ANS/NRC Workshop to Develop a Strategic Vision for Advanced Reactor Standards

May 2, 2018 | 8:30 a.m. to 4:30 p.m. EDT
U.S. Nuclear Regulatory Commission
Three White Flint North
11601 Landsdown Street
North Bethesda, MD

On May 2, 2018, the American Nuclear Society (ANS) and the U.S. Nuclear Regulatory Commission (NRC) sponsored a workshop for industry partners to develop a strategic vision and path forward for advanced reactors standards. The workshop provided an opportunity for designers, vendors, owners, regulators, and representatives of standards development organizations (SDOs) to discuss standards needs to support advanced reactors. There were 121 participants either in person or remotely. (see Attachment 1 for a full list of attendees and Attachment 2 for webinar participants). A summary of the workshop is provided below.

1. Introductions

ANS Standards Board Chair Steven A. Arndt welcomed and thanked all for participating. The purpose of the workshop was explained. ANS President Robert Coward was introduced. He emphasized the importance of this workshop. He explained that he has come to two conclusions this year during this travels: 1) There is no nuclear future without nuclear today, and 2) The nuclear future doesn't look like it does today. We need to firm up the foundation and create a new nuclear future. This workshop is building the bridge. Coward urged attendees to reach out and encourage young professionals to join this effort. Lastly, he stated that we need standards that lead and guide nuclear facilities that address user needs.

Arndt continued stressing that the workshop was a goal setting forum. He reviewed the logistics for the workshop and the breakout questions each technology was asked to address. See Attachment 3 for Arndt's presentation providing more detail.

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2. Presentations of Needs by Technology Working Groups

Technology Working Group (TWG) representatives for fast reactors, high temperature reactors, and molten salt reactors each presented information related to standards needs in there technical areas. Matthew Miller presented on behalf of the high temperature reactor group. Jason Redd presented for the molten salt reactor group. Paolo Ferroni stepped in at the last minute to represent the fast reactor group on behalf of TWG chair Jason DeWitte. Each presentation included a technology overview and indicated whether they have any unique features. Potential areas for future standards needs were identified. Presentations are available as follows:

- High Temperature Reactor Technology Working Group—Attachment 4
- Molten Salt Reactor Technology Working Group —Attachment 5
- Fast Reactor Technology Working Group—Attachment 6

TWGs recognized the benefit of standards, particularly endorsed standards. Standards were preferable, but if not available, designers would need to prepare their own guidance. The lack of a standard was not expected to delay development of advanced reactors. Several topical areas for standards were recommended for further discussion during the breakout sessions.

3. Breakout Sessions (by Technology)/Summary Preparations

Workshop participants divided into three groups by technology—fast reactors, high temperature reactors, and molten salt reactors—to discuss the assigned questions. Discussions were summarized to report back to the full group.

4. Presentations on Breakout Session Results

Workshop participants reassembled for a report of breakout sessions results. Representatives reporting on discussions were Peter Hastings for the high temperature breakout group, Jason Redd for the molten salt reactor group, and Paolo Ferroni for the fast reactor group. Responses to the five breakout questions for the three technology groups are provided below in table format for comparison. Presentations from the high temperature breakout groups (Attachment 7) and the fast reactor breakout group (Attachment 8) provide additional details.

1. For your technology, what would you say is the current status of standards to support the development, design, and licensing of advanced reactors? Are most of the needed standards available up to date? Do they cover the issues that have the most significant impact on the design? On the schedule?		
High Temperature Reactors	**Molten Salt Reactors**	**Fast Reactors**
• Generally speaking, sufficient for both licensing and design • ASME NQA-1, Quality Assurance, stability to be sought later • Evaluation of ANS-53.1, Modular Helium-Cooled Reactor (MHR) Design Process; ANS-30.1, Risk-Informed/Performance-Based (RIPB) Principles and Methods; ANS-30.2, Categorization and Classification of Structures, Systems, and Components (SSCs); in parallel with and informed by the Licensing Modernization Project (LMP) worthwhile and timely • LMP resolution • Consistency between ANS-53.1, MHR Design Process, and others	• Agrees that what is currently available is sufficient to move forward • Instrumentation and control (I&C) is the most important area • Environment safety also important • Would like to have a performance based-standard for acceptance criteria	• Existence of standards is not a requirement but is important to accelerate licensing • Existing standards represent a good starting point; however, they are not always up-to-date and/or best-suited for non-light water reactor (LWR) technologies • Some high-priority standards (schedule-wise) would benefit from modifications, (e.g. ASME NQA-1, Quality Assurance) • Would like existing standards (~860) grouped in high-level categories to facilitate their identification and priority-based use; work done at Oak Ridge National Laboratory for sodium fast reactor standards can be leveraged

2. List the five most current important standards (from any SDO) to your area that are in need of updating to support development, design, and licensing. Why are they your top five?

High Temperature Reactors	Molten Salt Reactors	Fast Reactors
• ASME/ANS RA-S-1.4-2013, PRA for Non-LWRs (trial use) • ANS-30.1, RIPB Principles and Methods (in development) • ANS-30.2, Categorization and Classification of SSCs (in development) • ANSI/ANS-53.1-2011 (R2016) MHR Design Process • ANSI/ISA 67.02.1-2014, Safety Related Instrument-Sensing Line Piping and Tubing • ASME BPVC, Sec III, Div. 5, and related codes for welds, piping, etc. • Potential revisions to ASTM standards consistent with code requirements	• ANS standards on research reactors (ANS-15.X) are the most important; these standards need to be reviewed to determine if changes are needed • ANS-30.1, RIPB Principles and Methods (in development) • ANS-30.2, Categorization and Classification of SSCs (in development) • ANSI/ANS-53.1-2011 (R2016) MHR Design Process • ASME Sec. III, Div. 5 • Inservice Inspection (ISI) in Sec. II, Div. 2, will be of interest as it is being revised technology neutral next year • Welding materials – ASTM and/or AWS may need to add; braising (like welding) may be needed • ASME Operation and Maintenance Code • ACI 349, Concrete Structures for high flux	• ASME NQA-1, Quality Assurance (design, construction, and operation) • ANS-3.2, Quality Assurance (managerial and administrative controls) • ANS-57.1, Design Requirements for Fuel Handling Systems • ANS-54.2 (withdrawn), Fast Breeder Reactor Spent Fuel Storage • ASME BPVC, Sec. III, Div. 5, for environmental effects (mainly corrosion), cladded structural materials • ASME BPVC, Sec. XI, to capture features specific to fast reactor technologies

3. List the five most important technical areas that need standards development (where they currently don’t have standards). Why are they your top five?

