INL/MIS-24-78770-Revision-0

Overview on ART-GCR DoE program experiments and software validation efforts

June 2024

Changing the World's Energy Future

Paolo Balestra

Idaho National Laboratory

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

INL/MIS-24-78770-Revision-0

Overview on ART-GCR DoE program experiments and software validation efforts

Paolo Balestra

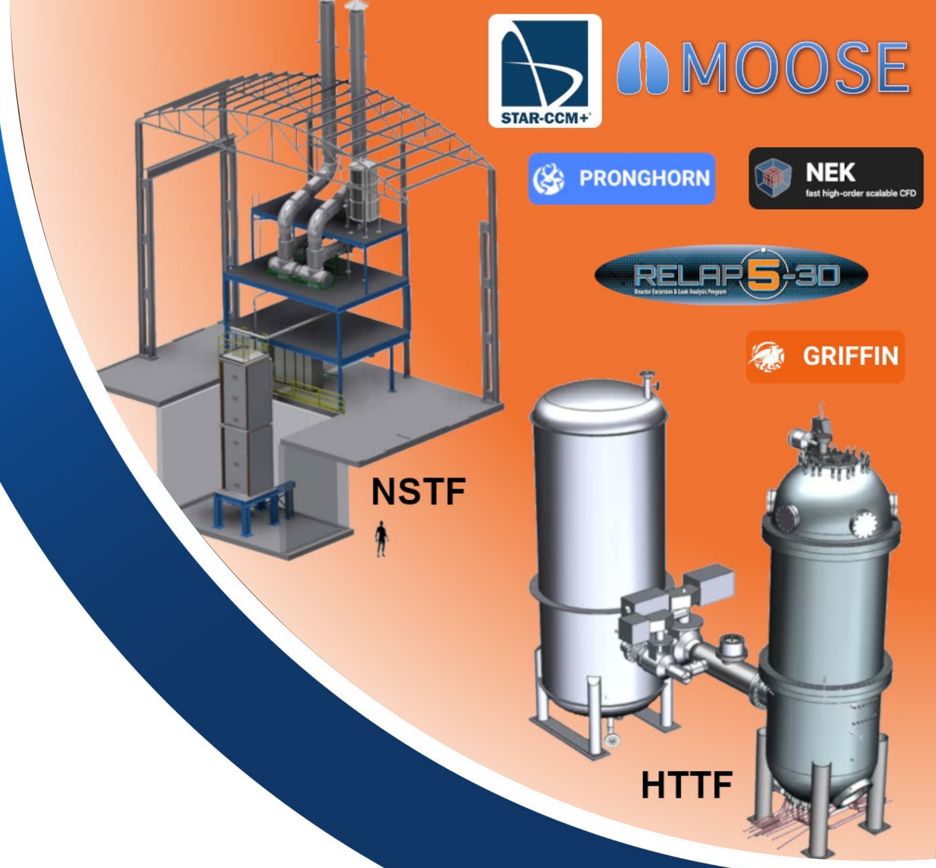
June 2024

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

GAS-COOLED REACTOR
ADVANCED REACTOR TECHNOLOGIES PROGRAM



June 20, 2024

Overview on ART-GCR DoE program experiments and software validation efforts

Paolo Balestra
ART-GCR Methods Lead at Idaho National Laboratory

Experimental Testing and Validation for Design and Safety Analysis Computer Codes for Small Modular Reactors

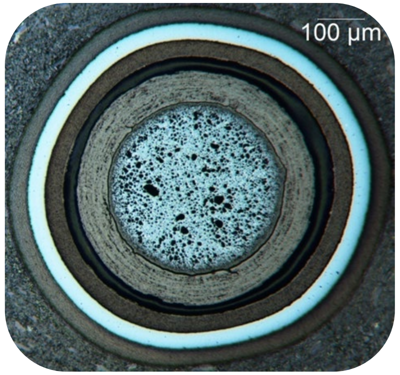
Interregional Workshop

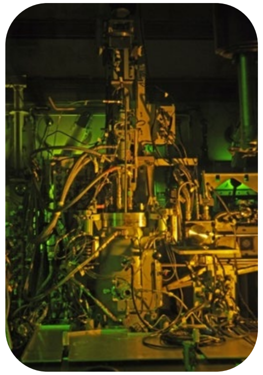
June 18-21, 2024

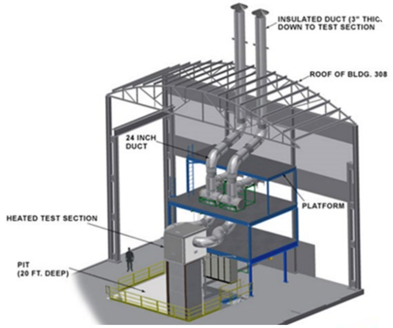
Content

- ART-GCR DoE Program Overview
- NSTF Facility Overview
- NSTF M&S and Validation Efforts
- HTTF Facility Overview
- HTTF Benchmark

DOE ART-GCR Program







Fuel development and qualification

- Establish a domestic commercial TRISO fuel fabrication capability.
- Generate UCO TRISO fuel performance data to support fuel qualification.

Graphite qualification

- Select, irradiate, and characterize existing nuclear grades.
- Qualify nuclear grade graphite and establish design rules for use in HTGR core.

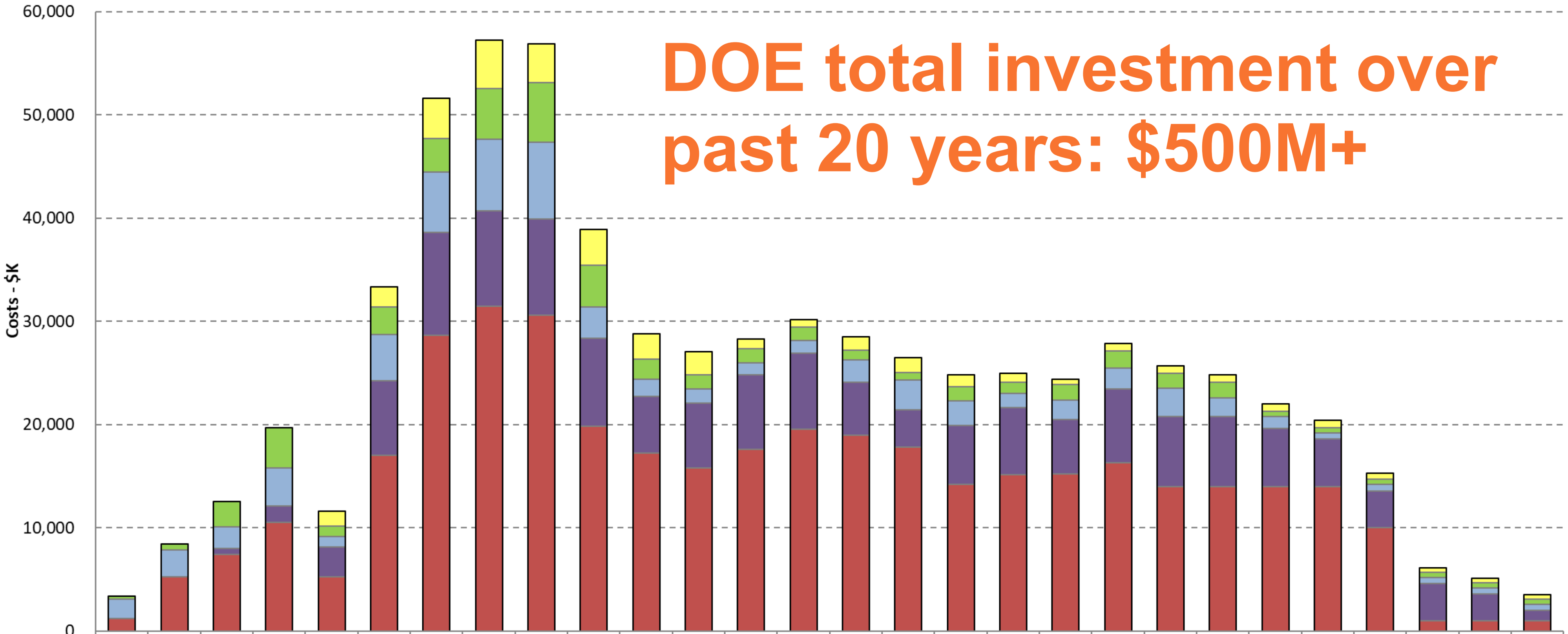
Advanced materials codification

- Achieve ASME codification of alloys and design methods for high-temperature duty pressure vessel, heat exchanger, and other primary circuit components.

Design, methods and validation

- Develop prismatic and pebble bed HTGR core analysis methods
- Validate codes via experiments, code-to-code benchmarks, and uncertainty analyses.

