INL/EXT-20-61193-Revision-0

FY2021 November Monthly Status Report for the VTR

December 2020

Kemal O Pasamehmetoglu

INL/EXT-20-61193-Revision-0

FY2021 November Monthly Status Report for the VTR

Kemal O Pasamehmetoglu

December 2020

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Versatile Test Reactor

SOLVING ENERGY CHALLENGES THROUGH SCIENCE

Jordi Roglans-Ribas, Program Overview

The draft Environmental Impact Statement (EIS) was sent to the Department of Energy-Idaho Operations Office (DOE-ID) and DOE Office of Environmental Management (EM) as well as the Savannah River Site (SRS), Waste Isolation Pilot Plant (WIPP), and Oak Ridge National Laboratory (ORNL) for their concurrence. We anticipate the Environmental Protection Agency (EPA) will publish the EIS in the Federal Register by the end of December and the 45-day public comment period will begin.

The 2020 American Nuclear Society (ANS) Virtual Winter Meeting was held November 16 - 19 and VTR occupied a significant presence throughout the conference. Five sessions were dedicated to VTR and 19 papers were presented covering topics such as safety, nuclear fuels, and current developments. VTR also participated in five panel sessions covering safety strategy, experiments, and the versatility of the VTR. VTR also sponsored a virtual booth.

The Program Management Office at Idaho National Laboratory (INL) assessed the VTR risk management program. Comments have been incorporated in the program which resulted in an upgrade of the assessment score to highly effective.

The Fiscal Year (FY)-2021 project baseline for the VTR project, including all other labs, industry partners and universities, has been completed and implemented. VTR will initiate earned value management processes in the coming month.

George Malone, Reactor Technical Integration

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

GEH completed a limited scope audit of TerraPower (TP) and approved the TP VTR Quality Plan to allow the start of TP Engineering Services work as a subcontractor to GEH for VTR Project Phase 1, Release 5.

The framework for the Technology Readiness Assessment (TRA) Program was updated and reviewed with Battelle Energy Alliance (BEA) to progress the approach and support low technology readiness level (TRL) component progression. GEH also developed a Technology Maturation Plan (TMP) sample template for review by BEA and for preparation of samples for B11 Reactor Module, B12 Control Rod Drive Mechanism (CRDM), B21 Electromagnetic (EM) Pump, and F42 In-Vessel Transfer Machine (IVTM).

Restarted 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. Under this activity GEH/Argonne National Laboratory (ANL) conducted regular discussions on the E11 primary flow/process flow diagram and SASSYS Model and the VTR Control Assembly Requirements.

Continued resolution of action items resulting from the Special Purpose Review (SPR) of the B24 Heat Rejection System. Continued preparation of B24 Pump Study and resolved comments with BEA.

Continued update of the VTR Project Master Parts List (MPL) to incorporate changes/additions requested by BEA and updates from the ETV SPR.

TerraPower Support

Completed all eight samples for cover gas Cesium (Cs) sequestration tests. Additional baseline tests will be run before finishing all tests.

ANL Support

Provided engineering support for reviews of various engineering documents provided by GEH and BNI. Supported the B11/J11 weekly meetings with GEH and reviewed their near-term schedule. Began writing the report for computational fluid dynamics (CFD) analysis of the plenum area. Completed the computer-aided design (CAD) model of the receptacle.

FFTF Documentation and Data Recovery

Continued identifying and collating sources of thermal stripping analysis methodologies and experience. Avoidance of thermal stripping is an important aspect of the design of a Sodium Fast Reactor (SFR). Adjacent sodium streams with different temperatures and oscillation, when impinging on steel structures, will impose high-cycle thermal stresses and high-cycle fatigue. These phenomena were investigated during design of the Fast Flux Test Facility (FFTF) and the Clinch River Breeder Reactor (CRBR).

VTR Control Rod Mechanical Design Analysis

Calculated a first-cut number of 760 Effective Full Power Days (EFPD) indicating the nominal mechanical lifetime of a VTR absorber assembly. The calculated value should be regarded as a bounding high number. A list of information was developed with ANL reactor physics staff to produce a more accurate mechanical lifetime.

