INL/EXT-20-59118-Revision-0

FY2020 June Monthly Status Report for the VTR

Jordi Roglans-Ribas

July 2020

The INL is a U.S. Department of Energy National Laboratory
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Versatile Test Reactor

Tom O'Connor, Federal Program Director

Patience. Everyone's patience is getting tried. We submitted a very high quality Critical Decision (CD)-1 package, and even with the cost range adjustments due to the Independent Cost Review (ICR) and the Project Risk Management Committee (PMRC), we are still waiting on the headquarters machinery to perform the last review by the Energy Systems Acquisition Advisory Board (ESAAB). And yes, the process has been complicated by driver fuel considerations. FY 2021 budget considerations, in light of our request for $295 million, are uncertain. Patience. Your hard work continues to turn out high quality and defensible products. My questions to you are turned around quickly which in turn have been used in presentations with the National Security Council, the Administrator of the National Nuclear Safety Administration (NNSA), Under Secretary Menezes and Secretary Brouillette. Your answers are also used extensively by Dr. Rita Baranwal as she interfaces with senior DOE management, other members of the Administration and Congress. Patience. We still have lots of work that needs to be done to further the conceptual designs and safety basis, reduce our technical risks and complete the Environmental Impact Statement analysis. And while we don't have answers on CD-1 or FY 2021 funding amounts, please know that your successes are translating very positively into the FY 2022 budget process. Everything you are doing is laying a solid foundation for VTR's success. Stay well.

Jordi Roglans-Ribas, Program Overview

The COVID-19 pandemic has changed how we work and interact. The VTR team continues to work remotely and much of our outreach and engagement with key stakeholders has also moved to a virtual format.

During June the VTR team helped move the CD-1 package forward to gain the necessary approvals and supported the PMRC with their review of the CD-1 package, including preparing responses to written questions. After the PMRC reviews, the team assisted the Department of Energy, Office of Nuclear Energy (DOE-NE) with information to support establishment of the Memorandum of Understanding between NE and the NNSA to agree on the supply of feedstock material for use in the VTR fuel.

The process to establish the Design and Build contract for the VTR continued as scheduled and multiple competitive proposals were received as planned by June 1. Proposals are being evaluated, with the goal of having a contract in place by the end of September.

Florent Heidet, Kevan Weaver, and Jordi Roglans, as well as Kim Webber of the Nuclear Regulatory Commission (NRC), presented at a Webinar organized by the Global America Business Institute (GABI) and Clearpath on the use of test reactors, the VTR in particular, in developing advanced fuels and materials and support modeling validation. Kemal also participated in a virtual panel session during the American Nuclear Society's summer meeting in June and is scheduled to present at Nuclear2020: ASME's Nuclear Engineering Conference powered by ICONE in August. Work continues on a new VTR web page and other communications tools to help amplify the role and need for VTR.

George Malone, Reactor Technical Integration

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

Initiated import of plant level documents into DOORS Next Generation. Once the import is complete, the impact of changes to requirements will be trackable in real time, allowing the project to understand how proposed changes impact existing documents and engineering deliverables. The import process will continue through the end of the conceptual design subcontract and the initial stages of preliminary design.

Issued thirteen engineering deliverables including documentation of requirements, equipment lists, analysis and calculations, piping and instrument diagrams, process flow diagrams, specifications, system design descriptions, and single line diagrams. Many of these documents are being reviewed by the VTR program office and comments are being incorporated. The information allows the project to continue to improve the VTR conceptual design.

TerraPower Support

Drafted and transmitted to Idaho National Laboratory (INL) and Argonne National Laboratory (ANL) for review the single assembly bending test specification report and test assembly fabrication plan for core component mechanical tests in March and May. The report is in comment phase and will be issued following comment resolution.

Due to COVID-19 restrictions, suspended the cover gas cesium sequestration test. FASTT modification and TAHM grapple installation work was also delayed due to COVID-19. The State of Washington relaxed restrictions near the end of June, enabling the IV lab to reopen and VTR support lab activities to restart.