ART-GCR Historical Costs and Projected Funding



	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23*	FY24*	FY25*	FY26*	FY27*	FY28*	FY29*	FY30*
PM	0	0	0	0	1,404	1,952	3,903	4,727	3,812	3,460	2,473	2,252	940	751	1,265	1,431	1,149	863	545	720	720	720	720	720	600	400	400	400
Materials	334	576	2,487	3,886	1,040	2,663	3,248	4,931	5,777	4,035	1,934	1,375	1,370	1,278	912	705	1,386	1,074	1,515	1,650	1,500	1,500	500	500	500	500	500	500
Methods	1,823	2,591	2,067	3,697	991	4,496	5,859	6,934	7,425	3,024	1,629	1,350	1,123	1,242	2,201	2,860	2,380	1,364	1,840	2,057	2,700	1,800	1,200	600	600	600	600	600
Graphite	0	0	592	1,601	2,931	7,201	9,931	9,210	9,286	8,512	5,542	6,313	7,237	7,330	5,104	3,657	5,679	6,509	5,302	7,125	6,800	6,800	5,600	4,600	3,600	3,600	2,600	1,000
Fuels	1,256	5,270	7,426	10,542	5,241	17,038	28,681	31,476	30,612	19,863	17,217	15,778	17,603	19,597	18,996	17,811	14,243	15,140	15,206	16,300	14,000	14,000	14,000	14,000	10,000	1,000	1,000	1,000
Total	3,413	8,437	12,572	19,726	11,607	33,350	51,622	57,278	56,912	38,894	28,795	27,068	28,273	30,198	28,478	26,464	24,837	24,950	24,408	27,852	25,720	24,820	22,020	20,420	15,300	6,100	5,100	3,500

4

Design, Methods and Validation

Methods Experimental Validation:

Support experiments such as HTTF tests, NSTF campaign and HTGR related NEUPs to fill the gaps of the validation matrix for High Temperature Gas Cooled reactors M&S tools.

Reactor analysis:

Development/assessment of methodologies for HTGRs modeling to improve fidelity or simplify the analyst workflow. An example of that are the testing on the engineering scale of start-up, run-in and equilibrium core calculation capabilities.

International collaborations:

Leveraging international collaborations to exchange data for validation of HTGRs M&S tools. Operational reactor data such as the HTTR LOFC tests and HTR-PM startup or data from integral effect test facilities are extremely rare but invaluable to prove the validity of the codes.

VHTR - Computational Methods, Validation & Benchmarks

- 5 Work Packages
  - WP1: PIRT
  - WP2: CFD
  - WP3: Reactor physics
  - WP4: Chemistry and Transport
  - WP5: Reactor and Plant Dynamics

CMVB PA	EU	JP	CN	KR	US	UK	CA	AU
	P	P	P	P	P	O	O	O

Date	Event
2018.10.05	• The Project Plan has been approved by all SSC.
End of 2020	• The confirmation of CMVB PA has been received from each signatory, comments have been received from the signatories: EU, Japan, China, Korea, and US.
2021.05.14	• The SSC members approved the updated project plan concerning the subject of signatories
2021.09.01-02	• Signatory from KAERI (05/21/2021), JAEA (06/17/2021), JRC (07/15/2021), and INET (08/31/2021).
2022.09.19-20	• At the 25th CMVB PMB Meeting Canada joined as observer and signatory from the DoE was announced by the end of the 2022.
2023.03.20-21	• Signatory completed KAERI (05/21/2021), JAEA (06/17/2021), JRC (07/15/2021), INET (08/31/2021), US (11/30/2022). Canada and UK expressed interest in becoming participant members, Frederik Reitsma is the new representative for EU and the new technical secretariat Franco Michel-Sendis joined the group.
2023.10.10-11	• Australia Joined the VHTR-CMVB as an Observer, OKITA Shoichiro is the new representative for Japan.
2024.04.15-18	• Dr. Minh Tran is the new observer for Australia

GEN IV International Forum
Expertise | Collaboration | Excellence

Nuclear Energy University Program (NEUP) Thermal-Fluid Experiments for HTGRs.

- From FY2009 to FY2023, there are in total 35 DOE NEUP projects focusing on the thermal-fluid experiments related with High-Temperature Gas-cooled Reactor (HTGR), producing a large amount of high-quality validation data.

FINISHED NEUP PROJECT # in RED — ONGOING NEUP PROJECTS # in BLUE

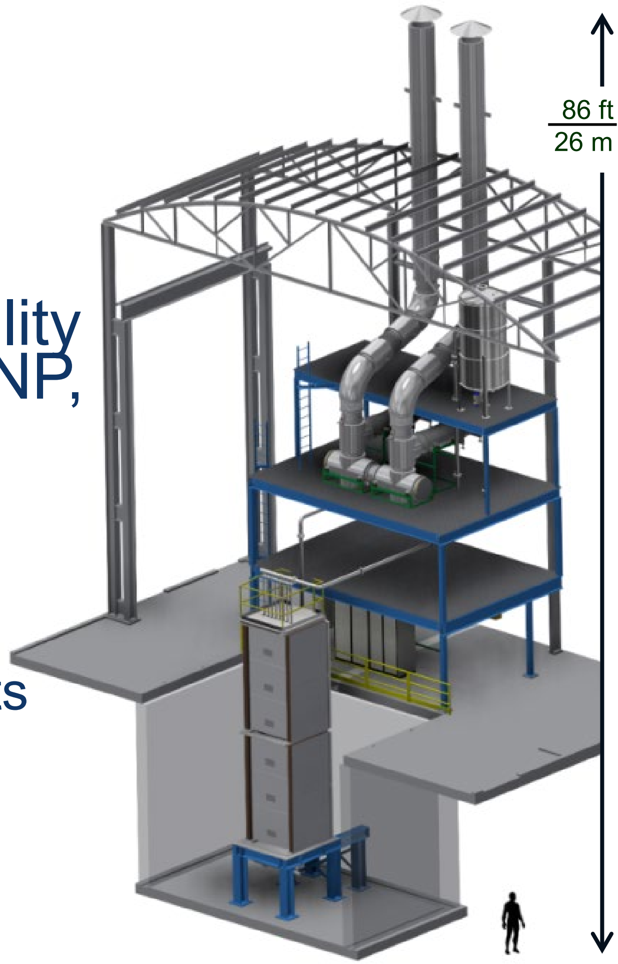
PHENOMENA		SCENARIOS: NORMAL OPERATION	PRESSURIZED LOSS OF FLOW	DEPRESSURIZED LOSS OF FLOW	LOAD CHANGE (TRANSIENT)	STEAM GENERATOR TUBE BREAK
PLENUM MIXING / JET IMPINGEMENT	LOWER PLENUM	12-3582, 15-8627	16-10244	16-10244		
PLENUM MIXING / JET IMPINGEMENT	UPPER PLENUM	12-3759	18-15058	18-15058		
PLENUM MIXING / JET IMPINGEMENT	PLENUM TO PLENUM	13-4953, 16-10509, 23-29598	20-20074	20-20074	23-29598	
INGRESS	AIR INGRESS		15-8205, 20-19896	09-784, 15-8205, 13-4884, 17-13115, 14-6435, 20-19896		14-6786, 19-17183
INGRESS	STEAM/WATER INGRESS		18-15058	18-15058, 21-24111		14-6786
CONJUGATE HEAT TRANSFER (CORE)	FORCED CONVECTION	09-771, 21-24104, 11-3081, 21-24287, 16-10509	11-3218, 21-24104, 21-24287	11-3218, 21-24156		
CONJUGATE HEAT TRANSFER (CORE)	NATURAL CONVECTION	14-6794, 16-10509	14-6794	14-6435, 21-24156		
RCCS PERFORMANCE		09-781, 13-4953, 09-817, 20-19896, 11-3079	20-19896	20-19896	09-781, 11-3079, 09-817, 13-5000	
CORE BYPASS FLOW		09-830, 15-8627, 20-19968	15-8205	09-840, 15-8205		
FLUID STRATIFICATION				14-6435		
MULTI-PHYSICS (FISSION PRODUCT, SAFETY ANALYSIS, THERMAL-MECHANICAL, ETC.)		20-19896, 22-26607	20-19896	19-17037, 21-24111, 20-19896, 21-24156	22-26607	

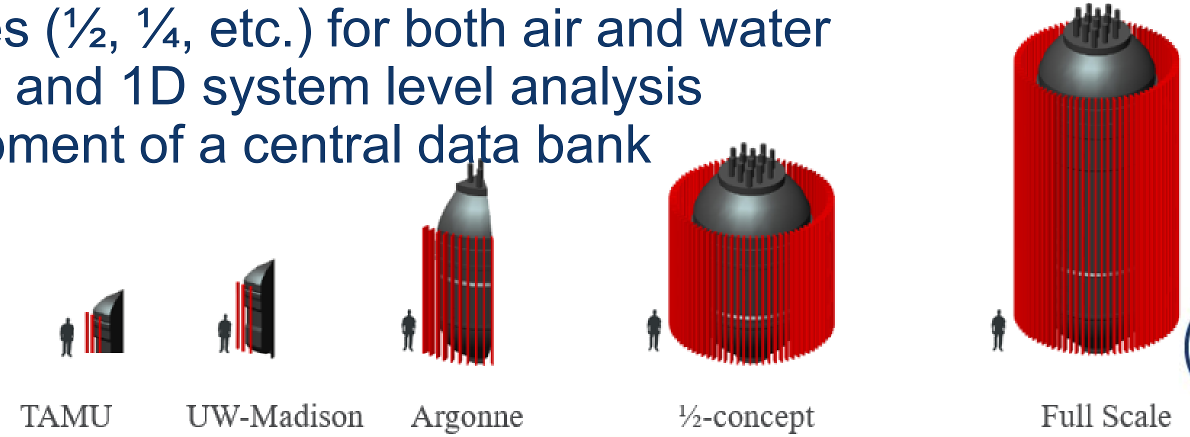
NEUP Nuclear Energy University Program
U.S. Department of Energy