Calculation Support for VTR Waste Form Analysis

Pacific Northwest National Laboratory (PNNL) continued researching historical FFTF and Experimental Breeder Reactor (EBR)-II documentation to support development of programmatic spent fuel treatment functions and requirements. PNNL and INL staff are establishing functional and operational requirements (F&OR) for all x-reactor processes and aspects. FFTF fuel related design description details, drawings, and other supporting information will aid in VTR F&OR maturation and fuel definition. This information will be developed into a spent nuclear fuel pretreatment storage and transfer report.

Thomas Fanning, Nuclear Technical Integration

Drafted a set of fuel analysis tasks addressing potential behavior of U-Pu-Zr-Ga fuel in VTR. Work at ORNL will be reprioritized to include these tasks and additional scope has been identified for the INL BISON team needed in support of the VTR fuel analysis. The ANL fuels team continued to finalize conceptual design of VTR assembly lower nozzles and their interface with the VTR core plate receptacles. The INL fuels team reviewed a draft addition to the VTR Fuel Performance Design Basis addressing HT9 properties, specifically the distinction between irradiation creep and thermal and associated contributions to cladding damage. Los Alamos National Laboratory (LANL) staff agreed to review the work and investigate improvements to the legacy HT9 thermal creep equation. TerraPower received comments from INL and LANL on the HT9 Qualification Plan.

Fuel Manufacturing

Focused on maturing the manufacturing equipment designs and defining the manufacturing process details. Advanced the quality assurance-related "slug processor" design work, incorporating all major design features, and preparing the design for a December comprehensive design review. Progressed casting equipment and glovebox prototype system design and finalized essential design documents. A procurement-ready package, including supplemental procurement documentation, should be complete by January.

Focused effort on feedstock and scrap analysis. LANL continued developing an analysis of life-of-program plutonium supply, in accordance with the related DOE Memorandum of Understanding. Accelerating progress on the SRNL-led trade study of Pu polishing technologies, as the scope has been established and technical analysis has begun. The fresh fuel scrap team continues to engage individuals with specific subject matter expertise as well as establish initial contacts with the LANL Carlsbad office to support assessment of WIPP applicability of VTR fresh fuel scrap. Focused activities on defining scrap material preparation and packaging, as well as information required for regulatory approval for the disposition strategy described in the draft VTR EIS.

Core Design: Performance assessment of shield assemblies

The team is investigating the design of in-core replaceable radial shield assemblies to identify cost savings through rotation. The radial shield is an important feature of the VTR core design as it provides neutron shielding to ex-core components, mitigates secondary sodium activation in the intermediate heat exchanger (IHX), and minimizes the fission rate in fuel assemblies stored in the Shielding Area Fuel Storage (SAFS) facility. For a select few shield assemblies, the depletion of the neutron absorbing isotope, B-10, is sufficient to cause significant power peaking in the in-core storage ring fuel assembly stored directly behind it, forcing early replacement of these shield assemblies. However, most of the shield assembly's core residency is limited by the swelling behavior of the B4C pellet itself, not shielding efficiency. The swelling performance can be further enhanced by rotating these assemblies half-way through their service life. With rotation, it is expected that most of the B4C shield assemblies will require replacement only once or twice during the 60-year life of VTR.

Core Design: Codes Verification & Validation

Continued software verification work. Table 1 lists the software in ARC and indicates which parts are verified for the VTR project. We are on track to complete a bulk of the verification work in the coming year having already completed some of the more difficult parts in FY2020.

