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Development of a Data Platform for High-Temperature Gas-cooled Reactor (HTGR) Nuclear Energy University Program (NEUP) Thermal-Fluid Experiments

Changing the World's Energy Future

Sunming Qin, Minseop Song, Cam Binh T Pham, Mitchell A Plummer, Stefan Hans Vietz, Gerhard Strydom

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Idaho National Laboratory
Idaho Falls, Idaho 83415

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Sunming Qin, Minseop Song, Cam Binh T. Pham, Mitchell Plummer, Stefan Vietz, Gerhard Strydom

Idaho National Laboratory, 2525 Fremont Ave., Idaho Falls, ID, 83415
Sunming.Qin@inl.gov; Minseop.Song@inl.gov; Binh.Pham@inl.gov; Mitchell.Plummer@inl.gov; Stefan.Vietz@inl.gov; Gerhard.Strydom@inl.gov

INTRODUCTION

Since the U.S. Department of Energy (DOE)'s Office of Nuclear Energy (NE) initiated the Nuclear Energy University Program (NEUP) in 2009, a total of 30 NEUP projects focused on High-Temperature Gas-cooled Reactor (HTGR) thermal-fluid experiments were funded up to fiscal year (FY) 2021. This represents a total DOE investment of approximately $23M over the 12-year period, covering thermal fluid phenomena important to both pebble bed and prismatic HTGR designs. The NEUP projects have produced a large amount of high-quality experimental and computational data that were published in final project reports, journal articles, dissertations, and conference proceedings, but in most cases the actual data sets and supporting information such as facility and instrumentation descriptions were not publicly disseminated to the HTGR community. To the authors' best knowledge, a data platform that organizes and summarizes these NEUP-funded projects for HTGR research does not currently exist.

To improve access to this HTGR validation data and optimize the return on the significant investment made by DOE, the Advanced Reactor Technologies (ART) Gas-Cooled Reactor (GCR) program started a survey of completed and ongoing HTGR NEUP projects with the aim of developing a public-access data platform that can be used to retrieve computational fluid dynamics (CFD) and system code validation data and guide future NEUP investments. This paper summarizes the status of the current ART-GCR database, provides an overview of the NEUP-funded HTGR-related research projects from FY2009 to FY2021 and identify validation knowledge gaps still existing in HTGR thermal-fluid research.

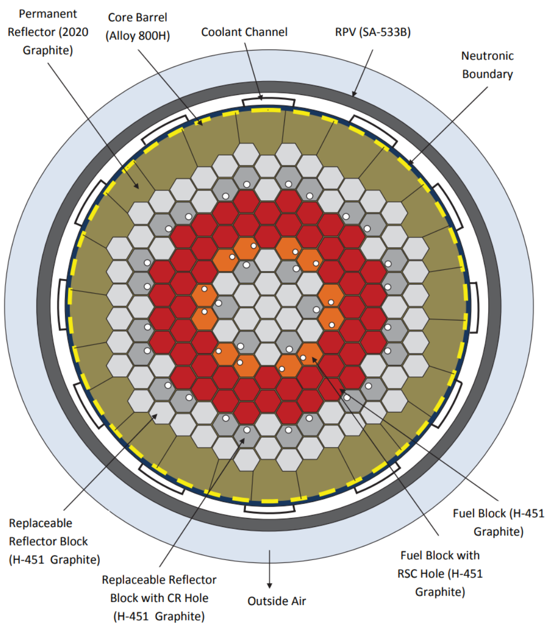
DOE-NE HTGR NEUPs

Nuclear energy is a key component of U.S. efforts to reduce dependence on fossil fuels and meet its commitments to drastically reduce greenhouse gas emissions, while continuing to ensure adequate domestic energy supplies. Given the importance of advancing nuclear power and its associated technologies, DOE-NE created the NEUP [1] in 2009 to consolidate its university support under one program. The NEUP funds nuclear energy research and equipment upgrades at U.S. colleges and universities and provides nuclear engineering educational support. The program supports projects that focus on the needs and priorities of key DOE-NE programs, including fuel cycle, advanced reactor concepts, and high-fidelity simulation code development efforts.