Content

NSTF

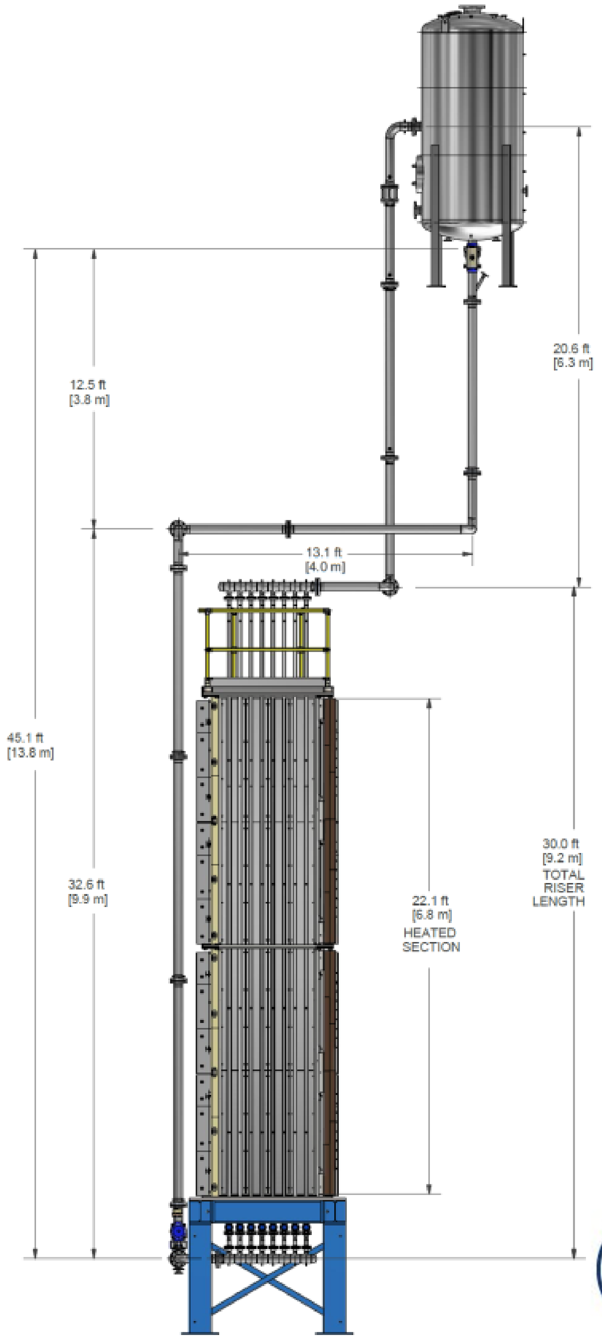
- Natural Convection Shutdown Heat Removal Test Facility (NSTF) was initiated in support of DOE programs: NGNP, SMR, and ART
  - Air-based testing program (completed, FY13 - FY16)
  - Water-based testing program (on-going, FY18 to present)
- Top level objectives of NSTF program at Argonne:
  - passive safety and decay heat removal for advanced concepts
  - generate NQA-1 qualified licensing data for industry
  - provide benchmark data for code V&V
- Concurrent with a broader scope and multiple collaborators
  - Experimental facilities at scales (½, ¼, etc.) for both air and water
  - Complimenting CFD modeling and 1D system level analysis
  - Collaborating towards development of a central data bank





Water facility overview

- Natural circulation boiling water test loop
  - Operating modes of natural or forced
- 4,260 liter water storage tank
  - H/D ratio of 2.0, rated to 2 bar over pressure
- Heat transfer panel:
  - Eight riser tubes and nine heat transfer panels
  - 316L stainless tubes, 1018 carbon fins
  - Full penetration HLAW weld to risers
- Network piping: 4.0” Sch. 40, 316L stainless
- ½ axial scale
  - Total height of 18 m (59-ft)
  - Heated length of 6.7 m (22-ft)



Program Quality Assurance

- Regular audits, or assessments, maintain compliance to NQA-1
  - Following requirements of ASME NQA-1 2008 with 2009 addendum
  - Small team of dedicated individuals with strong management support
  - Primary purpose is generating and packaging high-quality data

NQA-1 2008/2009a compliant

Date	Audit Type			Lead Auditor
Spring 2014, 03/18 – 20/2014	☐ MA	☐ Internal	☑ **External**	Kirk Bailey (INL)
Winter 2014, 02/16 – 18/2015	☑ **MA**	☐ Internal	☐ External	Roberta Riel (ANL)
Summer 2015, 07/20 – 23/2015	☐ MA	☑ **Internal**	☐ External	Roberta Riel (ANL)
Fall 2015, 11/3 – 5/2015	☐ MA	☐ Internal	☑ **External**	Alan Trost (INL)
Winter 2016, 01/21/2016	☑ **MA**	☐ Internal	☐ External	Roberta Riel (ANL)
Summer 2016, 06/29 – 30/2016	☐ MA	☑ **Internal**	☐ External	Roberta Riel (ANL)
Fall 2016, 11/29 – 30/2016	☑ **MA**	☐ Internal	☐ External	Roberta Riel (ANL)
Fall 2017, 11/07 – 09/2017	☐ MA	☑ **Internal**	☐ External	Roberta Riel (ANL)
Spring 2018, 02/06 – 08/2018	☐ MA	☐ Internal	☑ **External**	Michelle Sharp (INL)
Summer 2018, 05/30/2018	☑ **MA**	☐ Internal	☐ External	Roberta Riel (ANL)
Winter 2019, 01/29 – 30/2019	☐ MA	☑ **Internal**	☐ External	Roberta Riel (ANL)
Winter 2020, 02/18 – 19/2020	☑ **MA**	☐ Internal	☐ External	Roberta Riel (ANL)
Spring 2020, 03/17 – 19/2020	☐ MA	☐ Internal	☑ **External**	R. Dieter (Kairos)
Fall 2020, 08/25 – 27/2020	☐ MA	☑ **Internal**	☐ External	Roberta Riel (ANL)
Summer 2021, 09/07 – 09/2021	☐ MA	☑ **Internal**	☐ External	Roberta Riel (ANL)
Spring 2022, 4/25 – 28/2022	☑ **MA**	☐ Internal	☐ External	Roberta Riel (ANL)
Spring 2023, 02/21 – 23/2023	☐ MA	☐ Internal	☑ **External**	Michelle Sharp (INL)

Water-based Accomplishments to-date

- Since June 2018, logged 1,092-hr of active heated operation over 49 test cases
  - 32 data-quality matrix cases (22 Accepted); 17 Scoping/misc.
- Published 20 technical reports, conference proceedings, and journal papers
- Formal industry support with Kairos via CRADA; Framatome via ARPA-E, Boston Atomics/MIT via ARC-20; provided JAEA with validation data; advised Westinghouse on LFR DHR

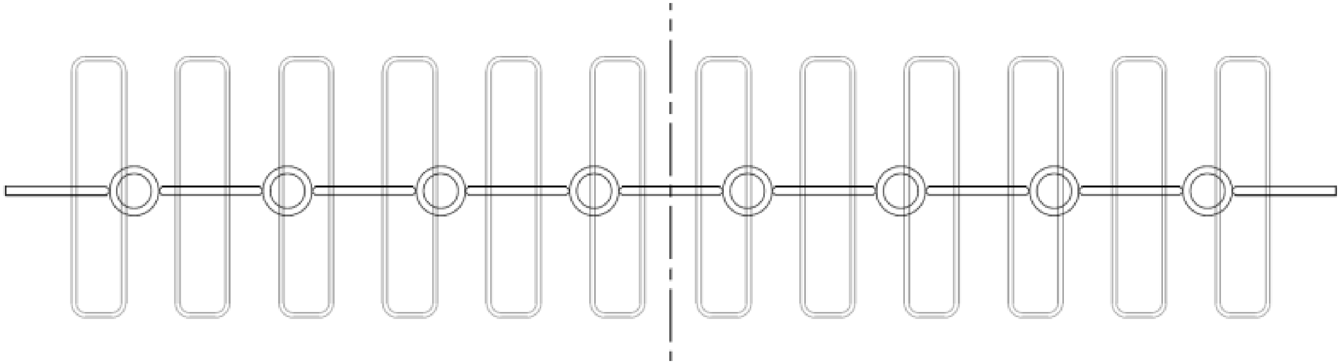
Testing Summary

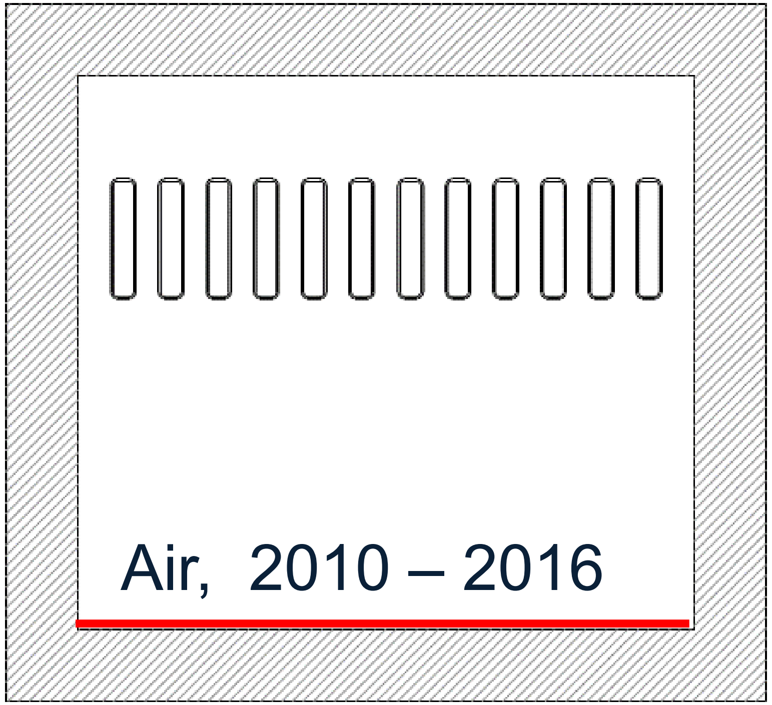
	Water	**Air**
Duration	54-month	33-month
Active Hours	1,092-hr	2,250-hr
Data-Quality	32	27
Accepted	*22*	*16*
Trending	*7*	*7*
Failed	*3*	*4*
Total Runs	49	40

