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Changing the World's Energy Future

FY2021 March Monthly Status Report for the VTR

April 2021

Jordi Roglans-Ribas, George Malone, Thomas Fanning, Kevan D Weaver

Idaho National Laboratory

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SOLVING ENERGY CHALLENGES THROUGH SCIENCE

Versatile Test Reactor

Program Highlights

Jordi Roglans-Ribas, Program Overview

The public comment period for the Draft Environmental Impact Statement (EIS) closed on March 2. Multiple comments have been received and are being sorted. A response to topics in the set of comments, as well as individual comments, is being compiled by the U.S. Department of Energy (DOE) and its subcontractor.

As part of the implementation of the Memorandum of Understanding (MOU) between the DOE Office of Nuclear Energy (NE) and the National Nuclear Security Administration (NNSA) on the availability of plutonium (Pu) for use in VTR fuel, a meeting was held between DOE and NA-10 (Defense), NA-80 (Facilities), and NA-23 (Defense Nuclear Non-Proliferation) to discuss the Los Alamos National Laboratory (LANL) reports on Pu batches identified for use within VTR fuel. In addition, a Savannah River National Laboratory (SRNL) report, developed during the same period, outlined potential treatment options to remove undesirable constituents for fuel source material. VTR will continue to engage NNSA to ensure VTR project objectives are supported and headed in the right direction and do not negatively impact NNSA activities at LANL or SRNL.

The Natrium™ white paper was finalized and distributed to DOE and the project team. A recommendation paper was also generated which includes background information that will help explain details to stakeholders in less technical terms. The governing document will remain the DOE-prepared MOU.

Negotiations continued for the design-build contract. While waiting to complete negotiations, a new release was established under the current contract with GE-Hitachi Nuclear Energy, LLC (GEH) to cover May and June activities. The Statement of Work (SOW) for the release is under development. Capital funded activities will also be initiated in this release. The project anticipates the design-build contract will be finalized in the coming months, eliminating the need for continuation of the GEH contract after June.

Planning for site characterization activities for the reference site has started. Site characterization is an important step due to the potential impact to the structural design of the building as well as systems inside the building. Idaho National Laboratory (INL) and GEH are working together to determine borehole drilling locations and methodology. Site characterization is a high priority as the window of opportunity for this field work is only available during non-winter months.

A workshop was held to discuss export-controlled information (ECI) and other sensitivities in planned VTR publications in March. A follow up will be suggested for the Experiment Integration meeting in June. A review will be conducted for papers being written and submitted to the International Atomic Energy Agency (IAEA) International Conference on Fast Reactors and Related Fuel Cycles (FR21, now FR22). The review will identify whether the papers disclose new and innovative information or methodologies for the first time or whether they deal with previously released information. Ron Omberg was designated as the reviewer for VTR papers. A review of ECI sensitivities will also be conducted for other conference papers such as the upcoming American Nuclear Society (ANS) Annual Meeting and 19th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-19).

VTR Executive Director Kemal Pasamehmetoglu and Eric Loewen (GEH) each published an article on LinkedIn (click on the images to access the hyperlink). These two articles were also featured on EnergyCentral at [Kemal's Energy Central article](#) and [Eric's Energy Central article](#).

Nuclear Design

The fuel team worked with TerraPower to complete a milestone report that provides guidance on areas where VTR and HT9 suppliers must focus to ensure a reliable manufacturing process that meets VTR specifications for critical components such as the fuel cladding and assembly hardware.

The core design and safety analysis teams participated in a meeting with the French Alternative Energies and Atomic Energy Commission (CEA) to discuss scope for collaboration in areas of common interest in sodium fast reactor (SFR) code validation, uncertainty quantification, and safety benchmarks, under the collaboration agreement between DOE and CEA.