High Temperature Reactors	Molten Salt Reactors	Fast Reactors
• RIPB “suite” • ASME BPVC, Sec. VIII, cyclic loads for high temp • Design life for ASME BPVC, Sec. VIII, and Sec. III, Div. 5 • Fiber optic (specifically) and qualification of I&C for high temp • ASME BPVC, Sec. XI, “fitness for service” high-temp failures ISI – team formed to evaluate	• Advanced manufacturing • Fuel salt purity • Radioactive material packaging, handling, shipping for products with salt residue; goal to reduce packaging. Tech neutral standard would be beneficial • Chemistry and corrosion control; inspection and testing for corrosion	• Source term assessment for non-LWRs (would support emergency planning zone size reduction) • Casks for shipping and dry-storage of high assay low-enriched uranium (LEU) • Startup testing and reliability measurement of passive safety systems. Note: highest priority is for reactor vessel auxiliary cooling systems (RVACS) (suggested to reach an industry-agreed method to assess RVACS and address it in licensing phase)

3. ***List the five most important technical areas that need standards development (where they currently don't have standards). Why are they your top five?***		
High Temperature Reactors	**Molten Salt Reactors**	**Fast Reactors**
		• Materials joining such as printed circuit heat exchangers (and diffusion bonding in general) and silicon carbide • Multi-use, inter-operability components—standardization of component interfaces to ease and increase level of modularity in construction • Additive manufacturing • Standards applicable to some specific features of micro-reactors for "niche" applications (e.g. remote control and security aspects) • Digital technology (e.g. use of off-the-shelf computer applications to standardize digital technology implementation)

4. ***Provide some prioritization of the two lists, both in overall need (must have to move forward) and in timing (need by a certain date). If possible, provide insights as to why the standard has priority and what aspect of the issues are driving the priority.***		
High Temperature Reactors	**Molten Salt Reactors**	**Fast Reactors**
1. RIPB-related standards 2. Everything else Sub-prioritized by what needs development, what needs revision, and/or what needs endorsement From question 2: 1. Any changes needed for RIPB licensing a) ASME/ANS RA-S-1.4-2013, PRA for Non-LWRs (trial use) b) ANS-30.1, RIPB Principles and Methods (in development) c) ANS-30.2, Categorization and Classification of SSCs (in development – related to LMP) d) ANSI/ANS-53.1-2011 (R2016) MHR Nuclear Safety Design	Felt it is too early to prioritize	Above list in question #3 is provided in decreasing order of importance

4. Provide some prioritization of the two lists, both in overall need (must have to move forward) and in timing (need by a certain date). If possible, provide insights as to why the standard has priority and what aspect of the issues are driving the priority.		
High Temperature Reactors	**Molten Salt Reactors**	**Fast Reactors**
2. ANSI/ISA 67.02.1-2014, Safety Related Instrument-Sensing Line Piping and Tubing 3. ASME BPVC, Sec. III, Div. 5, and related codes for welds, piping, etc. 4. Potential revisions to ASTM standards consistent with code requirements From question 3: 1. RIPB "suite" 2. Sec. VIII cyclic loads for high temp 3. Design life for Sec. VIII and Sec. III, Div. 5 4. Fiber optic (specifically) and qualification of I&C for high temp 5. Sec. XI "fitness for service" high-temp failures ISI – team formed to evaluate		

5. A) What cross-cutting issues do you believe need to be included in the development of new standards for advanced reactors or the updating of current standards? These could include analysis methods (like probabilistic risk assessment, thermal hydraulics, human factors, etc.) or other cross-cutting issues like staffing, emergency management, advanced instrumentation, and control, security, etc.		
High Temperature Reactors	**Molten Salt Reactors**	**Fast Reactors**

• All of the above (except for ANS-53.1, MHR Nuclear Safety Design)
• Process/understanding of how to raise code issues and get them resolved quickly
  o Accelerating research and standards development
  o Application of demonstration/prototype approach
• Recognition of/ideas for taking optimum credit for mod/sim vs. testing
	• Emergency management less of a concern with safer advanced reactors
	• Standardization of material accountability control method
	• Intersection of human factors, simulation assisted engineering, tightly coupled I&C
	• Alarms management
	• Digital I&C, ISG-05 on highly integrated control room
	• Molten salt reactor safeguards
	• Test procedure and data format for characterization of salt
		• High assay LEU fuel transportation/storage
		• Safety-significance-based classification of SSCs within ASME NQA-1
		• Source term assessment (accounting for coolant-specific radionuclide retention capability; confinement vs. containment)
		• Passive systems analysis/qualification

<table>
<tr><td colspan="3">5. B) Is there a preference across the advanced reactor industry that future advanced reactor standards be more performance based and use high-level, risk-informed principles compared to current standards? What should drive this decision?</td></tr>
<tr><th>High Temperature Reactors</th><th>Molten Salt Reactors</th><th>Fast Reactors</th></tr>
<tr>
<td>• Performance based?
o Maintain existing top level regulatory criteria
o Performance-based criteria as a more easily demonstrated metric to show we meet top level regulatory criteria is a good thing
o LMP-type approach identifies what is important in terms of functional outcomes, other prescriptive “requirements” should not apply
o Additional discussion needed to translate this concept (currently being applied at regulatory framework level) to standards level
• Risk informed?
o Yes, within reason
o Defense in depth is important, but so is knowing when “enough is enough”
• What is driver?
o Ensuring effective/efficient licensing process through safety-focused review
o Reducing cost of plant
o Lack of meaningful deterministic safety framework for non-LWRs</td>
<td>• Prefers performance-based standards over prescriptive standards
• Prescriptive method recognized as needed in some cases</td>
<td>• Key driver is cost
• Recognized that RIPB is likely more onerous effort on the regulator
• Standards should be outcome-focused to avoid need for design modifications to comply with overly prescriptive criteria</td>
</tr>
</table>

It was estimated that there are over 800 existing standards (current and withdrawn) but that very few people have a comprehensive knowledge of all standards. Participants were informed of a list of consensus standards used by the NRC that may be of interest. The list can be found on NRC’s website at https://www.nrc.gov/about-nrc/regulatory/standards-dev/consensus.html.