ANL Support

ANL and GEH continue to hold weekly J11/B11 interface meetings. ANL reviewed GEH comments on the CAD model update addressing minor interference and tolerance issues. Provided inputs to GEH for the seismic model supporting analysis of the reactor module. ANL is reviewing GEH comments of sodium process flow calculations and the orificing strategy and hold-down analysis. ANL continues to work on instrumentation strategy for core parameters to support startup and other testing.

FFTF Documentation and Data Recovery

Interest continues in the floor valves used during Fast Flux Test Facility (FFTF) operations. A floor valve functions as an air lock used to maintain the integrity of an argon atmosphere when making transfers through a fuel transfer port. Located several documents including: approximately 250 floor valve drawings; 30 top-level drawings; the Operation and Maintenance Manual (OMM); the Operations Training Manual (OTM); VITRO-R-404, *Reactor Fuel Transfer Port Floor Valves Adaptor Stuck Fuel Assembly Analysis, (*December 1975); and the normal operating procedure for the floor valves. When retrieved, these documents will be collected and combined with an overall summary report.

VTR Control Rod Mechanical Design Analysis

Drafted an initial outline for the Design Support Document (DSD) describing the approach needed to successfully perform the mechanical design of an absorber assembly. The DSD describes the purpose and basic functions of the three codes used to perform the mechanical design, the essential input data required by them, and the mechanical life-limiting characteristics which they calculate and the means by which they are calculated. This DSD will contain essential information necessary to effectively run the computer codes for the mechanical design of an absorber assembly.

The computer codes were used to ensure proper performance of the FFTF control rod absorber bundles during the design and operation of the reactor. While this is an advantage as these computer codes were proven during actual reactor operation, they had FFTF parameters embedded in them, which was convenient at the time. These embedded parameters, however, are not convenient when designing the VTR, as VTR design parameters are different. The activity to remove these embedded parameters in the mechanical performance code CNRD is nearly complete.

Calculation Support for VTR Waste Form Analysis

Completed preliminary thermal modeling calculations for the VTR storage cask. Drafted a report which addresses input on previous analyses and makes a complete evaluation of the canister concept. The report is undergoing final review.

Thomas Fanning, Nuclear Technical Integration

Fuel Design and Performance Analyses

Continued the fuel design effort to assess design equations and their databases for cladding creep (irradiation-induced and thermal) and Cumulative Damage Fraction (or CDF, indicating margin to stress rupture) as used for VTR strain and CDF limits. Currently, it appears that VTR fuel performance limits will be based on a cladding strain limit rather than CDF, because the stress rupture data may not be sufficiently complete to support a CDF limit.

Completed a draft analysis that documents options for near-term plutonium feed sources for VTR startup and initial operations. An evaluation of material equivalent estimates (Pu versus uranium enrichment) is 80% complete to support subsequent options analysis for long-term feed.

Continued work on the preliminary fuel performance assessment of VTR driver fuel using BISON for normal and off-normal operations. Several model performance matters are being resolved between the Oak Ridge National Laboratory (ORNL) and the Idaho National Laboratory (INL) BISON team. Consensus resolutions are sought prior to issuing reports to ensure all stakeholders support analysis conclusions and the path forward.

Completed and documented the Integral Fast Reactor (IFR)-1 BISON benchmark model in a report issued to OSTI. This new benchmark model builds confidence in the implemented models and helps prioritize needs for additional model development. A report documenting two additional benchmark models based on the X430 series of experiments is undergoing internal review at ORNL.

Drafted and transmitted to INL and ANL for review a single assembly bending test specification and a test assembly fabrication plan for core component mechanical tests in March and May. Reviews are on-going.

Several suppliers provided responses and budgetary quotes to the Expression of Interest (EOI) requests for HT9 material, cladding supply, and duct supply. The EOI and responses include production process development and qualification prior to volume production. Carpenter Technology and Veridiam responses are delayed due to COVID-19 but are expected in July.

Completed and transmitted for review a draft procurement strategy and supplier qualification document for HT9 starting material, duct, and cladding supply. Additional input from suppliers will be incorporated into the final version as necessary. Began drafting the HT9 component qualification report.

