Recent Developments in Codes and Standards for Advanced Reactors

- Opening Remarks by Mohamed Shams, Director, NRR/DANU

- **Moderator:** Michelle Hayes, Branch Chief, NRR/DANU/UART

- **Panelists/Speakers:**
  - Don Eggett (ANS)
  - Mark Richter (NEI)
  - Will Windes (INL)
  - George Flanagan (ANS)
  - Wendy Reed (NRC)

Recent Developments in Codes and Standards for Advanced Reactors

Mo Shams, Director,
Division of Advanced Reactors and Non-Power Production and Utilization Facilities
Office of New Reactors

October 13, 2020

Implementation Action Plans

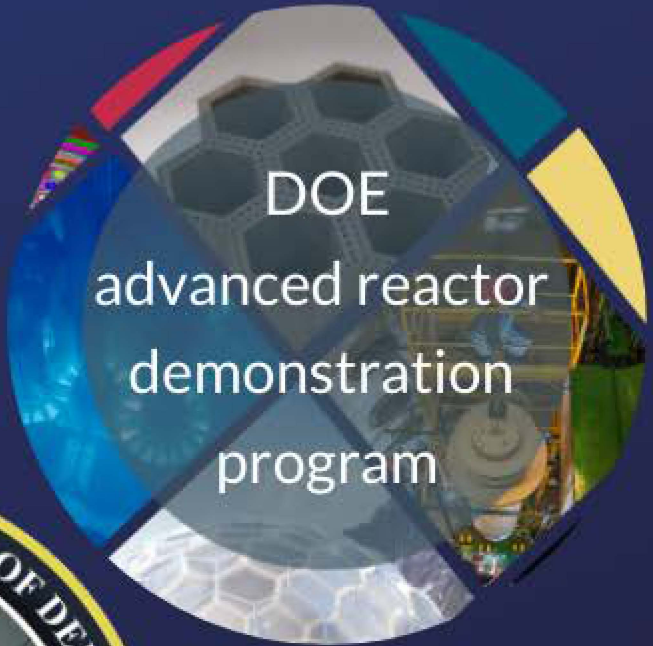
Strategy 1 Knowledge, Skills and Capability	**Strategy 2** Computer Codes & Review Tools	**Strategy 3** Flexible Review Processes	**Strategy 4** Consensus Codes and Standards	**Strategy 5** Policy and Key Technical Issues	**Strategy 6** Communication
ONRL Molten Salt Reactor Training ✓	Identification & Assessment of Available Codes ✓	Regulatory Roadmap ✓	ASME BPVC Section III Division 5	Consequence Based Security (SECY-18-0076) ✓	NRC DOE Workshops ✓
HTGR Training ✓	Code Development/V&V	Non-LWR Design Criteria ✓	ASME BPVC Section XI Division 2	EP for SMRs and ONTs (SECY-18-0103) ✓	Periodic Stakeholder Meetings
Fast Reactor Training ✓		Environmental Review Micro Reactor ISG	ASME/ANS Non-LWR PRA Standard	Functional Containment (SECY-18-0096) ✓	NRC DOE DOD Micro Reactor MOU
Competency Modeling ✓		Licensing Modernization Project (LMP)	ANS Standards 20.1, 20.2 30.2, 54.1	Siting near densely populated areas	NRC/DOE GAIN, VTR & NEICA MOUs
Knowledge Management		Technology Inclusive Content Applications Project (TICAP)		Environmental GEIS	Memorandum of Cooperation with CNSC
		New Rulemaking 10 CFR Part 53		Insurance and Liability	WGSAR
		Inspection and Oversight		Micro Reactor Policy issues	

Ensuring Readiness for Licensing and Safe Deployment of Advanced Reactors in the United States

NEIMA implementation

Part 53 rulemaking

First advanced reactor COL application



DOE advanced reactor demonstration program

Project Pele

NRC Standards Forum

October 2020

Recent Developments in Codes and Standards for Advanced Reactors

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

Presented by: *Don Eggett*
Chairman, ANS Standards Board

American Nuclear Society

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

Insights from and since June 23, 2020 Workshop

- Barriers
- Challenges
- Opportunities
- Accomplishments
- Endorsements

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

Need for Consensus Standards to Drive Advanced Reactor Development (Steven Arndt, ANS)

(ANS "SCARP REPORT") Need for all stakeholders to actively support accelerated development of advanced reactor standards. As a minimum, this included:

- U.S. Department of Energy
- Advance reactor developers
- Standards development organizations (SDOs)
- U.S. Nuclear Regulatory Commission

Follow-up Actions from SCARP Report included:

- ANS to work with DOE to develop methods for funding to assist SDOs and advanced reactor developers in conducting accelerated development of standards.
- ANS to work with SDOs to use current inputs and other resources to identify the highest priority standards.
- ANS to work with SDOs to ensure this work is a priority with all stakeholders.

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

Advanced Reactor Codes and Standards Need Assessment (NEI 19-03 Rev 1 March 2020) (Mike Tschiltz, NEI)

- Built on prior activities by Oak Ridge National Laboratory, American Nuclear Society, and Nuclear Regulatory Commission that identified technical areas warranting additional research and development to support standards development.
- Provided a list of prioritized standards that need revision/development to support deployment of advanced reactors.
- Eighteen (18) codes and standards evaluated to be “high priority” with potential to provide greatest benefit for near-term development.

Need for Accelerating Development

- Coordination, prioritization and funding of activities:
  - Forums for collaboration
  - Process and criteria for prioritization
  - DOE funding source / cost share with developers
- Shortening timeframe from “start to finish” of code/standard development and endorsement.

