



Presentations for June 14, 2018 Public Meeting Regulatory Improvements for Advanced Reactors

In order of discussion, the meeting included the following topics and presentations

- 1) NRC Slides
 - Opening / Outline
 - Licensing Modernization and Request to Identify Other Needed Guidance
- 2) Rightsizing Environmental Reviews
- 3) Emergency Planning Rulemaking (Small Modular Reactors and Other New Technologies)
- 4) DOE/ANL – Metallic Fuel Data and Qualification of Legacy Data
- 5) INL/EPRI – Limited Scope Topical for TRISO Fuel
- 6) ORNL – Fuel Qualification for Molten Salt Reactors





Public Meeting on Possible Regulatory Process Improvements for Advanced Reactor Designs

June 14, 2018

Telephone Bridge
(888) 793-9929
Passcode: 1811593



Public Meeting

- Telephone Bridge
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- Opportunities for public comments and questions at designated times

Outline

- Introductions
- Rightsizing Environmental Reviews
- Emergency Planning Rulemaking
- Fuel Qualification – Metal Fuel & Legacy Data
- Fuel Qualification – TRISO fuel
- Fuel Qualification – Molten Salt Reactors
- Fuel Cycle & Transportation
- Licensing Modernization Project Guidance
 - Other Needed Guidance ?
- Policy Issues, Future Meetings, Public Discussion

Rightsizing Environmental Reviews

Environmental Slides

- [Joe Williams](#)
- [Jack Cushing](#)
- [Michelle Moser](#)

Break

Meeting/Webinar will begin shortly

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Emergency Planning Rulemaking

[EP Rulemaking](#)

Lunch

Meeting/Webinar will begin at 1:00 pm ET

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Fuel Qualification – Metal Fuel Data Base & Legacy Data



ANL-ART-76

Pre-Licensing Evaluation of Legacy SFR Metallic Fuel Data

Nuclear Engineering Division

By: A. M. Yacout and M. C. Billone

<https://www.osti.gov/biblio/1418818>



ANL/NE-16/17, Rev. 0

Quality Assurance Program Plan for
SFR Metallic Fuel Data Qualification

Nuclear Engineering Division

<https://www.osti.gov/biblio/1418820>

[Metal Fuel Slides](#)

Fuel Qualification – TRISO

[TRISO Slides](#)

Break

Meeting/Webinar will begin shortly

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Fuel Qualification – Molten Salt

[Molten Salt Slides](#)

Fuel Cycle & Transportation

Updates: NRC, NEI, DOE

Licensing Modernization Project Guidance Document & Other Needed Guidance

[LMP Draft M](#) (ML18150A344)

[List of Topics](#)

[Guidance Slides](#)

Policy Table, Future Meetings & Public Discussion

Policy Table

Most Recent Version

[ADAMS Acc. No. ML18130A949](#)

Future Stakeholder Meetings Topics ?

July 26	
Sept 13	
Oct 25	
Dec 13	

ACRS Schedule (tentative)

Date	Committee	Topic
June 19	Sub	RIPB Guidance
Aug 22	Sub	EP Rulemaking
Oct	Full	EP Rulemaking
Oct 30	Sub	RIPB Guidance
Dec 6	Full	RIPB Guidance
2019		??

Public Comments / Questions



Licensing Modernization Project

(events, classification, PRA, defense in depth)

&

Other Needed Guidance Development



Licensing Modernization Project



Modernization of Technical Requirements
for Licensing of Advanced Non-Light Water Reactors

Risk-Informed Performance-Based Guidance
for Non-Light Water Reactor Licensing Basis Development

WORKING DRAFT

Draft Report Revision M

Document Number
SC-29980-xx Rev M

Topics List

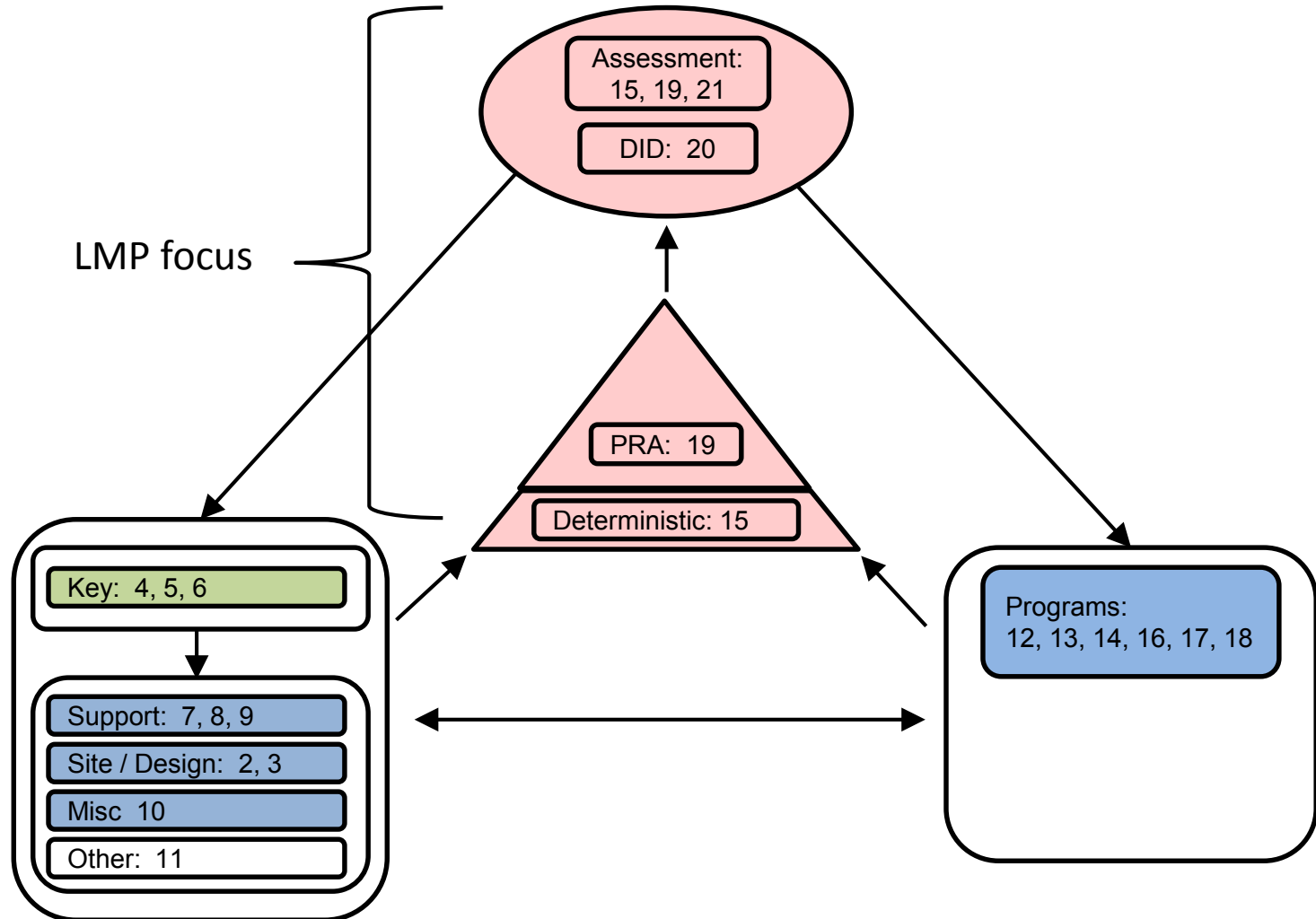
- Glossary/Terminology
- Analyses of consequences
- External hazards
- Flexibility
 - Maximum hypothetical accident
- Multi-module/multi-source
- AOO F-C Target (e.g., Part 20)
- Relationship to EPZ Proposals
- Scope of draft Regulatory Guide

- Selection of Licensing Basis Events
 - Role of PRA
- Safety Classification and Performance Criteria
- Evaluation of Defense in Depth Adequacy

ADAMS Accession No. ML18150A344



Informing Content of Applications (scope and level of detail)



Draft Regulatory Guide

- Draft Regulatory Guide (DG)
- *Guidance for a Technology-Inclusive, Risk-Informed, Performance-Based Approach to Inform the Content of Applications for Licenses, Certifications, and Approvals for Non-Light Water Reactors*
- Tentative Timeline:

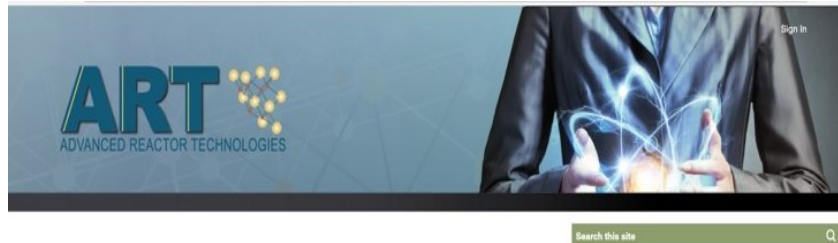
June 19	ACRS SC Meeting
mid-August	First Draft RG
September 28	Complete: LMP Guidance, draft RG, draft SECY
October 30	ACRS SC Meeting
December 6	ACRS FC Meeting
Mid-December	Issue draft RG
Early 2019	Complete SECY
TBD 2019	Final Regulatory Guide

Need to Identify & Prioritize Other Guidance Documents Needed for Advanced Reactors

NUREG-1368

NUREG-1226

Development and Utilization of the NRC Policy Statement on the Regulation of Advanced Nuclear Power Plants



Preapplication Safety Evaluation Report for the Power Reactor Innovative Small Module (PRISM) Liquid-Metal Reactor

