Sodium Fast Reactor Research Plan

M. Denman[1], J. LaChance[1], T. Sofu[2], G. Flanagan[3], R. Wigeland[4], and R. Bari[5]
[1]Sandia National Laboratories: P.O. Box 5800, Albuquerque, NM 87185 USA, mrdenma@sandia.gov, jllacha@sandia.gov
[2]Argonne Natinoal Laboratory: 9700 S. Cass Avenue, Argonne, IL 60439 USA, tsofu@anl.gov
[3]Oak Ridge National Laboratory: P.O. Box 1625Oak Ridge, TN 37831 USA, flanagangf@ornl.gov
[4]Idaho National Laboratory: P.O. Box 1625, Idaho Falls, ID 83415 USA, Roald.Wigeland@inl.gov
[5]Brookhaven National Laboratory: P.O. Box 5000, Upton, NY 11973,bari@bnl.gov

INTRODUCTION

While the Department of Energy Nuclear Energy (DOE-NE) has historically sought to work cooperatively with nuclear power vendors to license a Sodium Fast Reactor (SFR) domestically, recent support for these efforts has been intermittent. As a result, the ability for the DOE-NE to successfully support the safety-related aspects of a SFR license application has become uncertain. To better understand DOE-NE's current capabilities and provide insight into potential future research programs, a series of five safety-related gap analysis panels were formed in the following areas: Accident Sequences and Initiators [1], Sodium Technology [2], Fuels and Materials [3], Source Term Characterization [4], and Codes and Methods [5]. These panels were comprised of representatives from across the DOE lab complex, academia, industry and international bodies and identified key gaps relating to existing experimental databases and capabilities, computational abilities, human capital, and the knowledge-base. The resulting five gap analysis reports are analyzed in Volume I [6] and compiled in Volume II [7] of SAND reports entitled: "Sodium Fast Reactor Research Plan".

METHODOLOGY

Volume I of the Sodium Fast Reactor Research Plan is focused on consolidating the safety-related gaps identified by the five expert panels and evaluating these gaps to inform future decision-makers. Historical operating experience, licensing efforts, and proposed industry consensus standards were examined for insights concerning the relative importance of identified gaps to a safety case. Existing domestic and international facilities were cataloged to identify which safety gaps could be closed without new investment, for large, capital-intensive facilities. Experts were consulted to estimate costs associated with addressing identified gaps to help inform future decisions made with limited resources. Finally, existing research programs which were already addressing safety-related research needs were highlighted.

Once the safety-related gaps were evaluated, they were divided into six prioritization categories including: gaps which are estimated to cost less than a million dollars, time sensitive gaps which should be addressed in the near term, gaps with the potential for international cooperation, gaps related by precursors (other gaps or capabilities), gaps significant to normal operation of a SFR, and gaps which would be addressed with a fully funded SFR program. These categories were then examined for similarities under the assumption that resolving gaps which appeared under numerous prioritizations would be beneficial to the SFR community.

RESULTS

The following general areas emerged as high level research needs which the DOE-NE should address in the foreseeable future: knowledge preservation and management efforts, source term and sodium fire modeling capability, modernization of codes which support licensing, and improved abilities to model accident phenomena in a post-Fukushima world.

A sufficiently funded and coordinated knowledge preservation and management emerged as the most pressing need within the SFR community. Documentation for some codes significant to licensing have been lost (e.g., NUBOW), and other codes are not currently maintained (e.g., LIFE-Metal). Many documents and test data have been saved recently using funds from the Advanced Reactor Concepts program, but much of this information still needs to be sorted, interpreted, and transferred into retrievable storage. While patchwork efforts have ensured that information has not been lost, these efforts should be coordinated to make certain that the DOE-NE knows what it has preserved and what still needs to be determined. A key component to knowledge preservation and management is to ensure that the codes which are needed to support a safety case have the appropriate level of stewardship and user-base within the DOE labs and academia. While the user-base for even the highest profile SFR safety-related codes (e.g., SAS4a) needs improvement, the fuel performance code LIFE-Metal has only a few, nearly emeritus, stewards. Should they retire before the code has been transferred to the next generation of users, the DOE's capability to support and defend a fast reactor fuels qualification case may be lost. Finally, the current process for handling Applied Technology (AT) documentation was determined to occasionally be counterproductive to knowledge preservation efforts. DOE-NE should consider streamlining the AT review process, by allowing qualified researchers speedier access to AT documents, by allowing referencing of AT documents, and timely removal of the AT designation when no longer needed while still retaining the preservation of the technology for possible international exchange.