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

Department of Energy Perspective on Advanced Reactor Codes and Standards (Dirk Cairns-Gallimore, DOE)

Importance of Codes & Standards to Advance Reactors

- Standards provide basis for efficiency, standardized products, improved trade and commerce, and safety and quality objectives
- Incorporate evolving technical advancements and lessons-learned from real world use to ensure standards continue to be relevant.
- Set minimum requirements to protect health, safety, general welfare & affordability.
- Set an understandable and reliable basis that reduces vulnerability to a wide range of hazards.
- Serves as common language in increasing interconnected industrial complex.

DOE Sees Their Role in Codes & Standards As

- Providing technical experts to key working meetings and as coordinators.
- Accelerating the identification of gaps in the standards development process and the methods to close the gaps.
- Providing support for international standards meetings.
- Supporting research and development activities needed for standards development.
- Supporting the codes and standards adoption process.

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

Department of Energy Perspective on Advanced Reactor Codes and Standards (Dirk Cairns-Gallimore, DOE)

Conclusions

- DOE sustains investments to supports codes and standards development.
- Advanced Reactor Demonstration Program provides unique opportunity to advance development and application of new standards.
- DOE investments in Advanced Manufacturing increases stakeholder participation (Industry, DOE Offices, Standards, NRC, National Laboratories, etc.).

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

ANS

Advanced Reactor Developer Needs Versus SDO Capabilities

Terra Power: SFR and MSR. Timeline targeted for operating in 2028. Engaged in C&S as needed.

Kairos: Perspective on current standards aligns more with ASME, less with ANS.

SDOs aligning more with vendor priorities will engage vendor's participation.

Perspective on C&Ss more in line with NEI 19-03.

Westinghouse: General concerns:

- Ability of codes and standards bodies to respond to aggressive development timelines.
- Limited applicability due to design diversity, questioning need for industry codes and standards.
- What role will codes and standards play in the licensing of advanced reactor technologies.

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

Advanced Reactor Developer Needs Versus SDO Capabilities

Oklo, Inc.:

Perspective on current standards aligns more with ASME, less with ANS.

Standards should reflect industry's priorities, developed after a state-of-practice has been established, be mindful of ongoing regulatory activities and avoid conflict or overlap.

Prioritize resources that reflect industry priorities to maximize resource efficiencies.

Use trial use pilot applications.

Southern Company: Molten Salt Reactor Technology Working Group (Lauren Lathem, Southern)

Near-term, design specific demonstrations will lay the foundation for long-term codes and standards.

Collaborate on Technology Neutral Topics.

MSR TWG participation not exclusive to members.

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

Advanced Reactor Developer Needs Versus SDO Capabilities

Bechtel: Barriers to Standards Creation:

- Voluntary standards development may not be timely to support.
- Opportunities exist to develop practical approaches to funding and prioritization.

NuScale: Participation in standards development.

Significant involvement in ASME pressure vessel codes and standards (15+NuScale staff).

Chairing several ANS/ASME standards related to advanced light water reactor risk-informed performance-based design.

Active involvement with IEEE standards related to safety criteria and human factors engineering.

GEH: Active in Codes & Standards applicable to Sodium Fast Reactor (SFR) technology.

Active in advanced Light Water Reactor (LWR) Small Module Reactor (SMR) technology.

Active in Codes and Standards for technology that reflect risk and uncertainty.

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

ANS RAR (Research and Advanced Reactor) Activities

- ASME/ANS PRA standards
- Five ANS standards support advanced reactor designs
- Barriers become challenges
- Opportunities
  - DOE needs to recognize the development of standards is a part of the advanced reactors program.
  - Diversity of designs hinders development standards that benefits all developers.
  - Important that developers understand and recognize importance of standards over long term and encourage their staff and DOE to develop such standards.
  - Developers need to identify the need and priority for new standards in their area.

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

ASME’S Perspective on Specific Needs for Code Development

ASME Section III, Div. 2

- Small Modular Reactors present a wide variety of technologies with different safety requirements.
- Design requirements for the nuclear containments different when comparing to water cooled reactors.

Challenges and Opportunities

- ASME Section III, Div. 2 need to reinvent our expertise and provide technical leadership and a platform for development of viable concrete containments of the future
- Use advancements in materials, design and construction techniques
- Collaborate with all stakeholders and sponsor/oversea the necessary research and development

Others

ASTM: Extensive history with nuclear industry.
Additive Manufacturing (AM) Center of Excellence (CoE).

IEEE NPEC: Willing and ready to develop or modify codes and standards to support advanced reactor development.

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

NRC Codes & Standards Program Activities

- Actively participating in development and use of consensus codes and standards across multiple Standards Development Organizations (SDOs).
- Codes and standards improve effectiveness and efficiency of regulatory oversight.
- NRC Management Directive 6.5:
  - Identifying and prioritizing need for new and revised technical standards.
  - Participating in codes and standards development.
  - Endorsing codes and standards.

NRC Next Steps

- NRC to continue its participation on SDO activities for the development and or update of priority standards.
- Continue gathering feedback from utility/vendors, standards development organizations, and other stakeholders on codes and standards needs and related near term activities.
- Standards Forum – October 13, 2020 (Rescheduled dated from September 15, 2020)

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

NuScale Concerns on Development of Advanced Reactor Standards

- Too many groups trying to do the same thing with minimal effective coordination.
- Too many reviewers and commenters. Maybe need to redefine consensus?
- Lack of curiosity / support for adoption of new technologies and techniques.
- Understanding of why existing standards were written the way they were.
- Ability to support extension of existing standards to new technologies.
- Attracting and retaining next generation of engineers and scientists for standards development.
- Continuity of knowledge amongst standards members/developers.
- Lack of regulator involvement, turnover, or changes in positions.
- Lack of funding for basic research and sharing of results (i.e., proprietary).