6. Meeting Summary and Actions

Several standards and codes emerged as priorities between technology groups as candidates for updating and/or harmonization. Responsible SDOs are asked to follow up on the following standards and standards projects to insure their usefulness and availability to advanced reactors. It should be noted that TWG and stakeholder engagement will be necessary to adequately address needs.

American Society of Mechanical Engineers (ASME)

ASME NQA-1-2017, "Quality Assurance Requirements for Nuclear Facilities Applications"
ACTION: Examples of issues in applying NQA-1 to non-LWRs to be considered:

- Subpart 2.2 (QA Requirements for Packaging, Shipping, Receiving, Storage, and Handling of Items for Nuclear Facilities). Concerns with classification levels (a, b, c, d) "based on important physical characteristics and not upon the important functional characteristics of the item with respect to safety, reliability, and operation."
- Subpart 2.5 (QA Requirements for Installation, Inspection, and Testing of Structural Concrete, Structural Steel, Soils, and Foundations for Nuclear Power Plants). Implicit assumptions on installation, inspection and testing of different concrete, steel, foundation, soil, earthwork, equipment and other items and their quality requirements regardless of importance to safety and based on LWR experience.
- Subpart 2.15 (QA Requirements for Hoisting, Rigging, and Transporting of Items for Nuclear Power Plants). Similar concerns on classifications based off of LWR experience for categories A-C.
- Subpart 2.20 (QA Requirements for Subsurface Investigations for Nuclear Power Plants). Possibly less critical, but subsurface QA requirements based on LWR experience and LWR importance to safety of the soil and seismic effects.

ASME Boiler Pressure Vessel Code, various sections (III, VIII, XI) and various divisions
ACTIONS: Areas to be considered for potential inclusion or update include:

- welds, piping, etc.
- inservice Inspection
- Construction rules
- environmental effects (corrosion)
- cladded structural materials
- Cyclic loads
- fitness for service
- design life
- additive manufacturing

American Nuclear Society (ANS)

ANS-30.1-201x, "Integration of Risk-Informed, Performance-Based Principles and Methods into Nuclear Safety Design for Nuclear Power Plants" (new standard in development)
ACTION: Completion of standard; harmonization with other standards and the LMP effort

ANS-30.2-201x, "Categorization and Classification of Structures, Systems, and Components for New Nuclear Power Plants" (new standard in development)
ACTION: Completion of standard; harmonization with other standards and the LMP effort

ANSI/ANS-53.1-2011 (R2016), "Nuclear Safety Design Process for Modular Helium-Cooled Reactor Plants"
ACTION: Review current standard for consistency with other standards and the LMP effort

Institute of Electrical and Electronics Engineers (IEEE)

IEEE I&C standards including IEEE Std. 603 and IEEE Std. 323 and the supporting standards
ACTION: Incorporate fiber optics and qualification to higher temperatures and different environments.

Other areas that emerged as topics for potential new standards, standards that may need to be revised, or general areas to be considered by SDOs are listed below. It should be noted that TWG and stakeholder engagement will be necessary to define or clarify specific needs to proceed.

American Concrete Institute

ACI 349-13, "Code Requirements for Nuclear Safety-Related Concrete Structures"
ACTION: Explore need for revision of current standard to address advanced reactors

American Nuclear Society

ANSI/ANS-3.2-2012 (R2017), "Managerial, Administrative, and Quality Assurance Controls for the Operational Phase of Nuclear Power Plants"
ACTION: Explore need for revision of current standard to address advanced reactors

ANS-15.X, Series of standards for research reactors
ACTION: Evaluate research reactor standards for applicability to advanced reactors

ANSI/ANS-18.1-2016, "Radioactive Source Term for Normal Operation of Light Water Reactors"
ACTION: Explore need for revision of current standard to address advanced reactors

ANSI/ANS-54.2-1985 (W1995), "Design Bases for Facilities for LMFBR Spent Fuel Storage in Liquid Metal Outside the Primary Coolant Boundary"
ACTION: Explore need for reinvigoration of historical standard to address advanced reactors

ANSI/ANS-57.1-1992 (R2015), "Design Requirements for Light Water Reactor Fuel Handling Systems"
ACTION: Explore need for revision of current standard to address advanced reactors
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American Society of Mechanical Engineers (ASME)

ASME OM 2017, "Operation and Maintenance of Nuclear Power Plant Code"
ACTION: Explore need for revision of current code to address advanced reactors

American Society of Mechanical Engineers/American Nuclear Society (ASME/ANS)

ASME/ANS RA-S-1.2-2014, "Severe Accident Progression and Radiological Release (Level 2) PRA Standard for Nuclear Power Plant Applications for Light Water Reactors (LWRs)"

ACTION: Trial use standard to be finalized and seek approval of the American National Standards Institute

American Society of Testing and Materials (ASTM)

ACTION: General suggestion to evaluate need for revisions to ASTM standards consistent with code (e.g., welding materials, brazing, reactive and refractory metals and alloys under the B10 Committee); also to explore standardization of additive manufacturing

American Welding Society

AWS welding/brazing standards
ACTION: Evaluate welding/brazing standards for potential need to update for advanced reactor use

International Society of Automation (ISA)

ANSI/ISA 67.02.1-2014, "Safety-Related Instrument Sensing Line Piping and Tubing Standard for Use in Nuclear Power Plants"
ACTION: Evaluate need for update of current standard for high temperature

Unassigned topical areas needing standardization for advanced reactors that may be taken up by the most appropriate SDO

- Performance-based standard for acceptance criteria (all SDOs)
- Advanced manufacturing
- Fuel salt purity
- Radioactive material packaging handling, and shipping for products with salt residue

Topics for future workshop discussions recognized include:
- Defense in depth
- Harmonization with LMP approach
- Acceleration of standards development; possible funding support to help
- Unique aspects related to seismic
- Reducing loads and structures

Miscellaneous actions:

- Prepare and group a list of existing standards (~860) in high-level categories to facilitate their identification and priority-based use
- Encourage more vendor and international participation at subsequent meetings and workshops
- All SDOs to reinforce industry preference for RIPB methods to be used when developing or updating a standard or code

The next NRC Standards Forum will be scheduled for September of this year at NRC and was thought to be a good opportunity to continue discussions of need actions, prioritization, and next steps.