VTR Plant Engineering

Made the engineering decision to locate non-safety class electrical equipment outside the U11 VTR Reactor Building structure. Equipment will be housed in a modular structure that will be assembled prior to shipping to site. This decision will result in cost savings via reduced size of the U11 structure.

The VTR Engineering Team continues to work on the optimization of:

- The site plot plan and support of FY 2021 boring operations,
- U11 VTR Reactor Building to reduce cost, improve operational flexibility, and improve safety, and
- The refueling process and associated equipment (F15).

Two milestones were completed in March: M2TR-21IN0201010120, *Develop Technical Maturation Plans for Select low TRL items for the VTR*, and M3TR-21IN0201010112, *Code of Record*.

VTR Experiments

Continued work on the time-motion study where additional definition of each experiment vehicle is being used to populate the database that will be used for the study. The study will be used to provide input to the plant design. Progress has been made on the design and testing of miniaturized pumps and impellers that could be used in three of the four the cartridge loops. These pumps and components will be important for both the steady-state and safe operation of the loops.

Upcoming Events:

National Academies of Sciences, Engineering & Medicine April Meeting, April 6, 2021

VTR Quarterly Integration Meeting, May 25, 2021 (tentative)

Experiments Integration Meeting, June 8 – 9, 2021 (held virtually)

Virtual ANS Annual Meeting, June 14 – 16, 2021

NURETH-19, 19th International Meeting on Nuclear Reactor Thermal Hydraulics, March 2022, Brussels, Belgium

IAEA International Conference on Fast Reactors and Related Fuel Cycles (FR22), April 2022, Beijing, China

SOLVING ENERGY CHALLENGES THROUGH SCIENCE

Versatile Test Reactor

Technical Highlights

George Malone, Reactor Technical Integration

GE-Hitachi Nuclear Energy LLC (GEH)/Bechtel National Incorporated (BNI) Design Engineering Support

GEH and Battelle Energy Alliance (BEA) collaborated to provide decomposition of several DOE Regulations, Orders, and Standards that facilitated an update to the Code of Record, which contributed to the closing of a Level 3 milestone to update the VTR Code of Record on March 31, 2021.

Updated four Technical Maturation Plans (TMPs) that provided the basis for closing the Level 2 milestone to deliver select TMPs. The four plans are associated with: the Reactor Module, the Primary Heat Removal System Electromagnetic (EM) Pump, the Control Rod Drive Mechanisms (CRDM) and Drive Disconnects, and the In-Vessel Transfer Machine (IVTM).

Continued work on VTR risk reduction efforts including:

- Provided DRAFT Optimization Study of the VTR Reactor Building (U11).
- Initiated work on the Intermediate Heat Exchanger TMP.
- Continued work with Argonne National Laboratory (ANL) on the VTR Sodium Fire Analysis.
- Continued resolution of action items resulting from the Special Purpose Review (SPR) of the B24 Heat Rejection System (HRS). Continued work on Draft B24 Pump Study.
- Continued the approach for the time-motion study to address refueling and experimental handling strategies. The proposed approach approved by BEA will incorporate recommendations from multiple time-motion analysis iterations and reevaluate the conclusions given the fully integrated refueling and experimental handling processes. As a result, the VTR program and the refueling systems will have a firm technical basis leading into Preliminary Design.
- Completed the M21 Primary Sodium Processing System SPR report. During the SPR, selection of the ex-vessel ex-Head Access Area (HAA) M21 design was made. Documented the decision and issued the SPR report, which also identified the SPR action items to be addressed.
- Continued work on the VTR Plot Plan and Site Boring Plan and Specification.
- Developed scope plan for the capital funded portion of FY 2021 project.

Argonne National Laboratory

ANL provided technical subject matter expert (SME) support for the following technical reviews and meetings:

- Started the process of updating driver drawings and adding final fabrication details.
- Started literature search of stainless-steel wear due to sodium flow.
- Attended the briefing on Threats and Vulnerabilities Facing U.S. Advanced Reactor Developers on March 23.
- Participated in the Project Action Item #304 - Heat Transfer and Temperatures in Sodium Vault Rooms meeting with BNI on March 26.