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

IEEE NPEC Concerns on Development of Advanced Reactor Standards

- Sufficient experience with advanced reactors lacking to achieve a consensus for standard practice.
- Identification of advanced reactor standards needs in instrumentation and controls or human factors.
- Many committee members are practitioners in the current power industry, not researchers; their employers may not see advanced reactor standards of immediate relevance and continue funding.
- Additional representatives from advanced reactor design organizations and regulators to support new standard development.
- Integrating NPEC efforts with other the efforts of other SDOs.
- Time required to publish a new standard (approximately 4 years).

Recap of the June 23, 2020 NEI/ANS Advanced Reactor Codes and Standards Workshop

So what initiatives have been taken since workshop?

- ANS initiated meetings with NRC, DOE, NEI, SDOs (ASME).
- ANS discussed with NEI, report 19-03 “Advanced Reactor Codes and Standards Needs Assessment” including recommendations from report on options available to move forward.
- ANS has reached out to a few reactor designers to discuss approaches to better support codes & standards needs.

So where does the industry go from here?

- Improve communications.
- Improve SDOs, NRC, NEI, DOE, reactor designers, EPRI, National Labs, etc. working relationships.
- Need for better engagement by reactor designers with SDOs.
- Establish a central decision-making industry group (“steering committee”) that through input from all industry organizations previously mentioned above funnels proposals to DOE on financial needs for C&S development to support advanced reactors (proposed by NRC in ANS/NRC Sept 2020 meeting).

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Codes and Standards for Advanced Reactors: NEI Update

Mark Richter
Nuclear Energy Institute

NRC Standards Forum
October 13, 2020

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Background

- Advanced Reactor Codes and Standards (AR C&S) have been discussed since 2013, with a recognition that C&S for LLWRs may not be applicable or efficient to ARs.
- More recently, ANS and NEI have developed reports that highlight the challenges in this area.
- AR C&Ss can enable more efficient commercialization of ARs but not all C&Ss need/should be developed in the near-term
- ARs need a viable pathway to regulatory approval in the absence of C&S.

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Challenges

- Development and regulatory acceptance may not be timely
- Target dates for design approval ~2025 and operation ~2030
- Supporting technical bases for new C&S may require additional or new research
- Different AR designs have different C&S needs-one size does not fit all
- Facilitating communication between AR developers, C&S organizations and DOE/National Labs

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NEI and Industry Actions

- NEI /ANS workshop in June identified needs and path forward for C&S development.
- The next steps for NEI on AR C&S are
  - Facilitate coordination between developers and SDOs to identify high priority standards,
  - Ensure resources are available to develop high priority C&S,
  - Establish pathways for regulatory acceptance. NEI will also need to consider future needs for international harmonization of AR C&S.
  - NEI and ANS standing up new team to facilitate engagement
- NEI AR C&S actions are taken in coordination with the NEI Codes and Standards Task Force, working to bring code committees and new reactor developers together

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Licensing Considerations for Graphite Components