In closing, Steven Arndt expressed the sentiment that the workshop had great interaction and cooperation from all. He added that there were two main actions, they are to reach out to SDOs of standards that were identified and to reach out to the TWGs with the information gathered today to help establish the next steps.

7. Adjournment

Dr. Steven Arndt thanked all for participating before adjourning the workshop.

List of Attachments	
Attachment 1	Workshop Sign In Sheets
Attachment 2	Webinar Participation Reports
Attachment 3	Welcome/Logistic Presentation (ANS Standards Board Chair Steven Arndt)
Attachment 4	High Temperature Reactor TWG Presentation (Matthew Miller)
Attachment 5	Molten Salt Reactor TWG Presentation (Jason Redd)
Attachment 6	Fast Reactor TWG Presentation (Paolo Ferroni on behalf of Jason DeWitte)
Attachment 7	High Temperature Breakout Session Summary Presentation (Peter Hastings)
Attachment 8	Fast Reactor Breakout Session Summary Presentation (Paolo Ferroni)

ANS/NRC Advanced Reactor Standards Workshop

May 2, 2018

Attachment 1

Three White Flint North, North Bethesda, MD

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Thank You.

ANS/NRC Advanced Reactor Standards Workshop

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Thank You.

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Thank You.

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Sheet 4 of 4 *Thank You.*

Attachment 2

Advanced Reactor Standards Workshop (AM Session Webinar Report)

Report Generated:
5/2/18 4:33 PM EDT

Webinar ID	Actual Start Date/Time	Duration
900-706-611	5/2/18 8:05 AM EDT	2 hours 24 minutes

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Advanced Reactor Standards Workshop (PM Session Webinar Report)

Report Generated:
5/7/18 1:04 PM EDT

Webinar ID	Actual Start Date/Time	Duration
366-722-323	5/2/18 2:41 PM EDT	1 hour 58 minutes

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Attachment 3

American Nuclear Society

American Nuclear Society

Strategic Vision for Advanced Reactor Standards Workshop

May 2, 2018

Steven A. Arndt
ANS Standards Board Chair

American Nuclear Society

A special thanks to representatives of standards development organizations (SDO) and the NEI Technology Working Groups (TWGs).

American Nuclear Society

Welcome & Introductions

American Nuclear Society

Meeting Logistics

- The morning session from now until 10:30 a.m. EDT will be in these rooms.
- The breakout sessions will begin at 10:45 a.m. EDT in rooms
  - High Temperature TWG: 1C03
  - Fast Reactor TWG: 2A39
  - Molten Salt Reactor TWG: 1C05
- We will reassemble in this room at 2:45 p.m. EDT for breakout group reports and discussion.
- The first floor is public, but you need a NRC escort to get to the Fast Reactor TWG breakout room on the second floor.
- There are a number of NRC staff that are part of the workshop. If you have any questions about the logistics or the building, please ask one of them.

American Nuclear Society

Meeting Logistics–webinar

- About 40 individuals are expected to participate by webinar and/or teleconference.
- Webinar participants will be on mute during the presentations and are asked to use the chat feature for questions.
- Access to participate in the breakout sessions has been arranged by teleconference with no restrictions.

American Nuclear Society

Background, Purpose & Goal

- Need for this workshop identified at NRC Standards Forum held September 26, 2017.
- Platform provides designers, vendors, owners, regulators, and representatives of standards development organizations (SDOs) to discuss standards needs to support advanced reactors.
- Goal set to develop a strategic vision for a path forward and priorities for development of standards across all SDOs.
- Today is the first step.

American Nuclear Society

Workshop Agenda

Time (EDT)	Agenda Item
8:30 a.m.	Introductions
9:00 a.m. to 10:30 a.m.	Presentations of Needs by Nuclear Energy Institute (NEI) Technology Working Groups • High Temperature Reactors • Fast Reactors • Molten Salt Reactors
10:30 a.m. to 10:45 a.m.	Break
10:45 a.m. to 12:00 p.m.	Breakout Sessions (by Technology)
12:00 p.m. to 1:00 p.m.	Lunch – On Your Own
1:00 p.m. to 2:00 p.m.	Breakout Sessions (Cont'd)
2:00 p.m. to 2:30 p.m.	Breakout Session Summary Preparation
2:30 p.m. to 2:45 p.m.	Break
2:45 p.m. to 4:00 p.m.	Presentations on Breakout Session Results
4:00 p.m. to 4:30 p.m.	Meeting Summary and Actions
4:30 p.m.	Adjournment

American Nuclear Society

Breakout Questions for Each Technology Group

1) For your technology, what would you say is the current status of standards to support the development, design, and licensing of advanced reactors? Are most of the needed standards available up to date? Do they cover the issues that have the most significant impact on the design? On the schedule?
2) List the five most current important standards (from any SDO) to your area that are in need of updating to support development, design, and licensing. Why are they your top five?
3) List the five most important technical areas that need standards development (where they currently don't have standards). Why are they your top five?
4) Provide some prioritization of the two lists, both in overall need (must have to move forward) and in timing (need by a certain date). If possible, provide insights as to why the standard has priority and what aspect of the issues are driving the priority.

5a) What cross-cutting issues do you believe need to be included in the development of new standards for advanced reactors or the updating of current standards? These could include analysis methods (like probabilistic risk assessment, thermal hydraulics, human factors, etc.) or other cross-cutting issues like staffing, emergency management, advanced instrumentation and control, security, etc.