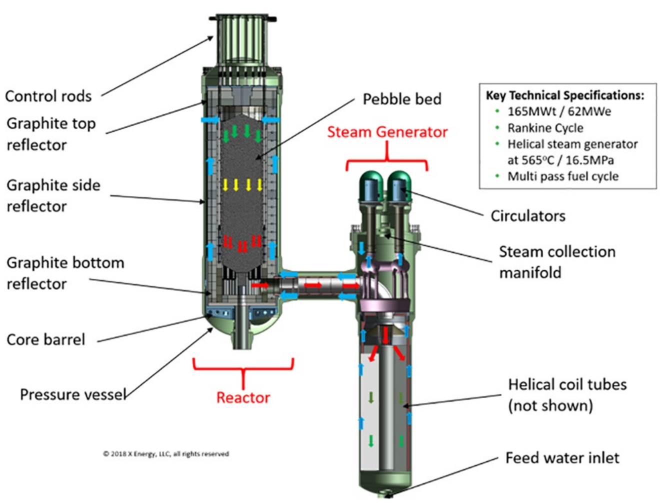
HTGRs supply high temperature heat energy by utilizing tri-structural isotropic (TRISO) fuel, inert helium gas as a coolant, and graphite as a moderator. As one of the Generation-IV advanced reactor designs, HTGRs are attracting attention from the end-user community due to their potential to provide high-temperature process heat in addition to high thermal-to-electric power conversion efficiency and inherent safety features [2, 3]. Fig. 1(a) shows the top view of the Modular High-Temperature Gas-Cooled Reactor (MHTGR) of the General Atomics MHTGR-350 design [4] as an example of a prismatic HTGR, while the X-Energy XE-100 reactor is shown in Fig. 1(b) as an example of a current demonstration pebble bed HTGR project in the US [5].

To develop, demonstrate and deploy HTGRs, it is crucial to identify phenomena that may occur during normal operation and transient conditions. An extensive HTGR Phenomena Identification and Ranking Table (PIRT) assessment was performed by the U.S. Nuclear Regulatory Commission (NRC) in 2007 [6], detailing the important phenomena related to heat generation, distribution and helium flows in the core and reflector regions during normal operation and transient conditions for both HTGR reactor types.

Some of the common and highest-ranked design-basis event scenarios for both prismatic and pebble-bed HTGR designs [7, 8] have been identified as Pressurized and Depressurized Loss of Forced Cooling (P/DLOFC), air/steam ingress following a DLOFC, and inadvertent reactivity insertions. Subsequent to the release of the NRC PIRT assessment, the phenomena ranking was utilized to determine the scope of the 30 NEUP projects at various US universities. The focus of these experiments were on those phenomena with high importance but medium-to-low knowledge level [7], such as core coolant bypass flow during normal operation, the Reactor Cavity Cooling System (RCCS) performance during accidents, air ingress rates and flow reversal during DLOFC transients, and flows in the upper and lower plena structures.



(a)



(b)

Fig. 1. HTGR reactor core design: (a) Prismatic fuel block [4], and (b) Pebble-bed core concept [5].

The U.S. universities that participated in NEUP HTGR-related projects are shown in Fig. 2. The completed NEUP project numbers are denoted in red boxes, while the ongoing projects are denoted in blue boxes, respectively. Until recently, at least the final summary reports of all the completed projects were available on the NEUP website (neup.inl.gov), but access to these products has been moved to the DOE's Office of Scientific and Technical Information (OSTI) website (osti.gov) since April 2022.

We found in our survey that important data related to these NEUPs are not readily available to researchers in the public domain: to develop a detailed CFD model, for example, the detailed facility description, instrumentation locations, and the measured data set would likely be required by most CFD analysts.

An additional challenge is that since all of these NEUP projects were also leveraged to obtain masters and doctorate degrees, these academic products were not always easy to find or publicly available.

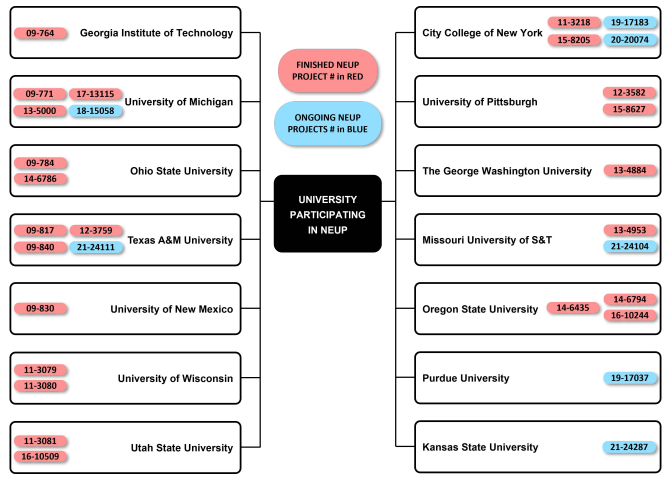


Fig. 2. The list of universities (PI affiliation shown) which has participated in NEUP, together with their finished (red) and ongoing (blue) NEUP project identification numbers.

A specific concern to the ART-GCR program is that the raw, or even processed, measured data sets for most of these NEUPs are not available in a central location (e.g., on maintained and redundant servers at INL) where access can be requested by the HTGR community. Since each university followed their own data storage procedures, access to the data vary widely from public websites maintained by the university or the Principal Investigator (PI) to personal email requests for the data to the PI or the student who processed the data and has since graduated. This is, in our view, not a transparent, sustainable, or equitable process for the HTGR community to harvest important HTGR thermal fluid validation data created with U.S. taxpayer funding. Therefore, the ART-GCR program identified an urgent need to create a central data platform at INL to identify, organize and store the results of these valuable research projects and provide future guidance for storage and transmission of important project documentation for NEUPs.