Continued collaboration with BNI to ensure the sodium fire mitigation strategy is implemented effectively in the VTR plant design.

Fast Flux Test Facility (FFTF) Documentation and Data Recovery

Requested information about key sodium purification components, including radiological conditions, which will support development of the Primary Sodium Purification System and its supporting system. Located information pertaining to the radionuclide content of the systems and components in the FFTF during deactivation. The information includes radiological surveys and estimates performed at that time, as well as the radionuclide content of the Cold Traps and Cesium Traps. As soon as those locations in the Laboratory can be accessed, information will be retrieved and converted into electronic format. Operational information regarding the ease or difficultly of accessing the Cesium Traps during deactivation will also be provided in a management report.

Thomas Fanning, Nuclear Technical Integration

Fuel Design and Analysis

Finalized the FY 2021 scope for fuel design analysis. Efforts related to Pu supply will focus on the Gallium (Ga) impact and will possibly include consideration of other contaminants in the Pu supply. Completed a literature review of Ga kinetic behaviors and scoping calculations are being conducted to assess the potential impact of Ga on VTR driver fuel performance. Documented experimental data needed to develop Ga models for BISON, and these are being used to identify U-Pu-Zr-Ga testing priorities. Documented metallic fuel performance code requirements for the VTR project in a draft report. Continued assessment of HT9 cladding creep behavior, with work to identify the updated data and creep equation available. Assessments indicate that VTR cladding damage will be primarily due to thermal creep, and fuel analysis work similarly indicates that primary thermal creep will dominate. Assessments indicate that thermal primary creep added to the BISON cladding creep significantly increased the overall HT9 cladding creep strain early in fuel lifetime, but the differences diminished at higher burnups. Continued support for the Pu feedstock supply option assessment, along with reviews of fuel rod welding recommendations.

Fuel Manufacturing

TerraPower completed a milestone report that provided guidance on areas where VTR and HT9 suppliers must focus to ensure a reliable manufacturing process that meets VTR specifications for critical components such as the cladding and ducts. Evaluating options for Pu feedstock sources continues to be a priority for the team. Significant analysis came together in two key reports. The Pu feedstock supply options Level 2 milestone report was fully approved through PICS on February 25, 2021. It summarizes options for sources of Pu for use in VTR fuel fabrication, narrowing them to a single primary option for excess pit-derived material and a single alternative for supplementing the primary with polished non-pit excess material. The draft Pu polishing report supporting a Level 4 milestone will be completed following the final review and approval process. It is expected to be available in early April. Work also progressed on the fuel manufacturing equipment, with the prototype casting equipment and glovebox posing the most technical risk, but also being the most mature. Final design is expected to begin in April to support procurement-ready completion near the end of FY 2021 to support potentially aggressive VTR planning scenarios. This work is an area of potential synergy with the Natrium™ Advanced Reactor Demonstration Program (ARDP), which is anticipated to deploy similar casting technology for their initial fuel manufacturing deployment. Created models for casting support equipment such as heel breaker, mold crusher, and brusher and sent out for initial review and comments. Prepared rod quality assurance (QA) equipment models and remain in the drafting queue for final fabrication drawing package preparation. Completed Functional and Operational Requirements (F&OR) for the VTR rod loading system and posted to the INL document control system. Continued conceptual design efforts regarding rod loading equipment and conceptual models of the equipment continue to be refined. Welding technologies are being investigated. Completed the F&OR document related to the sodium bonding machine.