Final Report

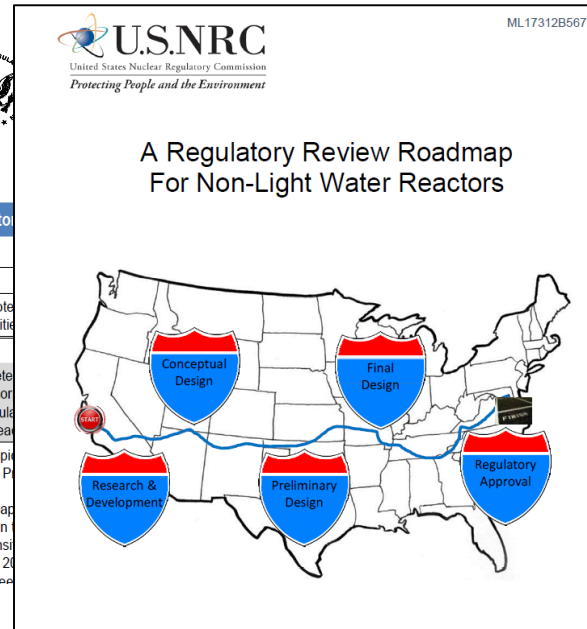
U.S. Nuclear Regulatory Commission

Office of Nuclear Reactor Regulation

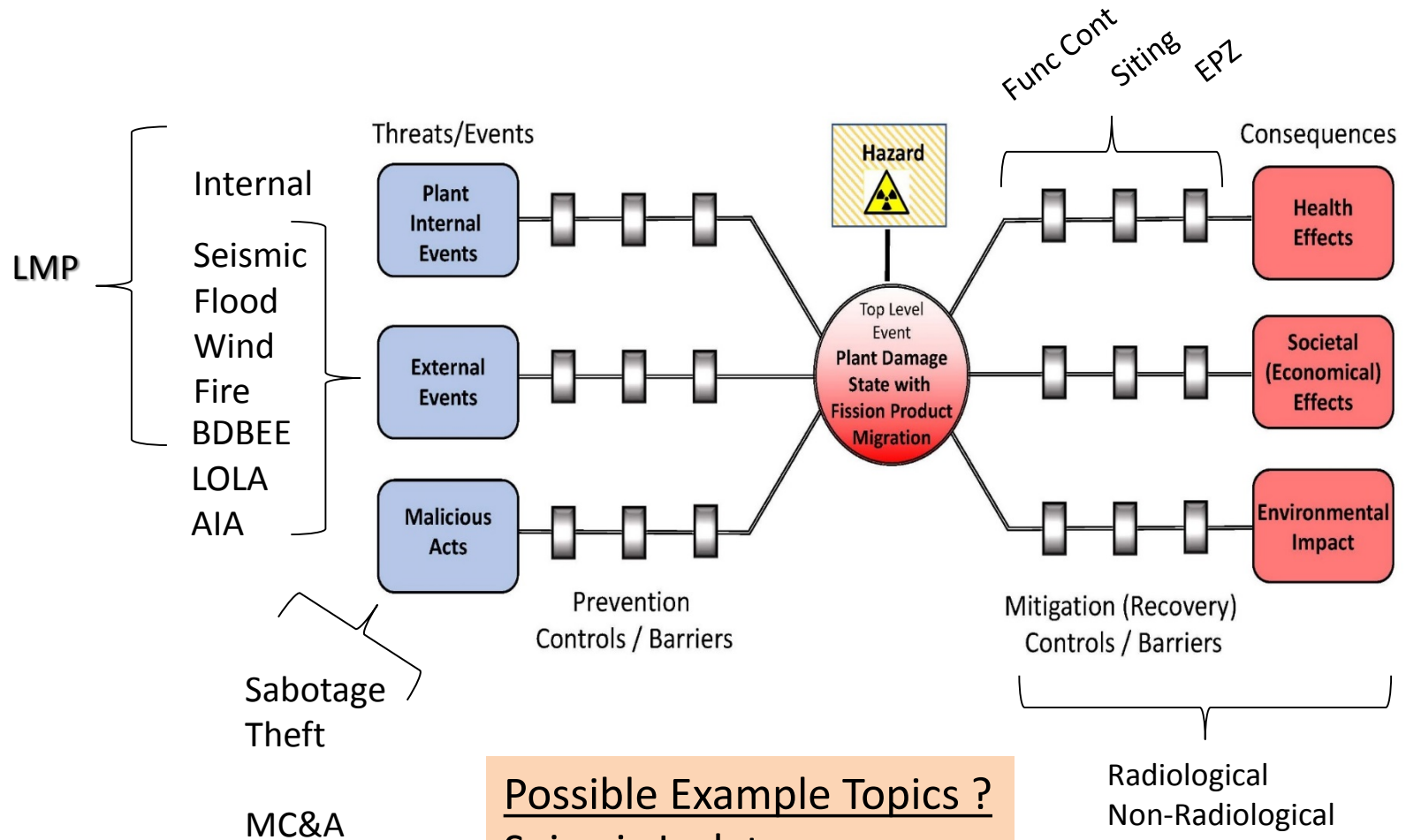
Next Generation Nuclear Plant Public Documents

- ▶ INL Documents
- ▶ NEAC 2010
- ▶ Presentations
- ▶ Public Meetings
- ▶ Subcontractors Documents
- ▶ Training Modules - HTGR Fundamentals
- ▶ Water Ingress Assessment Review Material

May 2018 UPDATE: Policy Issues – Non-Light Water Reactors		
Policy Issues – Non-Light Water Reactors		
Issue as presented on web page & previous meetings – raised questions related to applicability for LWR SMRs and non-LWRs		Updated Note activities
Issues with Ongoing Activities for non-LWRs		
License for Prototype Reactors	NRC staff drafting white paper	Action Complete Discussion incorporated into NRC's "A Regulatory Roadmap for Non-Light Water Reactors"
Appropriate Source Term, Dose Calculations, and Siting	SECY-16-0012, "Accident Source Terms and Siting for Small Modular Reactors and Non-Light Water Reactors,"	Parts of this topic are addressed in the NRC's "A Regulatory Roadmap for Non-Light Water Reactors" (December 14, 2016) stakeholder meeting.



Integrating Activities – Guidance Gaps?



Possible Example Topics ?
 Seismic Isolators
 Heat Removal Systems



Other Guidance Documents

- Requesting that stakeholders assess what additional guidance would be useful to resolve questions related to the design or deployment of advanced reactor technologies



U.S. NRC

UNITED STATES NUCLEAR REGULATORY COMMISSION

Protecting People and the Environment

Advanced Reactor Environmental Reviews

Introduction

Joe Williams

Advanced Reactors and Policy Branch

Office of New Reactors

June 14, 2018

Problem Statement

Advanced reactors have characteristics such as size, resource usage, and design simplicity that affect the scope and depth of the environmental review.

Based on these factors the NRC will appropriately scale its review.

Goals

- Efficiently conduct environmental reviews tailored to the various types of potential advanced reactor applications and spectrum of designs.
- Inform potential advanced reactor applicants of environmental review expectations.

Agenda

- Introduction: Joe Williams
- Regulatory requirements and guidance: Jack Cushing
- Medical isotope production facility lessons learned: Michelle Moser
- Potential challenges: Joe Williams
- Q&A

Potential Challenges

- Purpose and need, alternatives to address non-traditional usage
- Fuel cycle impacts
 - ⊕ High assay low enriched uranium (HALEU)
 - ⊕ Different fuel forms
 - ⊕ Different waste forms
 - ⊕ Long term storage
- Licensing processes for first-of-a-kind

More Potential Challenges

- Environmental impacts of new fuel facilities
- Transportation impacts
- Severe accident mitigation alternatives (SAMA)
- Decommissioning
- Reactor portability

Next Steps

- Planning
 - ⊕ What do you plan to do?
 - ⊕ When do you plan to do it?
 - ⊕ Identify and prioritize actions to provide sufficient application and review guidance
- Future meetings

Questions?

Comments?



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Protecting People and the Environment

**Advanced Reactor Environmental Reviews
Regulatory Requirements
and Guidance Documents**

Jack Cushing

Division of Licensing, Siting and Environmental Analysis

Office of New Reactors

June 14, 2018

General Information – NEPA and the NRC

- National Environmental Policy Act (NEPA)
 - ⊕ Applies to all Federal agencies, including the NRC, but not to NRC applicants
 - ⊕ Open process allowing for meaningful stakeholder and public participation
- NEPA is part of the myriad of statutes, Presidential executive orders, and regulations aimed at making informed decisions and protecting the environment
- NRC framework for implementing NEPA practices is 10 CFR Part 51
 - ⊕ Regulatory Guidance is in R.G. 1.206, R.G. 4.2, R.G. 4.7 and NUREG-1555 (ESRP)
 - ⊕ Focused on impacts from, alternatives to, and benefits assessment of proposal
- Protection of the environment under other statutes (Clean Air Act, Clean Water Act, etc.) is generally left to other agencies (USACE, USEPA, etc.) or the States

