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FY2021 GAIN Walk-in Work

Summary Report

GAIN
Gateway for Accelerated Innovation in Nuclear

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U.S. DEPARTMENT OF ENERGY

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ACRONYMS

ANL	Argonne National Laboratory
CANDU	Canada Deuterium Uranium
DOE-NE	Department of Energy Office of Nuclear Energy
FAI	Fauske and Associates, Inc.
FIPD	Metallic-Fuel Irradiation Database
FY	fiscal year
GAIN	Gateway for Accelerated Innovation in Nuclear
HALEU	high assay low-enriched uranium
INL	Idaho National Laboratory
LEU	low-enriched uranium
MCNP	Monte Carlo N-Particle
MSR	molten salt reactor
MSTDB	Molten Salt Thermal Properties Database
MSTDB-TC	Molten Salt Thermal Properties Database-Thermochemical
MUTBR	molten uranium thermal breeder reactor
NAED	Nuclear Archival Electronic Database
NaSCoRD	Sodium System Component Reliability Database
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
OSTI	Office of Scientific and Technical Information
QAPP	Quality Assurance Program Plan
SNL	Sandia National Laboratories
UF_6	uranium hexafluoride
UK	United Kingdom
WIW	walk-in work

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FY2021 GAIN Walk-in Work Summary Report

INTRODUCTION

Walk-in work (WIW) is defined as work that can benefit the nuclear industry and associated stakeholders. Throughout a fiscal year (FY), WIW projects are identified and evaluated by the Gateway for Accelerated Innovation in Nuclear (GAIN) team. Based on funding availability and industry need, the GAIN team determines whether to fund a WIW project and informs the Department of Energy Office of Nuclear Energy (DOE-NE) of these decisions.

PROJECT SUMMARIES

The following summaries describe the work that was completed in FY2021 and the benefits achieved.

Projects Completed in FY2021

Salt Characterization for Flibe Energy, Inc.

Lead Lab: Oak Ridge National Laboratory (ORNL)

Completion Date: January 2021

Flibe Energy, Inc. (Flibe) was founded in 2011 to design and develop highly efficient molten salt reactors (MSRs) for power generation and waste reduction. Their designs use lithium-fluoride and sodium-chloride salt mixtures coupled to closed-cycle gas turbines for power conversion. They requested assistance from ORNL to obtain salt characterization data through the use of the salt property database at ORNL. Feedback from Flibe indicated that for applicable salt systems in the Molten Salt Thermal Properties Database (MSTDB), they were able to request and quickly receive properly labeled ternary, binary, and quasi-binary phase diagrams and liquidus curves. With this data, they were not only able to accurately identify the most promising compositions for their MSRs, but they no longer had to rely on charts from the 1950s. These charts are not only important to engineering, but they also allow potential investors and partners to quickly grasp the basis and merit of Flibe ideas. Flibe commented that GAIN and ORNL helped move them forward in a big way because of this effort.

Molten Uranium Thermal Breeder Reactor Analysis for Neal Mann and Associates

Lead Lab: ORNL

Completion Date: January 2021

Neal Mann and Associates is a small business, sole proprietorship. Since 2007 the mission has been to develop an advanced nuclear breed and burn reactor design using mostly light water reactor used nuclear fuel. Their vision is a Molten Uranium Thermal Breeder Reactor (MUTBR) design that combines aspects of molten salt reactors and heavy water reactors (like the Canada Deuterium Uranium (CANDU)) with a unique reactor control system (U.S. patent 8416908, 04 2013) to create a molten uranium fueled reactor that operates on a breed and burn fuel cycle (or convert and burn), does removal of most of the

fission products from the circulating fuel, and uses fuel with low fissile content (~2% for a 1000 MWe version).

The objectives of the MUTBR analysis completed at ORNL, were:

1. Avoid the Transatomic Power result of finding out after five years of development that there was a fundamental flaw in the design.

2. Get a professional evaluation of the fuel evolution and burnup for a specific design configuration so that they could verify and correct their own evaluation and methods.

    a. As a background note, because of the January 31, 2021 deadline for NE voucher proposals the request was developed at a time of transition for their tools, both from the Monte Carlo N-Particle 5 code (MCNP5) to MCNP6 and to a new version of their analysis tools that create the input files for MCNP. Due to the transition in tools, the evaluated design was based on inaccurate burnup projections and was not yet determined to be the optimum design.

    b. The actual results have met both initial goals. In addition, they have provided the company with valuable information about using the MCNP6 burnup capability and about its shortcomings in evaluating novel reactor designs.

