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Summary of SMiRT20 Preconference Topical Workshop – Identifying Structural Issues in Advanced Reactors

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1 ABSTRACT

The Idaho National Laboratory (INL, USA) and IASMiRT sponsored an international forum Nov 5-6, 2008 in Porvoo, Finland for nuclear industry, academic, and regulatory representatives to identify structural issues in current and future advanced reactor design, especially for extreme conditions and external threats. The purpose of this Topical Workshop was to articulate research, engineering, and regulatory Code development needs. The topics addressed by the Workshop were selected to address critical industry needs specific to advanced reactor structures that have long lead times and can be the subject of future SMiRT technical sessions. The topics were; 1) structural/materials needs for extreme conditions and external threats in contemporary (Gen. III) and future (Gen. IV and NGNP) advanced reactors and 2) calibrating simulation software and methods that address topic 1. The workshop discussions and research needs identified are presented.

2 INTRODUCTION

The Idaho National Laboratory (INL, USA) and International Association of Structural Mechanics in Reactor Technology (IASMiRT) sponsored an international forum for nuclear industry, academic, and regulatory representatives to identify structural issues in current and future advanced reactor design, especially for extreme conditions and external threats. The purpose of this Topical Workshop was to articulate research, engineering, and regulatory Code development needs. The results will be presented in the Division X sessions on “Challenges of New Reactors,” and specific subtopics may be covered in panel discussions at SMiRT 20 (2009) technical sessions to summarize the issues and conclusions identified in the Topical Workshop. The results are anticipated to stimulate interest in developing research and papers for SMiRT 21 in 2011.

The workshop concept originated during meetings between INL and IASMiRT representatives to address the emergence of new commercial nuclear power reactor designs; “the Nuclear Renaissance.” The consensus was the need for more levels of SMiRT technical participation including topical workshops during the off-years between general technical meetings of SMiRT. The topics addressed by this first workshop were selected to address critical industry needs specific to structures and advanced reactor concepts that have long lead times, and to collect ideas from a broad spectrum of nuclear power professionals.

Invited speakers triggered interactive discussions on two sub-topics;

- 1) *Structural/Materials needs for extreme conditions and external threats in contemporary (Gen. III) and future (Gen. IV and Next-Generation Nuclear Plant (NGNP)) advanced reactors*
- 2) *Calibrating simulation software and methods that address Topic 1.*

3 WORKSHOP STRUCTURE

Co-chairmen Dr. Bennett and Dr. Kussmaul welcomed the participants and provided opening remarks. Plenary speakers presented high level overviews of research programs and interests.

Following the plenary addresses, the two topics were addressed by a panel of invited speakers. Each panelist presented a subtopic of interest followed by brief discussion. Once all panelists had presented a subtopic, in-depth, interactive discussions between panelists and audience participants were led by Workshop coordinators Stephen Novascone and William Richins.

Speakers' PowerPoint slides are available on the IASMiRT (<http://www.iasmirt.org/> SMiRT 20 Preconference Topical Workshop link) website. The results of the presentations and topical discussions are contained here in.

4 SUMMARY OF OPENING REMARKS BY CHAIRMEN

Karl F. Kussmaul, Professor Emeritus, University of Stuttgart Dr. Kussmaul opened the meeting with insights on past commercial reactor developments in Europe stressing the peaceful use of the atom as an international bond. Our common goal is "...to accelerate advances and produce clean and safe electricity for the benefit of people everywhere." Outlining the purpose of the Workshop, he identified the issues of high temperatures, high burn-ups, and long service life. These issues will put new challenges on materials, simulation, and performance. Dr. Kussmaul urged international organizations to cooperate again, just as in the early years of light and heavy water reactors.

Ralph Bennett, Director of International and Regional Partnerships, Idaho National Laboratory Dr. Bennett discussed the origins of the Workshop as the result of a meeting between the INL Director John Grossenbacher and the IASMiRT Board during SMiRT 19 (Mr. Grossenbacher presented one of the key note addresses). Collectively, a suggestion to hold off year meetings to identify emerging issues was supported, and Mr. Grossenbacher offered the organizational support of the Idaho National Laboratory. The vision for the off year meeting was a smaller gathering of diverse interests, but focused on a singular emerging topic. This Preconference Workshop is the first product of this effort. The value derived will be weighed to continue with an off year workshop, or make modifications for a more effective arrangement.