Due to the SFR's reliance on inherent and passive safety, little effort has been made to maintain domestic capabilities to characterize source terms and sodium fires. After Fukushima, these capabilities will likely receive greater attention in the SFR's safety case. The NRC currently uses MELCOR to examine severe accidents of Light Water Reactors. MELCOR has many similarities to the internationally supported SFR containment performance code Contain-LMR, making MELCOR an ideal code to absorb Contain-LMR's capabilities to become the domestically supported source term and sodium phenomenology code. Additionally, some U.S. facilities, such as Sandia National Labs' (SNL) sodium fire testing vessel Surtsey, are currently under-utilized and are capable of addressing many high-priority sodium phenomenology gaps. These facilities, if properly utilized, can help close the remaining sodium-related safety gaps in a sodium version of MELCOR.

In addition to the need for expanded user-base for SFR safety codes, the codes themselves need to be updated to take advantage of modern computing practices and infrastructure, and to improve their capabilities. SAS4A needs enhancements to improve modeling accuracy, functionality, and usability as well as to take advantage of the multi-processor capabilities which are the current trend in modern computing. Models within SAS4A also need to be improved, especially concerning transitions from full power to natural circulation if passive safety is to be an integral part of the SFR's safety case. In regards to LIFE-Metal, data from the new fuel tests should be incorporated into the code's empirical correlations, and the user manual needs to be updated to incorporate the new changes.

Another implication of Fukushima will likely be increased importance of seismic isolation and modeling. New experimental data concerning the response of SFR core materials and structures, systems, and components to earthquakes and other external events is needed to improve the current predictive modeling capability. Additionally, no validation experiments yet exist to gauge the model's predictive capability.

Finally, external stakeholders were given the opportunity to comment on this report's recommendations before final publication. While various stakeholders obviously would like DOE research to more closely align with their specific design needs (e.g., very high burnup fuel or a stronger emphasis on severe accident research), commonalities in their comments were also identified. A general agreement was reached concerning the importance of seismic-related modeling and validation efforts, as well as the need to preserve licensing codes.

CONCLUSIONS

Most gaps associated with SFRs are related to either the loss of historical data and capabilities or to new technologies designed to make SFR economically competitive. Assuming that much of the historical experimental database from the IFR program can be recovered and the licensing codes can be revalidated to current standards, a SFR can most likely be licensed with metallic fuel clad with stainless steel, in either a pool or a loop configuration, with a Rankine power conversion cycle, and with a fuel burnup within the range demonstrated by metallic fuel. Variations of this theme have been constructed multiple times in both the U.S. and internationally, if both oxide metallic fuel forms are considered. A more aggressive design, with different cladding options, higher burnups, possible use of TRansUranic (TRU) fuel elements or targets and advanced power conversion cycles, will likely require a new irradiation testing facility be built.

ACKNOWLEDGMENTS

The authors would like to express their appreciation to the Advanced Reactor Concepts (ARC) Program within DOE-NE for funding this multi-year effort. This effort was finished under the DOE-ARC work packages # AR-12SN040205, AR-12IN040205, AR-12OR040205, and AR-12BN040205.