Fuel Manufacturing

MarCom, LLC completed a draft ECAR, *Versatile Test Reactor (VTR) Fresh Fuel Dose Rate Evaluation*, which is being reviewed. This analysis is an extension of related calculations that MarCom performed for the VTR environmental impact statement (EIS) work. The analysis provides information needed to understand shielding requirements for fresh fuel assembly manufacture and for finished assembly handling, vault storage, and transport to the reactor hall. Analyses are based on the three fresh fuel compositions evaluated in FY 2019 to determine glovebox shielding requirements for fuel fabrication.

Drafted a report, *Evaluation of Effects of Fuel Slug Ovality on Fuel Performance*, which is undergoing technical review. This paper examines the effect of fuel slug abnormalities on cladding strain. This effort was undertaken to determine if tolerances on fuel casting molds can be relaxed as it may not be possible to find a vendor to make the quantity of precision bore quartz tubes needed for VTR fuel casting needs. The modeling and simulation effort concluded the fuel can tolerate abnormalities (e.g. ovality) without causing excessive strain in the cladding in early life, at less than 2% burnup, before fission gas bubbles interconnect.

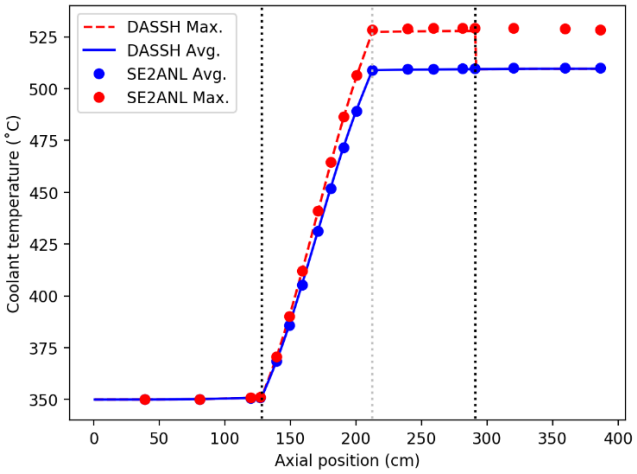
Continued to evaluate two multi-mission Pu gloveboxes which may be used by VTR for fuel casting, though the effort is not currently part of the VTR-funded scope. Submitted a material request including all the documentation required for the design and purchase of the gloveboxes and issued three GFE purchase orders to different suppliers for several glovebox subcomponents to supplement the main contract.

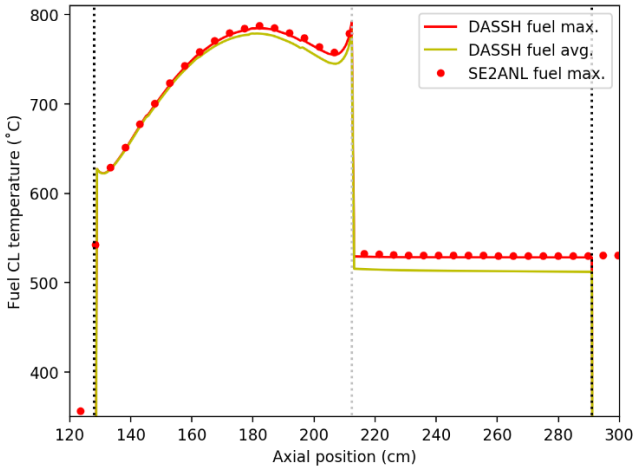
Core Design and Performance Analyses

Teams from ANL, INL and Los Alamos National Laboratory (LANL) completed analyses in support of confirming the results obtained for the reference conceptual VTR core performance characteristics. Different codes were used by the teams, and different levels of model details have been implemented. These analyses provide estimates on the impact of the various assumptions used when designing and determining performance of the conceptual VTR core. Documented overall findings of these confirmatory analyses in a Level 3 milestone. None of the findings identified any significant deficiency in the reference core model and assessments. However, the outcome of these confirmatory analyses will prove extremely useful when developing the core models for the post-CD-1 phase of the VTR project.