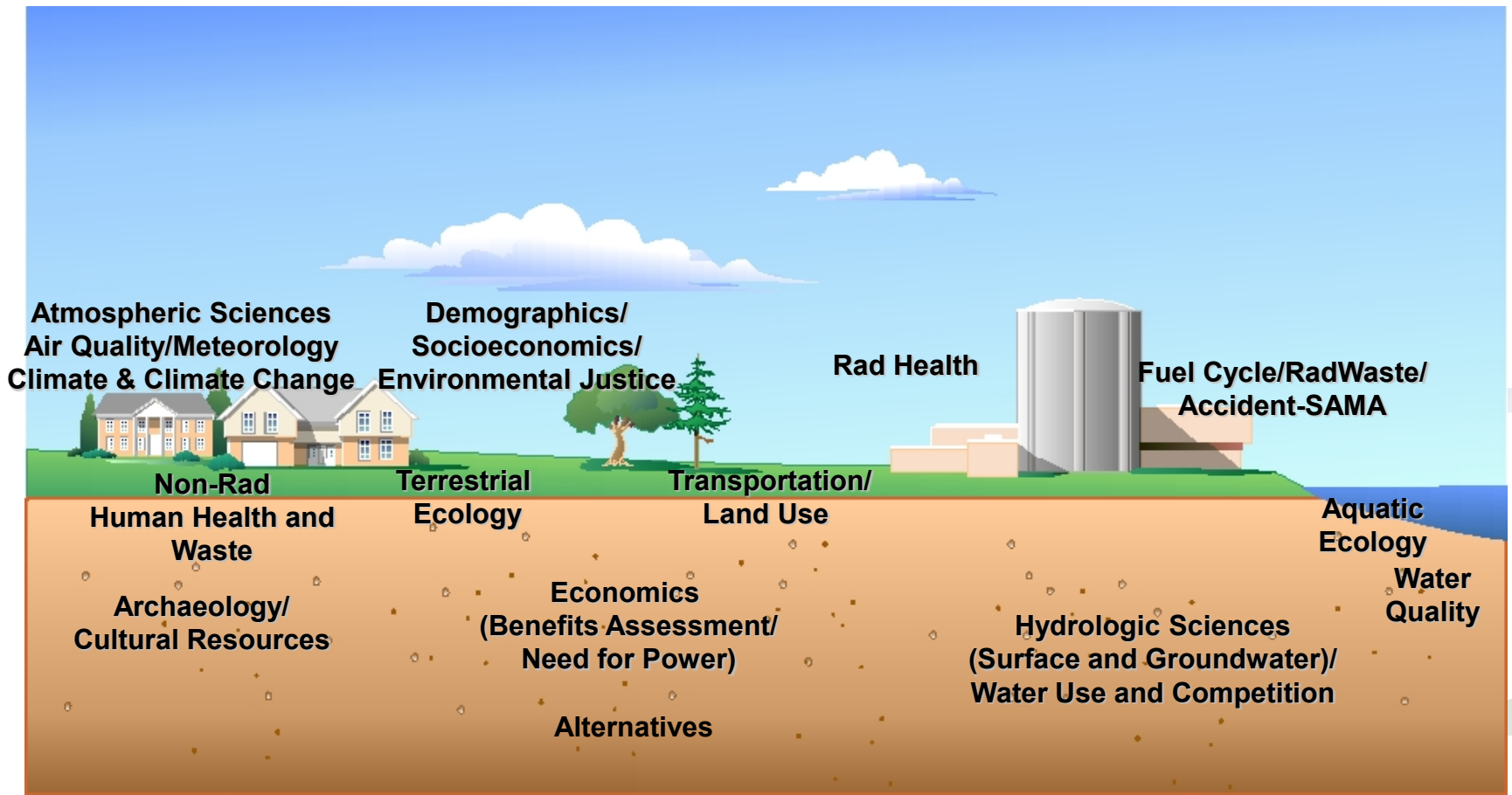
General Information – NRC Regulations

§ 51.41, 51.45, 51.50, 51.55 Requires that applicant provide information to assist the Commission in complying with section 102(2) of NEPA. This includes the preparation of an Environmental Report (ER) for a variety of licensing actions: early site permit, combined license, construction permit, operating license, and limited work authorizations.

Unlike the safety review, where the principal licensing basis document is the applicant's Safety Analysis Report, for the environmental review, the principal licensing basis document is the NRC's Environmental Impact Statement (EIS); the ER is the starting point for the staff's review.

§ 51.70 Requires staff to independently evaluate and be responsible for reliability of all information used in its EIS. Staff will scrutinize information provided on the docket and during its audits and review. NRC will develop its own sources of information, if needed.

Areas Analyzed in an Environmental Impact Statement



Environmental Report (ER) – EIS

- ER developed by applicant – RG 4.2 Preparation of Environmental Reports for Nuclear Power Stations. Contents of ER and EIS are similar.
- Chapter 1 Introduction – purpose and need statement
- Chapter 2 Proposed Site Affected Environment
- Chapter 3 Site layout and Project Description
- Chapter 4 Environmental Impacts from Construction
- Chapter 5 Environmental Impacts from Operation
- Chapter 6 Fuel Cycle, Transportation and Decommissioning Impacts
- Chapter 7 Cumulative Impacts
- Chapter 8 Need For Power
- Chapter 9 Environmental Impact of Alternatives
- Chapter 10 Conclusion

How does the EIS fit together?

Chap 1 contains purpose and need statement. P&N statement determines need for project (chap 8), the alternatives (chap 9).

Chap 2 describes the environment affected by the project

Chap 3, describes the project

Chap 4 and 5 describes the construction and operation impacts from the project on the affected environment

Chap 6 describes fuel cycle and decommissioning impacts

Chap 7 Cumulative – impacts of project plus other past present and future actions on the affected environment.

Chap 10 Conclusion and Recommendation

Success Path

Preparation is key to a successful review:

- Industry/applicants engage NRC to tailor guidance for advanced reactor reviews
- Identify and resolve issues
- Pre-application with NRC and other agencies issuing permits

Next presentation will discuss examples of lessons learned from first of a kind reviews

Questions

How can environmental reviews be improved for the various types of potential advanced reactor applications and spectrum of designs?

What needs to be done to inform potential advanced reactor applicants of environmental review expectations?

U.S. Nuclear Regulatory Commission Lessons Learned from Environmental Reviews Related to Molybdenum-99 Production

Michelle Rome Moser

U.S. Nuclear Regulatory Commission

Medical Isotope Projects

- Diverse proposed technologies
- Wide scope of potential environmental impacts
- First-of-a-kind review for NRC
- First-time NRC applicants
- Project uncertainty

Unique Considerations and Challenges

- Tailoring licensing and regulatory framework
- First-time NRC applicants
- Scope of environmental review
- Project uncertainty
- Related environmental regulations

Consideration: Tailoring Licensing and Regulatory Framework

Solution:

- Staff wrote Interim Staff Guidance (ISG) augmenting-NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors”
 - ISG covers a range of potential technologies
 - Information in the Environmental Report should be commensurate with potential environmental impacts

Consideration: First-Time NRC Applicants

Solution:

- **Pre-Application meetings**
 - Meetings to discuss the information needed to support an efficient and effective environmental review
 - Allows for NRC internal resource planning
 - May occur at the NRC, applicant headquarters, or proposed site
- **Interpretations to clarify NRC regulations**
 - Must be submitted in writing to the NRC staff
 - Questions may pertain to the licensing process and procedural requirements

Consideration: Scope of the Environmental Review

Solution:

- Understanding of connected actions (40 CFR 1508.25)
 - Automatically trigger other actions which may require environmental impact statements.
 - Cannot or will not proceed unless other actions are taken previously or simultaneously.
 - Are interdependent parts of a larger action and depend on the larger action for their justification.
- Full Life Cycle Review

Consideration: Project Uncertainty

Solution:

- Bounding assumptions
 - Engineering parameters
 - Workforce
 - Emissions
 - Land Disturbance

Consideration: Related Environmental Regulations

Solution:

- Understanding of related environmental regulations
 - Endangered Species Act
 - Clean Water Act (Wetlands, Water Discharges)
 - Clean Air Act
- Early coordination with natural resource agencies
 - Federal
 - State
 - Local

EP for SMR & ONT Rulemaking Update

**Advanced Reactor Stakeholder Working Group
June 14, 2018**

Ed Roach
Emergency Preparedness
U.S. Nuclear Regulatory Commission

Emergency Preparedness Rulemaking for SMR & ONT

- The following contains information that was provided to support the preliminary proposed Emergency Preparedness for Small Modular Reactors and Other New Technologies Rule.
- Although the Regulatory Basis was made public in November 2017, the proposed rule has not been issued for public comment.
- As such, the accompanying information and guidance may change and should not be considered final
- The Commission will vote on the rulemaking and provide a Staff Requirements Memorandum (SRM) with direction on how to proceed.

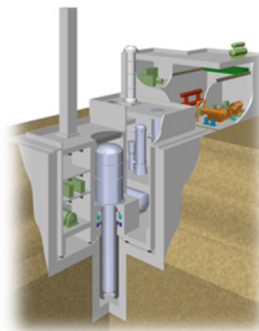
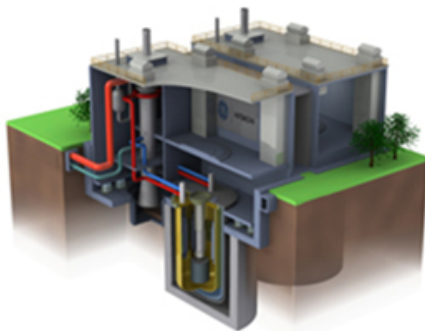
EP for SMR & ONT

- Rulemaking to develop a clear set of rules and guidance for small modular reactors (SMRs) and other new technologies (ONT)

Technology Inclusive

Risk-Informed, Performance Based

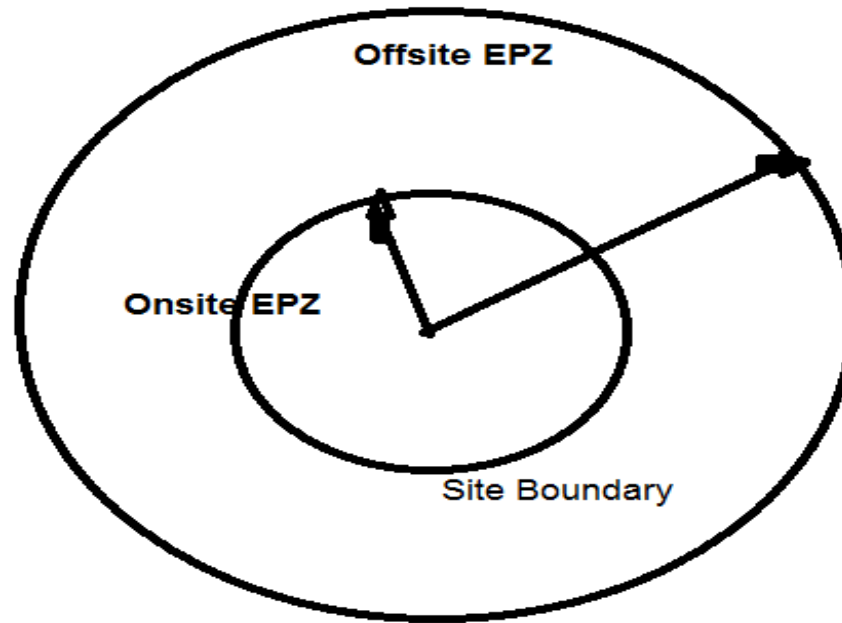
Principle of dose-at-distance and consequence-oriented approach to determine EPZ size