Core Design

Performed neutronics calculations to estimate the reactivity impacts of uncertainties relative to the fuel isotopic composition. This included exploring the effect of impurities as well as of the potential actinides present in the Pu feedstock. Each non-actinide impurity was evaluated by varying concentration relative to a constant Pu density. For most impurities, the reactivity impact can be approximated with a linear fit with respect to concentration (pcm/ppm), and the effect of each impurity was normalized to a "boron-equivalent" coefficient, shown for selected isotopes in Figure 1. Although many impurities had a negative impact on reactivity, some caused an increase in reactivity due to a reduction in leakage that outweighed the increase in capture. Understanding whether impurities occupy lattice site or are interstitials is essential to accurately characterizing their impact on VTR core reactivity. In separate calculations, the Pu density was reduced to match the presence of impurities, showing that the impact of displacing Pu atoms is strongly negative and more significant than the impact of impurities.

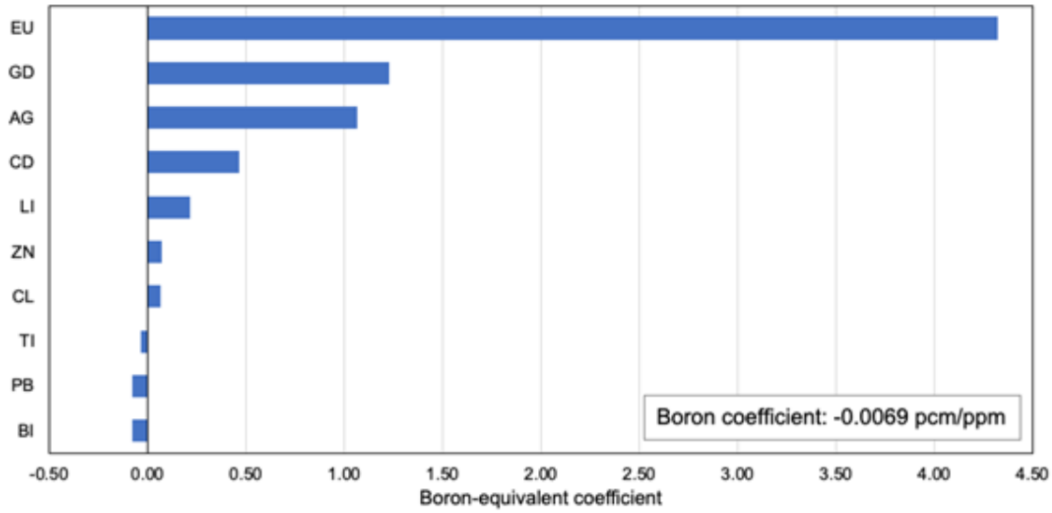

Figure 1. Boron equivalence of impurity isotopes

Assessed a variation of up to 5% in the quantity of potential actinides in the Pu feedstock. The reactivity impact can be approximated with a linear fit with respect to the variation in atom fraction (pcm/at%). The effects of individual isotope quantity variations can be summed to approximate the cumulative effects of varying Pu isotopics within a fixed Pu density, indicating minimal energy self-shielding between Pu isotopes. The linear coefficient of each isotope was normalized to a "Pu-239-equivalent" coefficient, shown in Figure 2. These observations and resulting equivalence factors will be used by the fuel team to perform an assessment of the impact of various feedstocks on the VTR core performance.