Neal Mann and Associates believe that the information provided by ORNL will allow the company to do reactor modeling based on rates of decay and neutron interactions derived from the MCNP6 burnup calculations rather than the MCNP tallies used previously, while retaining the ability to model some removal of fission products from the circulating fuel and having much of the reactor fuel circulated outside the reactor core.

Archival of Nuclear Safety Data – Phase I and II

Lead Lab: Idaho National Laboratory (INL)

Completion Date: March 2021

In FY2020, Fauske and Associates, Inc. (FAI) was tasked with identifying U.S. industry opportunities for accessible archival of nuclear technology experimental data. Below is the work that has been completed to date.

- Phase I – Virtually all the operating nuclear power plants in the United States were designed, built, and licensed before 2000. While many of these plants went through license extension evaluations, only two designs have gone through the original licensing process after that date. An unfortunate result is that many of those individuals involved in the design, construction, licensing, and operation of these plants are no longer in the work force and many of the important experimental facilities and individuals who performed the work under these experimental programs are also no longer available. In fact, much of the experimental data and in some cases the experimental test reports are not available or difficult to locate. FAI developed a process to archive important experimental data and provided a demonstration of how the archival status of experiments can be characterized and archived for different levels of experimental documentation. The FAI process is documented in the report titled, "U.S. Industry Opportunities for Advanced Nuclear Technology Development."

- Phase II – The limited scope study completed in FY2021 focused on preserving the results of experimental programs for the safety of light water cooled and advanced reactors by locating and documenting, to the extent possible, where the experimental test information for these programs has

been archived. The Light Water Reactor Data Preservation Activity Team initially identified seven experimental programs, which were determined to be “at risk" of potentially losing valuable data. The seven experimental programs/subject areas identified included the following:

- FERMI-1 Reactor Accident
- Fission Product Behavior During the In-Pile Severe Fuel Damage Test SFD I-4
- Containment Iodine Computer Code Exercise Based on Radioiodine Test Facility Experiment
- Wide Range Piping Integrity Demonstration Project
- Iodine Chemical Research in Canada
- High Temperature Fission Product Chemistry and Transport in Steam
- Anything related to radioactive Methyl Iodide.

With the experiences provided by this effort, the great value of having experimental data archived and easily retrievable is clear. The framework laid out as part of this effort showed that a common database can be used to organize and categorize the immense amount of reactor safety data available. The Nuclear Archival Electronic Database (NAED) was developed to capture the references to the identified “at risk” programs. This database can provide an extensive amount of information on the quality of data, reference source, and archival location. By adding user interface features within the database (filters and keyword search), a user can quickly display all available information pertaining to a specific topic. This will reduce the time required to find relevant experimental information when evaluating reactor safety on current or advanced reactor designs. The phase II final report is titled, “U.S. Industry Opportunities for Advanced Nuclear Technology Development Phase II.” Both reports are available through the Office of Scientific and Technical Information (OSTI) and on the GAIN website (gain.inl.gov).

Energy Calculator

Lead Lab: ORNL

Completion Date: March 2021

GAIN strives to provide consistent, authoritative, and independent information to a broad set of stakeholders (nuclear and non-nuclear users), and in a form that can be readily understood at a level suitable for the stakeholder and their application.

One example is the GAIN Energy Calculator. This tool was developed with similar capability as the United Kingdom (UK) Department of Energy and Climate Change 2050 Energy Calculator for the U.S. (http://2050-calculator-tool.decc.gov.uk/#/home). This application allows users to configure changes to energy supply and demand curves to visualize the impact on overall energy efficiency to meet the UK goal of reducing carbon emissions by 80% by 2050. GAIN, using the expertise at ORNL, built a U.S. version of this capability with updated models, calculations, and visualizations within the application to meet DOE requirements.

The ORNL research and development systems engineering group facilitated the development of the application in collaboration with the requestor and his colleagues with the project broken into two phases:

- Phase 1 – Develop a Proof of Concept with a functional user interface that performs the calculations provided, basic documentation in the GitLab wiki, and deployment via container to a customer device/internal server for demo purposes. A Gitlab pipeline was built to allow for the deployment of future updates and patches.
- Phase 2 – Enhance the user experience of the application, harden security, improve packaging and deployment via containers/Kubernetes, and provide support documentation for operational handoff.