The authors would also like to thank the chairs and members of the supporting gap analysis reports for their continued assistance and recommendations for resolving the gaps their panels identified. During this project, Thomas Wei (Argonne National Laboratory [ANL]), Richard Vilim (ANL), Richard Wood (Oak Ridge National Laboratory [ORNL]) and David Holcomb (ORNL) were tasked with identifying gaps in instrumentation and control for sodium reactor technology. Their assistance in this regard was invaluable. The expertise of Chris Grandy (ANL), Ken Natesan (ANL) and Abdellatif Yacout (ANL) was vital in helping compile the ranking tables in this report. Gratitude is also extended to Jesse Philips (SNL), John Sackett (Idaho National Laboratory [INL]) and Art Wright (ANL) for their assistance in editing the report.

The authors would like to thank TerraPower, Westinghouse and AREVA for their feedback regarding the results of the five gaps analysis reports. Their industrial insight was greatly appreciated.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

NOMENCLATURE

AT – Applied Technology
ARC – Advanced Reactor Concepts
DOE-NE – Department of Energy-Nuclear Energy
INL – Idaho National Laboratory
ORNL – Oak Ridge National Laboratory
SFR – Sodium Fast Reactor
SNL – Sandia National Laboratory
TRU - TRansUranic

REFERENCES

1. J. Sackett, R. Wigeland, R. Bari, R. Budnitz, J. Cahalan, C. Grandy, D. Wade, M. Corradini, R. Denning, G. Flanagan, and S. Wright, "Advanced Sodium Fast Reactor Accident Sequences Technology Gap Analysis," FCR&D-REAC-2010-000126, DOE Fuel Cycle Research and Development Program, 2010.

2. M. Corradini, A. Suo-Anttila, J. Hewson, T. J. Olivier, J. Philips, M. Farmer, G. Flanagan, and S. Miyhara, "Advanced Burner Reactor Sodium Technology Gap Analysis," FCR&D-REAC-2010-000034, DOE Fuel Cycle Research and Development Program, 2010.

3. L. Walters, J. Lambert, K. Natesan, A. Wright, A. Yacout, S. Hayes, D. Porter, F. Garner, L. Ott, and M. Denman, "Sodium Fast Reactor Fuels and Materials: Research Needs." SAND2011-6546, Sandia National Laboratories, 2011.

4. D.A. Powers, B. Clément, R. Denning, S. Ohno, and R. Zeyen, "Advanced Sodium Fast Reactor Accident Source Terms: Research Needs" SAND2010-5506, Sandia National Laboratories, 2010.

5. R. Schmidt, T. Sofu, T. Wei, J. Thomas, R. Wigeland, J. Carbajo, H. Ludewig, M. Corradini, H. Jeong, F. Serre, H. Ohshima, and Y. Tobita, "Sodium Fast Reactor Gaps Analysis of Computer Codes and Models for Accident Analysis and Reactor Safety," SAND2011-4145, Sandia National Laboratories, 2011.

6. M. Denman, J. LaChance, T. Sofu, G. Flanagan, R. Wigeland, and R. Bari, "Sodium Fast Reactor Research Plan Volume I," SAND2012- 4260, Sandia National Laboratories, 2012.

7. J. LaChance, J. Sackett, R. Wigeland, R. Bari, R. Budnitz, J. Cahalen, C. Grandy, D. Wade, M. Corradini, R. Denning, G. Flanagan, S. Wright, A. Suo-Anttila, J. Hewson, T.J. Olivier, J. Phillips, M. Farmer, S. Miyhara, L. Walters, J. Lambert, K. Natesan, A. Wright, A. Yacout, S. Hayes, D. Porter, F. Garner, L. Ott, M. Denman, D.A. Powers, B. Clément, S. Ohno, R. Zeyen, R. Schmidt, T. Sofu, T. Wei, J. Thomas, J. Carbajo, H. Ludewig, H. Jeong, F. Serre, H. Ohshima, and Y. Tobita , "Sodium Fast Reactor Research Plan Volume II," SAND2012-4259, Sandia National Laboratories, 2012.