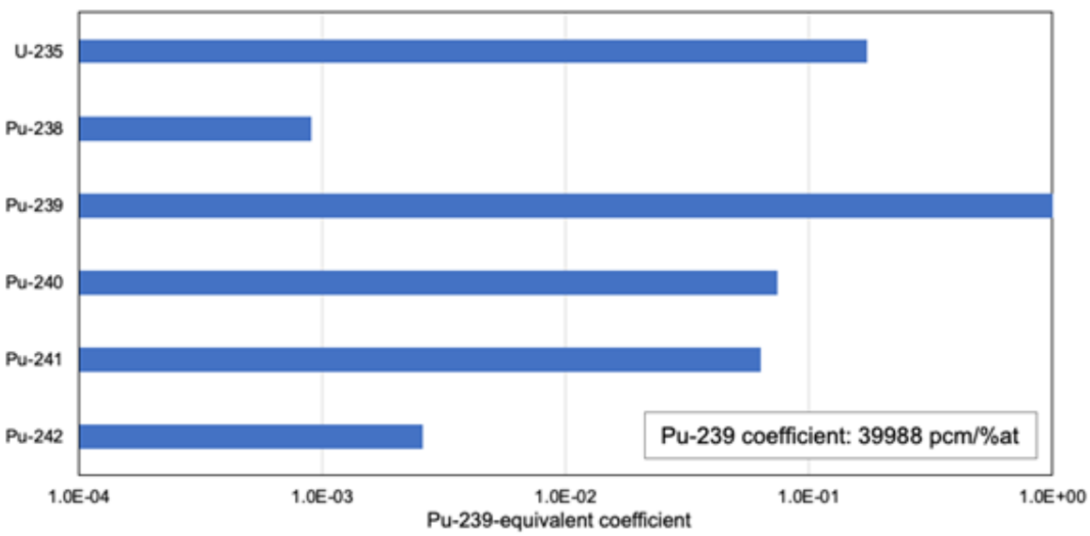

Figure 2. Pu-239 equivalence of actinide isotopes

Transient Safety Analysis

Updated the VTR SAS4A/SASSYS-1 model with a model of the new design of the B24 secondary heat transport system utilizing information provided by GEH and data obtained from the VTR Navisworks model. Simulated the full suite of transient cases to assess the impact of the model update. With the new B24 design included in the model, natural circulation in the secondary loop is slightly less than was predicted with the previous assumed model. Safety margins and peak temperatures were not significantly affected by this change. The draft Revision A of ANL-VTR-81, which documents the VTR SAS4A/SASSYS-1 model, is being updated to document the new B24 model. Software requirements and interfaces associated with the development of a new EM pump model are nearly complete. Began software development with major work on building the interfaces and implementing the code infrastructure required for the physics routines.

SAS Verification & Validation (V&V)

Participated in a meeting with French Alternative Energies and Atomic Energy Commission (CEA) to discuss opportunities for sodium fast reactor (SFR) validation and benchmarks between DOE and CEA. The purpose of the discussion was to define the modeling capabilities for SFR that could be leveraged, data exchange, and benchmark analysis in support of VTR. Revising the VTR V&V requirements ECAR to incorporate additional information on the V&V plan. Finalizing the detailed radial core expansion model verification. Issued a draft ECAR which documents the analysis of all the possible core restraint shapes that SAS can model based on thermal expansions of the grid support plate and load pad region. The MCTF benchmark case successfully modeled the temperature distribution of the experimental initial conditions. Successfully ran a transient SAS case and results demonstrated that the overall temperature behavior could be reproduced. Future updates to the model will include use of the thermal stratification models available in SAS.

Safety Basis

Began updating the ex-vessel hazard evaluation to incorporate waste streams and drafting natural phenomena hazards (NPH) facility categorization. Participated in a tabletop of the Technology Inclusive Content of Applications (TICAP) project on March 5, 2021, with members of the TICAP team and U.S. Nuclear Regulatory Commission (NRC) staff. The team provided feedback on the TICAP guidance, which will be documented in the upcoming tabletop report. Software V&V activities are nearly complete for the Simplified Radionuclide Transport (SRT) code Version 2.0, which is being used for mechanistic source term calculations. Continued to develop SRT model validation documents, focusing on validation of the radionuclide vaporization model within the code.

Probabilistic Risk Assessment (PRA)

Discussed transmittal of VTR conceptual design PRA files. This information will now be integrated into the new VTR PRA repository to improve multi-organization collaboration and enhance QA and version control protocols.

