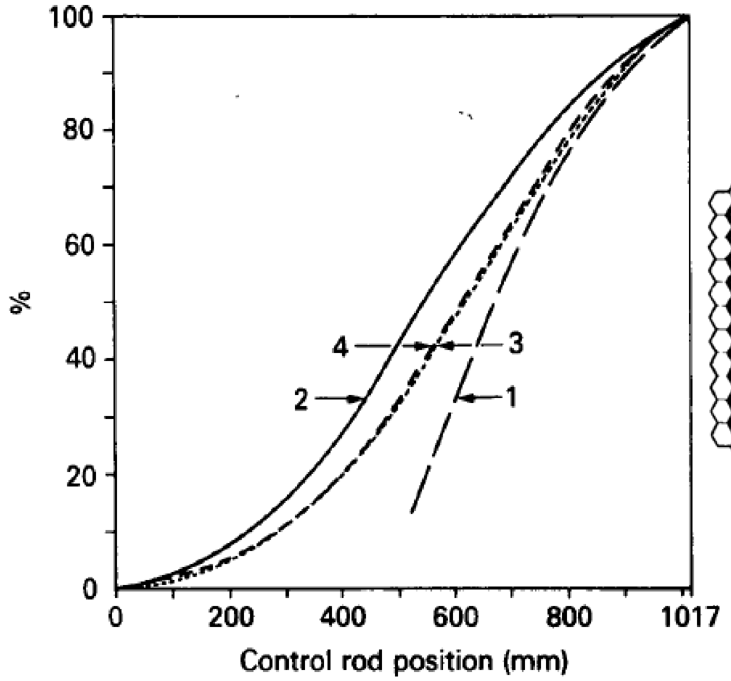
The worth of two EBR-II control rods was worth 6% less when they were withdrawn adjacent to each other.

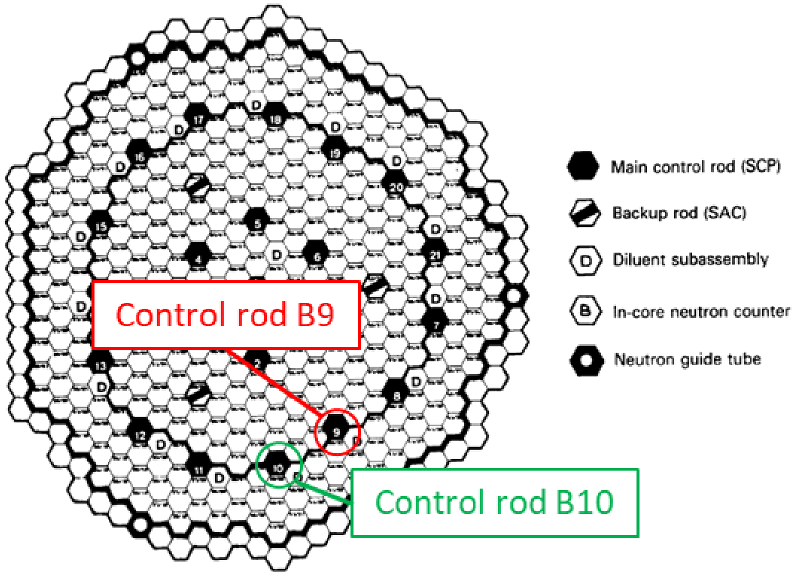
In EBR-II the control elements were fueled sub-assemblies that would be inserted into the core. A position of 0-inch is fuel not-inserted or negative reactivity. A position of 14-inch is fuel inserted or positive reactivity.

F. Kirn, et. al., “EBR-II Wet Critical Experiments”, Argonne National Laboratory, ANL-68684, (1964)

Super-critical versus sub-critical measurements

- Control rod/drum worth measurements should be made as close the critical state as possible to mitigate flux distortion effects, e.g., the FSV ex-core detector de-calibration issue.
- Sub-critical methods can provide supporting information but are generally not as sensitive to rod interference effects.





Reactivity worth of Superphénix control element B9 when balanced against B10 as measured by: half-balancing (1), full-balancing (2), MSM (3), temperature compensation (4).

