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FY2021 January Monthly Status Report for the Versatile Test Reactor

March 2021

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Changing the World's Energy Future

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FY2021 January Status

SOLVING ENERGY CHALLENGES THROUGH SCIENCE

Versatile Test Reactor

Program Highlights

Jordi Roglans-Ribas, Program Overview

Two public hearings for the draft Environmental Impact Statement (EIS) were held on January 27 and 28. An overview description of the VTR was presented by Tom O'Connor and an overview of the EIS was presented by Jim Lovejoy. Comments received during the hearings mostly expressed concerns, primarily related to the INL site option. The public comment period has been extended to March 2. Comments collected during the public sessions and those provided in writing are being collected by DOE.

VTR management efforts in January focused on the realignment of the programmatic scope and milestones based on the final Fiscal Year (FY) 2021 budget allocation. In addition to a replanning of the priorities, specific scope for the $2M in capital funds that have been provided to the VTR is being identified and will be planned to be performed in the last few months of the fiscal year. The Project is preparing a baseline change proposal (BCP) to the resource-loaded schedule implemented last Fall. The BCP will revise the scope, schedule, and budget of the integrated master schedule to align with the reduced funding received under the FY 2021 Appropriations vs. the original FY 2021 Continuing Resolution (CR) projected funding. In an effort to continue to mature the project controls aspects, we've begun taking performance (similar to earned value) against the schedule.

VTR welcomes Steve Unikewicz, a mechanical engineer with over 35 years of industry experience. Steve will provide oversight of several systems and processes including the Reactor Module.

The expanded VTR website https://inl.gov/vtr was launched January 15 and provides public communications related to several VTR topic areas of interest: What is VTR?, Why VTR?, Environment & Safety, VTR users, Workforce & Economy and Resources.

Outreach efforts included government affairs calls with Bechtel National Inc. (BNI) on January 14 and 28 to discuss questions that Hill staffers have about the VTR. Additionally, VTR Executive Director Kemal Pasamehmetoglu participated in the Idaho American Nuclear Society Lunch and Learn on January 26, providing an update of the VTR.

Nuclear Design

Replanned the FY 2021 nuclear design scope to accommodate the reduced budget. Most activities in the core design will continue at a reduced pace and others in the safety analysis and safety basis are postponed until next year. The program's top priority is continuation of work related to the material source for fuel and the fuel fabrication development. LANL completed a key report on the potential plutonium sources for VTR fuel that is the basis for a February milestone assessing fuel material options.

VTR Plant Engineering

January's engineering work advances under General Electric-Hitachi (GEH) in the areas of design risk mitigation and value engineering studies, technical maturation of key plant components, and nuclear supply chain evaluations and development.

The budget for the Engineering Department was finalized in January based on FY 2021 appropriations. Based on the reduced funding ultimately appropriated for FY 2021, the engineering scope was identified with focus on the items posing the largest risk to project schedule and success.

Congress appropriated $2M in capital funds for FY 2021. This funding was allocated to plant design to bridge Planning Phase activities and Execution Phase activities.

Started work on inter-department guidance to improve communications and design integration. Work also began on a design review procedure intended to be used by VTR Engineering staff to verify design requirements are met during different phases of the design.

VTR Experiments

Each of the main experiment vehicles, including the Extended Length Test Assembly (ELTA) cartridge loops, continued progress on their designs with a focus on more detailed design analysis and component development and testing. The component development and testing require "miniaturization" of sensors, instrumentation, and other components to fit inside the space provided in the experiment vehicles, while still providing the functions necessary to monitor and manipulate the test.

Upcoming Events:

VTR Quarterly Integration Meeting, February 25, 2021

NURETH-19, 19th International Meeting on Nuclear Reactor Thermal Hydraulics, postponed until March 2022, Brussels, Belgium. Abstracts due February 14, 2021

IAEA International Conference on Fast Reactors and Related Fuel Cycles (FR21), initially scheduled for May 10 -13, 2021, China, now rescheduled to April 2022. Full papers for DOE review due by February 19

Technical Highlights

George Malone, Reactor Technical Integration

General Electric-Hitachi (GEH)/Bechtel National Incorporated (BNI) Design Engineering Support

GEH continued efforts to plan and schedule Technology Maturation Planning activities.

Identified the approach and developed the schedule for the time-motion study to address the overall refueling and experimental handling strategies. The proposed approach approved by BEA will incorporate the recommendations from multiple time-motion analysis iterations and re-evaluate the conclusions given the fully integrated refueling and experimental handling processes. Given the output of this work, the VTR program and the refueling systems will have a firm technical basis leading into Preliminary Design.

