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

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.

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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.

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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.

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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";

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.

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.

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QUESTIONS?

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Advanced Reactor Standards Workshop

May 2, 2018

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