Table 1. Software to be Verified Under the VTR Program

Software Name	Verified by VTR	Requirements	Verification Report	Verification Status	Targeted Completion
ETOE	No				
MC^2-3	Yes	Draft		In Progress	09/2021
DIF3D	Yes	ANL-VTR-19	ANL/NSE-20/3	Completed	
REBUS	Yes	ANL-VTR-50	Under Review	In Progress	01/2021
RCT	No				
PERSENT	Yes	Reviewed	Draft	In Progress	05/2021
GAMSOR	Yes	Draft		In Progress	03/2021
DASSH	Yes	Draft		In Progress	>09/2021
NUBOW	No				
ARC Utilities	Yes			Not Started	09/2021
MCNP	Yes	Draft		In Progress	02/2021

To increase value to the project, the team is focusing neutronics validation on preexisting data from ZPPR-15, FFTF, and Experimental Breeder Reactor (EBR)-II measurements. The ZPPR-15 work is almost complete with minor analysis work to be done for the TLD measurements. Analyzed available FFTF measurement data with ARC and a summary report has been written and is under review. The EBR-II data measurements are extensive, but we hope to identify and complete the analysis work by the end of the fiscal year.

Transient Safety Analysis - Safety Analysis

Presented safety topics during the VTR sessions in the 2020 ANS Virtual Winter Meeting, including “Safety Analysis of the Conceptual Versatile Test Reactor Design,” “Impact of the Control Rod Withdrawal Rate during Power Ascension Operations,” “Versatile Test Reactor Pump Coastdown Assessment,” “Initial Sensitivity Analyses for the Versatile Test Reactor Transient Safety Performance,” and “Analysis of the Versatile Test Reactor Pump Overcooling Transients.”

A new baseline SAS4A/SASSYS-1 model for the VTR is nearly complete. Completed a detailed review of the updated conceptual design of the primary system to compile geometric updates and revisions to the VTR primary heat transport and Reactor Vessel Auxiliary Cooling System (RVACS) systems, and the SAS model was revised accordingly. Updated the SAS model to calculate the maximum fuel-cladding eutectic penetration during transients. Once the baseline SAS model is complete, a revised safety analysis will be performed and documented in a deliverable due in December.

CFD simulations are being performed of the upper plenum of the Primary Heat Transport System (PHTS) to assess the influence of thermal stratification on safety assessments of protected station blackout (PSBO) event. Figure 1 shows a snapshot of the CFD results approximately two minutes after the initiation of the PSBO. The predicted thermal stratification is apparent: the coolant entering the IHX inlet is still hot (red) despite the relatively cool sodium (blue) exiting the core following scram.

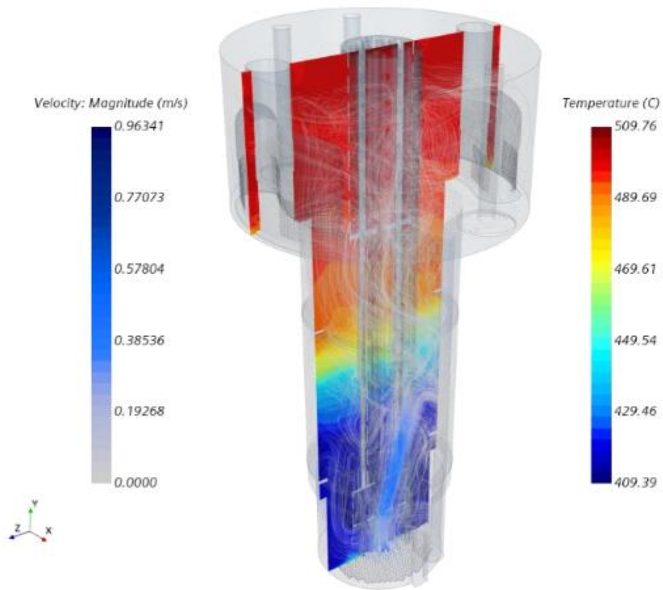

Figure 1. CFD Results Two Minutes after Protected Station Blackout

Began incorporating the effects of fuel constituent migration at various points in the fuel cycle. Fuel constituent distributions affect peak fuel temperatures during transients.

SAS V&V

Continued SAS V&V of the detailed core radial expansion model. The remaining core radial expansion shapes are being reviewed and documentation of the verification effort has started. Continued verification of the SAS/CFD coupling interface. Issued and reviewed a draft of the coupling interface software requirements. Continued development and documentation of a model of the 1/5-scale MCTF experiment based on PRISM Mod-A.