Emergency Preparedness Rulemaking for SMR & ONT

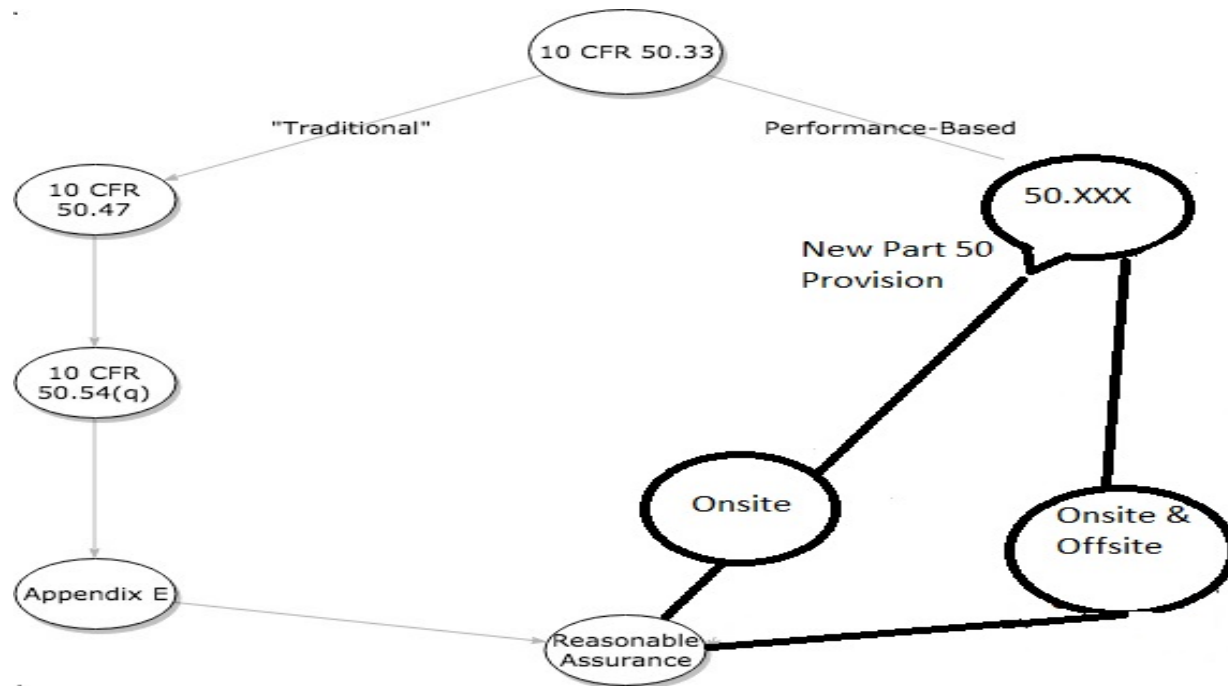
- Use a risk-informed dose-based process for determining the size of the Plume Exposure Pathway EPZ.
- Ingestion planning can be capabilities based
- There are two approaches: traditional and performance based.
- A new section under Part 50 to address EP for SMR & ONT – conforming changes to Part 52

Emergency Preparedness Rulemaking for SMR & ONT



Emergency Preparedness Rulemaking for SMR & ONT

- The regulatory framework proposed:



Emergency Preparedness Rulemaking for SMR & ONT

- The proposed rule:
 - Performance-based, risk-informed rule
 - Consequence-oriented, graded-approach
 - Technology-inclusive, but does not alter existing nuclear power reactor requirements
 - Plume exposure pathway EPZ will depend on analysis of spectrum of accidents (NUREG-0396 “like” analysis)

Emergency Preparedness Rulemaking for SMR & ONT

- Rule would:
 - Allow for smaller EPZ sizes than those for existing nuclear power reactors.
 - Require analysis of accident spectrum and consequences.
 - Require the use of performance indicators to monitor EP performance and trends.
 - NOT change the EPZs or EP requirements for existing nuclear power reactors.

Emergency Preparedness Rulemaking for SMR & ONT

- Performance based aspects of rule could include:
 - Event mitigation
 - Protective actions
 - Communications
 - Command and control
 - Staffing
 - Radiological assessment

Emergency Preparedness Rulemaking for SMR & ONT

- Guidance (DG-1350):
 - General information (non-design specific) one acceptable way to meet the performance based rule. Include a general methodology to determine plume exposure pathway EPZ.
 - NOT contain specific guidance for various designs, inspections, and decommissioning. These topics would be developed after rulemaking.

Emergency Preparedness Rulemaking for SMR & ONT

- The design specific information for source terms, release pathways, and accident types used in consequence assessments would be needed to determine the sizes of the EPZs.
- This information is included in the analysis for determining the potential radiological doses at various distances from a release point.

Emergency Preparedness Rulemaking for SMR & ONT

- Draft Regulatory Basis
 - April, 2017
- Final Regulatory Basis
 - November 2017 (ML17206A265)
- ACRS Subcommittee meeting
 - August 22, 2018
- ACRS full meeting
 - October 2018
- Commission Submission
 - October 2018
- Proposed Rule/Draft Regulatory Guidance
 - January 2019

Emergency Preparedness Rulemaking for SMR & ONT

- Rulemaking information
 - RIN Number: 3150-AJ68
 - www.Regulations.Gov
 - Docket ID NRC–2015–0225
 - Draft Regulatory Basis ADAMS No. ML16309A332
 - Final Regulatory Basis ADAMS No. ML17206A265

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Metallic Fast Reactor Fuels: QA Plan for Legacy Irradiation and Transient Testing Data

Tom Sowinski

Fast Reactor Technology Program Manager
Office of Advanced Reactor Technologies
Office of Nuclear Energy

Contributors: Tanju Sofu and Abdellatif Yacout (ANL)

NRC Public Meeting on Advanced Non-Light Water Reactors
June 14, 2018



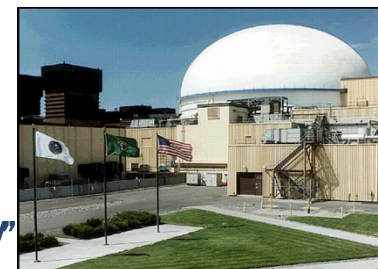
Background on DOE SFR Fuels Research (1/2)

- SFRs have long been studied and operated by DOE and its predecessors
 - Experience with EBR-I, EBR-II, and FFTF
- Decision on fuel type has been based on many criteria:
 - Fabrication, performance, safety, fuel cycle implications, etc.
- Early U.S. SFR experience focused on metal-alloy fuel
 - EBR-II tests in late 1960's achieved limited success due to low burnup
- Oxide fuel form was selected for further development in FFTF and CRBR projects
 - Based on experience in commercial LWRs and naval propulsion
- Following CRBR project cancellation, DOE again focused on metallic fuel research with the Advanced Liquid Metal Reactor (ALMR) and Integral Fast Reactor (IFR) programs
 - Emphasis on a pool-type SFR with metallic fuel to address regulatory concerns related to oxide fueled SFR severe accidents



Background on DOE SFR Fuels Research (2/2)

- Subsequent metallic fuel testing in the 1980s as part of the IFR program demonstrated:
 - Burnup limitation could be overcome by changing the fuel design
 - Lower smear density with more room for irradiation-induced swelling
 - Substantially different thermo-physical metal fuel properties (thermal conductivity, stored energy, melting point, failure mechanism) enhanced SFR safety performance
- PRISM (GE) and SAFR (Rockwell/WEC) concepts submitted Preliminary Safety Information Document (PSID) to NRC in 1986
 - NRC's Pre-application Safety Evaluation Reports (NUREG-1368 and 1369) identified "*incomplete information on the proposed metallic fuel*" as a source of technical uncertainty that could require increased conceptual conservatisms if not addressed
- IFR program (until its termination in 1994) as well as ongoing work under DOE's Advanced Reactor Technologies (ART) program and Advanced Fuels Campaign continue to address this uncertainty



DOE Metallic Fuel Irradiation Experience

- Metal-alloy fuels fabricated as slugs/rods (full-length in EBR-II) in SS (316) or advanced alloy (D9, HT9) cladding
- Fuel-cladding gap sized for a low smear density to accommodate fuel swelling and achieve a high burn-up (filled with bond sodium for high gap conductance)
- Large pin plenum to accumulate fission gases at high burnup
- Binary (U-Zr) fuel is the (initial) choice of fuel for many U.S. SFR developers

Reactor	Fuel Type	# of Fuel Pins	Clad	Peak Burnup
EBR-II	Mark-I/IA (U-5Fs)	~90,000	316SS, D9, HT9	~2.5%
	Mark-II (U-5Fs)	~40,000		~8%
	Mark-IIC/IICS/III/IIIA/IV (U-10Zr)	~16,000		~10%
	U-Pu-Zr	>600		~15-20%
FFTF	U-10Zr	>1050	HT9	~14%
	U-Pu-Zr	37		~9%

DOE Metallic Fuel Design Parameters

Key Parameter	EBR-II/FFTF
Peak Burnup, 10 ⁴ MWd/t	5.0 – 20
Max. linear power, kW/m	33 – 50
Cladding hotspot temp., °C	650
Peak center line temp., °C	<700
Peak radial fuel temp. difference, °C	100 - 250
Cladding fast fluence, n/cm ²	up to 4 x 10 ²³
Cladding outer diameter, mm	4.4 - 6.9
Cladding thickness, mm	0.38 – 0.56
Fuel slug diameter, mm	3.33 – 4.98
Fuel length, m	0.3 (0.9 in FFTF)
Plenum/fuel volume ratio	0.84 to 1.45
Fuel residence time, years	1 - 3
Smear density, %	75

Metal Fuel Irradiation and Physics Analysis Databases (FIPD)

■ EBR-II Metallic Fuel Irradiation Testing Databases (ANL):

- PIE reports, digitized micrographs, profilometry measurements, gamma scans, porosity and cladding strain measurements, and scans for other microstructural characteristics to support fuel qualification and code validation
- Pin-by-pin fuel fabrication and core load information for each EBR-II operating cycle (operating parameters, temperature, fluence, and burnup predictions as input to fuels performance codes)