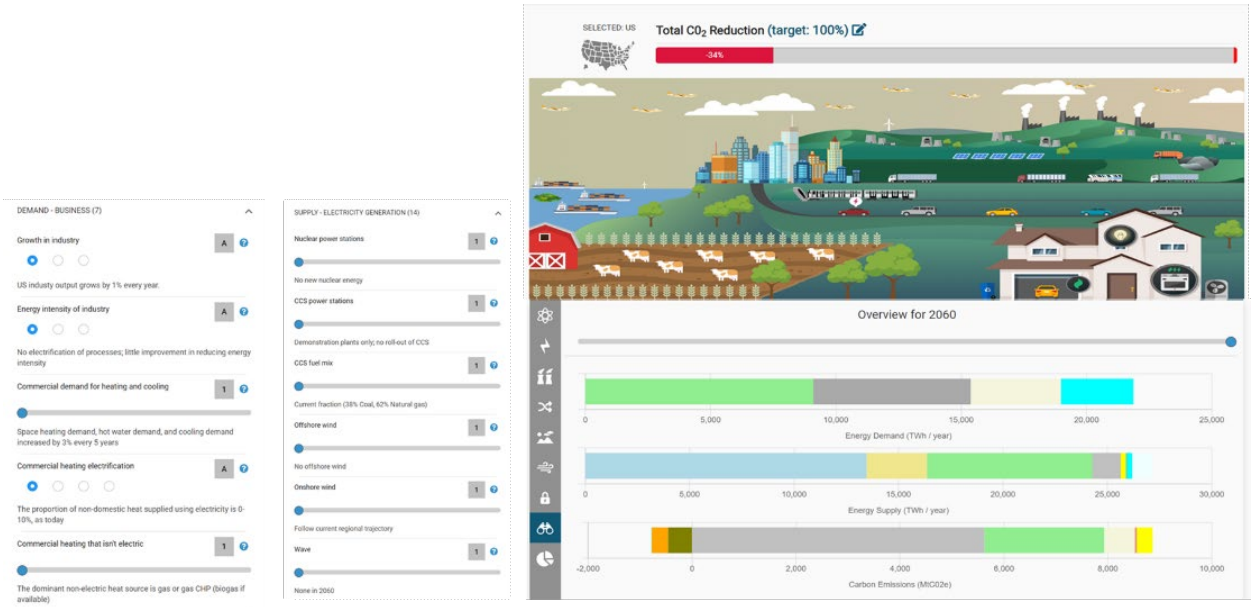

Figure 1. Screen capture from the GAIN Energy Calculator.

The GAIN Energy Calculator became available to the public in March 2021. It allows the user to set a target for carbon reduction within the next 40 years and to customize their choices on both the demand side (i.e., require more electric transportation) and the supply side (i.e., more wind and solar with stable nuclear). The interface is specifically designed to be user friendly, making it simple and quick to look at the impact of different scenarios. The GAIN Energy Calculator is available at https://gain.ornl.gov/#/ .

Phase Equilibria Calculations for Chloride Systems Using the Molten Salt Thermal Properties Database for TerraPower

Lead Lab: ORNL

Completion Date: March 2021

TerraPower is a nuclear innovation company that originated with Bill Gates and a group of like-minded visionaries. TerraPower's mission is to solve the world's toughest problems in energy, climate, and human health through innovative nuclear technology. Using the current version of the Molten Salt Thermal Properties Database-Thermochemical (MSTDB-TC) being developed by the Nuclear Energy Advanced Modeling and Simulation Program in coordination with the MSR campaign and the Nuclear Energy University Program, phase equilibria calculations were performed by ORNL personnel to generate liquidus projections for a range of pseudo-ternary systems, representative of those of interest to TerraPower. To aid with the comparison to TerraPower's models/data, open literature was also reviewed.

Analysis of the 30B UF_6 Container for Use with Increased Enrichment

Lead Lab: ORNL

Completion Date: May 2021

The development of advanced reactor fuel requires High Assay Low-Enriched Uranium (HALEU). One of the challenges with HALEU is transportation, specifically for the uranium hexafluoride (UF6) in the existing 30B cylinders.

Through GAIN, in conjunction with the U.S. Nuclear Regulatory Commission and the Nuclear Energy Institute, ORNL expanded the existing criticality safety analysis, increasing the ^{235}U enrichment of the UF_6 from low enrichment (<5 wt.% ^{235}U) to low-enriched uranium+(LEU+) (10 wt.% > ^{235}U > 5 wt.%) and HALEU (20 wt.% > ^{235}U > 10 wt.%).

