



**UNITED STATES  
NUCLEAR REGULATORY COMMISSION**  
WASHINGTON, D.C. 20555-0001

January 30, 2020

MEMORANDUM TO: Louise Lund, Director  
Division of Engineering  
Office of Nuclear Regulatory Research

FROM: Raj Iyengar, Acting Deputy Director */RA/*  
Division of Engineering  
Office of Nuclear Regulatory Research

SUBJECT: SUMMARY OF DECEMBER 9-11, 2019, INTERNATIONAL  
WORKSHOP ON ADVANCED NON-LIGHT WATER  
REACTORS – MATERIALS AND COMPONENT INTEGRITY

On December 9-11, 2019, the U.S. Nuclear Regulatory Commission (NRC) met with representatives from the international nuclear community to discuss the state of knowledge, operating experience, and research activities related to high temperature materials, coolant chemistry, reactor component integrity, and applicable codes and standards for advanced non-light water reactors (ANLWRs). In addition, members of the public participated by teleconference.

Engineers and scientists from the U.S., United Kingdom, Japan, Canada, China, Malaysia, Italy, Turkey, and the Netherlands attended the workshop. Organizations represented at the workshop included regulators, national research organizations, national laboratories, and universities. Enclosure 1 contains a list of the organizations represented at the workshop.

The first day of the workshop focused on overviews of vendor reactor designs and general research areas for the major national research organizations.

Overview of Vendor Designs (Monday, December 9, Session I)

Several vendors summarized their proposed reactor designs and provided details on materials for structural and internal applications and testing to address data and knowledge gaps for these materials. Molten salt reactors (MSRs), liquid metal cooled reactors (LMRs), and high temperature gas cooled reactors (HTGRs) are under development. A common feature of these advanced reactors is their operation at much higher temperatures than current commercial light water reactors. Some key observations from this session are that a variety of nuclear technologies are being developed to fulfill the unique energy strategies being pursued by each vendor. Both American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) qualified and non-code qualified materials are being proposed. Significant challenges include qualification of appropriate materials. Even for qualified materials,

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additional understanding is needed to ensure that design requirements will be satisfied. Regulatory and technical approaches should focus on ensuring that safety goals are met for each unique reactor design and material combination. The NRC reiterated its commitment to be prepared for licensing.

#### Technical and Research Activities (Monday, December 9, Sessions 2 and 3)

These sessions summarized research programs underway at major national and international organizations. NRC and the US Department of Energy (DOE) summarized research supporting ANLWR material use and development. The Office of Nuclear Regulation (ONR, United Kingdom) and the Canadian Nuclear Safety Commission (CNSC) discussed regulatory and technical frameworks being used (or developed) for licensing ANLWRs. The International Atomic Energy Agency (IAEA) discussed activities to support ANLWR development and knowledge management. In summary, there are significant technical and regulatory efforts underway internationally and the need for technical and regulatory flexibility is universally recognized. Challenges faced by these organizations include the fact that commercial ANLWR operating experience is much less than that for conventional light water reactors (LWR). Specific expertise in each ANLWR reactor type (for the specific materials selected) will help ensure an appropriate safety focus. Therefore, leveraging international ideas, knowledge, and capabilities is a foundational strategy that can benefit all countries and organizations.

The second and third days of the workshop featured sessions focused on the following specific technical topics.

#### Graphite (Tuesday, December 10, Sessions 1 and 2)

Graphite has long and successful history as a core support material in gas-cooled reactors in the United Kingdom. However, there is little operating experience with graphite in MSR. Due to highly vendor-specific and proprietary manufacturing methods, it may not be possible to standardize graphite adopting conventional approaches used for metallic materials. Performance based, risk-informed standards for graphite may be necessary for ANLWR applications. Understanding irradiation effects on graphite, particularly dimensional changes, and chemical behavior of graphite in a molten salt environment are also key gaps.

#### Materials Qualification (Tuesday, December 10, Sessions 3 and 4)

There are very few metallic materials that are approved in the ASME Code for use in high temperature reactors. Due to the need to test materials for time-dependent mechanisms such as creep and fatigue gaps in high-temperature, long-term materials performance are challenging to fill with experimental data alone. Advanced materials qualification methods, such as physics-based modeling and data analytics, may provide an approach to accelerate the typical ten-year, or more, time cycle for qualification of structural materials for nuclear reactors.

#### Inspection and Monitoring (Wednesday, December 11, Session 1)

Non-destructive examination (NDE) of ANLWR components will not be possible in the same way it is performed in LWRs due to the design of these components and the fact that ANLWRs will not have refueling outages like LWRs. Components such as compact heat exchangers will require new NDE techniques. Techniques such as on-line monitoring may be necessary to provide reasonable assurance of component integrity. Japan's Joyo and Monju sodium fast

reactors provide some useful operating experience relative to non-light water reactor inspection. For ANLWRs, it may be necessary to implement a systems-based approach, such as has been used in Japan and is incorporated into the ASME Code, Section XI Division 2 (Reliability and Integrity Management), rather than a traditional inservice inspection program. In-situ surveillance programs will also be important to monitor changes in materials properties due to irradiation, creep, and fatigue. The detailed methods for these surveillance programs do not currently exist, which represents a gap that should be addressed to support ANLWR operation.