J. Gauthier, et. al., "Measurement and Predictions of Control Rod Worth", Nuclear Science and Engineering, vol. 106, pp 18-29, (1990)

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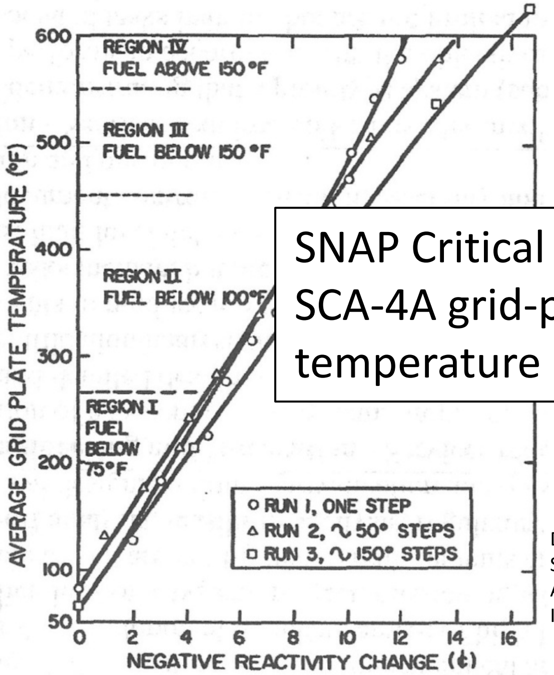
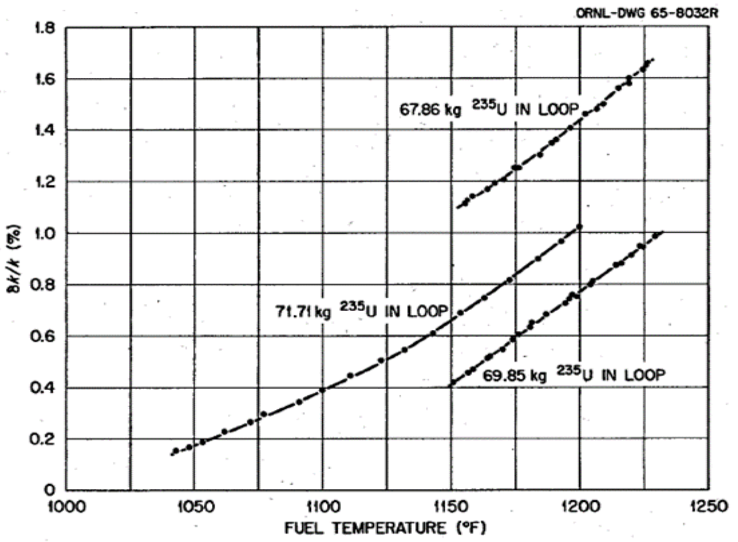
Isothermal temperature coefficients

- The ITC measurement should be conducted in a way that exercises all relevant Doppler, coolant density, and thermal expansion effects in core, coolant, and structures.
- The ITC should be made below the point of added heat, i.e., reactor power is equivalent to energy lost to ambient.



SNAP Critical Assembly, SCA-4A grid-plate temperature coefficient.

D. Clifford, "Final Report on the SNAP10A Prototype Critical Assembly Studies", Atomics International, NAA-SR8613, (1964)



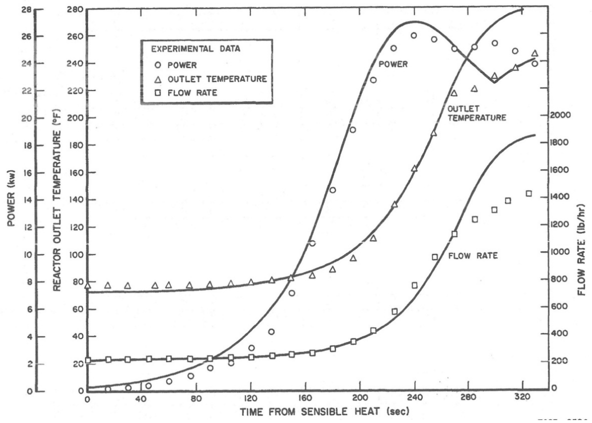
MSRE reactivity as a function of fuel salt temperature.