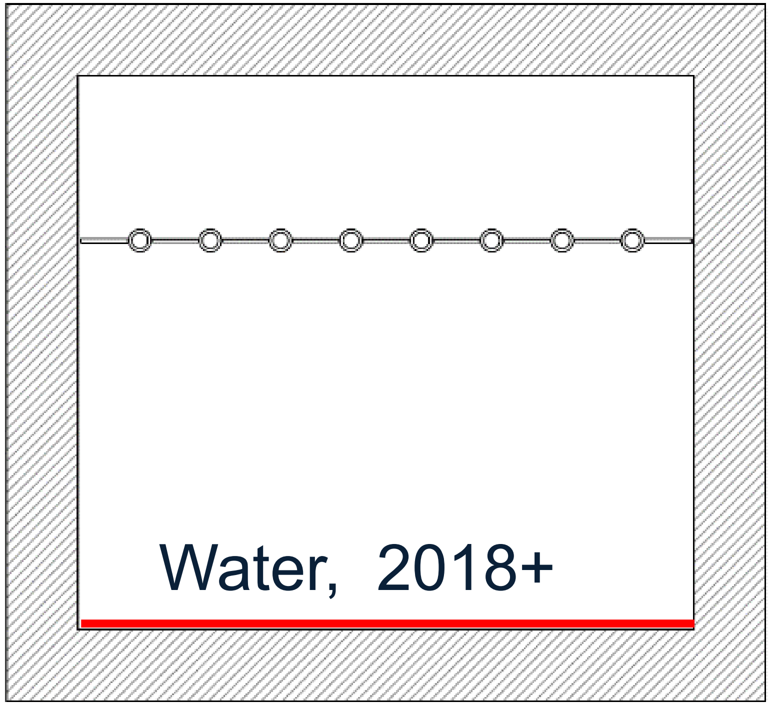
Publication Summary

	Water	**Air**
Technical reports	8	9
Conference proceedings	10	12
Journal papers	2	5
Patents	0	1

Air/water comparison

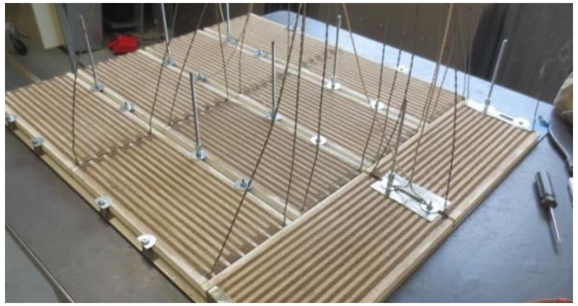




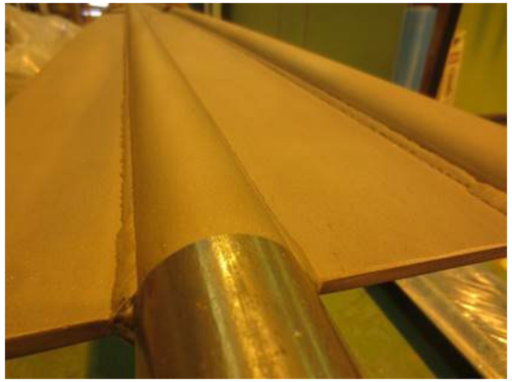


NSTF Components

Primary tank installed 10.5-m above grade

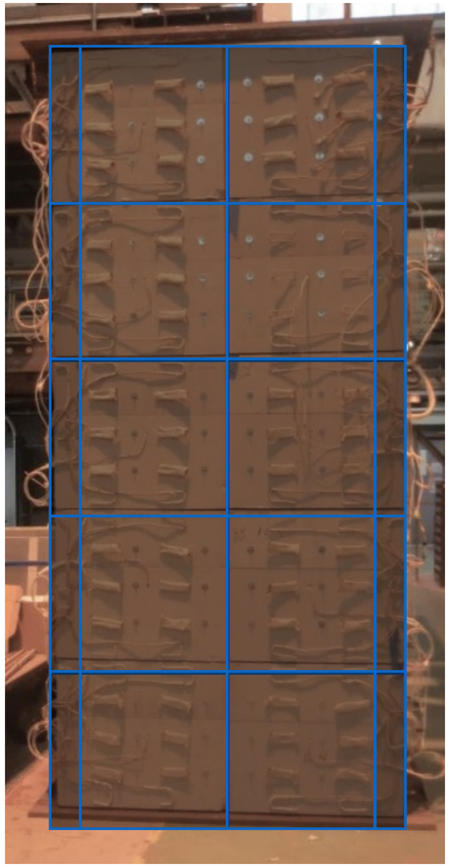


New ceramic heater plate assembly (1 of 20)



Bead blasted cooling panel surface

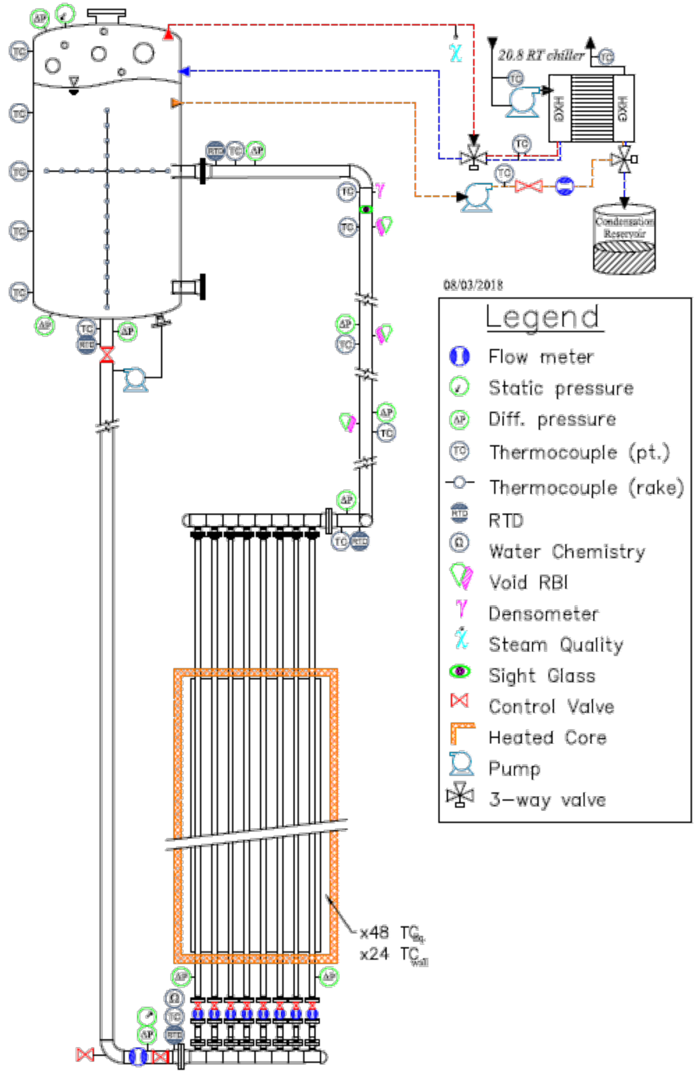
Panel hoisted vertical prior to install



One half of cavity completed with TC and heater assemblies

Water Instrumentation

Measurement	Sensor	Location	Qty.	Mfg.	Model	Range
Flowrate	Magnetic	Inlet header	x1	Krohne	Optiflux 4000	±5kg/s
Flowrate	Magnetic	Inlet riser	x8	Krohne	Optiflux 4000	±1kg/s
Static head	Strain	Inlet header	x1	Rosemount	3051S	0 - 10bar
Steam pressure	Strain	Gas space	x1	Rosemount	3051S	0 - 2bar_{abs}
ΔP	Strain	Chimney	x2	Rosemount	3051S	±6kPa
ΔP	Strain	Risers	x3	Rosemount	3051S	±62kPa
Liquid level	Strain	Tank	x1	Rosemount	3051S	0 - 3m
Void fraction	Optical	Chimney	x2	RBI	Twin-tip	0 - 100%
Void fraction	γ-Density	Chimney	x1	ThermoFisher	DensityPRO	0 - 100%
Temperature	RTD	Fluid	x4	Omega	UP1/10DIN	0 - 250°C
Temperature	T-type TC	Fluid	x128	ARi	T-31N	0 - 400°C
Temperature	K-type TC	Test section	x24	ARi	T-31N	0 - 600°C
Temperature	K-type TC	Strain	x286	ARi	Silica20AWG	0 - 600°C
Temperature	DTS	Test section	x20	LUNA	ODiSI-A	0 - 300°C
Water pH	pH meter	Inlet header	x1	Emerson	RBI547	0 - 14pH
TrDO O_2	Amperometric	Inlet header	x1	Emerson	499A	0.1ppb-20ppm
Conductivity	Magnetic	Inlet header	x1	Krohne	Optiflux 4000	1 – 6000μS/cm