Sodium Fire Hazard Analysis and Software

Completed a technical review of Rev. C of the GEH report "Piping Layout, Piping Stress Analysis, Pipe Support Leak Before Break Considerations." Leak before break considerations are important to limit bounding sodium leak scenarios analyzed as design basis events in the safety analysis.

Presented three sodium fire papers during the 2020 ANS Virtual Winter Meeting including "Comparison of the NACOM Sodium Fire Code with the AB5 and AB6 Experiments," "Comparison of the SOFIRE II Sodium Fire Code with the AB1 and F2 Experiments," and "Flame Sheet Model for Sodium Pool Burning."

Probabilistic Risk Assessment (PRA)

Completed a set of initial sensitivity analyses regarding RVACS performance using SAS4A/SASSYS-1 and the uncertainty analysis tool Dakota. Based on these results, the number of uncertain parameters will be down selected before completion of the detailed uncertainty analysis.

Final versions of the software V&V activities for the Simplified Radionuclide Transport (SRT) code Version 2.0, which is being used for mechanistic source term calculations are being documented and a new beta version of the code is being tested for initial release in December.

A new PRA model and document GitLab repository are being deployed, which will facilitate PRA development efforts by multiple organizations, including assisting with version control, ensuring QA requirements compliance, and expediting both internal and peer reviews.

Kevan Weaver, Experiments Technical Integration

The Experiments Team within the VTR program is currently aligned with four main experiment vehicle types: Normal Test Assembly (NTA), Dismountable Test Assembly (DTA), Extended Length Test Assembly (ELTA), and the Rabbit Test Assembly (RTA).

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

- Continued work on the sodium purification and monitoring system to be deployed in the SFR cartridge loop.
- Continued work on operational testing of a proposed SFR cartridge impeller design in a small PVC water loop. This includes measurement of a pump head curve for a candidate impeller design to verify the pump can meet SFR cartridge loop pumping requirements.
- Continued fabrication of the prototype magnetic pump coupler. Parts that will house the coupling magnets were machined and will be shipped to the magnet manufacturer for custom machining and placement of the magnets within the stainless-steel components. Magnet installation should be completed in January. Completed a safety review meeting for the bench top test stand to verify the coupler performance at both room and planned operating temperature (500ºC). Work will be initiated once the coupler is received from the magnet manufacturer.
- Continued to provide technical input and support to Framatome who is assembling a model for the current design for the SFR cartridge loop to carry out design support and preliminary safety analysis calculations for selected reactor transients as predicted with the SASSYS code. Framatome has succeeded in running a variety of cases to analyze the performance of the SFR cartridge design under a variety of transients that includes loss of flow, loss of heat sink, transient overpower, and station blackout conditions. Compiled the data and results are being analyzed.

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

- Modified the cartridge loop design to accommodate the excess gamma heating generated from the coolant (Pb) and structure material around the cartridge test article. This was accomplished by reducing the Pb and structural material in the high flux region.
- Performed a parametric study using TRACE to demonstrate that the new design would keep Pb coolant temperatures <500ºC.
- The pump test rig is delayed under the current funding level, which impacts available work force at the labs.
- Started preliminary design of a system for externally pre-heating the cartridge loop, and for maintaining the Pb molten when out of reactor. Developing requirements and methods for an in-core heating system.
- Pb Loop
  - Added new heat exchanger (HX) plumbing with enhanced safety, and the HX was tested using chilled water after the original HX burst while being heated to 350ºC.
  - Worked to develop generalized empirical relationships to describe the pressure losses in sample holder designs and investigated the effect of surface roughness on pressure losses.

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

- Annular Flow Characterization
  - Verified the TerraPower results for the annular design as reported in "VTREV-ENG-STDY-004 Rev.0". The table below shows the differences between Modelica/TRANSFORM and TerraPower's model.