Figure 1. Dr. Mulder stimulates discussion during the SMiRT20 Preconference Workshop

5 SUMMARY OF IDENTIFIED RESEARCH AND DEVELOPMENT NEEDS

Discussion between panelists and audience participants was captured by scribe. Those rough notes were condensed into approximately 20 pages of text. The Workshop coordinators met with several panelists the morning following the Workshop to review and identify the salient discussion from the 20 pages of text. The final result is listed below.

5.1 General

- Previous work should be studied for extrapolation opportunities. Many technologies and manufacturing methods from the early days of nuclear energy research are adaptable to address current designs.
- Life extension to 80 years addressing concrete, cabling, and pressure vessel issues is of interest. If this can be understood for present plants, the solutions should be useful for advanced reactors.
- The industry needs to work on transferability of knowledge across reactor types and encourage international involvement. For example, IASMiRT should have involvement with the American Society of Mechanical Engineers and other Code organizations – a disconnect currently exists. IASMiRT needs to lead efforts for the exchange of information and further communication.
- There is a need for increased collaboration between regulatory bodies and the international harmonization of regulatory code language.

5.2 Graphite

- Numerous issues specific to graphite were identified including:
 - Stress ratios for combined stress states
 - Aging
 - Non-destructive investigation
 - Irradiation testing
 - Inspection methods - work is being done to inspect by testing small specimens and relating results to actual size specimens
 - Creep models - considerable uncertainties exist regarding creep models in stress analysis and life prediction of graphite components.
- Many challenges exist for Code development specific to graphite including:
 - Performance based Code versus prescriptive.
 - Standards for acceptance testing - these will have significant impact on manufacture of graphite.
 - Codes language to capture and deal with variability of graphite properties
 - Relaxation or modification of Codes since graphite is not used as a pressure boundary - primary stresses are typically lower than secondary stresses, however many problems exist with creep, micro structure, and cracks
 - Application of reliability analyses and designs to consider a crack tolerance - cracks in the core must be accepted to keep the core operational

- International consensus on Standards for graphite is needed - France, South Africa, Britain, and China have started this process.
- Strain ratios are needed for three dimensional models (combined stress states), as opposed to one dimensional, but experimental data of lateral creep is very limited.
- Research is needed to determine if graphite will last 40 years.
- The fatigue life of both virgin and irradiated graphite needs to be determined.
- Changes to methods of fabricating graphite should be studied to minimize variability.

5.3 Concrete

- The long term environmental conditions of concrete components – specifically high temperatures – need to be identified.
- Long term life and material properties of concrete at high temperatures needs to be quantified.

5.4 Components

- Heat exchangers – there are issues with high temperatures and the helium impurities.
- Other components identified for better understanding include: vessels, core components, carbon fiber composites.
- The high in-service and off-normal temperatures, high burn-up, long service life (60 years), and new coolant compatibility with materials (corrosion from impurities in helium) needs to be addressed.

5.5 Welding and Joining Technologies

- Multiple topics are of research interest:
 - Constitutive models for tensile loading at high temperatures for creep and creep fatigue
 - Methods to predict weld degradation
 - High temperature driven creep damage (reheat cracks)
 - Quantification of crack driving forces and fracture toughness
 - Environmentally assisted corrosion fatigue and stress corrosion cracking
 - Qualified methods and inspections of heavy section welding necessary for new large containment vessels
 - Long term aging
 - Identification and prediction of stress corrosion cracks
 - Methods to calculate (and measure) secondary and residual stress.