Will Windes

Idaho National Laboratory, Distinguished Scientist

DOE Advanced Reactor Technologies (ART), Graphite Technical Lead

NRC Standards Forum

October 13, 2020

ADVANCED REACTOR TECHNOLOGIES

Primary parameters needed to understand graphite

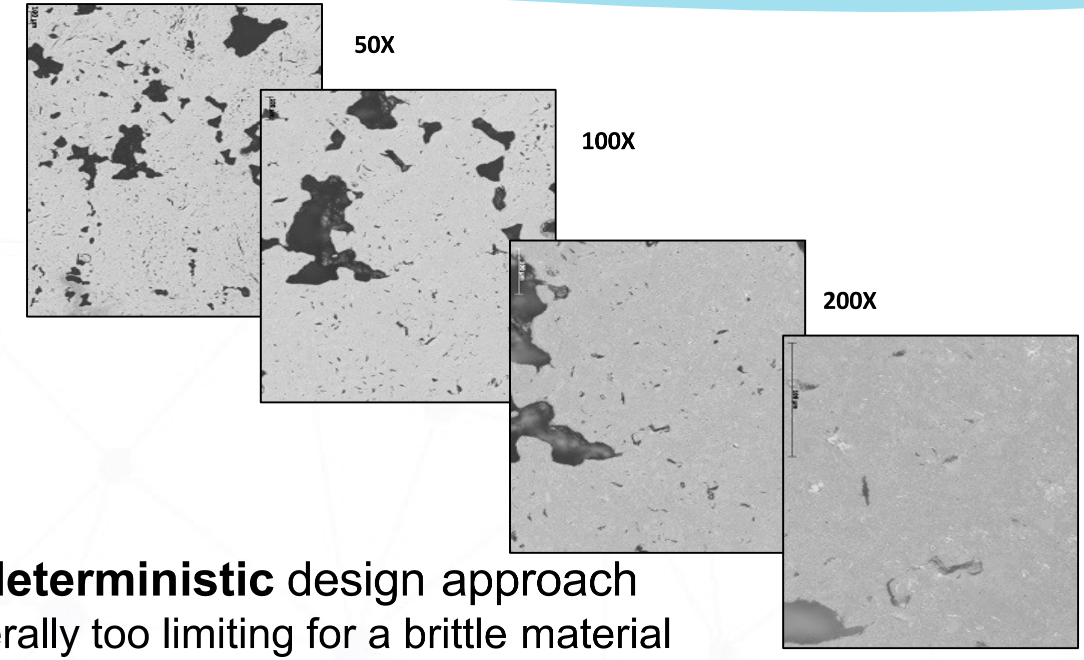
ADVANCED REACTOR TECHNOLOGIES

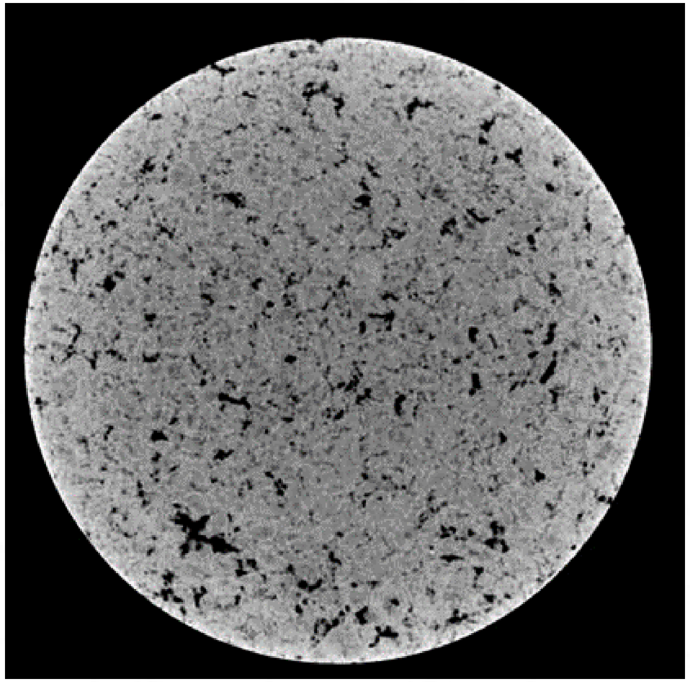
1. There is no single “nuclear” grade of graphite
   - We can’t design around a specific nuclear grade as metals can (i.e., 316, 316L, 617, etc.)
2. Graphite has significant flaws (pores/cracks) – by design
   - We do not want to eliminate these flaws
3. Graphite is **not** ductile
   - Brittle or quasi-brittle fracture behavior
4. Irradiation significantly alters the graphite behavior
   - Behavior is completely different before and after Turnaround dose is achieved.

Material Considerations

ART
ADVANCED REACTOR TECHNOLOGIES

- All “nuclear” graphite has significant flaws
  - Some amount of failure (i.e., a crack) is certain
- Therefore, core components need to be designed to accept some amount of failure.
  - *Probability of failure approach is taken*
  - *Based upon overlap of applied stresses and inherent strength of the nuclear grade used*





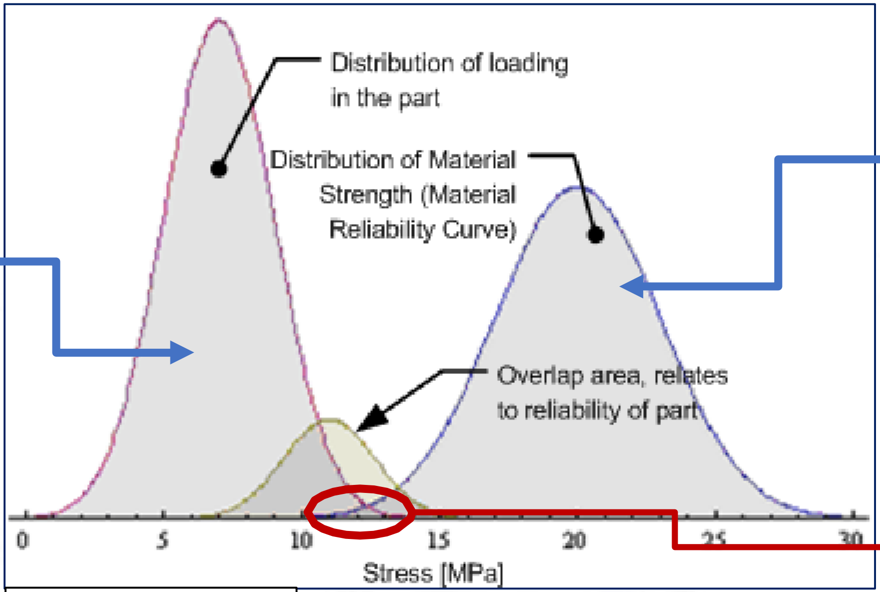
- **Probablistic** verses **deterministic** design approach
  - Deterministic is generally too limiting for a brittle material
  - A distribution of possible strengths in a material is needed for quasi-brittle materials (i.e., flaw size for graphite).
  - Probability of failure in component based upon inherent strength of graphite grade ***and*** applied stresses during operation.
- New graphite grades are consistent and ready for codification
  - Unfortunately, historical nuclear grades are no longer available
  - We also lack significant quantitative data on new graphite behavior at higher temperature and high dose applications
  - Need to correlate defined material changes to assist in failure analysis.

Probabilistic Approach

ADVANCED REACTOR TECHNOLOGIES

Design

- *Values calculated from the reactor design.*
- *Received dose and temperature for all core components.*
- *FEM volume elements of core components*
  - *Normal and off-normal conditions*



From Dr. Mark Mitchell – PBMR Inc.

Material Property

- *Inherent material properties of selected graphite.*
- *Strength and thermal conductivity.*
  - ***Not** just average strength.*
- *Approach = Weibull str. analysis*

Reliability of Part

Probability of failure (POF)

Overlap of ***design stress*** and inherent ***material strength***

Where is “loading” coming from?

- Thermal gradients
- Physical loads (extremely small)
  - Unless taken into volumetric expansion regime
- **Irradiation effects**
  - Dimensional shrinkage is dose dependent
  - Huge internal stresses
  - These stresses *will* lead to cracks (see U.K. bricks)
  - Stress buildup = Dependent upon component dose and temperature

How is strength measured in graphite?