Sodium Fire Hazard Analysis and Software V&V

Participated in a meeting with BNI to discuss heat transfer and temperature limits in the sodium vault rooms. Identified and discussed possible strategies for heat removal from the vault and each strategy will be further investigated before recommendations are made. Issued a VTR Project Memo describing a newly developed method to evaluate the following parameters for sodium drops moving through air: burning rate, flame sheet diameter, flame temperature, drop heatup, and total burning time. It is anticipated that this method will be incorporated into existing sodium fire modeling software being utilized for VTR. Continued to improve sodium fire modeling software based on comparisons of simulation results to experimental test data. Prepared a report section with improvements which will be incorporated into software documentation.

Kevan Weaver, Experiments Technical Integration

Selected key accomplishments within the four experiment vehicle types and support areas are included below.

ELTA – Sodium Cartridge Loop Development
Technical Lead: Mitch Farmer, ANL
Partners: University of Wisconsin, Purdue, Framatome

- Redesigned the pump impeller to fit into a 2.0-inch ID impeller housing as opposed to the previous 3.0-inch impeller, thus freeing up some space for the purification equipment.
- Generated the mesh for the entire 7-pin sodium cartridge loop and initiated computational fluid dynamics (CFD) simulations. Regarding the cartridge loop hydrodynamic test facility, the machining of the test section is in progress as well as the support structure construction. Developed and are testing a system for wire wrapping. Other components, such as flow instrumentation, pressure transducer, and data acquisition system are being ordered.
- Continued work on operational testing of a proposed SFR cartridge impeller design. Installed additional instruments (i.e., shaft torque meter) to provide data needed to support the development of the complimentary magnetic pump coupler and follow-up testing is underway. Completed design for a reduced-scale impeller and parts fabrication initiated (see first bullet).
- Contacted a pump manufacturer and developed a pump design that can meet the test loop requirements. That pump is being integrated into the loop layout.
- Changes are being made to the CARLITA model to reflect that the cartridge loop design is evolving (due to the integration of the purification system into the loop flow path).

ELTA – Lead/Lead Bismuth Cartridge Loop Development
Technical Lead: Cetin Unal, LANL
Partners: University of New Mexico (UNM), Westinghouse

- Successfully tested two pumps with water. The first is a simple 12-vane centrifugal pump (shown in Figure 3). The flow requirement at 2 and 3 m/s is based on the velocity of the lead coolant through a 3-rod fuel test bundle. 2 m/s is the baseline design point based on corrosion data with lead or lead-bismuth, while 3 m/s or higher is the goal for lead-cooled fast reactor (LFR) operations. The pump meets the required flow and head at 2500 rpm for both velocity conditions, while 2000 rpm meets the 2 m/s operating requirement.

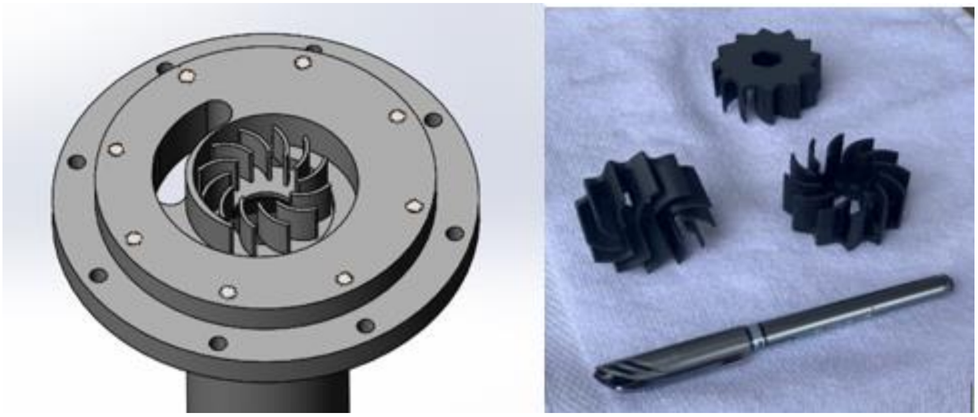

Figure 3. Illustration of the 12-vane pump. Photos of the printed pump on the right, pump with volute on the left. Cover plate removed.