5b) Is there a preference across the advanced reactor industry that future advanced reactor standards be more performance based and use high-level, risk-informed principles compared to current standards? What should drive this decision?

Question responses to be summarized and presented to group under "Breakout Session Results" scheduled from 2:45 p.m. – 4:00 p.m. EDT.

American Nuclear Society

NEI Technology Working Group Presentations

NEI Technology Working Groups (TWGs) will provide a short summary of their technology including any design features outside current LWR technology that make current standards not applicable. Each TWG has been asked to provide their standards needs with priorities.

Presenters include the following:

- High Temperature TWG—Matt Miller
- Fast Reactor TWG—Jacob DeWitte
- Molten Salt Reactor TWG—Jason Redd

American Nuclear Society

Teleconference Details for Breakout Sessions

Parallel Breakout Sessions (10:45 a.m. to 2:30 p.m. EDT)	Teleconference Details
High Temperature Reactors Breakout Session Teleconference	Call in #: 888-324-7512 Participant passcode: 61172
Fast Reactors Breakout Session Teleconference	Call in #: 888-469-1550 Participant passcode: 22236
Molten Salt Reactors Breakout Session Teleconference	Call in #: 877-918-1353 Participant passcode: 31015

American Nuclear Society

Results and Actions

- Most important technical areas that need standards development?
- Cross-cutting issues?
- Need for High-level, risk-informed principles?
- Do we need follow up workshops to refine recommendations?
- How do we best communicate recommendations to SDOs and other stakeholders?

American Nuclear Society

Questions?

Attachment 4

High Temperature Reactors

Codes and Standards

ANS – NRC Workshop
May 2, 2018

Developers
BWXT
Framatome (previous AREVA)
Kairos Power
Star Core Nuclear
X-Energy

Supporters
DOE, Duke Energy, EPRI and NEI

Technology Overview

High Temperature Gas-Cooled Reactor
(Framatome, X-Energy, StarCore)

- Graphite moderator and Helium coolant
- Tri-Isotropic (TRISO) coated particle fuel
- Block or pebble type fuel elements
- Fixed (block) or moving (Pebble) core
- Epithermal neutron spectrum
- Primary system pressure (~6 MPa)
- Core inlet/outlet Temperature (~325 °C / ~750 °C)
- Steam conditions Temp/Press (~16 Mpa, ~560 °C)

5/2/2018

Technology Overview

KP-FHR
(Kairos Power)

- Fluoride Salt-Cooled High-Temperature Reactor, which leverages TRISO particle fuel in pebble form and a high-temperature, chemically inert, single phase coolant, flibe ($^7Li_2BeF_4$).
- FHR technology requires high temperature, but low-pressure (and thus stress) materials. Inherent fission product retention with the combination of TRISO particle fuel and flibe coolant would benefit from updated standards on SSC classification and treatment of source terms.

Codes and Standards

- Similar to any other reactor design our designs will be governed by hundreds of codes and standards.
- Most will be of little consequence; since they govern routine design, fabrication, construction, and installation activities
  - Heat exchanger design standards for air blast heat exchangers which we will simply order out of a catalog
  - Relevant standards which the NRC would be most interested in are various ASME, IEEE, ASCE standards
  - These standards will be invoked for major parts of the nuclear island, e.g. ASME B&PV Sect III , Div. 5 High Temperature Reactors

Codes and Standards

ASME Section III, Div. 5

- Section III, Div. 5 includes graphite and other high temperature materials
- It provides high temperature design rules for some conventional materials
- The value of the graphite section of Div. 5 remains to be seen, since they have never actually been applied in practice to the design of an actual reactor
- We believe they are usable and beneficial beyond the laboratory context
- The parts for metallic materials will be useful to us and essential for our next generation of HTGRs, i.e. the V-HTGR
- Good progress has already been made on Div. 5, we are not certain whether substantial additional efforts are needed until we start our design activities

Typical Standards for for HTGRs

• Vessels	ASME Section III
• Reactor Internals	TBD - Section III Div. 5
• SGs	TEMA helical coil standard
• Graphite	ASME Section III Div. 5
• I&C	IEEE Standard (Analog or Digital)
• RCCS	ASME Section III
• Valves	TBD - ASME Section III
• Circulator	TBD - ASME Section III
• Silo Concrete	ACI standard
• Refueling machine	TBD robotics or elevator standards

HTGR-TWG

Priority Standards

- ASME/ANS RA-S-1.4-2013, “Probabilistic Risk Assessment Standard for Advanced Non-LWR Nuclear Power Plants,” (TrialUse)
- ANS-30.1-201x, “Integration of Risk-Informed, Performance-Based Principles and Methods into Nuclear Safety Design for Nuclear Power Plants” (new standard)
- ANS-30.2-201x, “Categorization and Classification of Structures, Systems, and Components for New Nuclear Power Plants” (new standard)
- ANSI/ANS-53.1-2011, “Nuclear Safety Design Process for Modular Helium-Cooled Reactor Plants”, R2016
- ANSI/ANS 67.02.1 -2014, “Nuclear Safety-Related Instrument-Sensing Line Piping and Tubing Standard for Use in Nuclear Power Plants”
- ASME Section III Division 5 and related ASME Codes for welds, piping, etc.
- ANS-20.1-201x, “Nuclear Safety Criteria and Design Criteria for Fluoride Salt-Cooled High-Temperature Reactor Nuclear Power Plants”
- Potential revisions to ASTM standards that are consistent with ASME code requirements (e.g. Sec. III Div. 5, 316SS composition in Table HBB-U-1, Revised Case 2581)

Missing Standards

- At this time we cannot readily identify any additional standards outside the context of an active design program

Q&A

HTGR
Simple Safe Secure

Attachment 5

Strategic Vision for Advanced Reactor Standards Workshop

May 2, 2018

Molten Salt Reactors Technology Working Group Report

By Jason Redd, PE

Technology Overview

- Molten Salt Reactors (MSR) utilize salt compounds in a liquid phase to provide reactor core cooling, neutron moderation, and/or fuel form. Typically operating at low pressure and high temperature, MSRs are capable of providing high quality steam or process heat for numerous uses. A wide combination of nucleonics, fuel, and coolant designs are under development.
- Characteristics of some MSR designs that differ from the operating LWR fleet include: higher coolant temperatures, potentially corrosive salt compounds, higher fast neutron exposure of reactor internals and vessel, and liquid fuel circulating outside of a conventional reactor vessel.