- Graphite is a brittle (quasi-brittle) material
  - Dependent upon flaw sizes.
  - Large scatter in strength data (It can break at any stress)
- Must determine range of strength values
  - Determine failure over entire stress range
  - Can’t use average strength
- Variations of the Weibull distribution best describe the graphite reliability curve.

How the graphite (and composite) ASME Code works

ART
ADVANCED REACTOR TECHNOLOGIES

Three methods are provided for assessing structural integrity

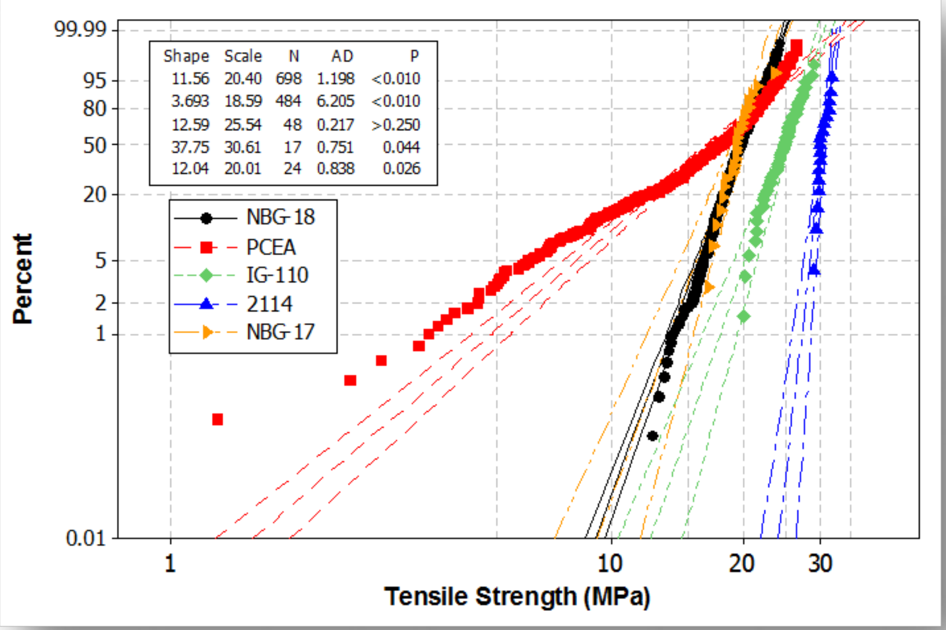
1. Simple Assessment (Deterministic)
   - *Simplified, conservative method based on ultimate strength derived from Weibull statistics (2-parameter Weibull).*
   - *Irradiation changes well contained within the safety/operational envelope*
2. Full Analysis Method
   - *Detailed structural analysis taking into account stresses, temperatures, irradiation history, and chronic oxidation effects.*
   - *Weibull statistics used to predict failure probability (3-parameter Weibull)*
   - *Maximum allowable probability of failure defined for three Structural Reliability Classes (**SRCs**), which relate to safety function*
3. Qualification by Testing
   - *Full-scale testing to demonstrate that failure probabilities meet criteria of full-analysis method.*

The graphite code is a "**<u>process</u>**". Not just picking a preapproved material

- *The applicant must demonstrate the graphite grade selected will consistently meet the component requirements.*

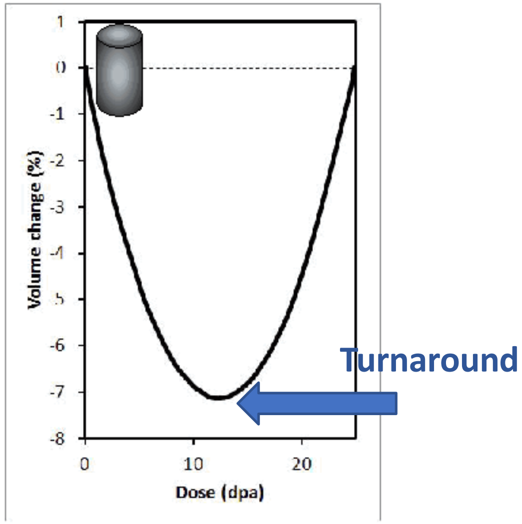
Getting the material property "proof" is responsibility of the applicant

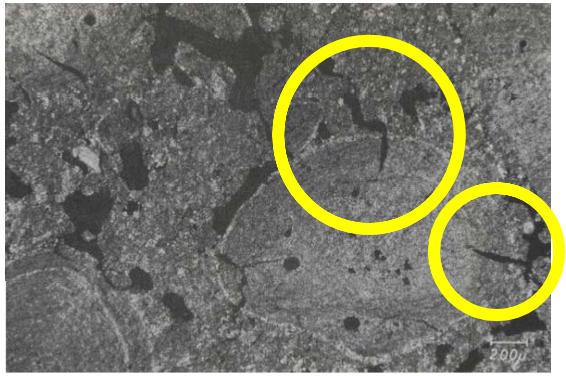
Structural Reliability Class	Maximum Probability of Failure
SRC-1	1.00E-04
SRC-2	1.00E-02
SRC-3	1.00E-01