- One design option for preventing freezing of the Pb during the standby operating condition of 200°C Na pool is to raise the Pb-filled portion of the cartridge about 30 cm to reduce the thermal coupling of the Pb to the Na. A bellows section above the reactor head is one possibility for achieving this and discussions have been initiated to examine the feasibility of this approach. A second option is a double O-ring sliding seal which has been designed and sketched. One advantage of the bellows approach is that it would be easier to automate.
- Started ELTA-CL model and boundary conditions for the structural calculations. Potential cases to consider is being developed.
- UNM Pb-loop
    - Installed new heat tape and radiant heaters, shown in Figure 4.

Figure 4. New heat tape on the loop and new insulation.

- Installed and tested a new pneumatic isolation valve (between the loop and the melt tank) and remote-control.

  - Designed and installed a new lid on the melt tank.
  - Tested the entire loop and started an initial run. However, a leak was found in the upper section of the loop.
  - Installed a new lid for the stagnant chamber after the initial test revealed a crack.
  - Three presentations were given at The Minerals, Metals & Materials (TMS) 2021 virtual conference in the Heavy Liquid Metal Materials Interactions Seminar co-organized by UNM.

ELTA – Molten Salt Cartridge Loop Development
Technical Lead: Joel McDuffee, ORNL
Partners: University of Utah, University of Idaho, MIT, TerraPower

- Annular Flow Characterization
  - The first conceptual pump for use in the Oak Ridge National Laboratory (ORNL) flow test loop has been 3D printed (see Figure 5) based on the design provided by ANL for the sodium cartridge loop. The print was performed using a Form Labs Form 2 stereolithography printer with a material resembling ABS. We plan to improve print quality by modifying the geometry and exploring new print orientations. Based the pump concept on a centrifugal pump design consisting of a diffuser body, single inlet closed impeller, and diffuser plate. We plan to operate the pump in the new test section and use it to iterate on various pump design components to characterize the thermal hydraulics in the cartridge loop experiment.

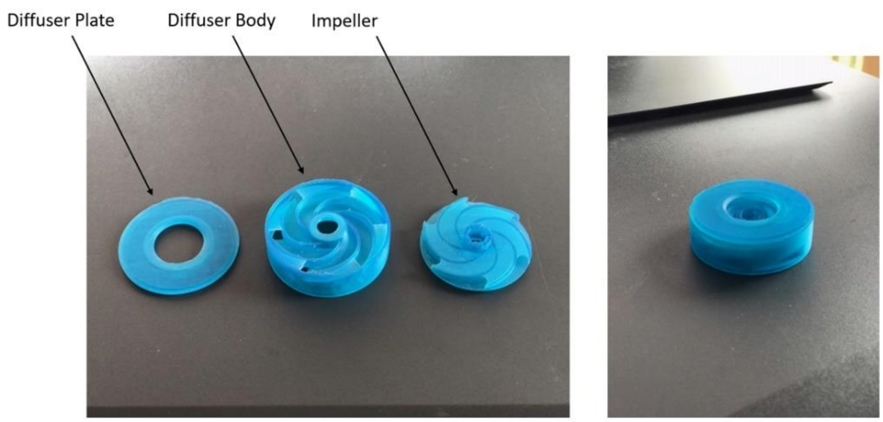

Figure 5. Printed pump components

  - Presented a Modelica/TRANSFORM model of the annular MSR EV to TerraPower which verified their initial conclusions of heat removal performance for anticipated operating limits (see Figure 6).