Electromagnetic flow meters

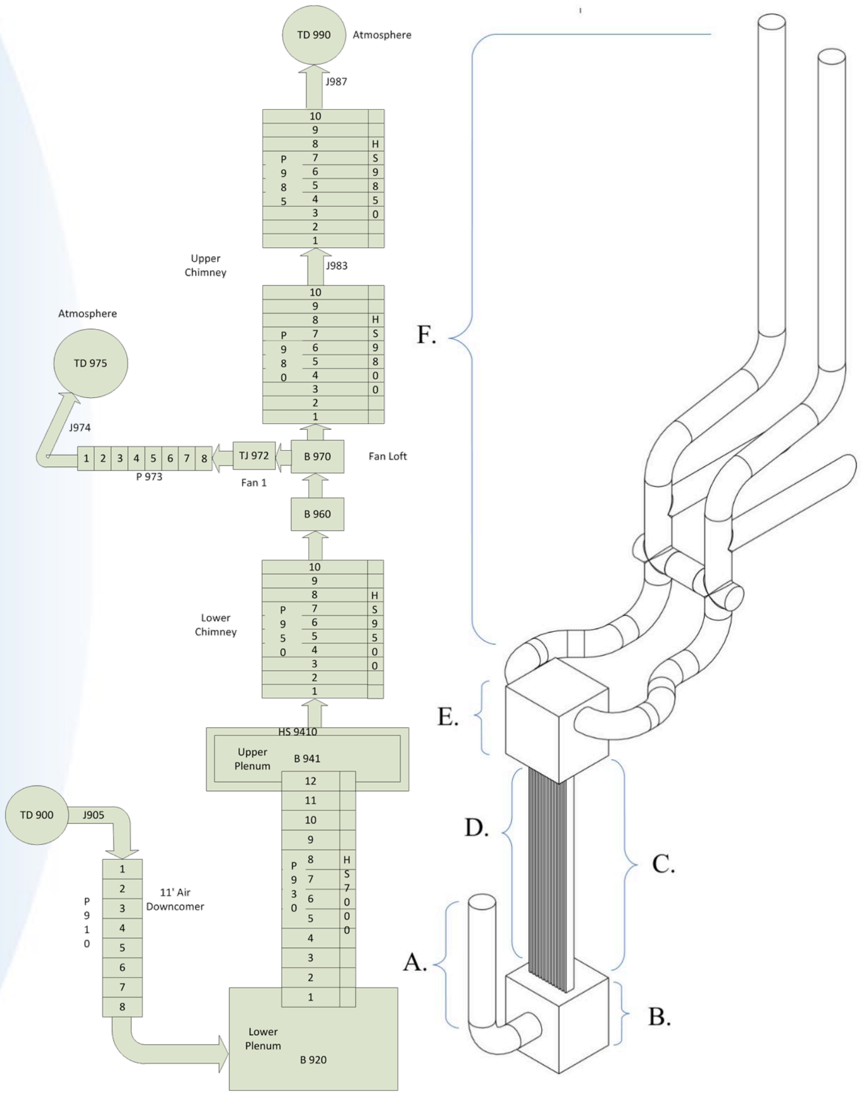
Gamma densometer

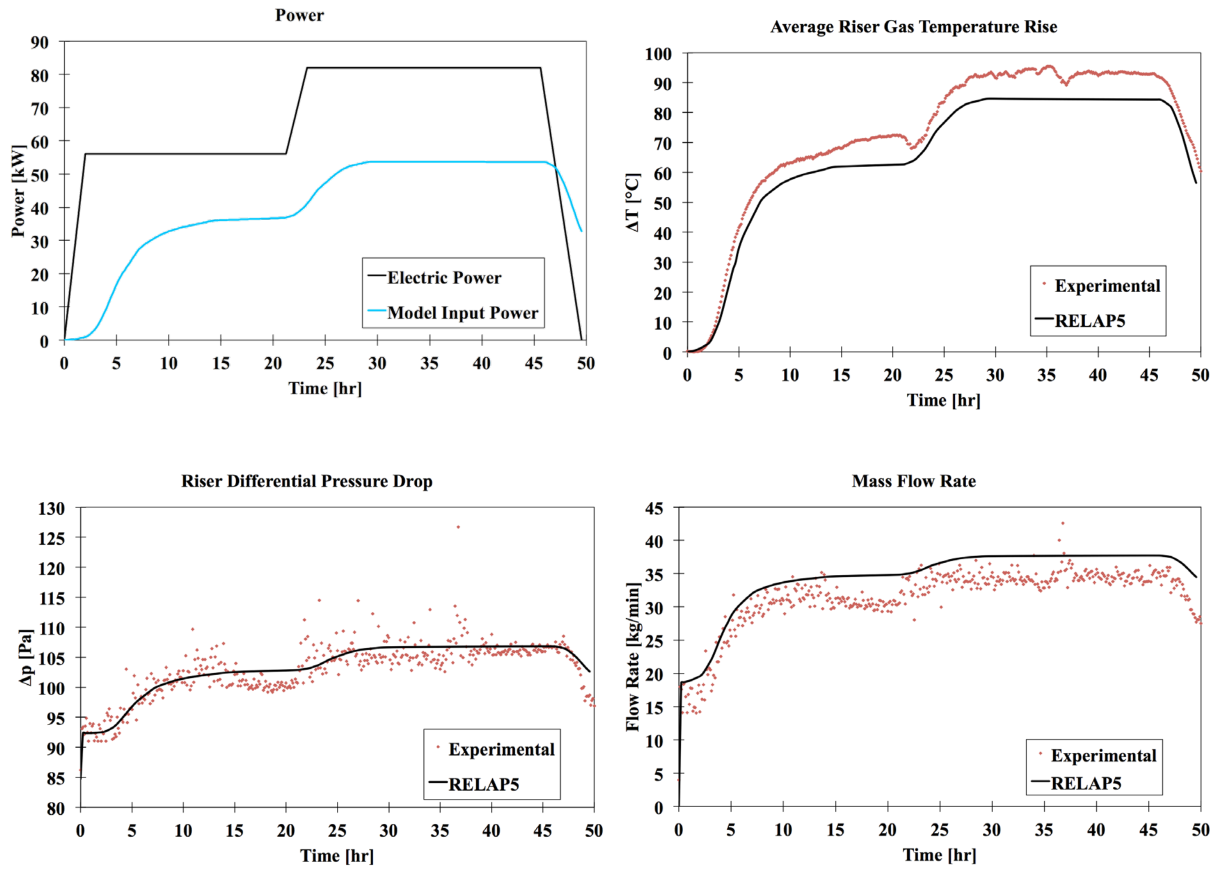
Content

- ART-GCR DoE Program Overview
- NSTF Facility Overview
- NSTF M&S and Validation Efforts
- HTTF Facility Overview
- HTTF Benchmark

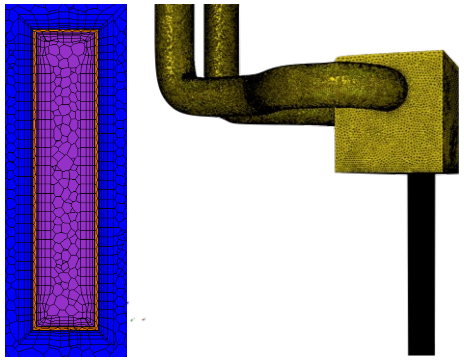
RELAP5 Simulation of Air- NSTF Run011

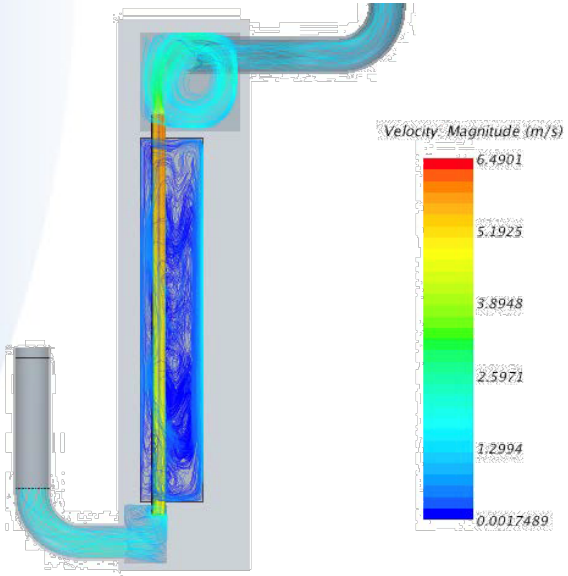
Bucknor, M., Hu, R., Lisowski, D., & Kraus, A. (2016). Comparisons of RELAP5-3D Analyses to Experimental Data from the Natural Convection Shutdown Heat Removal Test Facility. Argonne National Lab.(ANL), Argonne, IL (United States).





STARCCM+ Simulation of Air- NSTF Run011 (56kW)





Kraus, A. R., Hu, R., Lisowski, D. D., & Bucknor, M. (2016, June). Simulation of Buoyancy-Driven Flow for Various Power Levels at the NSTF. In International Conference on Nuclear Engineering (Vol. 50046, p. V004T10A022). American Society of Mechanical Engineers.