#### Molten Salt Chemistry (Wednesday, December 11, Session 2)

This is an evolving and complex field of study since there are several different salts proposed by the various vendors, along with several different structural materials. The Nuclear Research and Technology Group (NRG, Netherlands) has a robust molten salt chemistry and irradiation testing program. Argonne National Laboratory (ANL) discussed development of online monitoring of molten salt chemistry. Continued research is important to further understand molten salt chemistry, including both salt properties and modeling methods, and to refine monitoring techniques for molten salt chemistry.

#### Environmental effects on Metallic Materials (Wednesday, December 11, Session 3)

The talks in this session summarized knowledge of environmental effects, and strategies for managing environmental effects, in liquid metal cooled reactors (LMRs), HTGRs, and MSR. The Electric Power Research Institute (EPRI), summarized the importance of coordinated test programs and use of harvested materials to address knowledge gaps (analogous to LWR materials). Key observations from this session are that the research framework used to address environmental effects in LWRs remains applicable for addressing structural material performance in ANLWRs. While unique environmental effects exist for each reactor type, good basis exists for understanding effects, especially in LMRs and HTGRs. Knowledge gaps exist particularly for higher temperatures and for MSR environments. Uncertainty in performance requirements and environments for reactor applications makes it challenging to prioritize research activities.

#### Summary

The NRC held a 3-day workshop on ANLWR materials and component integrity with representatives of international regulators, reactor vendors, research organizations, national laboratories, and universities. There is a considerable amount of research underway in the technical areas of materials qualification (graphite and metallic materials), molten salt chemistry, inspection and monitoring, and environmental effects on metallic materials. Knowledge gaps exist in the following areas:

- Standardization of graphite, which may necessitate performance based and/or risk-informed standards.
- Understanding irradiation effects on graphite, particularly dimensional changes, and chemical behavior of graphite in a molten salt environment.
- Advanced methods represent a promising approach to expedite qualification of new materials developed to withstand the more severe operating environments in ANLWRs.
- New methods of performing NDE of components, or alternatives to NDE, are needed for ANLWRs due to the design of these reactors and lack of regular shutdowns for refueling.

- Detailed methods for obtaining data during service on materials degradation due to irradiation effects, creep and fatigue should be developed.
- Additional research is important to understand molten salt chemistry, including both salt properties and modeling methods, and to refine monitoring techniques for molten salt chemistry.
- More research on environmental effects on metallic materials in molten salt and high-temperature environments is important to close current gaps.

All presentations and information related to this public meeting (e.g., meeting notice, agenda, and presentations) can be found in NRC's Agencywide Documents Access and Management System (ADAMS) ML20030B755. An additional document will be developed summarizing formal responses to questions posed during the panel discussions.

SUBJECT: SUMMARY OF DECEMBER 9-11, 2019, INTERNATIONAL WORKSHOP ON  
ADVANCED NON-LIGHT WATER REACTORS – MATERIALS AND  
COMPONENT INTEGRITY PUBLIC MEETING DATED January 30, 2020.

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**ADAMS Accession No.: Pkg: ML20030B755**

**Public Notice Agenda: ML19336C987**

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DATE	1/30/2020	1/30/2020	1/30/2020	1/30/2020

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## List of Organizations Participating in the Workshop

### Regulators

Nuclear Regulatory Commission (NRC)  
Canadian Nuclear Safety Commission (CNSC, Canada)  
Office for Nuclear Regulation (ONR, United Kingdom)  
International Atomic Energy Association (IAEA)

### National Research Organizations

United States Department of Energy (DOE)  
Japan Atomic Energy Agency (JAEA , Japan)  
Canadian Nuclear Laboratories (CNL)  
Nuclear Research and Technology Group (NRG, Netherlands)

### Reactor Vendors

FLiBe Energy  
Kairos Power  
Terrapower  
Framatome  
X-Energy

### U.S. National Laboratories

Oak Ridge National Laboratory (ORNL)  
Idaho National Laboratory (INL)  
Argonne National Laboratory (ANL)  
Pacific Northwest National Laboratory (PNNL)  
Sandia National Laboratory

### NRC Contractors

NUMARK  
Southwest Research Institute

### Universities

University of California – Berkeley  
University of Michigan  
Brigham Young University  
University of Tennessee  
University of Wisconsin (Madison)  
Virginia Institute of Technology  
Massachusetts Institute of Technology  
Ohio State University  
Clemson University  
University of Texas  
Rensselaer Polytechnic Institute

### Other

American Nuclear Society  
US Nuclear Industry Council