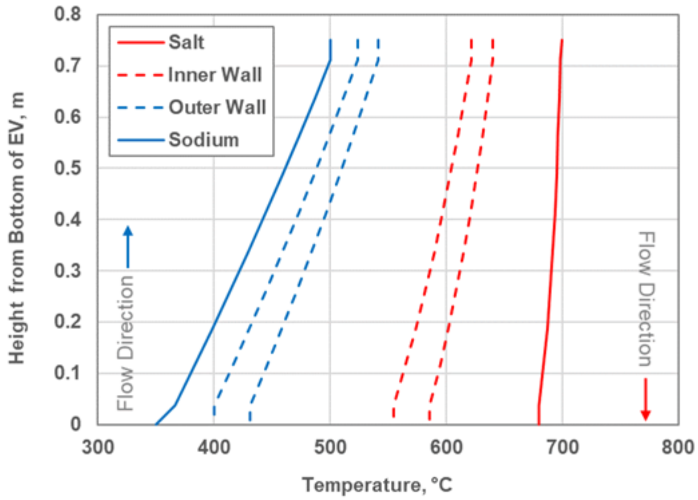

Figure 6. Transform temperature profile.

- Initiated a study on improving the annular EV heat removal performance.
- Modified the helium gas-gap conductivity away from a conservative point value (0.3 W/mK) to a function of the local thermodynamic (temperature and pressure) state.
- Updated the RELAP5 model to use a realistic sodium area and using a controller to adjust sodium flow rate to give the 500°C sodium outlet. Current power level is 40 kW (~2 kW higher than the Terrapower analysis).
- Modified TRACE models to simulate single-phase water tests conducted in 2019. Achieved good agreement between simulations and most experiments (within ~5% for peak pressures, temperatures, and predicted natural circulation flow rates.

- Pressure and corrosion sensor development
  - Preparing to perform the first corrosion test with the stainless steel sensor in molten salt and have developed a test plan to improve safety while utilizing molten salts during experimentation. Finished assembly and functional testing of the nickel and 304 stainless steel sensors and have also performed a test with the MS-2 salt to identify any issues which may arise during corrosion testing. Data from the first corrosion tests with the 304 stainless steel sensor will be collected by the end of the month.

ELTA – Gas Cartridge Loop (GCL) Development
Technical Lead: Piyush Sabharwall, INL
Partners: Texas A&M (TAMU), University of Michigan, General Atomics

- Development of an integrated multi-functional Experimental Vehicle for GFR Irradiation Testing in VTR (University of Michigan)
  - Performed emissivity measurements for the SiC composite sample using the *in-situ* thermal property measurement platform to study the effect of carbon irradiation on surface emissivity.

- Obtained baseline scanning electron microscope (SEM) images of sapphire fibers.
- Established irradiation and temperature parameters with the University of Houston for sapphire fiber irradiation testing.
- Completed modifications to the TAMU's emissivity measurement apparatus.
- Completed CFD simulation of the University of Idaho's emissivity measurement test rig.
- Finalized the design of the lens insertion mechanism for a high-temperature and high-pressure test chamber for LIBS measurement.
- Updated GCL CFD simulation model.

- Development of Innovative Measurement Techniques for Fission Product Transport Quantification (TAMU)
  - The SS316 loop is is being fabricated and should be completed by mid-April.
  - Completed gas concentration measurement technique shakedown. Integrated solenoid valves into the system for remote selection and multiple sample location selection.
  - Obtained preliminary results for gas concentration measurements in optically clear low pressure/temperature facility.
  - Performing experimental and numerical studies of multicomponent gas mixtures air and argon.

ELTA – Materials Capability Development
Technical Lead: Tarik Saleh, LANL
Partners: Oregon State University (OSU), Purdue, Electric Power Research Institute (EPRI)

- Continued development of specialized sensors and devices for in situ measurement of creep, fracture toughness, and stress/strain.

RTA – Rabbit Capability Development
Technical Lead: David Wootan, Pacific Northwest National Laboratory (PNNL)
Partners: Texas A&M

- Shifted work from the pool to the lab to focus on specific areas of the rabbit system, e.g., the in-core components.