Developing the DASSH code as the alternative to the challenges identified with the verification of the SE2-ANL code. DASSH will offer the same capabilities as SE2-ANL but will also implement additional

capabilities and significantly increase ease of use and flexibility through simplified input format and visualization capabilities. DASSH development has reached the testing stage and is being used to compare with results previously obtained with SE2-ANL, shown in Figures 1 and 2 below. Developed additional mockup models for benchmarking the two codes. Work now focuses on improving DASSH runtime and adding additional capabilities. DASSH will be validated with experimental results from the PELICAN loop and will be maintained under NQA-1 requirements.





Continuing verification and validation of the ARC codes. Prepared a draft validation report based on the existing Zero Power Reactor (ZPR) and Zero Power Physics Reactor (ZPPR) experimental results, which summarize all the validation efforts completed in the last year or so. This extensive validation work demonstrates that the ARC tools are adequately predicting performance characteristics of critical systems representative of the VTR core. The draft validation report will undergo review before it is finalized and released. On the verification side, with the completion of the verification of the DIF3D code, the focus is now on the GAMSOR, MCC-3 and REBUS codes. The expectation is to have this verification effort well under way by the end of the fiscal year.

Safety Analysis

Continue to coordinate with GEH ongoing design activities and SAS4A/SASSYS-1 modeling approaches for the B11/B21 (primary heat transport) systems, E11 (Reactor Vessel Auxiliary Cooling System (RVACS)) system, and B11/J11 (core and primary) systems interface. The Safety Analysis team has reviewed and provided feedback on several documents including the B11/B21 process flow calculations report from GEH and supports GEH's development of the VTR fault list.

Completed deliverable report ANL-VTR-55, *Initial Sensitivity Studies for VTR Safety Analysis*, which is undergoing final review. This report documents the techniques being implemented for sensitivity analysis and uncertainty quantification for VTR transient safety analysis.

Continued refinements of the VTR SAS4A/SASSYS-1 model based on design dimensions extracted from the VTR Inventor model. Updated key elevations and other dimensions throughout the primary system, including the geometry through the fixed shielding, primary pumps, and core inlet piping. Reviewed recent updates to the Navisworks model of the VTR and drafted a memo documenting necessary dimensions in the B24 (secondary) system to further develop the SAS4A/SASSYS-1 model.

Finalized two ECARs which are undergoing the formal signature process: ECAR-5133, *Software Requirement Report: Verification and Validation of SAS4A/SASSYS-1 for VTR*, Rev. 1, and ECAR-4761, *Verification and Validation of SAS4A/SASSYS-1 Model of RVACS/RACS System*, Rev. 2.

Continued verification of the radial expansion model. Completed preliminary verification of the simplified radial expansion model and drafted results for inclusion in release of a SAS4A/SASSYS-1 reactivity feedback ECAR. Focus will shift toward verification and validation of the detailed radial expansion model.

Drafted an initial software requirements framework for SAS-CFD coupling. These requirements will support verification of the coupling interface (e.g. data transfer mechanisms) and confirmation of applicability to VTR modeling.

Safety Basis, Probabilistic Risk Assessment (PRA), and Sodium Fire Hazard Analyses

Continued activities in support of advanced conceptual design with an effort on advancing the models and methods for analyses as well as clarifying requirements and firming up guidance to support clarity of design and safety interface requirements.

Continued software verification & validation (V&V) activities for the Simplified Radionuclide Transport (SRT) code Version 2.0, which is being used for mechanistic source term calculations. Completed an updated version of the Software Requirements Specification (SRS) document. The staff also completed the evaluation of the software classification category and designated risk level, which is part of the SRT VTR Software Implementation Plan. The PRA group initiated a detailed reliability analysis of RVACS performance during transient scenarios, including an exhaustive review of uncertainties under a variety of operating conditions. The detailed analysis is important for proper assessment of RVACS reliability within PRA event tree sequences.

After receiving updated VTR building drawings from GEH/Bechtel, initiated efforts to perform preliminary sodium fire analyses for rooms containing secondary sodium components. Performed bounding and conservative sodium spray fire calculations to determine recommendations and requirements for the sodium fire mitigation strategy. Performed additional spray fire calculations to assess various sodium fire protection system options. Staff began drafting a report documenting the preliminary analyses and recommendations for the sodium fire protection system.

Continued software V&V efforts for SOFIRE-II and NACOM including developing the V&V status tables for each code. The tables document a list of phenomena relevant to sodium fire modeling and whether a particular phenomenon is currently modeled by the code, either by equation or by user input.