B. Prince, et. al., "Zero-Power Physics Experiments on the Molten-Salt Reactor Experiment", Oak Ridge National Laboratory, ORNL-4233, (1968)

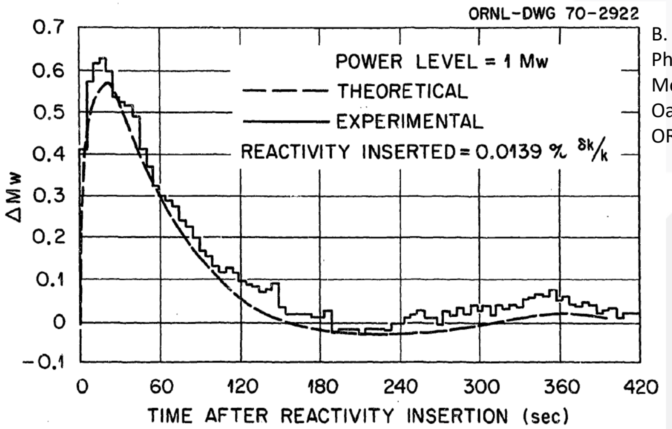
Transient response

- Reactors with self-regulating, inherent, or passive temperature feedback safety features were tested for design basis transients.
- These are transients at low power. Power-to-flow ratio is controlled to produce similar temperature response as at full-power but not temperatures high enough to challenge safety limits.

R. Johnson, "SNAPTRAN 10A/2 Kinetics Testing and Destruct Reactor Experiments" Atomics International, NAA-SR-11906, (1966)



SNAP10A FS-3 Startup Transients



MSRE step reactivity insertion at 1 MWth.

B. Prince, et. al., "Zero-Power Physics Experiments on the Molten-Salt Reactor Experiment", Oak Ridge National Laboratory, ORNL-4233, (1968)

Self-stabilization test at zero power in Superphénix.

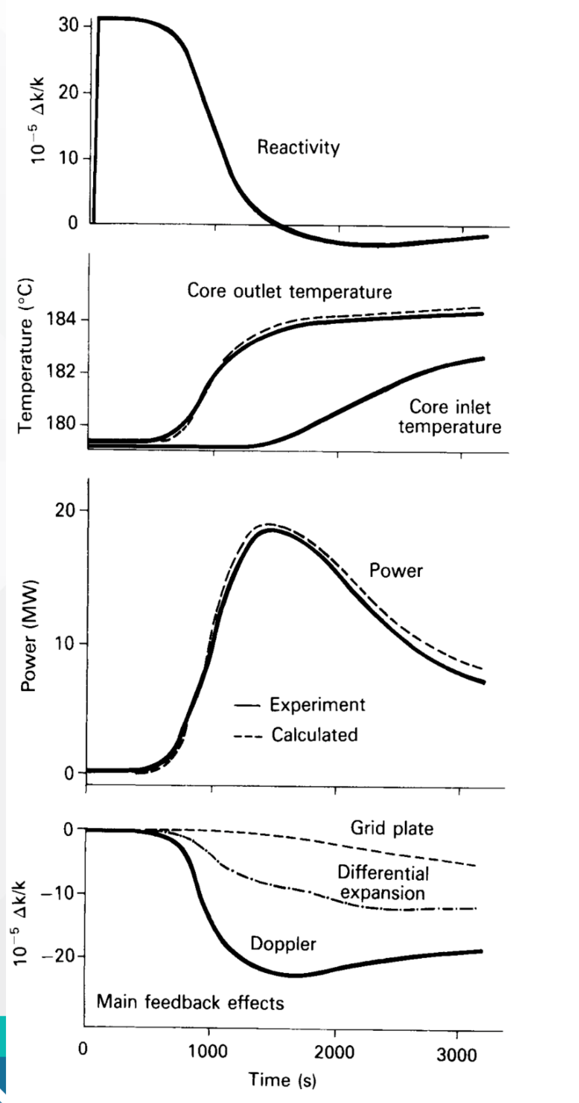
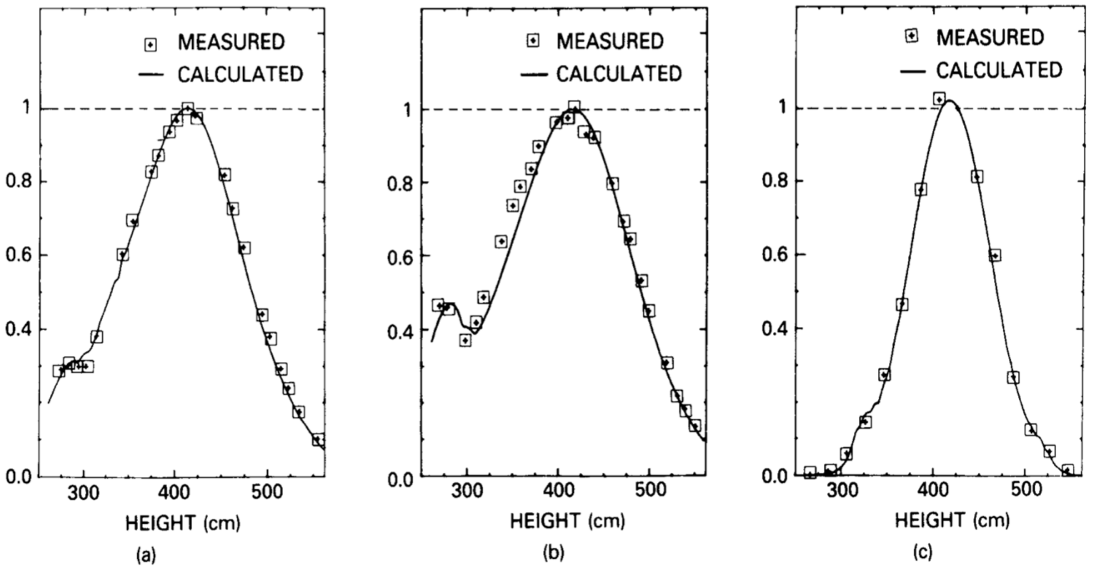