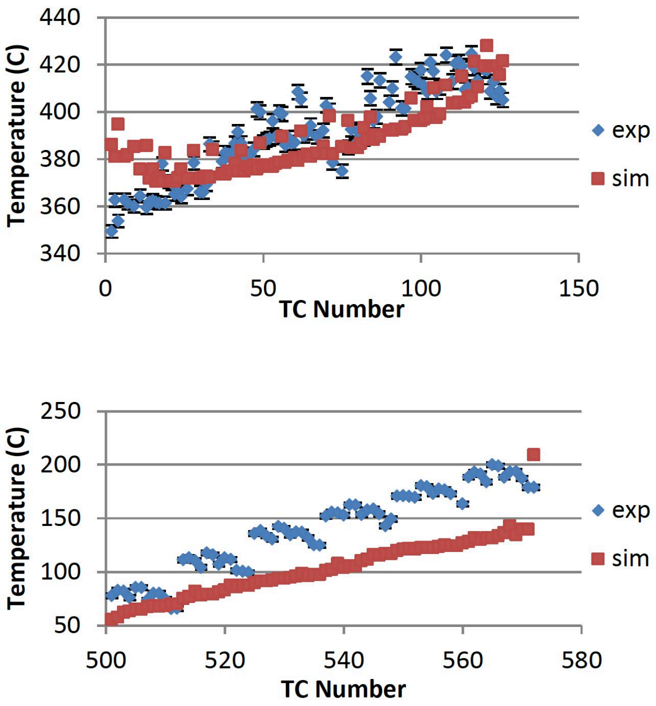


FIG. 4. Temperatures for the heated surface (top) and west wall (bottom) for the base forced-flow case.

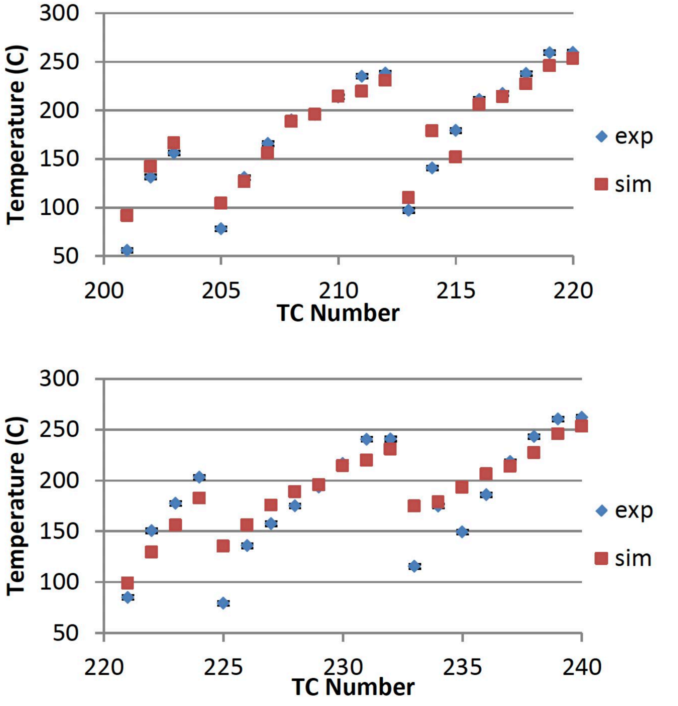
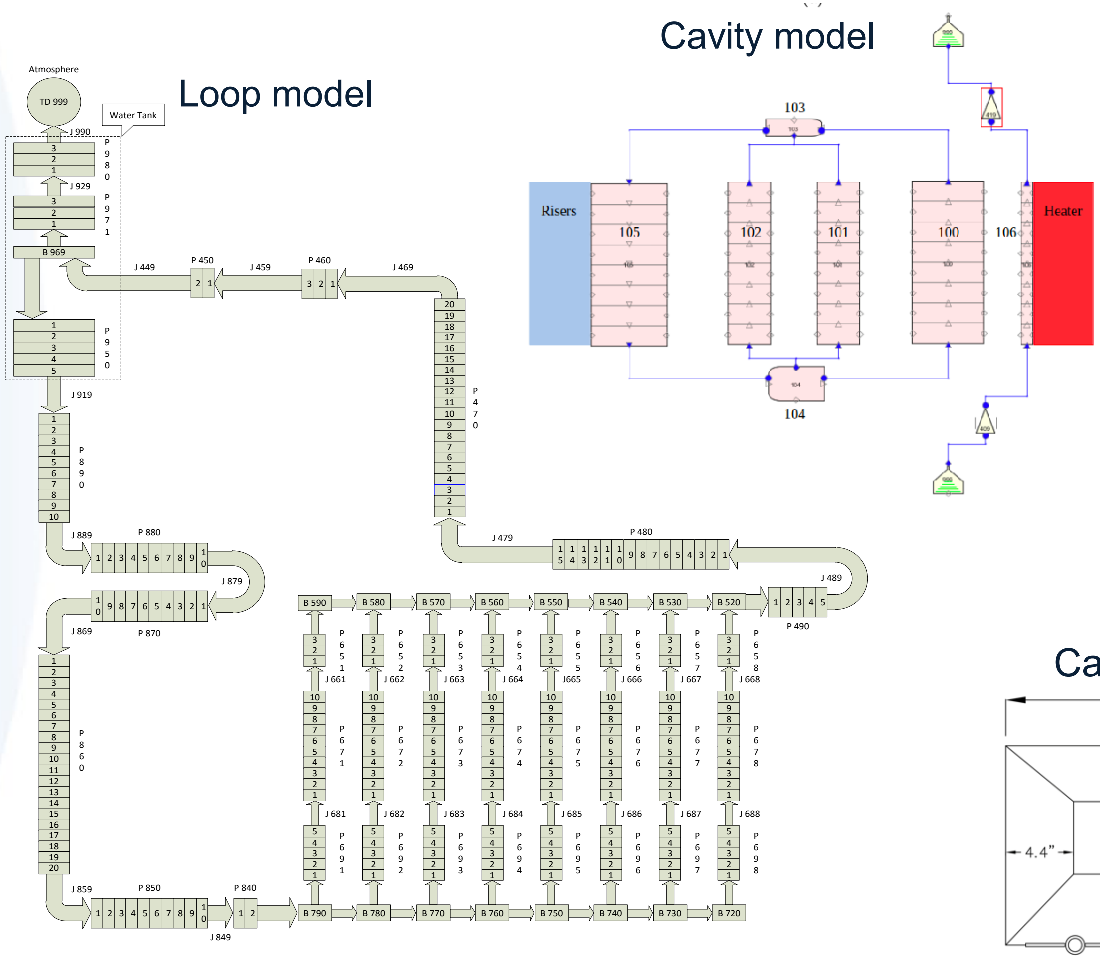
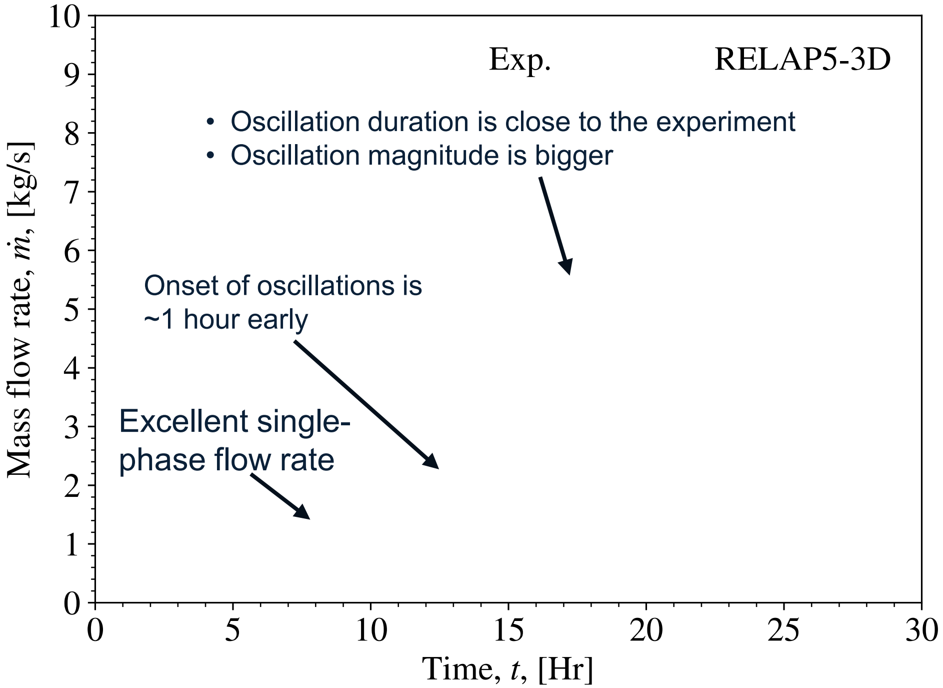


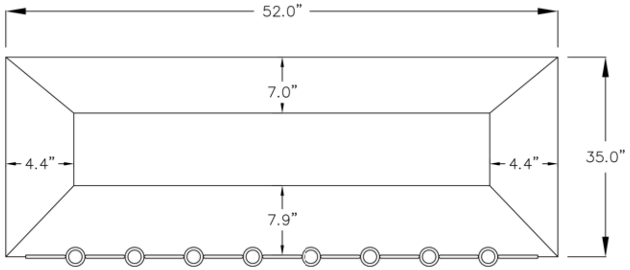
FIG. 5. Temperatures for the north (top) and south (bottom) cavity walls for the base forced-flow case.