Argonne NATIONAL LABORATORY
Nuclear Engineering Division
EBR-II Fuels Irradiation & Physics Database

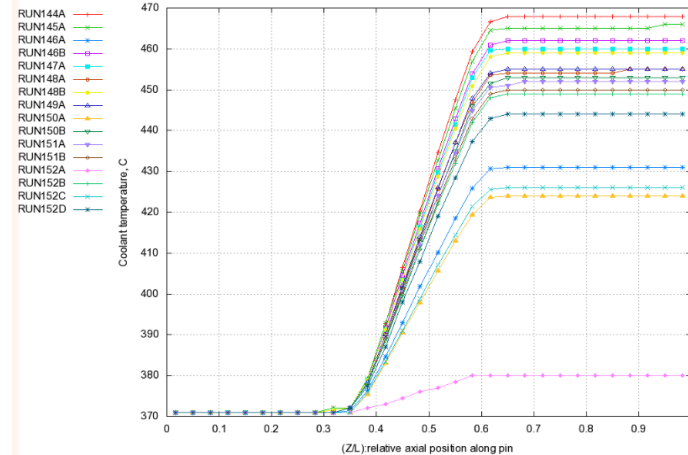
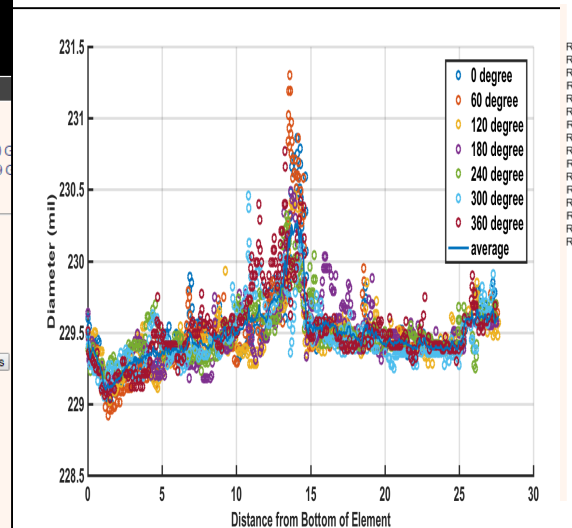
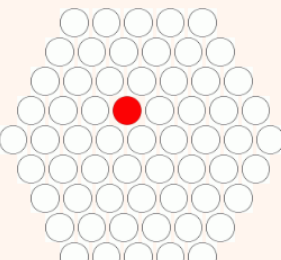
Contact | Pick Experiment

Pick a Pin for Experiment: X450

G238 G240 G264 G265 G267 G268 G275 G279 G280 G283 G287 G290 G295 G297 G298 G311 G315 G316 G320 G341 G346 G349 G354 G372 G375 G379 G383 G396 G401 G402 G414 G415 G426 G428 G433 G438 G442 G449 G491 G502 G506 G507 G509 G515 G519 G524 G527 G539 G540

Subassembly=X450 Pin=G428

Thermal Data | Neutronics Data | Isotope Data | Documents
IMIS pin data



FFTF Metallic Fuel Irradiation Database

- FFTF Metallic Fuel Irradiation Testing Database (PNNL):
 - Data from aggressive irradiation testing of 8 metallic fuel assemblies containing long fuel pins (prototypic of commercial SFR fuels)
 - No cladding breaches up to burnups approaching 150 MWd/kgM
 - Test design descriptions (fabrication data and QA documentation) for IFR-1 and MFF series of metal fuel tests
 - Available operational data for irradiation cycles
 - Power, flow rates, temperatures
 - Test reports
 - Fabrication records, irradiation reports, PIE reports
 - Results for impact of metal fuel tests on reactor operating parameters such as reactivity feedbacks and direct measurement data (in-core assembly growth, assembly pull forces, IEM cell exams)

DOE Metallic Fuel Transient Testing Experience

■ EBR-II passive and inherent safety tests

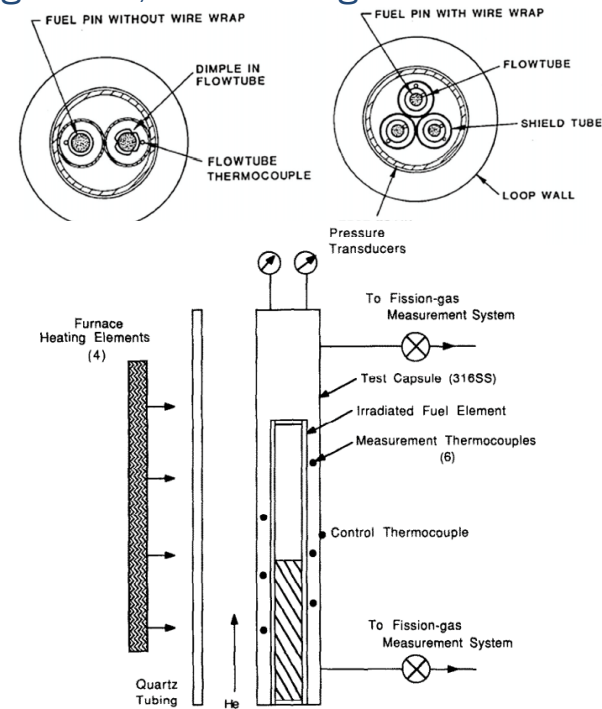
- Approx. 80 integral experiments from comprehensive shutdown heat removal, BOP, and inherent plant control testing program during 1984-87 period
 - Including several unprotected (without scram) LOF and LOHS tests
- No challenge to any fuel integrity during entire safety testing program

■ TREAT M-series tests

- Rapid transient overpower tests to examine margin to cladding failure, fuel melting and relocation
- Whole irradiated EBR-II pins in flowing Na loops
- U-5Fs/SS, U-10Zr/HT9, U-19Pu-10Zr/D9 fuel types

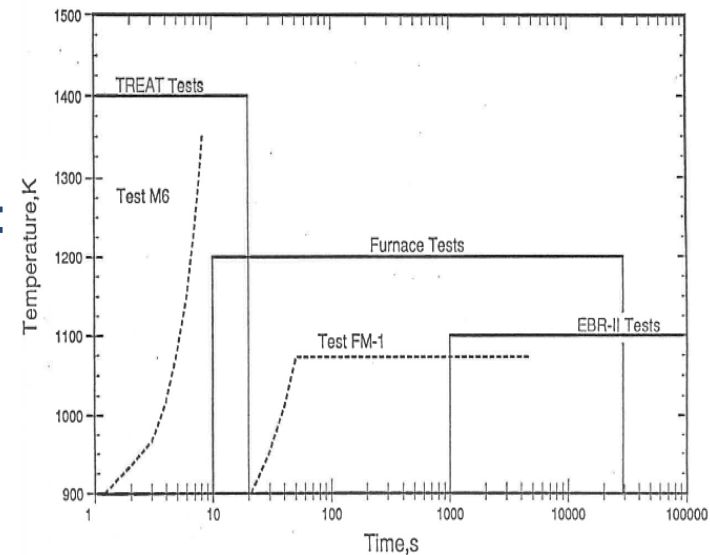
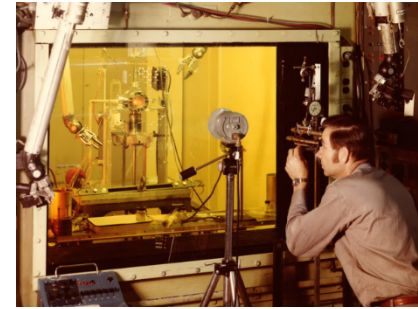
■ Out-of-pile tests in radiant furnaces

- Fuel Behavior Test Apparatus (FBTA)
 - Irradiated U-10Zr, U-Pu-Zr pin segments
 - Examined liquid phase formation and FCCI rate
- Whole Pin Furnace (WPF) Tests
 - Irradiated whole U-Zr, U-Pu-Zr pins
 - Examined margin to cladding failure



Database for Out of Pile Experiments

- Transient furnace tests in hot cells
 - Chopped irradiated pin segments in Fuel Pin Test Apparatus (FBTA)
 - Full length irradiated pins in Whole Pin Furnace (WPF)
 - Simulated reactor accidents, varying ramp rates and peak temperatures
 - Showed significant safety margin for selected transient conditions
- U-(O-26)Pu-10Zr pins in D9, HT9, 316SS clad
 - Burnup: 2-3 a/o in WPF, 6-12 a/o in FBTA
 - Fuel compatibility tests on clad fuel segments
 - Fission gas retention examinations
 - Measurements for cladding penetration depth
- Results being archived in an online database:
 - Metallurgical examination of the tested materials
 - Fission product release measurements

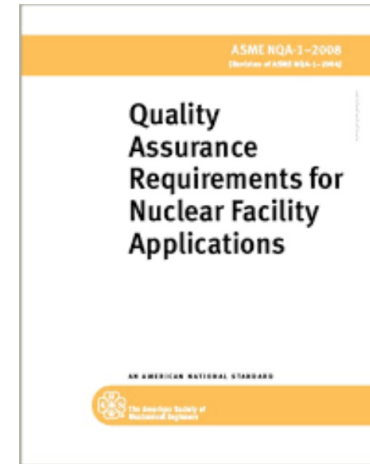


DOE SFR Metallic Fuel Data Qualification Plan (1/3)

- Database development efforts have so far emphasized preserving historical information and its organization in electronic format for online access
 - Data and information has been entered and managed in accordance with applicable regulatory requirements, but the pedigree of legacy data is currently being evaluated
- A QA program plan has recently been developed to evaluate the historical metallic fuel irradiation information in support of fuel qualification during a licensing effort
- Following methods are considered for qualification of the legacy data:
 - QA Program Equivalency: Determine if the acquisition, processing and archiving of data have been performed in accordance with sound technical, administrative practices in compliance with NRC requirements and guidance
 - Peer Review: Independent evaluation of data to determine if the originally employed QA methodology is acceptable and confidence is warranted in the data acquisition
 - Data Corroboration: Determine if subject matter data comparisons can be shown to substantiate or confirm parameter values
 - Confirmatory Testing: When tests can be designed and performed to establish the quality of existing data