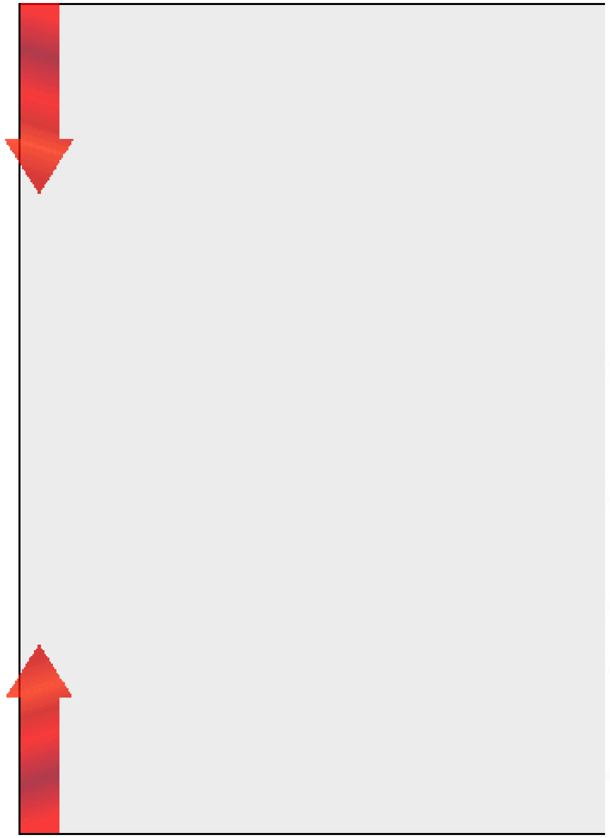
And then … the hard part

- Fundamental material properties change with irradiation/oxidation must be addressed
  - Applicant must assess changes to design of component due to Irradiation effects
    - *New cracks formed after Turnaround*
    - *Internal stresses from dimensional change. Need creep response, too*
    - *Changes to density, strength, CTE, thermal conductivity*





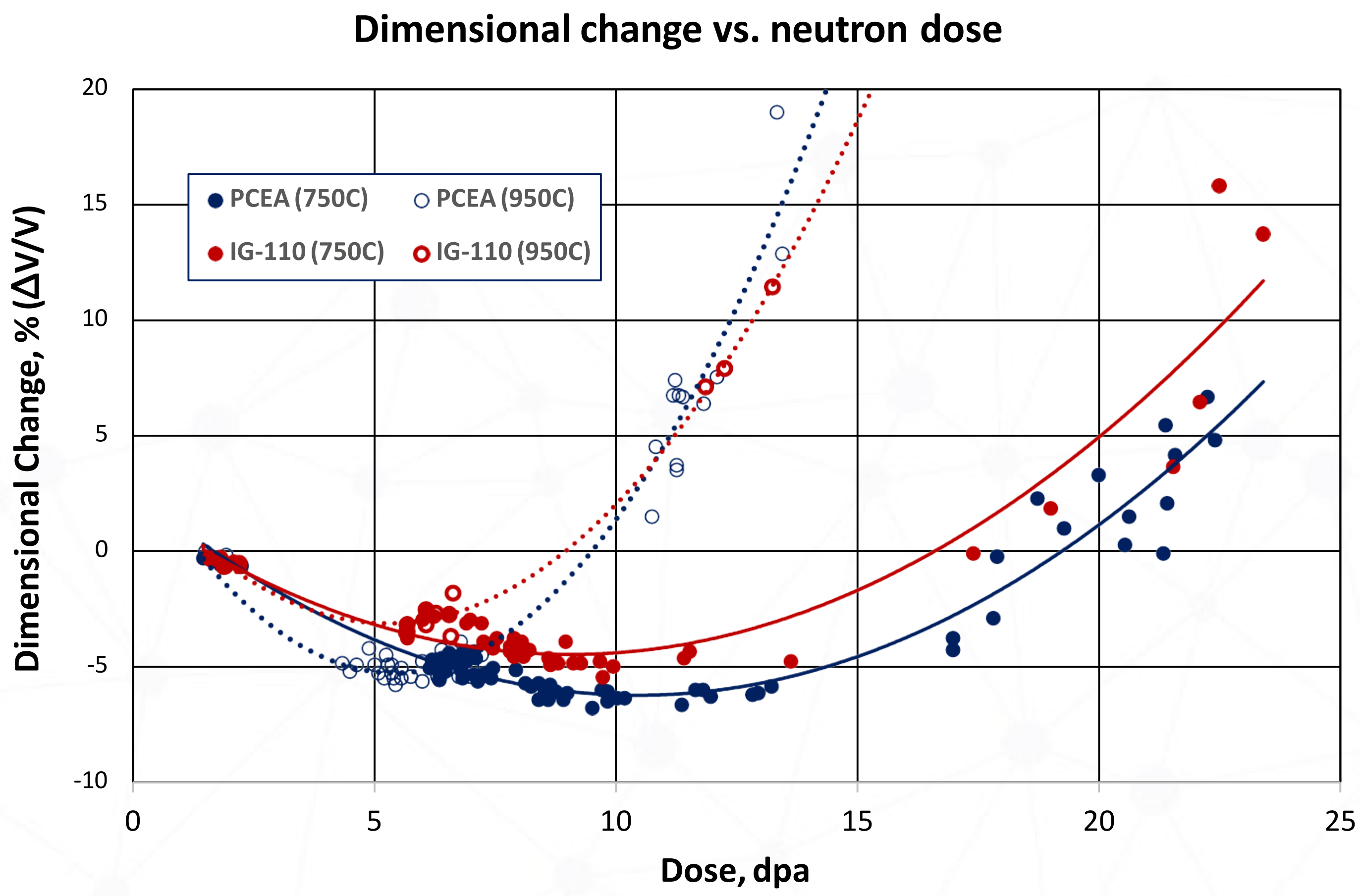
G. Haag," ***Properties of ATR-2E Graphite and Property Changes due to Fast Neutron Irradiation", Juel-4183, 2005***



  - Applicant must assess changes to design due to Oxidation degradation
    - *Changes in density, strength, modulus, CTE, neutron moderation, and thermal conductivity.*