The Requirements Management Team continued defining plant-level requirements to ensure such requirements are available and traced in DOORS.

GEH engineers continued work in the following areas:

- Advanced the M21 Primary Sodium Processing System study for ex-vessel design and risk assessment of the selected three design options. Once completed, the risk assessment will allow the selection of the M21 design that will be developed in the preliminary design phase.
- Continued to update the framework for the Technology Readiness Assessment (TRA) Program and to review this framework with BEA in order to progress the overall program approach and to support low TRL component progression.
- Completed Technology Maturation Plan (TMP) samples for the identified four long lead items, B11 Reactor Module, B12 CRDM, B21 EM Pump, and F42 In Vessel Transfer Machine (IVTM).
- Performed additional review of the Critical Technology Elements (CTEs) with BEA in support of the TRA program. Additional CTE were identified and added to the existing list. The additional CTEs were screened to identify the Technology Readiness characteristics that needs to be addressed in the next steps of the TMPs.
- Continued ANL-GEH interfacing work activities between J11 (Core and Fuel Services) and B11 (Reactor Module System). This effort provides a key framework for collaboration to facilitate critical interfaces definition, coordination, and risk reduction.
- Continued resolution of action items resulting from the Special Purpose Review of the B24 Heat Rejection System. Completed Draft B24 Pump Study. Provided initial responses to BEA comments on B24 system requirements.
- Continued Requirements Management work to reduce overall project risk, specifically firming stakeholder, plant, and common requirements with BEA via regular review meetings, workshops, and training. The review of stakeholder requirements was completed.
- Continued Analysis-Design Interface discussions. This initiative is aimed to increase of the integration of analysis works performed by BEA with the design work performed by GEH-BNI-TP. The objectives to ensure needed inputs and outputs are timely scheduled and planned, and interfaces activities and impacts on ongoing

work in various organization are well understood. This initiative will streamline the work and reduce iterations and rework between analysis and design teams. The short-term goal is to capture key interfaces activities within the L3 MCS schedule. The long-term goal is to facilitate the implementation of a fully integrated schedule among all organizations performing work for the VTR project.

FFTF Documentation and Data Recovery

All Thermal Striping documents for the Fast Flux Test Facility (FFTF) and the Clinch River Breeder Reactor (CRBR) have been located, retrieved, and converted into electronic format. There is a total of 27 FFTF documents, 36 CRBR documents, and several documents showing the interaction between the FFTF and the Prototype Test Reactor (PFR) at Dounreay regarding thermal striping. All the documents are being assembled along with a management-level summary report for processing and review by Export Control and Information Release. As soon as they clear, which is anticipated in a few weeks, they will be put up on the VTR SharePoint Site. The significance of these documents is as follows. Avoidance of thermal striping is an important aspect of the design of a Sodium Fast Reactor. Adjacent sodium streams, with different temperatures and oscillating, when impinging on steel structures will impose high-cycle thermal stresses and eventually high-cycle fatigue will occur. As an indication of the importance of avoiding thermal striping, temperature differences necessary to avoid thermal striping in an operational sense were contained in the Tech Specs in the FSAR for the FFTF and more importantly in the Limiting Conditions for Operation (LCOs).

The process of assembling an HT-9 fuel assembly from its respective components, such as wire warp, clad pins, end caps, rails, and ducts has become a concern of interest. The PNNL FFTF Finding and Retrieval team has identified and located a total of 105 FFTF fabrication procedures dealing with this subject. A search is currently underway by the PNNL Finding and Retrieval Team to retrieve these procedures and convert them into electronic format. These procedures are associated or related to the assembling of the seven HT-9 Metal Fuel Fabrication (MFF) tests that were assembled and tested in the FFTF. After retrieval, these procedures will be processed through Export Control and Information Release. It is anticipated that this will be completed in late February or early March.

VTR Control Rod Mechanical Design Analysis

A first-cut number indicating the nominal mechanical lifetime of a VTR absorber assembly has been calculated. The VTR absorber bundle contained 37 pins with HT-9 cladding and with an HT-9 inner duct and outer duct. The calculated value of 760 Effective Full Power Days (EFPD) should be regarded as a bounding high number for the following reason. VTR dimensions, core physics, and thermohydraulic information was used wherever and wherever available, and where not, FFTF placeholder or default information were used. A list of the missing information has been developed and incorporated into a Design Information Request (DIR). A meeting is being set up with the reactor physics staff at ANL to obtain the VTR information to replace the FFTF placeholder numbers. Incorporation of the missing VTR reactor physics information into the analysis will produce a more accurate mechanical lifetime. The current factor limiting the design lifetime is excessive contact stresses between the B4C pellet and the cladding. However, when the new information in the DIR is incorporated into the mechanical lifetime analysis, elimination of bundle looseness and absorber bundle over-compaction may become the limiting factor. Whether this will produce a shorter lifetime has yet to be determined.