NEUP HTGR VALIDATION STATUS

Another focus point of the current NEUP survey was to map completed project scopes with PIRT phenomena and operational conditions, to determine what gaps remain in HTGR code validation space, and to inform future HTGR NEUP scope calls. Table I shows a summary mapping of the HTGR thermal-hydraulics phenomena covered during various operating scenarios in the finished (denoted in red boxes) and ongoing (blue) NEUP projects.

Table I. Thermal-hydraulics phenomena summary for the HTGR-related NEUP projects (FY2009 to FY2021). Finished projects numbers are denoted in red boxes while ongoing projects in blue.

FINISHED NEUP PROJECT # in RED / ONGOING NEUP PROJECTS # in BLUE		SCENARIOS: NORMAL OPERATION	PRESSURIZED LOSS OF FLOW	DEPRESSURIZED LOSS OF FLOW	LOAD CHANGE (TRANSIENT)	STEAM GENERATOR TUBE BREAK
PHENOMENA: PLENUM MIXING / JET IMPINGEMENT	LOWER PLENUM	12-3582, 15-8627	16-10244	16-10244		
	UPPER PLENUM	12-3759	18-15058	18-15058	13-5000	
	PLENUM TO PLENUM	13-4953, 16-10509	20-20074	20-20074		
INGRESS	AIR INGRESS		15-8205	09-784, 13-4884, 14-6435, 15-8205, 17-13115		14-6786, 19-17183
	STEAM/WATER INGRESS		18-15058	18-15058, 21-24111		14-6786
CONJUGATE HEAT TRANSFER (CORE)	FORCED CONVECTION	09-771, 11-3081, 16-10509, 21-24104, 21-24287	11-3218, 21-24104, 21-24287	11-3218		
	NATURAL CONVECTION	14-6794, 16-10509	14-6794	14-6435		
NATURAL CONVECTION IN RCCS		09-817, 11-3079, 13-4953			09-817, 11-3079, 13-5000	
BYPASS		09-830, 15-8627	15-8205	09-840, 15-8205		
FLUID STRATIFICATION				14-6435		
NUCLEAR (DECAY HEAT, REACTIVITY FEEDBACK, FISSION PRODUCT, ETC.)		09-764, 11-3080		19-17037, 21-24111		

It can be seen in Table I that at least two high-importance with low-to-medium knowledge level areas remain not yet been covered extensively with NEUP-funded projects: thermal fluid stratification and plenum mixing.

Many of the DOE NEUP projects shown in Table I have produced valuable results with both computational and experimental studies involved (such as Ref. [9-11]), but the data from these projects are still only available directly from the university PIs. One example of an optimal NEUP project close-out can be found in NEUP Project No. 11-3081. The Utah State University (USU) team conducted their experiments using a Rotatable Wind Tunnel (RoBuT) to establish very high-quality validation data for vertical plate heat convection, and at the conclusion of the project set up a public online access website for the dataset and all supporting documentation which will be necessary to develop detailed validation models [12].

Our current vision of the INL HTGR NEUP data platform is to provide a similar summary webpage for all the completed NEUP projects, with links to the datasets and documentation for both the computational and experimental work.

Based on the extensive literature review, we initialized the construction of a test data platform powered by Microsoft® SharePoint Platform to link the available technical reports, journal publications, and conference proceedings resulting from the corresponding research projects. In FY23, datasets generated by CFD or system code models (and in best-case scenarios, the actual models themselves), experimental facility descriptions, and all academic products related to the project will be also included in the platform for each NEUP project as part of the future work scope. The ultimate goal is that access to this platform will be publicly available to the HTGR research community via the ART-GCR program website [13] in the near future.

CONCLUSION AND FUTURE WORK

A total of 30 NEUP-funded HTGR thermal-fluid projects were funded by DOE-NE between 2009-2021, but a comprehensive database (or platform) that identifies, collects, and stores the products of these projects is currently not available for code validation and verification (V&V) by the HTGR community. An extensive literature review has been performed for all the NEUP-funded HTGR projects from FY2009 to FY2021, and a preliminary test data platform has been constructed summarizing the completed project meta data. Potential phenomena and data knowledge gaps have also been identified to support for future NEUP funding decisions.

As future work, we will incorporate the available experimental and computational data generated by these NEUP projects and disseminate it on a publicly accessible online data platform, most likely via the ART-GCR website. The ultimate goal is to deliver on the initial potential of these DOE-funded experimental datasets by providing a comprehensive single-entry access point for researchers in the HTGR industry, national laboratory, regulator, and academic communities.

ACKNOWLEDGEMENTS

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