Turnaround dose – critical parameter

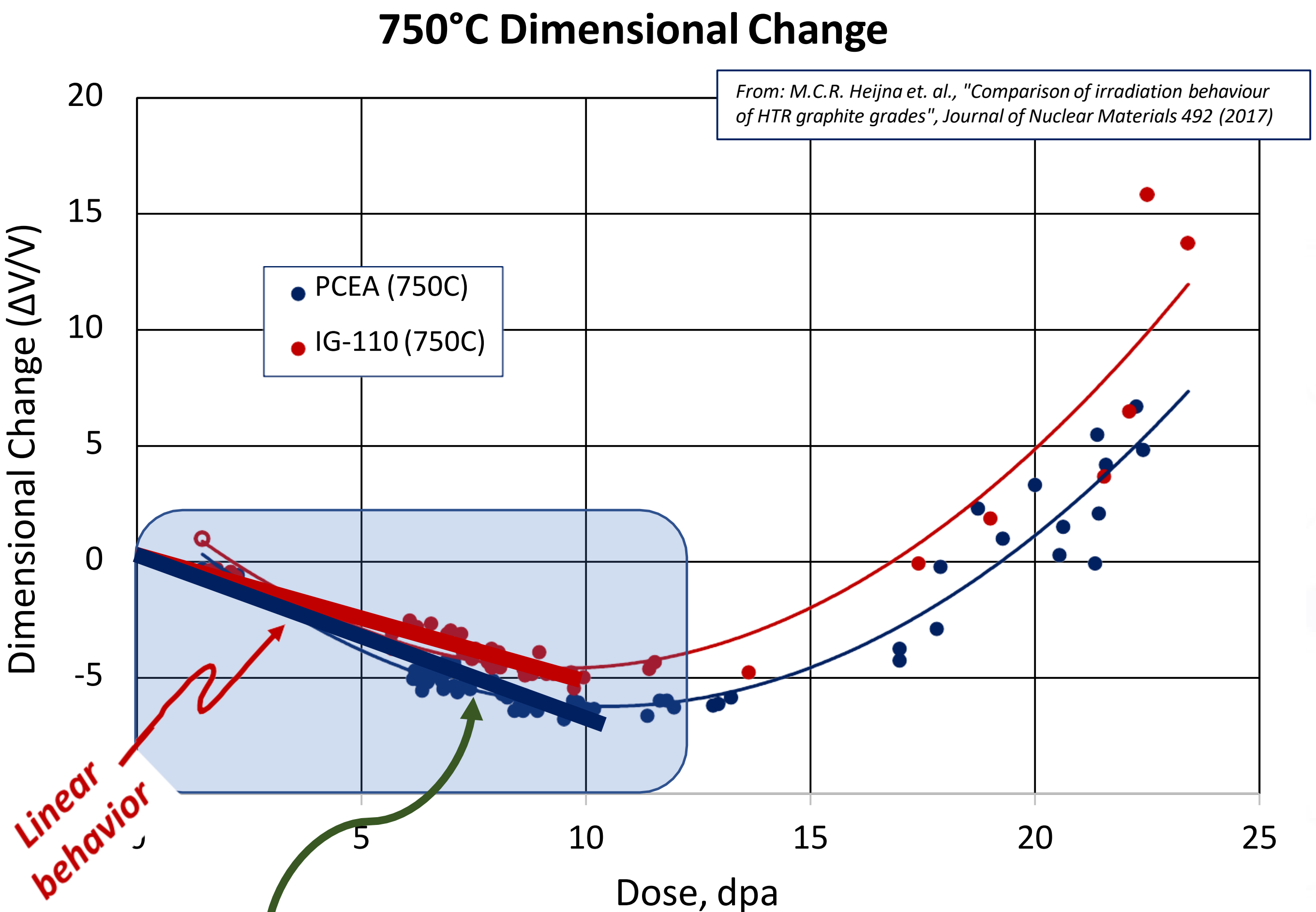
All vendors must establish turnaround dose for their graphite grade



From: M.C.R. Heijna, S. de Groot, J.A. Vreeling, "Comparison of irradiation behaviour of HTR graphite grades", Journal of Nuclear Materials 492 (2017) 148e156

- Why do we care?
  - Point where irradiation induced material property changes begin to reverse.
  - Point where microstructural **densification** stops. Microcracking begins.
- Think of "before" and "after" turnaround
  - Behavior is much more predictable for all graphite grades ***before*** turnaround
    - *Much less predictable (more data scatter)* ***after*** *turnaround*
  - Crack propagation retarded in compressive stress fields.
  - Crack propagation accelerated in tensile
- Turnaround dose changes significantly with temperature
  - IG-110 (50μm) ➔ 10 dpa to 5 dpa
  - PCEA (1800μm) ➔ 11 dpa to 6 dpa

How will ASME handle irradiation response?



- Larger grain grades (PCEA) demonstrate longer life
- Small grain grades (IG-110) demonstrate less change

But both exhibit linear response

- Observations (**before** turnaround)
  - "Linear" response
    - *Both dimensional change and creep*
  - Densification, compressive stress state
    - *Conservative since no cracks form*
- Observations (**after** turnaround)
  - Non-linear response
    - *Much less predictable behavior*
  - Volume expansion
    - *Major crack formation throughout*
- ASME approach (each T_{Irr})
  - Restrict ASME code to **before** turnaround dose
    - *Predictable behavior (for all grades)*
    - *Majority of data in this regime*
  - HTR licensee **must** determine turnaround dose
    - ***Or demonstrate** linear response to expected maximum design dose*
    - ***Or use** most conservative behavior*
  - Licensee must determine oxidation response
    - *Oxidation rate*
    - *Residual strength after oxidation*
    - *Residual strength of irr. graphite after oxidation?*

INL

Idaho National Laboratory

PROGRESS on the ANS-20.2 MOLTEN SALT REACTOR DESIGN STANDARD

American Nuclear Society

Dr. George Flanagan

Chairman, ANS Research and Advanced Reactors Consensus Committee

October 13, 2020

History of the ANS-20.2 Design Standard

The standard working group was organized when a decision was made by NRC Regulatory Guidance, RG 1.232, drafting group that the regulatory guide would consider only gas-cooled, sodium-cooled, plus a generic set of design criteria. This was 2016.