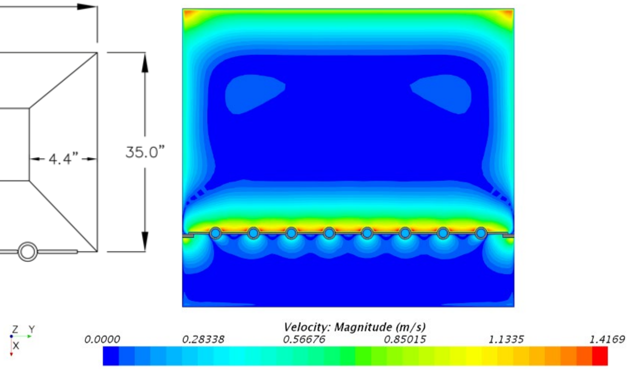
RELAP5-3D Simulation of Water-NSTF Run057





Cavity schematic (top view)





Ooi, Z. J., Lv, Q., Hu, R., Jasica, M., & Lisowski, D. (2022). FY22 Progress on Computational Modeling of the Water-Based NSTF (No. ANL-ART-257). Argonne National Laboratory (ANL), Argonne, IL (United States).

STARCCM+ Simulation of Water-NSTF Run052 (51.6 kW)

Lv, Q., Kraus, A., Ooi, Z. J., Hu, R., & Lisowski, D. (2021). Progress on Computational Modeling of Water-Based NSTF (FY2021) (No. ANL-ART-235). Argonne National Lab.(ANL), Argonne, IL (United States).

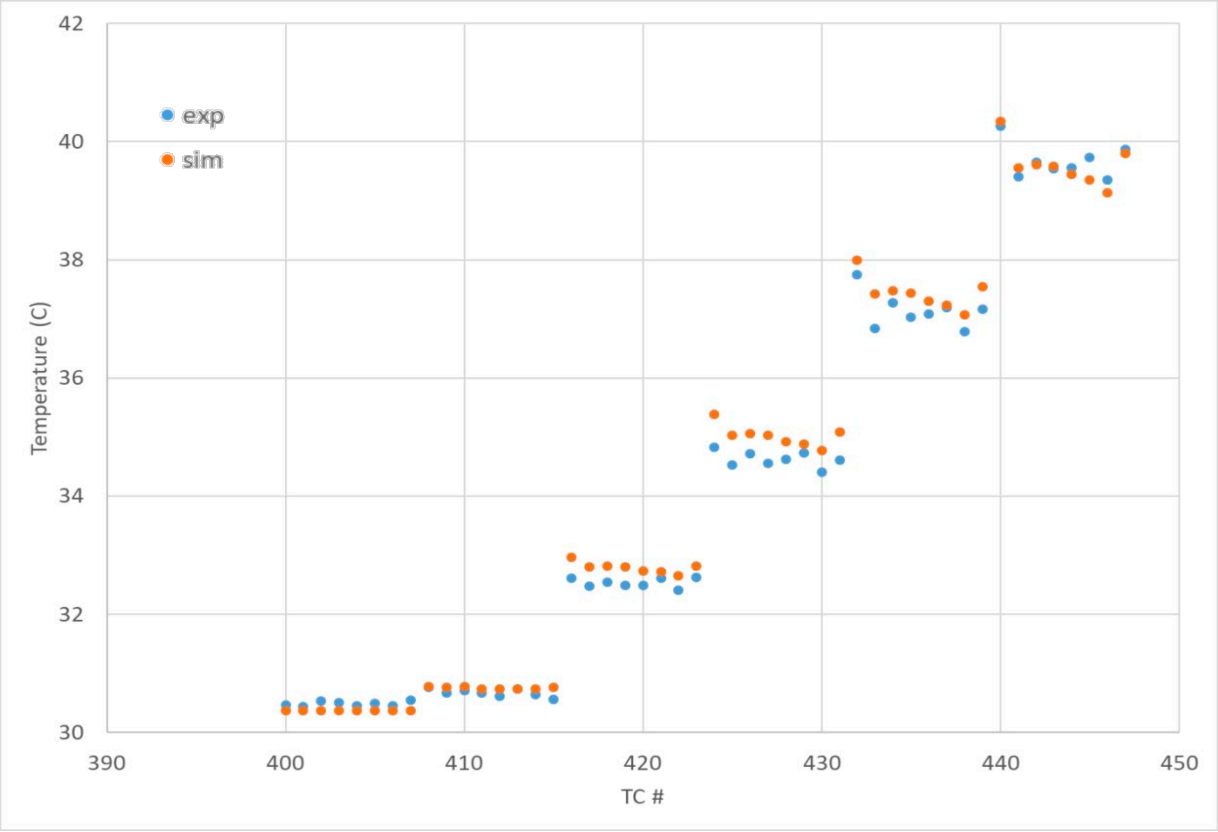
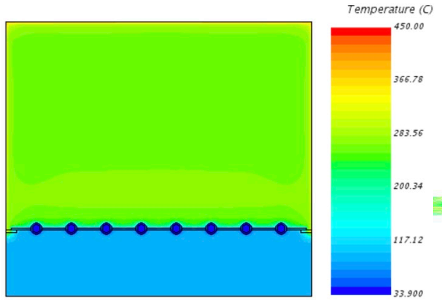
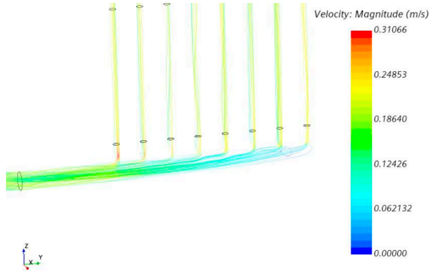


Figure 3-16. Riser liquid temperatures for the case with headers modeled.

Cavity model

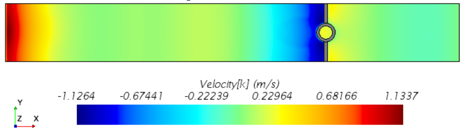


Inlet header

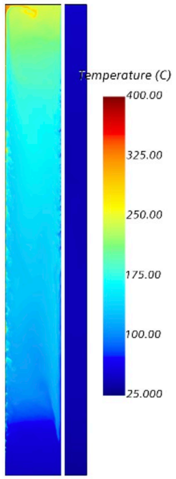


LES unit cell model

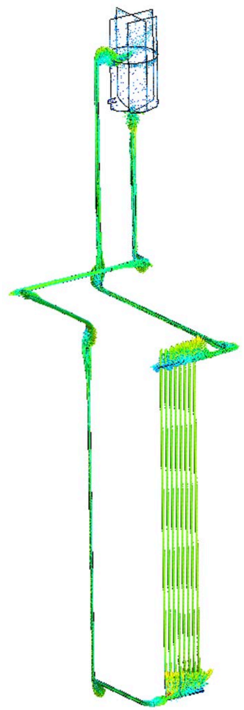
Top view



Side view



Full system model

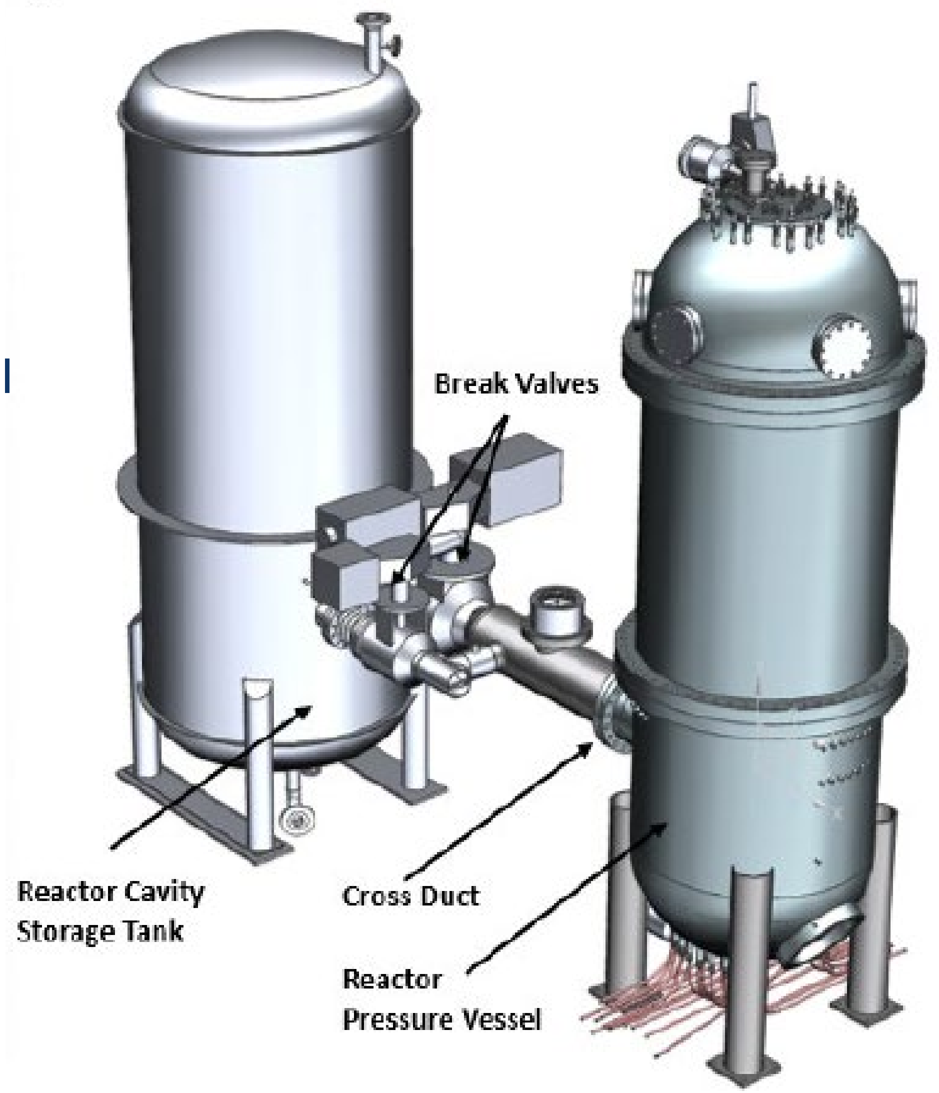


Content

- ART-GCR DoE Program Overview
- NSTF Facility Overview
- NSTF M&S and Validation Efforts
- HTTF Facility Overview
- HTTF Benchmark