5.6 Materials

- Material data needs include:
 - Long term aging data for new reactor pressure vessel materials
 - Methods and strategies for mitigation of aging effects
 - Strength and ductility data at high temperatures - 900 C is the target outlet temperature for some advanced gas cooled reactors (likely to be reduced to 750 C for prototypes)
 - A material data base from existing reactors
 - A more consistent basis for developing fragility curves to eliminate assumptions.
 - Quantification of the effects of supercritical water systems on stress corrosion cracking
 - High strain-rate material experiments
 - Improved steels or choose ferretic steels over austenitic steels for better high temperature performance.
- Procedures for accelerated aging tests should be expanded.
- Alloys for heat exchangers will be a challenge. Alloy 617 and 230 are the candidate materials, with Alloy 800H as secondary choice. Code qualification of materials to the needed temperatures. Alloy 617 has adequate creep strength, good cyclic oxidation resistance, good weldability, low thermal expansion. A draft Code case exists, and the material retains toughness after exposure to high temperatures. New test data needs development for inclusion in the Code. Creep-fatigue, weldments, constitutive models for tensile loading at high temperatures for creep and creep fatigue, long term aging information are needed. Alloy 230 has good resistance to oxidizing, good weldability, but less data exists than for Alloy 617. Alloy 230 has higher tensile strength up to 800 C, is not in the American Society of Mechanical Engineers (ASME) code, and would need a lot of code development work. Alloy 230 Haynes is coming off Patent - need to address material properties from other vendors as use.

5.7 Design

- The feasibility of designing secondary systems first, then primary systems should be studied.
- Criteria for mitigation of malevolent events (blasts, impacts, etc.) should be established.
- Regulatory acceptance and implementation of seismic base isolation systems as appropriate is of interest.
- Large scale structural testing is a need.

5.8 Analysis

- Misuse of simulation software is a significant concern. IASMiRT should provide/develop simulation guidelines, such as quantitative modeling guidance for users, through forums such as NAFEMS. (NAFEMS is an independent not-for-profit body with the sole aim of promoting the effective use of engineering simulation methods such as finite element analysis, multibody system dynamics and computational fluid dynamics. See <http://www.nafems.org/>)

- Variability for application of structural simulation software to highly nonlinear events (i.e. different analysts producing different results when using sophisticated simulation software) should be addressed.
- Methods for coupled analyses rather than sequential for in service transients, earthquake, air and ground shock and impact should be developed.
- Development of multi-scale modeling methods describing microstructure in FeCr alloys under thermal aging and irradiation, to correlate micro structural changes to changes in mechanical properties is of interest.
- The acceptance of modeling codes needs to be modernized.
- Strain-based acceptance criteria for energy limited accident events, and the material properties to support strain based criteria should be developed, in addition to triaxiality factors calculated within the finite element codes, and monotonic loading capability.
- Validation and Verification issues to address:
 - Too much use of typical text book calculations and expecting to validate won't work - it can only verify a model - many examples exist of different modelers using same problem and codes and getting very different results indicating that finite element codes have become too easy to use
 - Define a level of code accuracy to be estimated, and uncertainty stated
 - Define the sensitivity of the mode.
 - Development of realistic problems to benchmark against
 - IASMIRT should collect and publish these kinds of analysis, and consider providing criteria for bench marking, and maintaining a database of validation analyses.

5.9 Probabilistic Risk Assessment (PRA) and Risked Informed Performance

- The United States Nuclear Regulatory Commission (NRC) perspective is that PRA is not enough, for example, once the plant is built and operating, how do you satisfactorily incorporate operational changes into the PRA? Design refinements would require re-doing the PRA.
- Better strategies for probabilistic risk assessment are needed. The Canadian Nuclear Safety Commission has presented a new method to NRC using fragility functions of probability of failure against design parameters in the form of Seismic Qualification Utility Group (SQUG) data.
- Risk informed performance is of interest in Europe. Probability of failure is a significant factor, while the US approach is to assume it is secondary.

6 CONCLUSION

The Workshop successfully produced interactive discussion on the two topics resulting in the above list of research and technology needs. It is recommended that IASMiRT communicate the results of the discussion to industry and researchers to encourage new ideas and projects. In addition, opportunities exist to retrieve research reports and information that currently exists, and encourage more international cooperation and collaboration. It is recommended that IASMiRT continue with an off-year workshop series on select topics.

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