Prior to that consideration, the DOE advisory team had made the same decision that there was insufficient information available to advise NRC on non-light water MSR designs.

What is ANS-20.2?

“Nuclear Safety Design Criteria and Functional Performance Requirements for Liquid-Fuel Molten Salt Reactor Nuclear Power Plants” consists of 4 chapters:

1. Overview
2. Acronyms and Definitions
3. Design Criteria
4. Design Process which includes a PRA consistent with the ASME/ANS non-LWR PRA standard

References

Status of the ANS-20.2 working group as it currently stands

- The ANS-20.2 working group contains over 40 members both domestic and non-USA.
- The domestic members are eager to bring the standard to ballot within the consensus committee.
- The international partners are somewhat restricted because of the different regulatory issues that they face vs. the domestic NRC approach.
- The working group has been meeting nearly every week by phone in order to complete a draft for working group approval.
- The group has been struggling with how to incorporate risk-informed and performance-based principles into the standard considering the lack of MSR data or operational experience.

Approach taken to overcome lack of data

As result, the working group has developed a simplified PRA section in the draft standard that would satisfy NRC requirements but would in 5 years (maintenance interval for ANS standards) allow ease of data integration when it becomes available for the next revision.

Another obstacle is that there are several sets of guidance and requirements (NRC Regulatory Guidance 1.233, NEI-18-04, are examples) that are being separately written and approved, thus keeping up is a struggle for the working group.

The working group has completed Chapters 1-3 and is working on Chapter 4 “Design Process” which includes the PRA section.

The working group intends to submit the standard for a consensus ballot in 2021.

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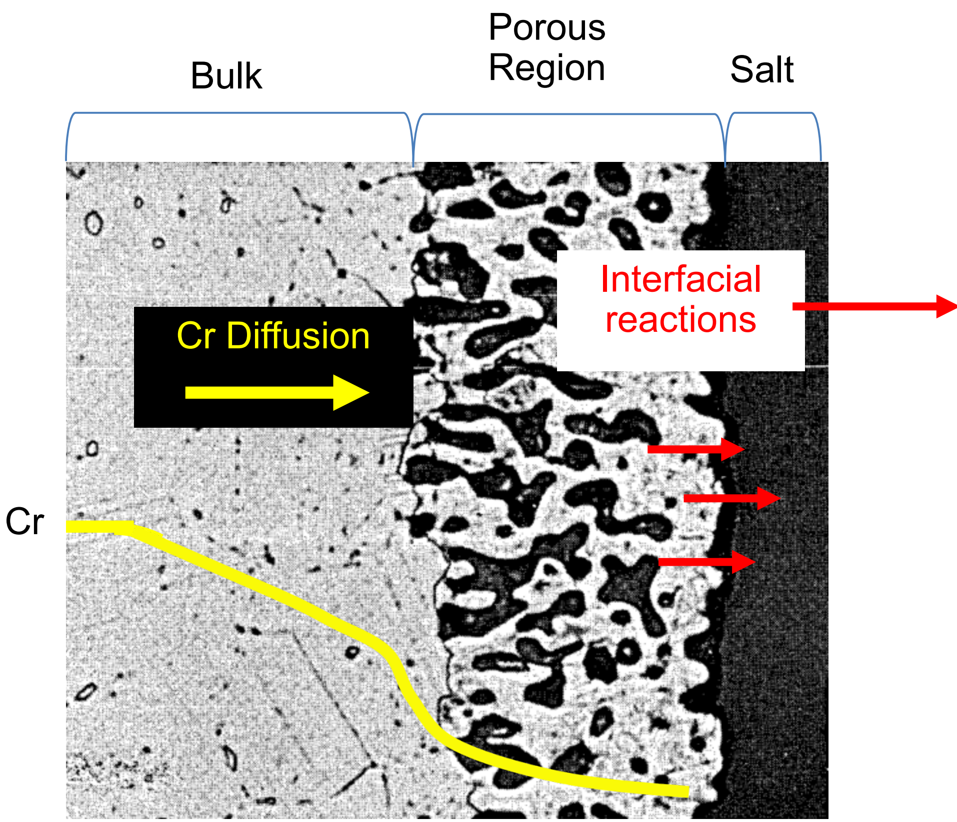
Molten Salt Purity

Wendy Reed
Office of Nuclear Regulatory Research
October 13, 2020

Why is Salt Purity Important?



- Trace water can react with salts to make HCl and HF:

$$H_2O + NaF \rightarrow NaOH + HF$$
$$H_2O + NaCl \rightarrow NaOH + HCl$$

- Salt impurities react with structural alloys:

$$2HF + Cr(s) \rightarrow CF_2 + H_2$$
$$2HCl + Cr(s) \rightarrow CrCl_2 + H_2$$

Slide courtesy of Stephen Raiman, ORNL

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Is there a need for a salt purity standard or best practices guidelines?

- Oxygen and moisture content have a significant impact on corrosion
- Tritium formation during operation could lead to corrosion

Questions to consider:

Describe a method or provide impurity limits?
Different best practices needed for chloride and fluoride salts?
Would different materials affect purity limits?
Would the type of reactor affect the purity needed?

How do we set limits?

- On what basis do we make guidelines?
  - Blanket standard for salt/material combination?
  - System specific?

Data needs

- Can we draw this fictional graph with actual data?
- How do we relate lab exposures to in-service conditions?