The analysis indicates that enrichments up to 10 wt.% ^{235}U or slightly higher (~ 12 wt.%) may be feasible in 30B cylinders in small arrays; but use of the 30B cylinder for the entire LEU+ and HALEU enrichment range at industrial scale appears difficult at best.

Remaining challenges involve the distribution of hydrogenated uranium residues, appropriate credit for the cylinder overpack, and benchmark experiment selection for validation. The analysis is documented in ORNL/TM-2021/2043, available through OSTI.

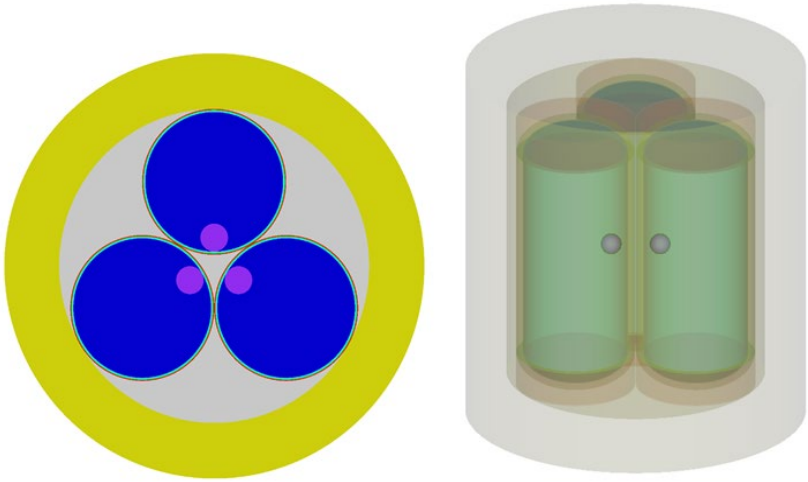

Figure 2. 3x1 array with axially centered hydrogenated uranium residue spheres.

U.S. Electricity Tracker App

Lead Lab: ORNL

Completion Date: July 2021

GAIN, in conjunction with ORNL, developed the "U.S. Electricity Tracker" app that illustrates to users the source of their electricity production in the U.S. and the associated carbon emissions. This app is free and can be downloaded from both Apple and Google app stores. It is a great companion to the GAIN Energy Calculator.

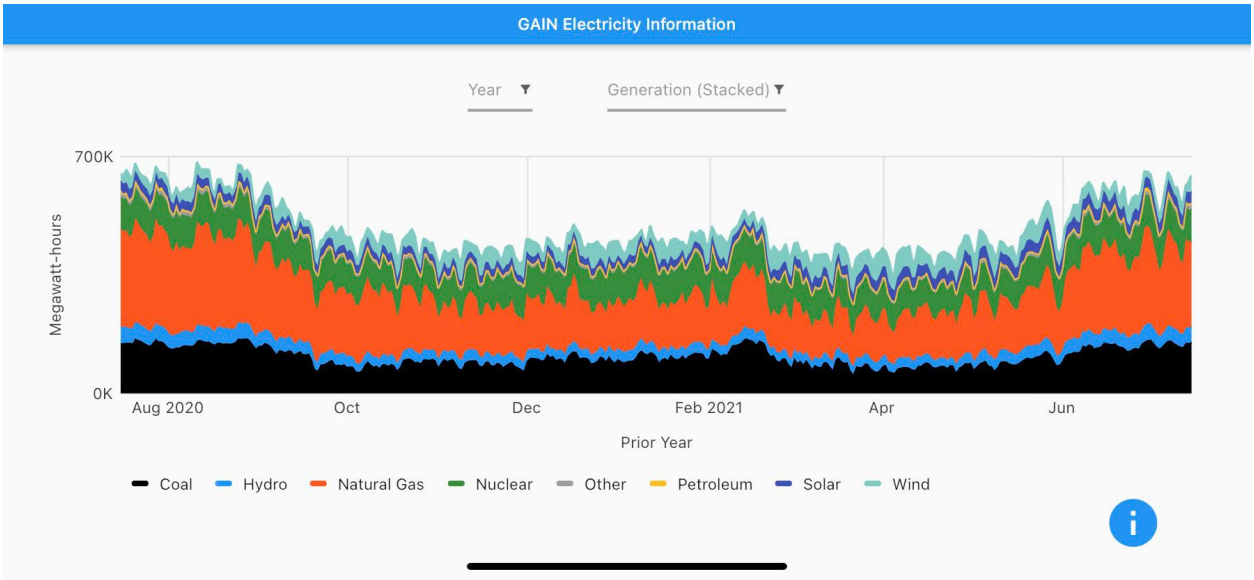

Figure 3. Screen capture from the U.S. Electricity Calculator app.