2

Benefit of Standards in the Licensing Process

- The National Technology Transfer and Advancement Act (March 1996) codified existing OMB guidance to Federal agencies to utilize consensus standards were appropriate.
- Reactor developers and the NRC Staff benefit from standards which can be reviewed once, and then be recognized as acceptable for use within the scope of the standard for other reactor designs.
  - Costs savings include designers not having to each develop and justify to the NRC Staff common techniques and processes.
  - NRC Staff benefits by not having to repeatedly consume review time and resources on issues common to multiple reactors.
- Consensus standards reflect a broader knowledge and experience base than any one reactor developer could provide which reduces the uncertainty inherent in any new design.

3

Standards Needs

- MSR technology can be deployed today based on existing consensus standards and reactor-specific design details.
  - Such an approach is not preferable due to the resources required to individually develop and defend the design details which would be better addressed by industry standards.
- Many general industry and LWR-centric standards are completely appropriate for MSR plants; the "further from the reactor", the more existing standards are applicable or may be easily adopted in MSR licensing via limited exceptions.
- As a rapidly developing technology, standards acceptance criteria needs to be performance based, rather than prescriptive.
- MSR standards needs are focused around materials and design standards.

4

Top 10 Standards

- ACI – Standard for concrete exposed to high service and accident temperatures;
- ANS-20.2 "Nuclear Safety Design Criteria and Functional Performance Requirements for Liquid-Fuel Molten-Salt Reactor Nuclear Power Plants";
- ANS-30.1 "Integrating Risk and Performance Objectives into New Reactor Nuclear Safety Designs";
- ANS-30.2 "Categorization and Classification of Structures, Systems, and Components for New Nuclear Power Plants";
- ASME/ANS RA-S-1.4 "Probabilistic Risk Assessment Standard for Advanced Non-LWR Nuclear Power Plants";

5

Top 10 Standards (Continued)

- ASME BPV Sec. III Div. 5 – Seek additional content on considerations for corrosion and contact irradiation damage;
- ASME BPV Sec. III Div. 5 – Need more material options such as high strength nickel alloys to broaden the approved material choices for high temperature structural applications;
- ASME BPV Sec. III Div. 5 – Need more material options (metallic, graphite, etc.) for core components in a high fast neutron flux environment;
- ASME BPV Sec. III – Direction regarding design, materials, and fabrication of structural components clad or lined with corrosion-resistant materials;
- ASTM and AWS – Refractory alloys need development work – i.e. welding techniques, fabrication techniques, joining techniques, understanding of embrittlement and fracture behavior.

6

Priority Standards

- Among the preceding Top 10 standards, the below topics are the highest priority to a broad cross section of MSR developers; representatives of the MSR TWG will volunteer to support the below efforts:
  - ASME BPV Sec. III Div. 5 – Need more material options such as high strength nickel alloys to broaden the approved material choices for high temperature applications;
  - ASME BPV Sec. III – Direction regarding design, materials, and fabrication of structural components clad or lined with corrosion-resistant materials;
  - ASTM – Refractory alloys need development work – i.e. welding techniques, fabrication techniques, joining techniques, understanding of embrittlement and fracture behavior.

7

QUESTIONS?

8

Attachment 6

FRWG
Fast Reactor Working Group

Advanced Reactor Standards Workshop

May 2, 2018

Fast Reactor Working Group

FRWG
Fast Reactor Working Group

- Multiple developers working on multiple technologies
- Spans variety of fast reactor technologies in development

ARC	Columbia Basin	Elysium Industries
General Atomics	GE	Hydromine
Oklo	TerraPower	Westinghouse
Duke	Exelon	Southern
Studsvik Scandpower	EPRI	NEI

Industry Engagement

- Fast reactors offer a near limitless source of clean and affordable energy, which have attracted the participation of a diverse group of technology developers and other stakeholders
- The FRWG works with developers and fast reactor stakeholders to further the state-of-the-art
  - Technology development
  - Regulatory
  - International collaboration

High Level Perspectives

- Diverse technologies spanning a spectrum of technical readiness with varying needs
- General consensus that standards need to be modernized as the industry grows, but are generally adequate to support initial deployment strategies
  - Concerns about certain technology-specific gaps
  - Concerns about standards development timeframes and delays

High Level Perspectives

- Standards are most effective when there are multiple industry stakeholders with significant technology maturity and overlap, who have a sophisticated understanding of what is needed in particular areas
- Must consider industry needs in light of industry maturity
- Standard modernization will become increasingly useful as the advanced reactor industry grows

Paradigm Shifts from LWRs

	LWRs (PWR & BWR)	Non-LWRs
Fuel	UO_2	Metals, oxides, carbides, nitrides, salts
Cladding	Zirconium alloys	Steels, ceramics, no cladding
Coolant	Water	Sodium, lead, other liquid metals, gas, salts
Moderator	Water	Graphite, hydrides, no moderator
Spectrum	Thermal	Fast, epithermal, thermal
Temperature	280ºC to 320ºC	300ºC to >850ºC
Fuel cycle	1 to 2 years	Up to 60 years, possibly more

Standards of Interest

- NQA-1
  - Useful to advanced reactor work currently
  - Continue to modernize as appropriate and as needed

Standards of Interest

- Materials
  - Structural alloys, cladding materials, and coating materials for the temperature ranges and fluences of interest
    - BPV code for GFR
  - Concrete considerations at high temperature and fluence
- I&C
  - Spectral, material, temperature, and lifetime considerations
- Fuel and material handling variations

Standards of Interest

- Decay heat
  - Different from LWR standard due to fast spectrum, fuel management, and fuel configuration variations
- Risk-informed design and risk analysis
  - Important to consider implications of inherent safety characteristics
- General reactor design standards
- Varying considerations for fire protection, operations, offsite/backup power, and seismic standards