	Cold Leg Salt Velocity [m/s]	Sodium Cooling [m^2]	Salt Cooling [m^2]	Salt Volume	Cooling Capability [W]
TerraPower's Model	0.72	0.17	0.16	1.2	38480
Modelica/TRANSFORM	0.75	0.17	0.16	1.2	**32095**

  - The TerraPower model is also based on CFD so it may predict higher heat transfer in plenum regions with more complex design features that are only simply modeled in the Modelica/TRANSFORM model. Therefore, given these and other sources of uncertainty, the Modelica/TRANSFORM model is reasonably close to TerraPower's assessment.

- Pressure and corrosion sensor development
  - Thermal testing yielded some results that were initially inconsistent with the Finite Element Models (FEM) used in our analysis. Determined that the sensor is sensitive to the thermal expansion of the internal gas, which slightly deforms the diaphragm as it is heated, prior to it escaping out an orifice in the rear of the sensor, which has a larger flow resistance. Performing a follow-up test to confirm our understanding. Demonstrated that the sensor can be re-calibrated after the transition between two temperatures.

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

- Gas concentration measurement technique shakedown test underway.
- Performing necessary vacuum procedures (i.e. bake out, pump down, and leak detection).
- Achieved required vacuum pressures to operate residual gas analyzer (10^{-5} Torr).
- Constructed optically clear thermal-hydraulic scaled low pressure/temperature facility for instrumentation shakedown testing
- In-situ thermal and microstructural property measurements
  - Tested a new high-temperate (up to 1800°C) heating stage in the vacuum chamber
  - Integrated the 2 × 1.7 MV tandem accelerator with the high-temperature sample heater
  - Completed the in-situ thermal property measurement platform construction.
- Volumetric temperature/strain monitoring
  - Measured in-situ temperatures at > 500°C in the 3D-printed HX
  - Demonstrated effectiveness of index matching gel for improving fiber sensor quality
  - Specified preliminary Linear Variable Differential Transformer (LVDT) experimental design
  - Started procurement of sapphire fibers
- Surface emissivity measurement of SiC cladding
  - Optimized calibration technique through a series of shakedown tests to further reduce measurement uncertainty
  - Completed emissivity measurements (room temperature to 350°C)
- Trace Xe detection in He-Xe mixture via LIBS
  - Investigating scaling of signal with number of shots and reliable detection of 1-ppm level trace Xe
- Helium gas flow direction for fuel testing in ELTA-CL-G
  - Completed CFD simulation of steady-state forced helium circulation with maximum test fuel loading and corrected gamma heating in structures.

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

- Installation of the Rabbit proof of principle test is progressing and includes hooking up sensors and gas lines to the Rabbit test.

Support Area – Instrumentation and Controls
Technical Lead: Sacit Cetiner, ORNL
Partners: ACU, Georgia Tech, MIT, University of Pittsburgh, Cosylab

- Eddy Current Flow Meter (ECFM)
  - Restarted the ECFM design and testing activities based on the computational design and optimization and laboratory testing results.
  - Revising the COMSOL ECFM model to be validated in the ORNL Mercury Loop facility (room temperature operation). COMSOL model shows an optimal interrogation frequency around ~200Hz for mercury flowing in a 1" sch 10 stainless steel piping (shown in Figure 2 below). As expected, the model confirms rapid attenuations with increasing frequency due to the high SS conductivity and thicker wall. Nevertheless, the measurement system is expected to generate a reasonable signal-to-noise ratio (SNR) for the frequency band of interest.