Fig. 3. Self-stabilization test (control rod raised by 30 × 10^{-5} $\Delta k/k$ at zero power).

Flux (power) mapping

- Radial and axial flux (or power) distribution measurements assess the predictions of the hot-channel in the core physics calculations.
  - This was done using activation wires (or foils), by in-core flux detector traverses, or removing the fuel after irradiation for ex-core gamma scanning.



J. Cabrillat and M. Martini, "Power and Neutron Flux Distributions in the Core and Shielding", Nuclear Science and Engineering, vol. 106, pp 37-44, (1990)

Axial profiles in the radial shields of Superphénix: (a) fission of U-235 in row 18, (b) capture of gold in row 20, and (c) Ni(n,p) reaction in row 14 .

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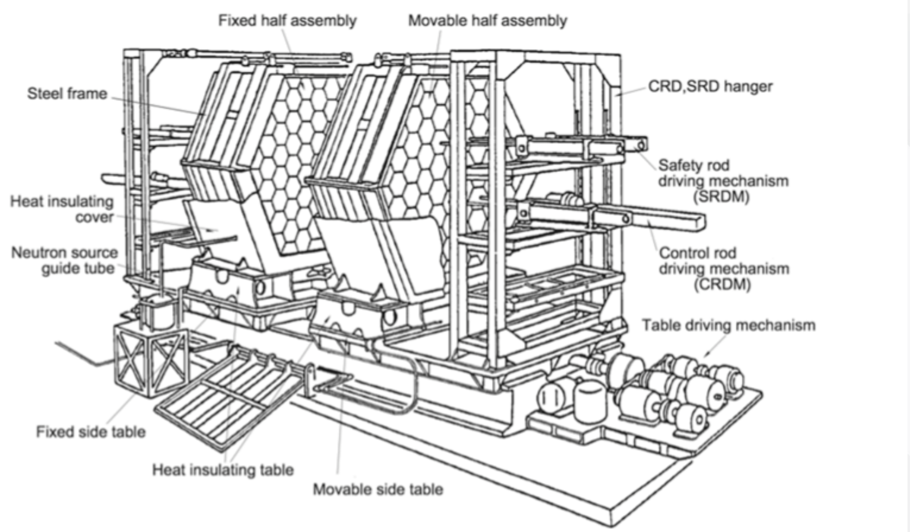
The role of zero power critical assemblies (ZPCA)

- SNAP10A, EBR-II, and HTTR benefited from extensive zero power critical assembly tests which were prototypic of the actual reactor.
- Though not actually part of reactor commissioning, ZPCAs sometimes provided direct predictions of the startup physics measurement.