Standards Gaps

- Standards gap analysis efforts for sodium fast reactors provides initial insights into future standards needs
- This work benefits other technologies
  - Similar investigations may be desired, but results must be kept in context to technology and industry maturity

Attachment 7

HIGH TEMPERATURE TWG BREAKOUT

Advanced Reactor Standards Workshop

02 May 2018

IDENTIFIED AT MEETING INTRO

- ASME/ANS RA-S-1.4-2013 PRA for Non-LWRs (trial use)
- ANS-30.1-201x RIPB Principles and Methods (new)
- ANS-302.-201x Categorization and Classification of SSCs (new)
- ANSI/ANS-53.1-2011 MHTGR Nuclear Safety Design R2016
- ANSI/ANS-67.02.1-2014 Safety Related Instrument-Sensing Line Pipng and Tubing
- ASME Sec II Div 5 and related codes for welds, piping, etc.
- Potential revisions to ASTM stds consistent with code requirements

High Temperature TWG Breakout

ADDITIONAL BRAINSTORMING

NQA-1 (CROSS-CUTTING)

- Treatment of legacy data
  - Materials
  - Fuel qualification
- Stability of NQA-1
  - Periodic incremental changes
  - RG-1.28 (Rev 5) vs NEI template (NEI 11-04A)
- Need for code modifications?
  - For different license types (besides COL, DC)
  - For different materials

- Related: what data are needed for material qualification – ASME Sec II

RISK-INFORMED, PERFORMANCE-BASED (CROSS-CUTTING)

- Overall approach
  - Licensing Modernization Project (LMP) product
    - NRC endorsement may moot/obviate need for certain code changes in near term
      - Is ANS 53.1 still needed given LMP?
      - Alignment needed with LMP; make broader?
      - 30.1 supposed to be tech-inclusive but 30.1 and 53.1 not closely aligned
  - Limit inspections based on risk significance
    - Existing code at component level – may not be readily apparent how system-level risk analysis translates
    - Ensure SSC classification is translated to component level
    - Non-safety-related but safety significant – can be gray area (special treatment)
  - RIPB for other areas, e.g., security
- Defense in depth quantification/specification

High Temperature TWG Breakout

RISK-INFORMED, PERFORMANCE-BASED (continued)

- Overall conclusion
  - More coordination/strategizing needed to clarify where standards treatment/update needed (cf. LMP status)
    - Top-tier process for safety system infrastructure, system classification, etc.
    - Communication to design community
  - Special treatment varies
    - Programmatic controls
    - Additional monitoring surveillance
    - Selected design codes
  - Process layers within LMP
    - SSC classification
    - Defense in depth
- Other design classifications (e.g., IEEE categories, joint IEEE/IEC definitions)
- Safety basis and design basis not the same thing

High Temperature TWG Breakout

OTHER

- Cross-SDO – related to but different from cross-cutting
- Salt chemistry
  - Radioisotope retention
  - Corrosion
  - Address in MSR TWG
- Human factors for passive plants
  - Simplification to reflect limited reliance on operator action
  - Remote/autonomous operation
  - Fuel handling, robotic operations
  - Load following, demand-based power level
- Environmental review
  - Comparison with other agencies' NEPA implementation
  - Not good candidate for standards treatment

PRIORITIZATION/ WORKSHOP QUESTIONS

1. CURRENT STATUS

- Generally speaking, sufficient for both licensing and design
- NQA-1 stability sought (later)
- Evaluation (e.g., 53.1, 30.1, 30.2) parallel with and informed by LMP worthwhile and timely
  - LMP resolution
  - Consistency between 53.1 and others

High Temperature TWG Breakout

2. TOP FIVE MOST IMPORTANT STANDARDS

- ASME/ANS RA-S-1.4-2013 PRA for Non-LWRs (trial use)*
- ANS-30.1-201x RIPB Principles and Methods (new)*
- ANS-302.-201x Categorization and Classification of SSCs (new)*
- ANSI/ANS-53.1-2011 MHTGR Nuclear Safety Design R2016
- ANSI/ANS-67.02.1-2014 Safety Related Instrument-Sensing Line Piping and Tubing*
- ASME Sec III Div 5 and related codes for welds, piping, etc.*
- Potential revisions to ASTM stds consistent with code requirements*

High Temperature TWG Breakout

* cross-cutting

3. TOP FIVE TECHNICAL AREAS

- Risk-informed, performance-based “suite”*
- Sec VIII cyclic loads for high temp*
- Design life for Sec VIII and Sec III Div 5*
- Fiber optic (specifically) and qualification of I&C for high temp*
- Sec XI “fitness for service” high-temp failures ISI – team formed to evaluate*

* cross-cutting

4. PRIORITIZATION OF LISTS

1. RIPB-related standards
2. Everything else

Sub-prioritize by what needs development, what needs revision, and/or what needs endorsement

* cross-cutting

4. PRIORITIZATION OF LISTS

- From question 2:
  1. Any changes needed for RIPB licensing
     a) ASME/ANS RA-S-1.4-2013 PRA for Non-LWRs (complete and endorse – currently trial use)*
     b) ANS-30.1-201x RIPB Principles and Methods (in development)*
     c) ANS-302.-201x Categorization and Classification of SSCs (in development – related to LMP)*
     d) ANSI/ANS-53.1-2011 MHTGR Nuclear Safety Design R2016
  2. ANSI/ANS-67.02.1-2014 Safety Related Instrument-Sensing Line Pipng and Tubing*
  3. ASME Sec III Div 5 and related codes for welds, piping, etc.*
  4. Potential revisions to ASTM stds consistent with code requirements*
- From question 3:
  1. Risk-informed, performance-based “suite”*
  2. Sec VIII cyclic loads for high temp*
  3. Design life for Sec VIII and Sec III Div 5*
  4. Fiber optic (specifically) and qualification of I&C for high temp*
  5. Sec XI “fitness for service” high-temp failures ISI – team formed to evaluate*