MSR Component Reliability Database

Lead Lab: ORNL

Completion Date: September 2021

Significant progress was made on the development of the MSR Component Reliability Database. MSR experiment valve data was collected, cleaned, and grouped under defined failure modes, operational fluid, and type. The SQL database was created in a test version, coordinated with the Sodium System Component Reliability Database (NaSCoRD) at Sandia National Laboratories (SNL) on valve data. Failure rates and expansion of the data were also completed to include solar test loops at SNL with a collection of component reliability data at ORNL. The data request form was created and was checked by the Electric Power Research Institute for standardized data collection functionality.

Projects in Progress

Archival of Nuclear Safety Data – Phase III

Lead Lab: INL

Planned Completion Date: November 2021

In Phase III, FAI will perform the following tasks:

1. Organize the list of experimental programs that were identified in Phase I by the reactor coolant type that the experiments represent. Each of the experimental programs will be grouped into one of five coolant types: (a) water (both light and heavy), (b) liquid metal (specific coolant type will be identified), (c) gas (helium), (d) molten salts (specific coolant type will be identified), and (e) organic fluids. Coolant characteristics have a huge influence on the design, operation, and licensing of commercial plants. From a practical viewpoint, these influences are so important that there is little commonality between the behaviors of the reactors under operational and possible accident conditions. Therefore, organizing the relevant information in the database based on this subject would be beneficial.

2. Determine and document, in the NAED database, if experimental programs/experiences of the reactor safety experiments under study have already been archived by another organization. This will narrow down the list of experimental programs/experiences requiring a deep dive to archive. Also, a definition will be formulated for the minimum requirement of a program/experience to be considered archived. All experimental programs/experiences will then be compared against this definition. If a program is considered archived, it will be documented within the electronic NAED database. If not, it will be added to the list of programs/experiences requiring a deep dive.

3. Perform a deep dive on one of the experimental programs that are found to be "not currently archived." The experimental program to be researched will be selected, by a joint FAI and GAIN team, after completion of the first two tasks to ensure the selected program provides significant value to the advanced reactor community. This will provide the framework to guide all future archival activities on the programs/experiences which currently are not archived by another organization.

4. Capture the firsthand experiences of the experts who work on these programs/experiences through a series of interviews and oral histories. In this task a single program/experience will be selected, and existing oral histories will be researched and captured in the database, to provide a framework for capturing future oral histories on other key programs/experiences.

Sodium System Component Reliability Database Expansion

Lead Lab: SNL

Planned Completion Date: December 2021

NaSCoRD at SNL was expanded to incorporate a broader range of past sodium system events. It will have a framework by which data from current sodium test facilities can be incorporated into the database in the future. NaSCoRD is enabling fast reactor designers to a) deploy highly reliable, operationally robust, and safe reactor designs capable of securing a place in a range of economically competitive energy markets, and b) develop high quality, risk-informed safety cases adopting the Licensing Modernization

Project critical for cost-effective reactor licensing. NaSCoRD enhancements, which are planned to be completed in December 2021, are immediately applicable in support of commercialization, ensuring that nuclear energy technology innovation will maintain U.S. leadership in nuclear energy.

Metallic-Fuel Irradiation Database

Lead Lab: Argonne National Laboratory (ANL)

Planned Completion Date: December 2021

Significant progress has been made on the GAIN-supported effort to improve, augment, and qualify the EBR-II Metallic Fuel Irradiation Database (FIPD), consistent with the Nuclear Regulatory Commission (NRC) approved Quality Assurance Program Plan (QAPP). New data has been incorporated for several experimental subassemblies deemed to be of high priority for developers. Efforts included location of additional fuel examination data, comparisons of FIPD pin design information to independent loading data at INL for experimental fuel assemblies, and comparison of FIPD fuel expansion information to new analyses of expansion based on radiographic imaging. Fission gas release data measured at INL's High Flux Examination Facility, and associated QA documentation were located. A revision (Rev. 1) of the QAPP was issued and a virtual audit of the database by the NRC was completed in June 2021.

CONCLUSION

As described previously, WIW projects have contributed to the expansion and availability of highly valuable data and capabilities that are important to the nuclear industry, stakeholders, and clean energy advocates.

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