- ZPCAs have high accessibility.
  - Less occupational exposure hazards.
  - No expensive vessel penetrations.
  - Can directly attach electrical heaters.
  - Can use many more activation dosimeters.

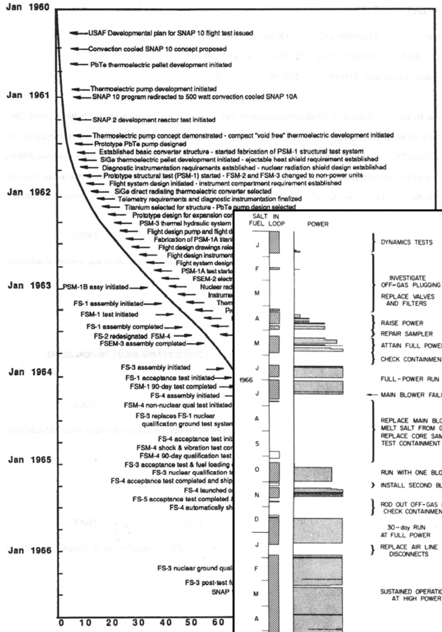


Very High Temperature Reactor Critical (VHTRC) supported HTTR

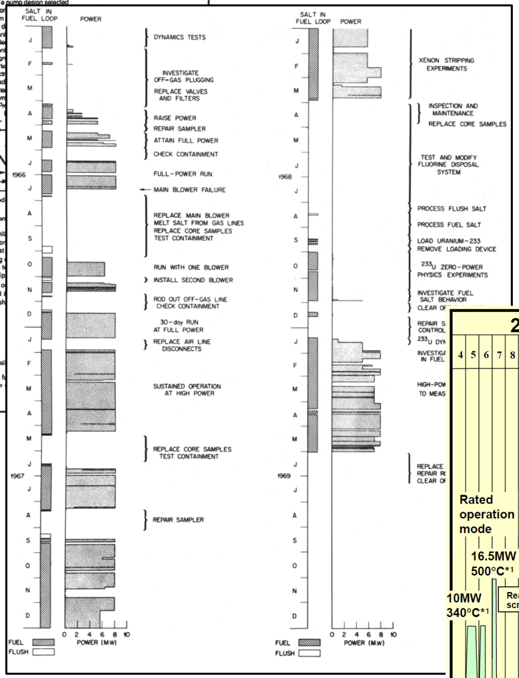
H. Yasuda, et. al., "Construction of VHTRC", Japanese Atomic Energy Institute, JAERI-1305, (1987)

Questions?

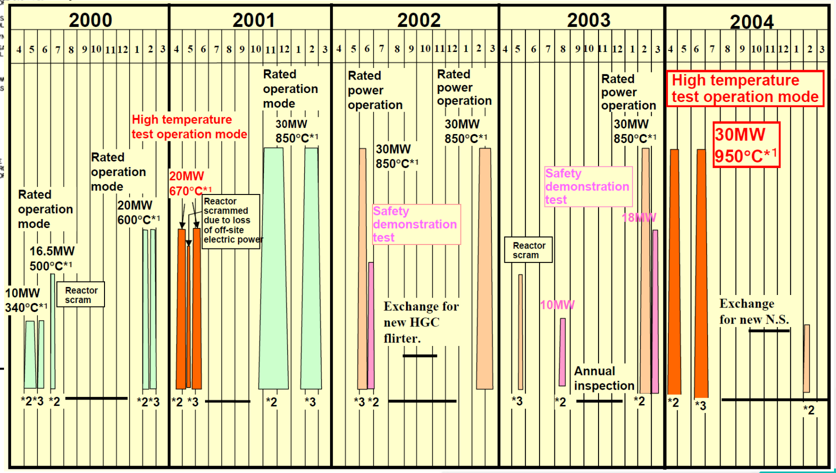
SNAP10A Test Program



SNAP10A Test Program



HTTR Test Program



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