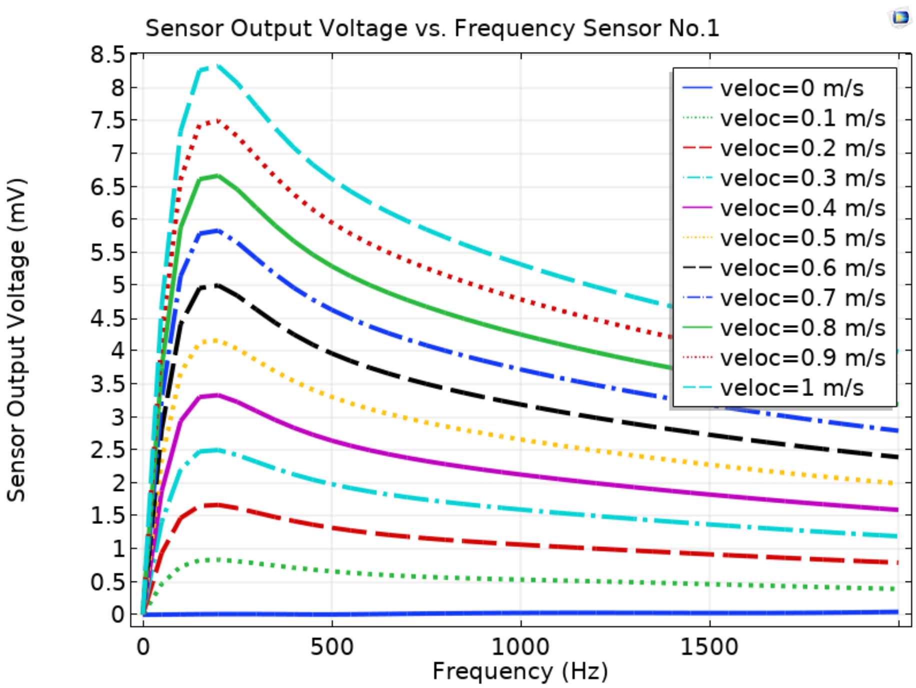

Figure 2. COSMOL Model

  - Simulated sensor voltage output (i.e., potential difference between the two secondary coils, no lock-in detection) as a function of driving frequency to the primary coil at different mercury flow rates.

- Worked on the design of the bypass loop that will be attached to the Mercury Loop facility. The bypass loop will have an independent flow control and flow measurement capability (NIST traceable qualified flow meter) to calibrate the ECFM probes and validate the computational models.
- Reran the COMSOL simulations to determine the minimum distance allowed with negligible cross talk between adjacent ECFM sensors on the same pipe.

- Self Powered Neutron Detectors (SPND)
  - Submitted the FS-SPND paper to *Nuclear Instruments and Methods in Physics Research Section A* (NIM-A) journal for review.
  - Submitted the paperwork to the ORNL Commercialization Office for two provisional patents on the identification and down selection for candidate emitter materials.
  - Made improvements to the Geant4 code; added the capability to generate a transient detector response as a result of a step change in neutron flux amplitude.
  - Adding the capability to observe the effect of local delayed neutron flux on the detector output as a result of a step change in neutron flux amplitude.
  - Started developing a reduced-order mathematical model to estimate the detector transient response to be used in development of dynamic compensation methods for estimation of actual reactor power. This model will later be improved to incorporate the impact of local temperature variations due to changes in experimental conditions and to eventually make dynamic compensation for temperature corrections.
- Development of Advanced Flux Monitoring Methods Based on Activation Dosimetry
  - Expect to begin irradiation of the base samples (6 foil samples for benchmarking with MCNP). Discussing fabrication methods for the dosimeters, including electroplation, additive manufacturing, as well as ion implantation.
  - Added the AmBe source term to the MCNP model as well as the spheres for flux modulation. Once the bare foil irradiation is complete, irradiation using spheres to continue data acquisition will begin.
- Development of VTR Experiments Data Acquisition System
  - Held a project kick-off meeting and internal meetings with the CosyLab ITER system design team, and received feedback and recommendations on the VTR Experiment DAQ system architecture.
  - CosyLab is reaching out to technical experts and users of similar facilities to hold a workshop. Preparing a draft methodology document that shows examples of the existing documents to understand the type of information CosyLab intends to seek in the workshop.

In addition to the above, several team members from the VTR experiment development effort provided papers and presentations at the 2020 ANS Virtual Winter Meeting.

Upcoming Events:

IAEA International Conference on Fast Reactors and Related Fuel Cycles (FR21), May 10 -13, 2021, China

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