DOE SFR Metallic Fuel Data Qualification Plan (2/3)

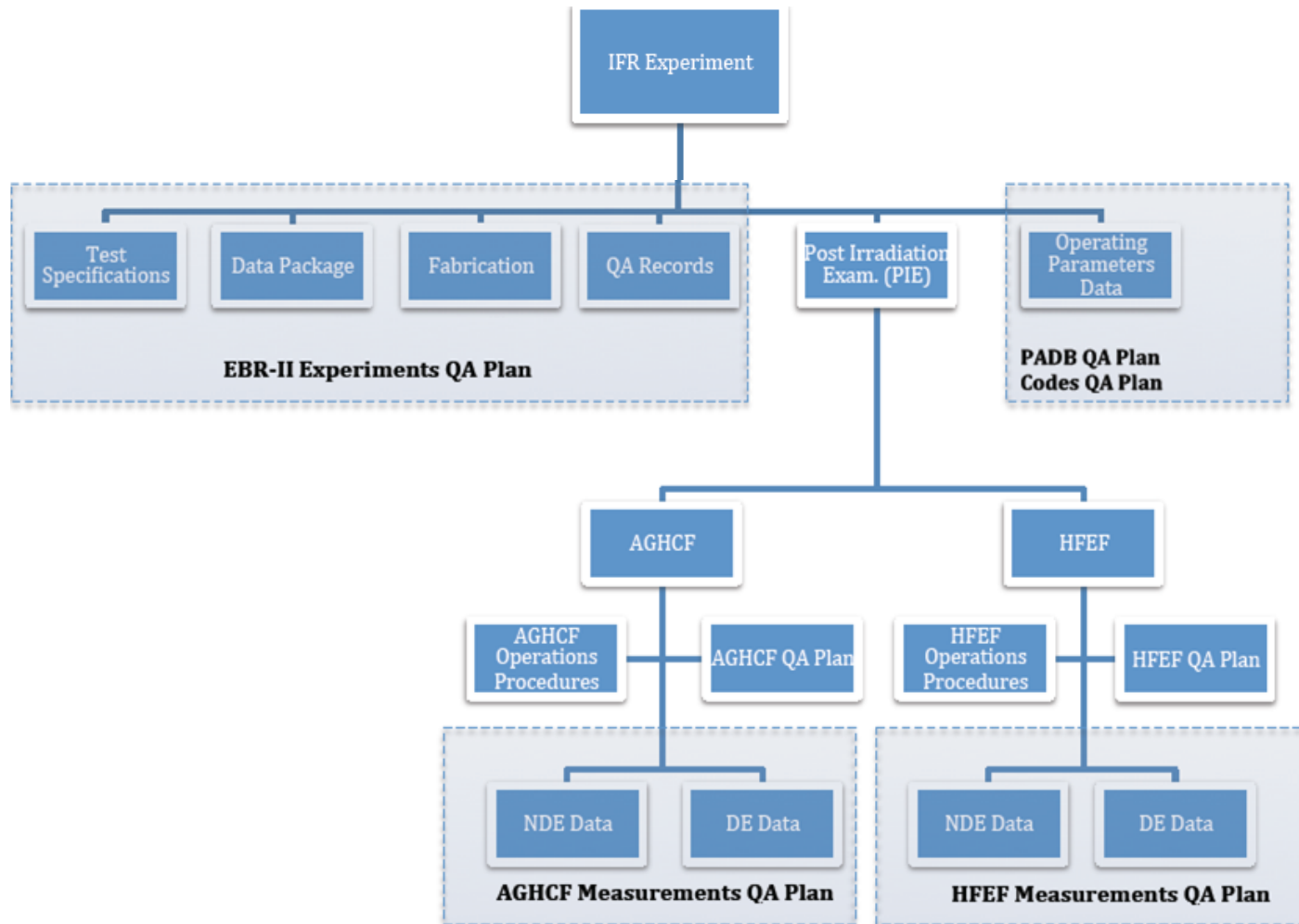
- DOE and national laboratory teams believe that the legacy metallic fuel irradiation and transient testing databases provide quality information to:
 - Assure sufficient tolerance with large margin to failure within operating envelope
 - Demonstrate safe performance during postulated accidents
 - Identify failure mechanisms/thresholds
 - Establish specified acceptable fuel design limits
- A program plan has been developed to qualify the legacy data from metallic fuel irradiation and transient testing to support future license applications
 - ANL-ART-76 “Pre-Licensing Evaluation of Legacy SFR Metallic Fuel Data”
 - ANL/NE-16/17, Rev. 0: “Quality Assurance Program Plan for SFR Metallic Fuel Data Qualification”
- Compliance with ASME’s NQA-1 2008/2009a requirements for data and software is targeted
 - Part III, Subpart 3.3, Appendix 3.1: Guidance on Qualification of Existing Data
 - Part II, Subpart 2.7, Quality Assurance Requirements for Computer Software for Nuclear Facility Applications



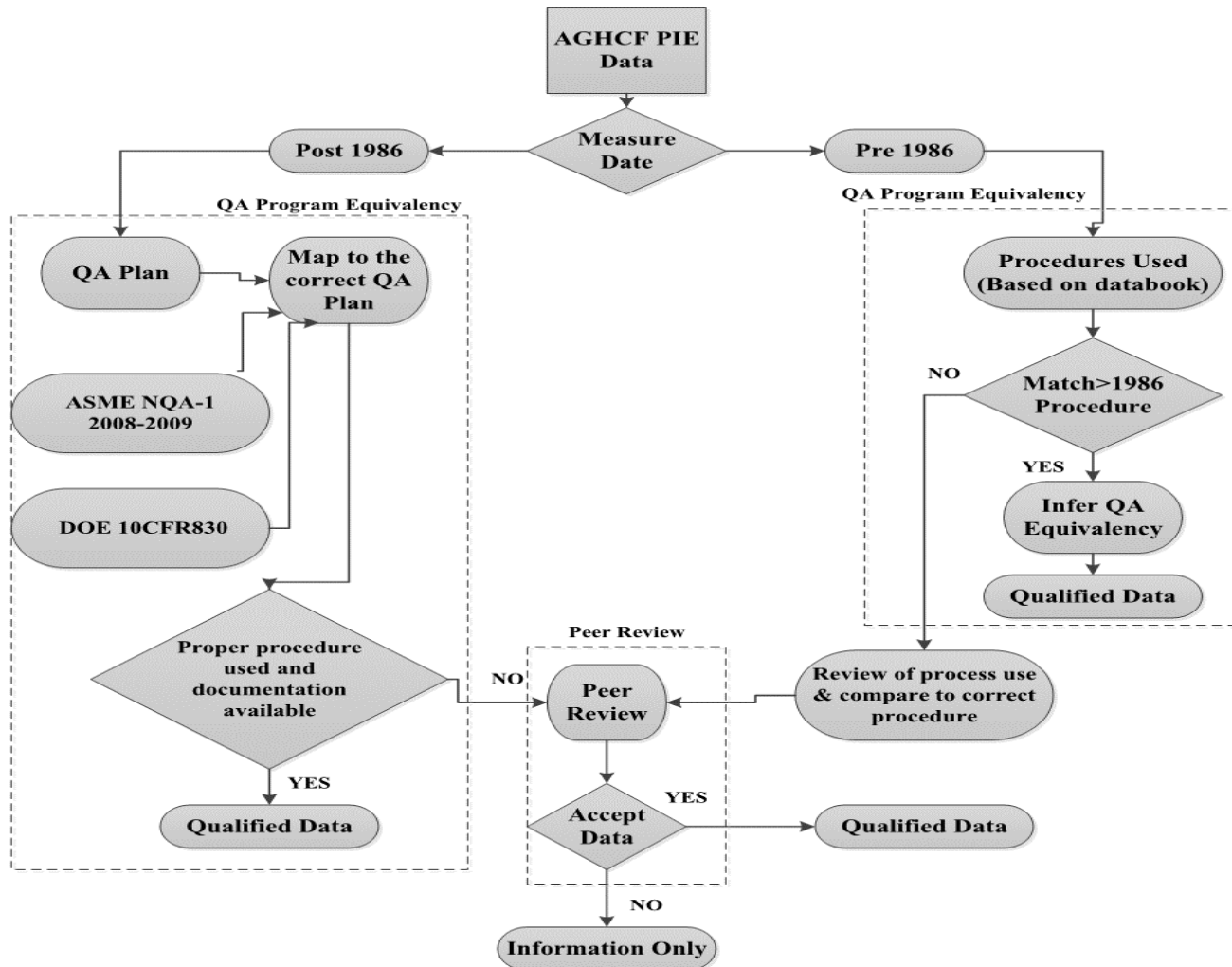
DOE SFR Metallic Fuel Data Qualification Plan (3/3)

- Implementation of legacy data QA program plan expected in FY19
 - Path forward and schedule dependent on funding level and available resources
 - Would likely start with FIPD qualification at ANL first
 - **NRC involvement to assess and potentially approve the QA program plan and its implementation is encouraged**
- Broader DOE ART program goal is to qualify and maintain the historical metallic fuel irradiation and transient testing data and make it available to NRC and designers for reference
 - Designers should have the flexibility to take the lead in demonstrating suitability of the legacy data to support qualification of their own specific fuel design as part of a license application
 - New data from planned confirmatory tests by the developers can supplement the existing data to further support NQA-1 compliance

EBR-II Qualification Data Sets



Example Data Evaluation: Process for AGHCF PIE Data



Example Data Evaluation

- Process for Historical SFR Metallic Fuel Data Qualification Procedure (NE-NSA-PROC-1) is followed (for binary U-Zr fuel with SS cladding)
 - All information relevant to the specific measured data are identified including reports, data logs, drawings, instrument calibration data, memos, etc.
 - Relevant hot cell operations procedures and QA program plans existing at the time of measurements are identified and used in the evaluation process (e.g., Operations Manual and Measurements QA Plans for Alpha Gamma Hot Cell Facility - AGHCF)
 - Both QA equivalency and peer review methods are used to evaluate the data based on all collected information with participation of subject matter experts
 - NRC's participation in the future subject matter experts panel is encouraged
- Procedure is used to evaluate the following data from specific experiments:
 - Metallographic Examination Data for Cladding FCCI
 - Fuel Diameter Measurements
 - Cladding Density Measurements
 - Low-Burnup Fuel Density Measurements
- Peer review method was satisfied by technical evaluation of the employed methodology, data acquisition and development, test plans, interpretations, and potential uncertainties in the results