* cross-cutting – didn’t spend much time ranking

5A. CROSS-CUTTING ISSUES

- All of the above (except for 53.1)
- Process/understanding of how to raise code issues and get them resolved quickly
  - Accelerating research and standards development
  - Application of demonstration/prototype approach
- Recognition of/ideas for taking optimum credit for mod/sim vs testing

5B. PREFERENCE FOR RIPB

- Performance based?
  - Maintain existing top level regulatory criteria
  - Performance based criteria as a more easily demonstrated metric to show we meet TLRC is a good thing
  - LMP-type approach identifies what is important in terms of functional outcomes, other prescriptive "requirements" should not apply
  - Additional discussion needed to translate this concept (currently being applied at regulatory framework level) to standards level
- Risk informed?
  - Yes, within reason
  - Defense in depth is important, but so is knowing when "enough is enough"
- What is driver?
  - Ensuring effective/efficient licensing process through safety-focused review
  - Reducing cost of plant
  - Lack of meaningful deterministic safety framework for non-LWRs

High Temperature TWG Breakout

Attachment 8

Fast Reactor Working Group

Summary of break-out session

ANS/NRC Advanced Reactor Standards Workshop

May 2, 2018

Key points

- Availability of standards is not a requirement for developing advanced reactors. It is an aid
- Very few people have comprehensive knowledge of status of standards (past and present standards).
  - It would be helpful to include, in the highlights of this workshop, info on where a summary table of existing and past Standards can be found
- Developers of standards cannot work in a vacuum: the effectiveness/pace of their work depends on stakeholder input

Q1: For your technology, what would you say is the current status of standards to support the development, design, and licensing of advanced reactors? Are most of the needed standards available up to date? Do they cover the issues that have the most significant impact on the design? On the schedule?

- Existing standards represent a good starting point
- However, they are not always up-to-date and/or best-suited for non-LWR technologies / fast reactors. Some high-priority standards (schedule-wise) would benefit from modifications, e.g. NQA-1
- Overall suggestion is to have existing standards (~860) grouped in high-level categories, to facilitate their identification and priority-based use. Work done at ORNL for SFR Standards can be leveraged

Q2, 4: List the five most current important standards (from any standards development organization) to your area that are in need of updating to support development, design, and licensing. Why are they your top five?

1) NQA-1 (ANS 3.2, 2012; 2015 version of NQA-1 which was approved in 2017 NRC guidance on QA). See footnote*
2) Fuel transportation/handling/dry-storage (ANS 57.1), to capture general features of fast reactor fuel. (Note: ANS 54.2 exists, but it refers to wet storage of LMR fuel)
3) Supplementing ASME Div.5:
   - Implementation of environmental effects, mainly related to corrosion
   - Implementation of cladded structural materials
   - **However: efforts are needed to find a way to accelerate the pace with which changes are made and finalized in Div.5**
4) Component inspection (ASME Pressure Vessel Section in Section XI of 2001 edition) to capture features specific to several fast reactor technologies (high-temperature, opaque coolant)

* Examples of issues in applying NQA-1 to non-LWRs:
Subpart 2.2 (QA Requirements for Packaging, Shipping, Receiving, Storage, and Handling of Items for Nuclear Facilities). Concerns with classification levels (a, b, c, d) "based on important physical characteristics and not upon the important functional characteristics of the item with respect to safety, reliability, and operation."
Subpart 2.5 (QA Requirements for Installation, Inspection, and Testing of Structural Concrete, Structural Steel, Soils, and Foundations for Nuclear Power Plants). Implicit assumptions on installation, inspection and testing of different concrete, steel, foundation, soil, earthwork, equipment and other items and their quality requirements regardless of importance to safety and based on LWR experience.
Subpart 2.15 (QA Requirements for Hoisting, Rigging, and Transporting of Items for Nuclear Power Plants). Similar concerns on classifications based off of LWR experience for categories A-C
Subpart 2.20 (QA Requirements for Subsurface Investigations for Nuclear Power Plants). Possibly less critical, but subsurface QA requirements based on LWR experience and LWR importance to safety of the soil and seismic effects.

Q3, 4: List the five most important technical areas that need standards development (where they currently don't have standards). Why are they your top five

The areas that need standards development are (decreasing order of importance):

1) Source term assessment for non-LWRs (would support EPZ size reduction)
2) Casks for shipping and dry-storage of High Assay LEU
3) Startup testing and reliability measurement of passive safety systems. Note: highest priority is for RVACS (suggested to reach an industry-agreed method to assess RVACS and address it in licensing phase)
4) Materials joining. Examples are Printed Circuit Heat Exchangers (and diffusion bonding in general), and Silicon Carbide
5) Multi-use, inter-operability components. Standardization of component interfaces to ease and increase level of modularity in construction
6) Additive manufacturing
7) Standards applicable to some specific features of micro-reactors for "niche" applications, e.g. remote locations (e.g. remote control and security aspects)
8) Digital technology (e.g. use of off-the-shelf computer applications to standardize digital technology implementation)

Q4: Provide some prioritization of the two lists, both in overall need (must have to move forward) and in timing (need by a certain date). If possible, provide insights as to why the standard has priority and what aspect of the issues are driving the priority

- Prioritization already shown on previous slides

Q5a: What cross-cutting issues do you believe need to be included in the development of new standards for advanced reactors or the updating of current standards? These could include analysis methods (like probabilistic risk assessment, thermal hydraulics, human factors, etc.) or other cross-cutting issues like staffing, emergency management, advanced instrumentation and control, security, etc

- High Assay LEU fuel transportation/ storage
- Safety-significance-based classification of SSC within NQA-1
- Source term assessment (accounting for coolant-specific radionuclide retention capability; confinement vs containment)
- Passive systems analysis/qualification

Q5b: Is there a preference across the advanced reactor industry that future advanced reactor standards be more performance based and use high-level, risk-informed principles compared to current standards? What should drive this decision?

- Yes, there is such a preference!
- Key driver for risk-informing is COST
- Caveat in risk-informing: it will likely result in more onerous efforts by the regulator
- Recommendation for risk-informing: don't be too prescriptive. Standards should be outcome-focused. Need to avoid that developers are forced to modify their designs resulting in sub-optimal performance (especially economics) "just" because they need to comply with criteria that are not outcome-based