Calculation Support for VTR Waste Form Analysis

Pacific Northwest National Laboratory (PNNL) staff continued evaluating fuel processing scenarios that included mitigating approaches from a safety perspective for fuel handling, cleaning, transport, processing, and final disposition. Continued researching historical documentation to support development of programmatic spent fuel treatment functions and operational requirements (F&ORs). Finished reading background, safety and function and requirements documentation from the Fast Flux Test Facility (FFTF) and Experimental Breeder Reactor-II (EBR-II) and are beginning work on the VTR F&ORs alongside INL. Reviewed and contributed to a draft F&OR document primarily drafted by INL. Once this concerted initial design draft effort for historical reactor approaches completion, PNNL will work with INL to integrate this information into the final deliverable.

Thomas Fanning, Nuclear Technical Integration

Fuel Design and Analysis

Concentrated on examining potential effects of Ga on VTR fuel behavior, including testing and analysis. While the low concentrations of Ga are not expected to have a profound influence on performance, thermodynamic analysis of potential effects on fuel phase composition and physical properties will be analyzed. In this way fuel property changes, or the lack of, can be suggested and used in performance models. Diffusion couples of U-Pu-Ga-Zr with HT-9 began construction for testing at typical cladding operating temperatures. Fuel/cladding interactions will be examined.

Continued to assess HT-9 creep behavior and associated design equations to ensure that the right effects are included to account for fuel behavior, where stress increases with fuel burnup and decreases with operating temperatures. The goal is to reduce uncertainty in calculating cladding strain against strain limits provided by the fuel Design Basis. The results will be applied to the fuel performance modeling efforts.

ORNL completed two reports of the results of their fuel pin modeling efforts. The HT-9 sourcing and supplier qualification milestone report with TerraPower is nearly complete in preparation to meet an upcoming level 3 PICS milestone

Fuel Manufacturing

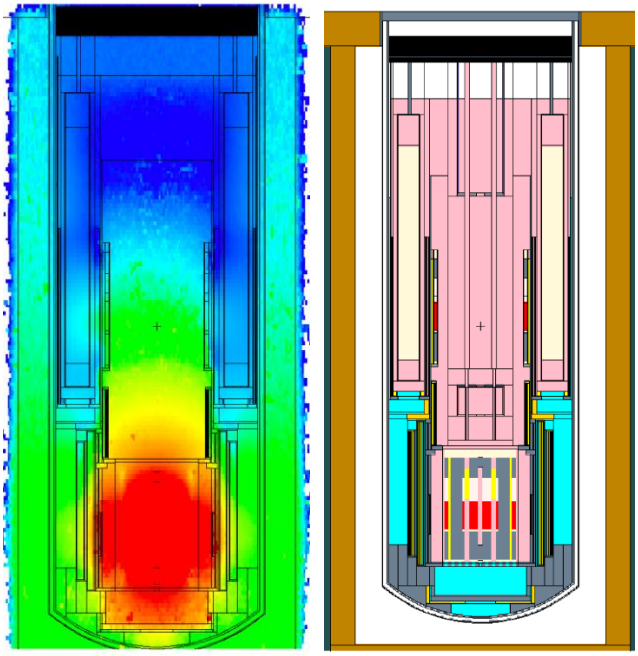
Continued to focus on maturing the manufacturing equipment designs and defining the manufacturing process details. Los Alamos National Laboratory (LANL) completed a Pu supply evaluation, completing a level 4 PICS milestone. Savannah River National Laboratory (SRNL) and INL are investigating manufacturing impacts of using different sources of Pu as this could be a budgetary risk to the project. Completed contract documents for procurement of a prototype casting furnace and safety enclosure for early completion of a level 3 PICS milestone. SRNL, LANL Carlsbad office and INL subject matter experts continue to meet and plan for disposition of casting scrap materials and are trying to mitigate processing efforts required for disposition. After a successful design review in December, the team completed equipment modeling efforts and began drafting fabrication drawings for the Quality Assurance-related “slug processor” prototype equipment. The team also began preparing models for demolding equipment pieces. INL and TerraPower completed a review of the rod loading equipment Functional and Operational Requirement (FOR) document and are incorporating comments. Began consolidating information and data regarding the rod welding available technologies in preparation for down-selecting the appropriate welding technology. TerraPower completed a settling furnace FOR. LANL prepared a systems model

to evaluate manufacturing throughput/bottlenecks to support equipment development and are maturing that model.