Summary

- DOE has over 30 years in-reactor experience with metallic fuel irradiation
 - Extensive data set that covers wide range of design parameters, operating conditions, and rigorous transient testing
- Databases being developed at ANL and PNNL include steady state and transient fuel behavior data to support regulatory evaluation of a reactor design that utilizes metallic fuels
- A data and software quality assurance program has been established to evaluate the data and qualify the analytical/database software
 - ANL-ART-76 “Pre-Licensing Evaluation of Legacy SFR Metallic Fuel Data”
 - ANL/NE-16/17, Rev. 0: “Quality Assurance Program Plan for SFR Metallic Fuel Data Qualification”
- DOE’s ART program is expected to support national laboratory efforts to evaluate and qualify the historical/legacy data for use by NRC and industry stakeholders
 - Early NRC engagement to assess the QA program plan and provide input (or directly contribute) to the QA implementation process is encouraged

TRISO Limited Scope Topical Report Status

**NRC Meeting on Possible Regulatory Process
Improvements for Advanced Reactor Designs**

June 14, 2018

**Paul Demkowicz
ART Program Technical Lead
Idaho National Laboratory**

**Mark Holbrook
INL Regulatory Affairs
Idaho National Laboratory**



www.inl.gov



Need and Opportunity

- TRISO fuel performance is fundamental to reactor safety
- TRISO fuel safety qualification success is critical for:
 - Prismatic/pebble bed modular HTGRs: Framatome, X-energy, and StarCore
 - Certain types of molten salt-cooled reactors (FHRs): Kairos Power
- AGR has and still is generating information essential to TRISO fuel safety evaluations
- While the applicant is ultimately responsible for qualifying their design's fuel, assistance in developing a portion of TRISO fuel's qualification basis is currently available from:
 - INL/AGR Project
 - BWXT
 - EPRI

Advanced Gas Reactor Fuel Development and Qualification Program

Objectives and motivation

- Provide data for fuel qualification in support of reactor licensing
- Support establishing a domestic commercial TRISO fuel fabrication capability

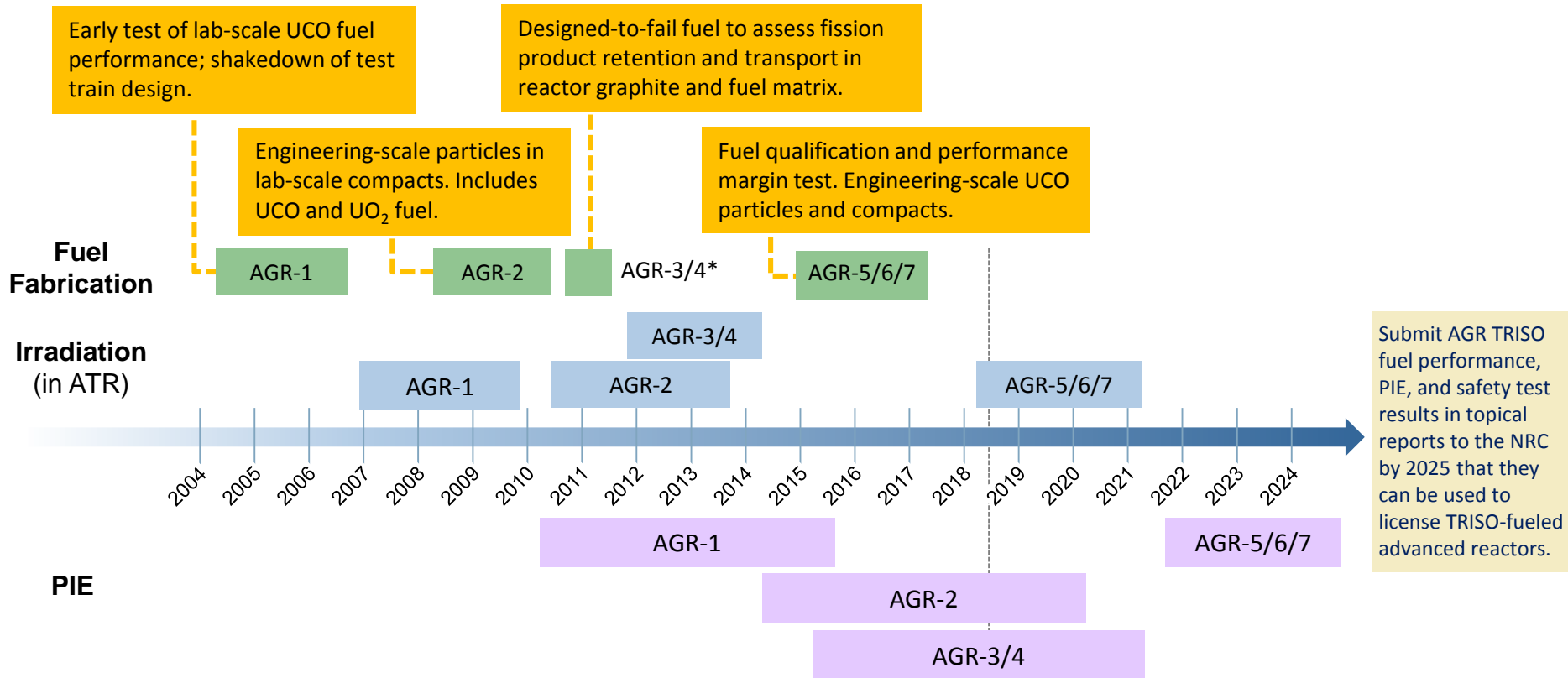


Reduce market entry risk

Approach

- Focus is on developing and testing **UCO** TRISO fuel
 - **Develop fuel fabrication and QC measurement methods**, first at lab scale and then at industrial scale
 - **Perform irradiation testing** over a range of conditions (burnup, temperature, fast neutron fluence)
 - **Perform post-irradiation examination and safety testing** to demonstrate and understand performance during irradiation and during accident conditions
 - **Develop fuel performance models** to better predict fuel behavior
 - **Perform fission product transport experiments** to improve understanding and refine models of fission product transport
 - **Data acquisition adheres to the NRC-endorsed ASME NQA-1 2008 Edition w/2009 addenda quality assurance program**

Advanced Reactor Technologies AGR Program Overview and Timeline



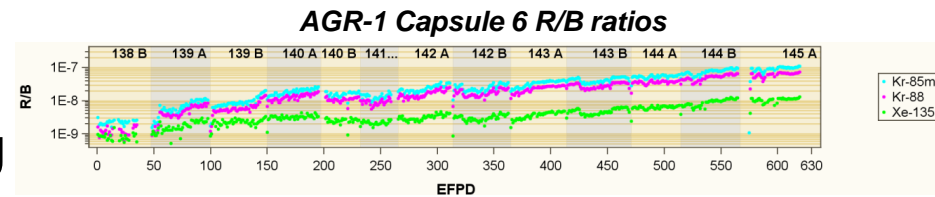
*Includes fabrication of DTF particles; driver fuel taken from AGR-1 fabrication campaign

AGR-1 Objectives

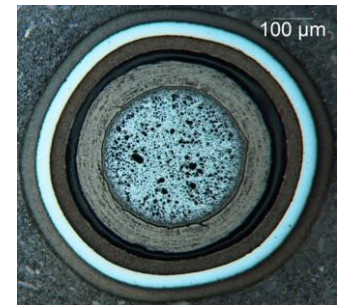
- Shakedown test of lab-scale coated fuel particles and compacts
- Establish methods for irradiation, post-irradiation examination, and safety testing
- Explore effect of coating variations on fuel performance
- Early confirmation of performance of the AGR UCO particle design
- Support selection of reference particle design for the AGR-2 irradiation
- Test performance of fuel at expected accident temperatures and beyond
- Improve understanding of TRISO fuel behavior

AGR-1 Results Summary

- Most successful TRISO fuel irradiation in US history
 - 300,000 particles irradiated in 6 capsules
 - Peak burnup 19.6% FIMA
 - Zero TRISO layer failures
- Fission gas release very low during irradiation
- Excellent UCO particle performance in safety tests at 1600-1800°C
 - No TRISO failure at 1600-1700°C
 - Particle failure fractions better than design specifications by up to a factor of 10
- Greatly expanded understanding of fuel behavior using newly developed PIE methods



X-ray tomogram of irradiated AGR-1 particle showing fission product attack of the SiC layer



Irradiated AGR-1 particle

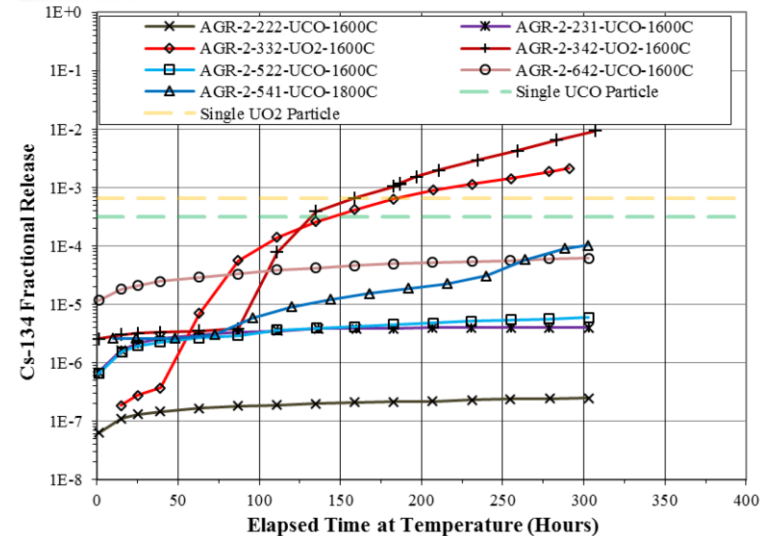
AGR-2 Objectives

- Performance demonstration for particles produced at the production scale (compacts produced at lab-scale at ORNL)
- Comparison between UCO and UO_2 fuel kernel types
- Test fuel at in-pile temperatures well in excess of normal services conditions (time-average peak temperatures $\leq 1360^\circ\text{C}$ in Capsule 2)
- Test performance of fuel at expected accident temperatures and beyond
- Further advance understanding of TRISO fuel behavior