Kevan Weaver, Experiments Technical Integration

The Experiments Team within the VTR program currently includes nine "functional" areas aligned with the experiment vehicle types, along with related capabilities and initiatives, anticipated to be utilized within the VTR. Each area is led by a national laboratory technical expert and is supported by other national laboratory personnel, university partners, and industry partners. In the future, these areas will be realigned with the upcoming VTR Decision Document that outlines new nomenclature for the experiment vehicles, which will include the following: Normal Test Assembly (NTA), Dismountable Test Assembly (DTA), Extended Length Test Assembly (ELTA), and the Rabbit Test Assembly (RTA). This will better align with the project as it moves toward preliminary design.

Selected key accomplishments within specific functional areas are included below.

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

- Work continued to be slowed in June since a major component of VTR experimental support work at Argonne is based on work in the laboratory. Wave 1 of limited operations at Argonne was initiated on June 15, which allowed some laboratory work for VTR to resume.
- No progress this month on the under sodium separable instrument harness design (currently for 24 wires, or 12 two-wire instruments). A few pins on the connectors still need to be wired up, then the component will be ready for testing under water. If successful (likely since this is the 2nd version that has been made; this one was redesigned based on lessons learned from the 1st) we will start planning for elevated temperature testing (500°C) in an inert atmosphere. Once that hurdle is cleared, we will begin to scope out a plan for under-sodium testing.
- Resumed operational testing of a proposed sodium fast reactor (SFR) cartridge impeller design in a small PVC water loop in ANL Bldg. 206. In particular, steps were taken to 3-D print new impeller prototypes for additional testing in the small water loop.
- With respect to development of a magnetic pump coupler, since receipt of shaft torque measurements for the cartridge loop pump have been delayed, a decision was made to develop a prototype design using a 50% design margin on torque (as well as magnet strength) over that expected at a conservative operating temperature of 550°C. As reported in May, this design was completed, and magnet material (SmCo) was ordered so a prototype can be fabricated for testing at room temperature and then at expected operating temperatures. Drawings were sent to Argonne shops and fabrication was initiated.
- The software licensing process for the cartridge transient analysis tool CARLITA, including an export control review, was completed. The code and supporting materials were issued to LANL, INL, and industry partner Framatome to support their cartridge loop development activities. The software and materials will also be sent to ORNL once the license paperwork is complete.

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

- Develop a pre-conceptual design for a Pb/Pb-Bi reactor cartridge test loop.
  - Finalized a baseline lead ELTA-CL design for VTR, and performed a parametric study using TRACE-Pb to evaluate the effect of linear heat generation rate (LHGR) on the lead temperature in the baseline design.
  - Initiated pump failure scenarios (transient modeling) to assess natural circulation flow in the loop.
- Design and testing of centrifugal pump for a lead cartridge loop.
  - Completed design of the water test loop for mechanical pumps. Drawing package going out for fabrication bid. Completed Piping and Instrumentation Diagram (P&ID) and instrumentation on order. Preparing lab space.
  - Working with the UNM pump design team to secure details and models of their mechanical pump design. Evaluating possible changes in baseline piping sizes to accommodate possible Alternating Linear Induction Pump (ALIP) concept.
  - Working with UNM materials test team to prepare their facility for higher temperature tests, 600-700°C. This includes modified material sample holder, heat exchanger, and flow measurement.
- Irradiation data needs and lead cartridge requirements and interfaces.
  - Continuing development of requirements. In addition, began an assessment on the technology readiness of the materials envisioned for the lead cartridge.
- Technology readiness assessment and gap analysis of instrumentation for monitoring lead cartridge performance.
  - Compiling information to identify the technology readiness level (TRL) of each variable to be measured and to suggest R&D where necessary. The final report will contain detailed sections summarizing each variable to be measured and discusses the current state of the technology.
- Pump optioneering study for the VTR Pb cartridge.
  - The list of and rationale for pump design criteria remains unchanged, with the following pump options being evaluated: centrifugal pump, annular linear induction pump, conduction electromagnetic pump, gas lift pump.
- Corrosion and erosion studies of selected clad and structural materials.
  - Restarted long-term corrosion experiments at 500°C and 3m/s in the loop.
  - Conducted analytical calculations of heat transfer to estimate constraints on mass flow rate for different heating conditions.
  - Conducted CFD simulations to validate there is enough pressure drop for the new sample holder at the target flow rate.