Core Design

VTR Shielding Analysis

Continued VTR shielding activities and will continue through the design process and lifetime of VTR. An early focus has been on secondary activation, which has a direct impact on potential worker exposure and therefore need for appropriate design choices. Leveraging GEH engineering details regarding the vessel layout and the shielding model used was updated to be consistent with the engineering drawings and CAD model. The new calculations shown below helped investigate the main contributions to the increase in the secondary sodium activity and the path through which neutronics contribute to it. Examined new shield configurations to further reduce the secondary sodium activity by blocking the major neutron streaming paths observed in the current model.



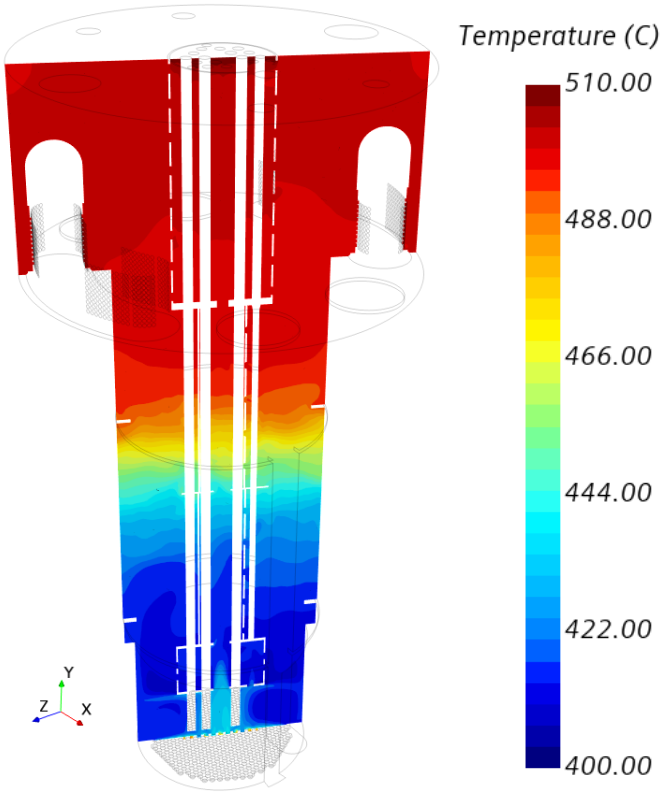
Predicted VTR Fuel temperature distribution at BOEC

Safety Analysis

Documented significant portions of the SAS4A/SASSYS-1 VTR model that was used for ANL-VTR-46 and ECAR-4733, Rev. 3 reports. A first draft of the model documentation report will be completed by the end of February.

Following a thorough literature review and discussions with colleagues at GEH, model features and requirements for a new electromagnetic (EM) pump modeling capability in SAS4A/SASSYS-1 have been identified and formally defined, laying the groundwork for development and implementation of the model during the next few months.

Coupled SAS/CFD simulations of the VTR hot pool during the Protected Station Blackout scenario were performed out to 2 minutes (120 seconds) following scram. For these simulations, the bypass flow path was ignored, which permitted significantly (10x to 100x) larger time step size because it avoids instabilities associated with flow reversal. The thermal stratification phenomenon is rather pronounced in these simulations, as the cold front leaving the core outlet does not reach the intermediate heat exchanger (IHX) inlet at the end of the 120 second transient duration. By contrast, the IHX inlet temperature is reduced immediately following the scram in the standalone SAS simulations, where perfect mixing is assumed. These calculations were performed on 2400 cores of the INL HPC computing cluster and required nearly 1 week to perform. The thermal profile two minutes after the scram is shown in the figure below.



Continued to investigate discrepancies between the SAS safety analysis results and the TRACE confirmatory calculations. Noted differences between the core axial pressure distributions and the IHX temperature predictions. Identified different assumptions in the models and the TRACE model was updated to be more consistent with the SAS model. Achieved reasonable agreement for the core pressure drop. Investigated inlet and outlet temperature effects in the TRACE IHX model.