AGR-2 Results Summary

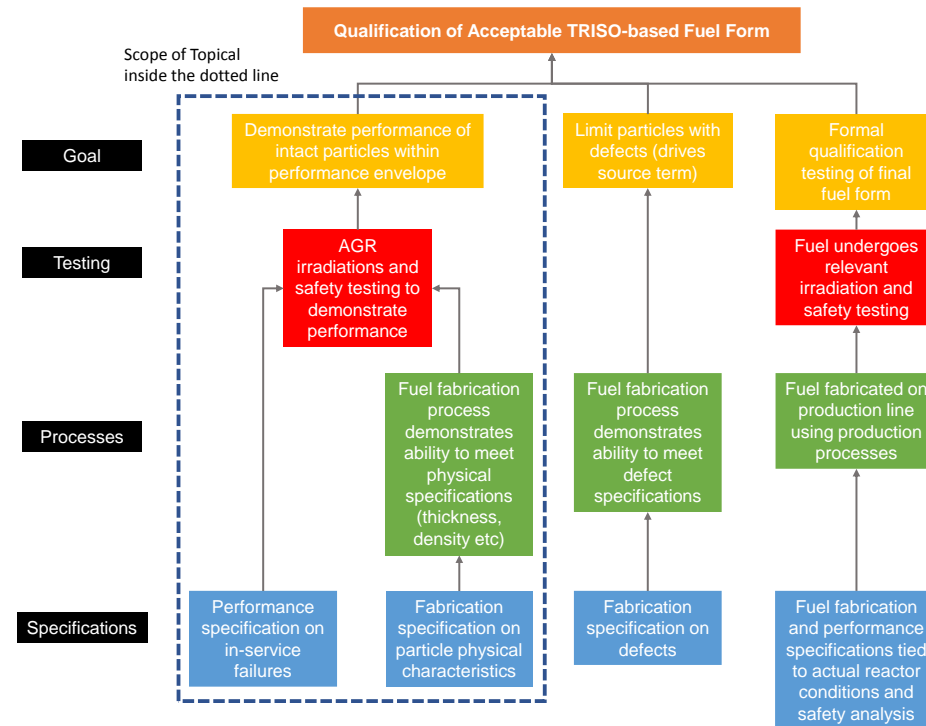
- Excellent in-pile performance
 - Likely zero TRISO failures during irradiation
 - UCO fission product retention appears similar to AGR-1 levels
 - UCO fuel microstructures similar to AGR-1
- Performance of UCO fuel at 1600-1800°C appears slightly better than AGR-1
- High in-pile temperatures result in higher Eu and Sr release both in-pile and during post-irradiation heating tests
- Post-irradiation heating at $T \geq 1600^\circ\text{C}$ demonstrates superior performance of UCO compared to UO_2
- Tentative confirmation that reduced buffer-IPyC adhesion can reduce SiC layer failure
- **PIE and safety testing still in progress**

AGR-2 UCO and UO_2 compact Cs-134 release



TRISO Fuel Performance Demonstration Topical Report: Approach

- Focus on the demonstration of intact coated particle performance based on the AGR-1 and AGR-2 experience
 - Establish that the current UCO TRISO particle design meets expectations for in-service and accident condition performance based on AGR program performance envelope
- Does not include:
 - As-fabricated particle defect specifications; these are imposed at the compact/sphere level, and are influenced by both particle and compact/sphere fabrication processes
 - Verification of particle performance based on specifications developed for specific reactor design: constitutes formal fuel qualification
- Future applicant’s full-scope topical report will discuss other AGR tests, TRISO fuel specification details, etc.

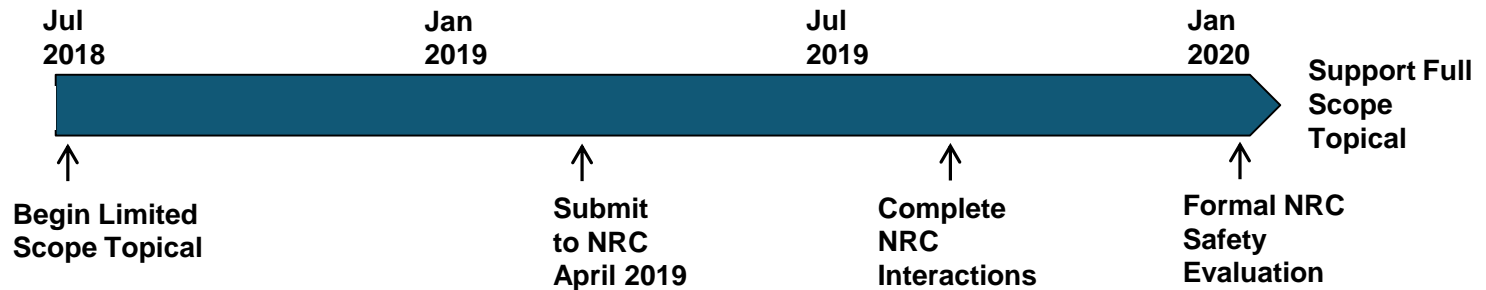


TRISO Fuel Performance Demonstration Topical Report Scope

- TRISO fuel background
 - History, experience base, particle failure mechanisms, reference particle design
 - Basis for service conditions targeted by AGR program fuel performance envelope
- AGR program overview and approach
- AGR-1 and AGR-2 fuel kernel, particle, and compact fabrication
 - Includes discussion of coating parameter variation. This provides a demonstration that some degree of process variation is acceptable to produce fuel with acceptable performance
- AGR-1 and AGR-2 irradiation performance data
 - Fission gas release-to-birth ratios, indicating acceptable particle failure levels and gas release
 - Fission product release levels from fuel particles
 - Detailed kernel and coating behavior observations, including SiC layer failure statistics
- AGR-1 and AGR-2 safety testing data
 - Fission product release from particles
 - Coating behavior and layer failure statistics

Schedule Considerations

- **Limited Scope Topical Report** (notional schedule)



Resources and Roles

COST SHARE:

- DOE – Financial & lab staff support of report content development
- EPRI – Financial & in-kind staff support to coordinate report preparation, review, publication, and submission for NRC review
- Industry – In-kind staff support for report development, reviews, and follow-on regulatory interactions

ROLES:

- INL and EPRI will jointly draft report, coordinate reviews and comment resolutions, and lead interactions with NRC staff
- Industry will assist report development/finalization as requested, work proprietary issues, and support NRC staff interactions
- NRC off-fee review of this broadly applicable (“generic”) topical report with anticipated approval via safety evaluation

Conclusions

Goal: Generate an endorsed resource that can be incorporated into subsequent applications and licensing decisions

Benefits:

- Enable early understanding of key technical areas relative to qualifying TRISO UCO fuel
 - Allows time for clarifying issues without adversely impacting plant deployment timelines
- Minimizes later efforts by applicant and NRC staff by:
 - Eliminating the need for repeated regulatory review of same subject
 - Capitalizing on “tribal knowledge” currently available from the AGR TRISO Program team



Fuel Qualification for MSRs (Additional Thoughts for Consideration)

George Flanagan, Ph.D.
Advanced Reactor Engineering
Reactor and Nuclear Systems Division

Presentation for:
NRC/Nuclear Industry Group/Stakeholder
Meeting on Regulatory Improvements for
Advanced Reactor Designs

Date:
June 14, 2018



Fuel Qualification Needs to be Defined for MSRs (Focus as of August 2017 Presentation)

- Fuel Qualification—MSRs: Based on definition provided by NRC—Joe Williams
- “Fuel qualification is a process which provides high confidence that physical and chemical behavior of fuel is sufficiently understood so that it can be adequately modeled for both normal and accident conditions, reflecting the role of the fuel design in the overall safety of the facility. Uncertainties are understood such that any calculated fission product releases include appropriate margin to ensure conservative calculation of radiological dose consequences.”

Fuel Qualification Needs to be Defined for MSRs (Focus as of August 2017 (cont.))

- Need for basic information to be generated to assure that all parameters associated with fuel salts that can affect safety or operations are understood (impurity limitations/cliff edge effects) – Properly accounted for in models
 - Radionuclide retention (source term)
 - First Wall corrosion (fission makes fuel salt more oxidizing)
 - Possible progressive degradation (long time scale) of heat removal capabilities and restoration via chemistry control system - fuel is the coolant
 - Identify Parameters of concern
 - Density
 - Boiling point
 - Melting point
 - Viscosity
 - Thermal conductivity
 - Heat transfer properties
 - Fissile material plate-out
 - Solubility (fuel, actinides, fission products)

Focus was on In-reactor Aspects of the Role The Fuel Plays in Overall Safety of a MSR

- There are other aspects of the reactor and operation where if physical and chemical behavior of fuel is not- sufficiently understood safety may be impacted
 - Onsite Fuel Preparation
 - Criticality Safety
 - HALEU
 - Liquid solutions - first loading
 - Make up
 - Transportation and on-site storage of rad-waste/fuel
 - Criticality safety (disassociation of solid fluoride fuel salts)
 - Shielding
 - Lack of licensed containers

Focus was on In-reactor Aspects of the Role The Fuel Plays in Overall Safety of a MSR (cont.)

- Maintenance
 - Shielding
- Cleanup systems
 - Off-gas
 - Polishing
 - Processing

Safety Implications of Liquid (mobile) Fuel Needs to be Addressed

- Not solely related to chemical compositions
- Need to determine which parameters (mobility, chemistry) are important to the safety case and degree of variability allowed
- What is the impact on current regulatory practices?
 - Several NRC functions are impacted
 - Reactor Safety(NRO)
 - Security and Safeguards
 - Radiation Protection
 - Waste Management
 - Criticality Safety
 - Transportation