- Submitted a manuscript to the Journal of Applied Physics on a new method for convergence assessment in molecular dynamics simulations applicable to atomistic modeling of corrosion.

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

- Submitted the ORNL 2020 annual progress report on technology maturation for future molten salt cartridge experiments in VTR for internal review.
- Continued review for journal paper, *Single-phase, natural circulation annular flow measurements for cartridge loop irradiation experiments*. The paper provides critical experimental data for validation of thermal hydraulics models of natural circulation flow in annular geometries representative of expected VTR cartridge experiments. Non-dimensional analyses indicate that natural circulation flow can provide liquid salt Reynolds numbers similar to those of some molten salt reactor concepts at relevant power densities.
- ORNL successfully demonstrated in situ measurement of corrosion using a metal-embedded optical fiber. The fiber monitors the displacement of a metal diaphragm during active pressurization of the sensor with inert gas. The aluminum prototype sensor (shown in Figure 3) was used to measure micron-scale changes in the diaphragm thickness during simulated corrosion in a sodium hydroxide solution. A journal manuscript will be prepared describing the concept and the initial experiments.

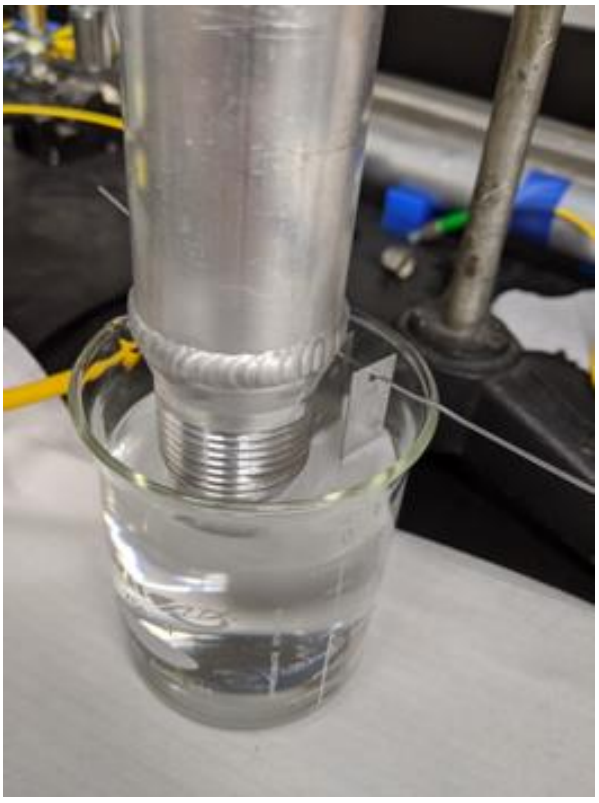


Figure 3. Prototype corrosion sensor for the MSR cartridge loop.

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

- Continued work and progress on the in-situ sensors, neutronic streaming, thermal-hydraulic, and mechanical aspects of the VTR Rabbit. Weekly meetings are held with the Texas A&M team to monitor and ensure progress.
- Delayed the schedule for putting the Rabbit Proof-of-Principle test into the Texas A&M University reactor (NESC) water pool until July 3, 2020, due to restrictions regarding reactor maintenance activities.
- Working with Texas A&M, began development of schedule, scope, and a budget for FY 2021. This activity will provide the necessary input for the Lab/University/Industry status report for VTR Experiments Integration, which is due the end of July. A meeting will be held on July 6 to discuss and ensure that the needed input is as requested, expected, and on schedule.

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

- Updated the small-scale DAQ with new features: added basic external clock distribution for two digitizers, added synchronized triggering, added a second thermocouple, and made various data plotting improvements.
- Initiated set up for EPICS-based readout software for testing with the local small-scale data acquisition system.

Upcoming Events:

July 23, 2020, VTR Quarterly Integration Meeting