Sodium Fire Hazard Analysis and Software Verification & Validation (V&V)

Drafted a memo, "*Analysis of Fundamental Phenomena Relevant to Sodium Drop Sprays*," summarizing recent investigations of phenomena associated with sodium droplet formation and breakup. The goal is to identify sodium drop size input for spray fire analysis computer codes and to provide perspective to properly interpret the results of sodium spray fire computer code calculations.

An improved sodium spray fire modeling capability was incorporated to include the ability to simulate upward sprays. This improvement enables additional V&V efforts utilizing data from experiments such as the AB5 test which included upward sodium spray injection.

Probabilistic Risk Assessment

Continued preparing for a Technology Inclusive Content of Applications (TICAP) tabletop exercise. Prepared a draft report outlining how the safety basis information developed for VTR could be assembled into a SAR document utilizing the TICAP guidance.

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. Formally released a beta version of code for testing and validation documents are being finalized for distribution to the authorization body.

Reviewed external event screening analyses performed by GEH and initial insights and areas requiring further development are being noted for PRA development.

Continued work on quantifying the reliability of Reactor Vessel Auxiliary Cooling System (RVACS) performance during transient scenarios utilizing SAS4A/SASSYS-1 simulations. Performed sensitivity studies on 15 model parameters in the SAS4A/SASSYS-1 model, supported by the Dakota optimization and uncertainty quantification tool. Performed more detailed simulations for a subset of these parameters for which the influence on the hot pool temperature was not intuitive, and more detailed plots of the SAS4A/SASSYS-1 results have been included.

Kevan Weaver, Experiments Technical Integration

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

- Annular Flow Characterization
  - New test section delivery was delayed by vendor due to COVID-19 supply chain. It is now expected in February.
  - RELAP5-3D model of annular design is set up and matches the TerraPower total power within 10%. A new RELAP fluid will need to be created to more realistically represent the ELTA-CL-MS.
  - Verified the TerraPower 37 tube conceptual design in Modelica/TRANSFORM. Similar to the annular model, Modelica is predicting 20% lower total power. Various different heat transfer corrections were tested and this could result in some additional performance.
  - Initiated improvements to the annular model in Modelica to improve heat transfer modeling. This includes the lower and upper plenum regions which previously were only modeled as single volumes with very little heat transfer from the ELTA-CL-MS to the sodium.
- Pressure and corrosion sensor development

- After completing our initial prototyping of the corrosion sensor system and testing in a laboratory setting, a manuscript for submission to a scientific journal was prepared. Submitted a draft of the concept paper on this technology for internal review and are on track to submitting that to a scientific journal by the end of the month.
- Initial thermal testing showed that the sensor can record data during elevated temperature testing, but fluctuations appear in the data. Subsequent testing has identified air currents as the potential source for these fluctuations and have designed experiments to test methods to mitigate the effect of these fluctuations. We are continuing to perform functional testing at elevated temperature to optimize sensor operation within a fluidic environment more representative than air for the sensor's target application in VTR.
- Completing the design phase of a refined sensor design to improve the design by: decreasing the footprint of the sensor, decreasing the impact of thermal gradients on the corrosion measurement, and improving the manufacturability of the corrosion sensor.

ELTA – Materials Capability Development
Technical Lead: Tarik Saleh, LANL
Partners: OSU, Purdue, EPRI

- In-situ Crack Growth Testing and Monitoring in VTR Cartridge Loop Environments
  - Molten salt testing: characterization of Slow Strain Rate samples in FLiNaK at 600°C showing increased corrosion attack in stressed gauge region versus the grip region.
  - Sodium testing: the Corrosion Experimental Loop (CEL) in the Glovebox for Experimental Liquid Sodium (GELS) has realized phase 1 of its design and fabrication, and elevated temperature and pressure tests are currently underway.
  - Gas testing: characterization has begun of the potential drop method by comparing against the crack length derived from images taken during cracking.

RTA – Rabbit Capability Development
Technical Lead: David Wootan, PNNL
Partners: Texas A&M University

- A mockup of the shuttle transfer system for the Rabbit is being constructed to evaluate hardware performance before installing the shuttle transfer system in the reactor pool. Rabbit performance may be sensitive and affected by adjacent experiments. Performing simulation analyses to assess the sensitivity of the Rabbit to possible adjacent experiments.
- The MCNP model for the VTR and the Rabbit has been evaluated and found consistent with the current VTR configuration.
- Initiated an extensive literature review on flow-reducing components. Initial findings suggest that the flow physics for the Rabbit are well understood and such components can be designed and implemented with a high degree of confidence.