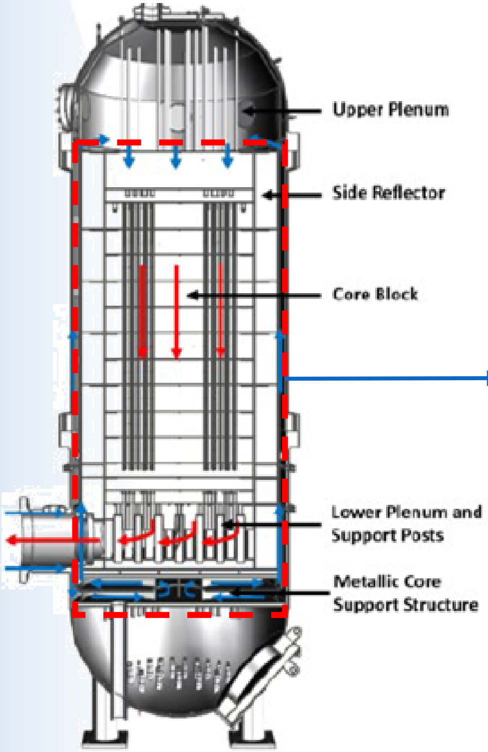
OSU High Temperature Test Facility

- Integral test facility
- Provides data for system code validation
- Primarily designed to model the DCC transient
  - Variety of break size and location
  - Four distinct phases
  - Reactor Cavity Cooling System as boundary condition
- Other scenarios can be examined: PCC and Normal operation
  - Working fluids: Helium and Nitrogen
- Reference design: MHTGR
- Facility Scaling
  - 1/4 length scale
  - 1/4 diameter scale
  - 1/8 pressure scale (0.8 MPa)
  - Prototypical temperatures (Tmax =1400ºC, Tin=259˚C, Tout=687˚C)
  - Electrically Heated, Power ~2.2 MW
- Operates under NQA-1 program

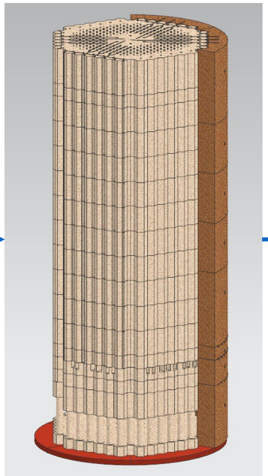


OSU HTTF

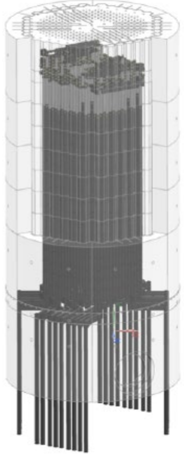
RPV & Flow Path

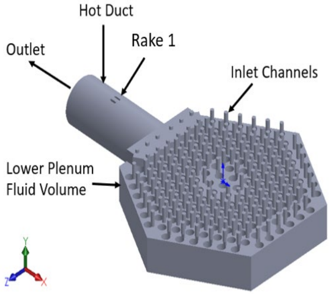


Core stack, lower plenum, lower, upper and side reflectors



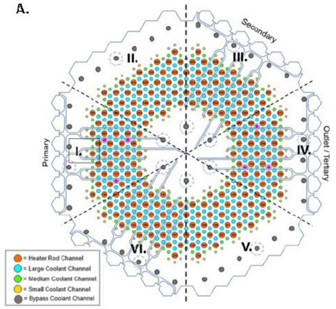
Heaters distribution

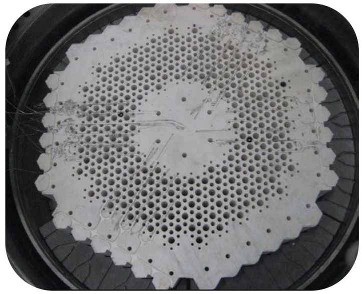




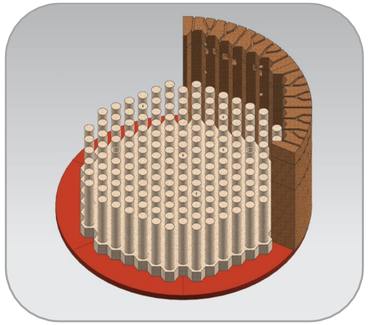
Upper Plenum

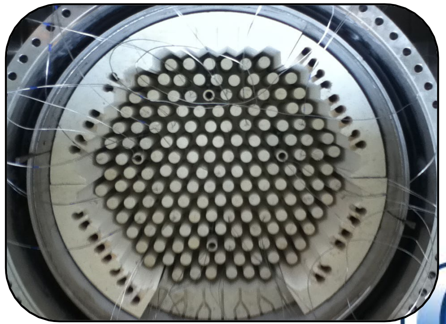
Core Block





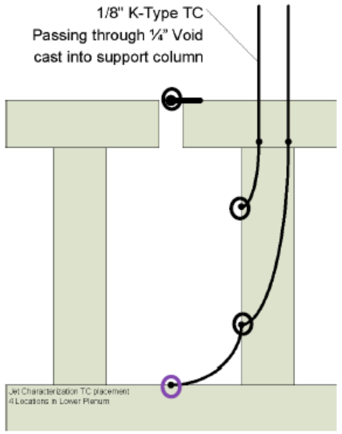
Lower Plenum



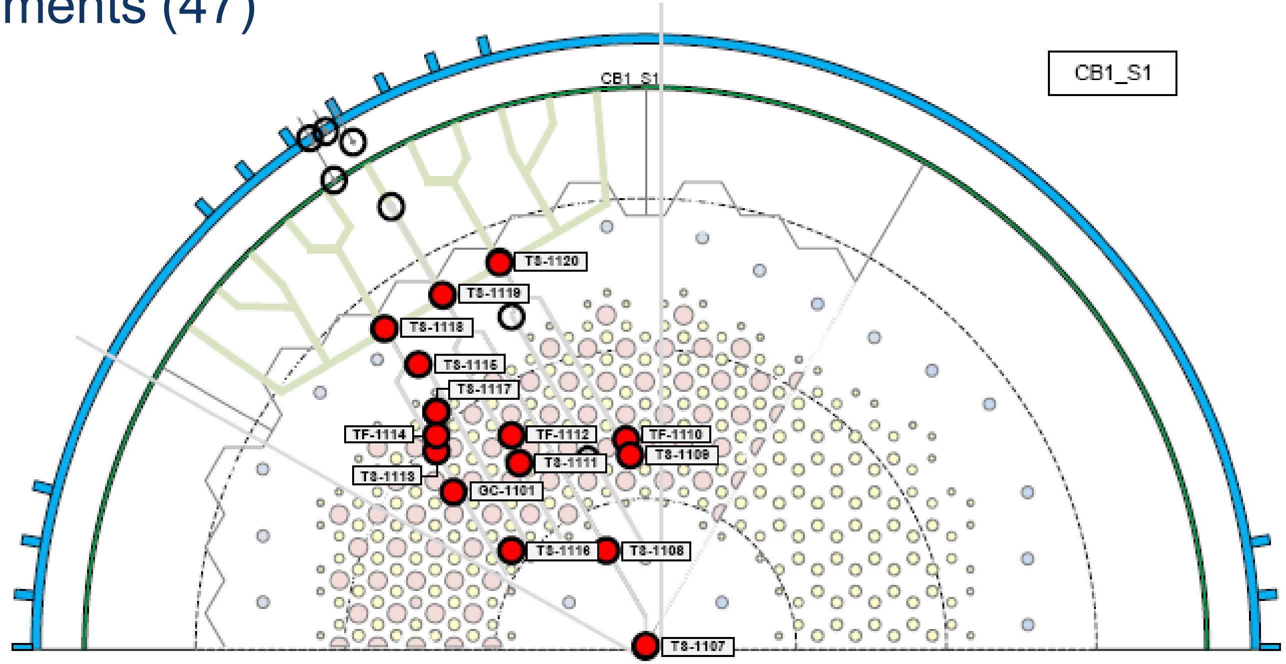


HTTF RPV Internals

- HTTF has ~429 sensors that can be used for matrix testing
- Type K, R thermocouples (340)
- Pressure Transmitters, Voltage Taps, Mass flow meters
- Gas Concentration Instruments (47)
- Data Acquisition System



LP, instrumented post TCs locations



Core block, TCs and GCs locations: TF – fluid, TS-solid thermocouple, GC – Gas Concentration

HTTF – Tests Performed

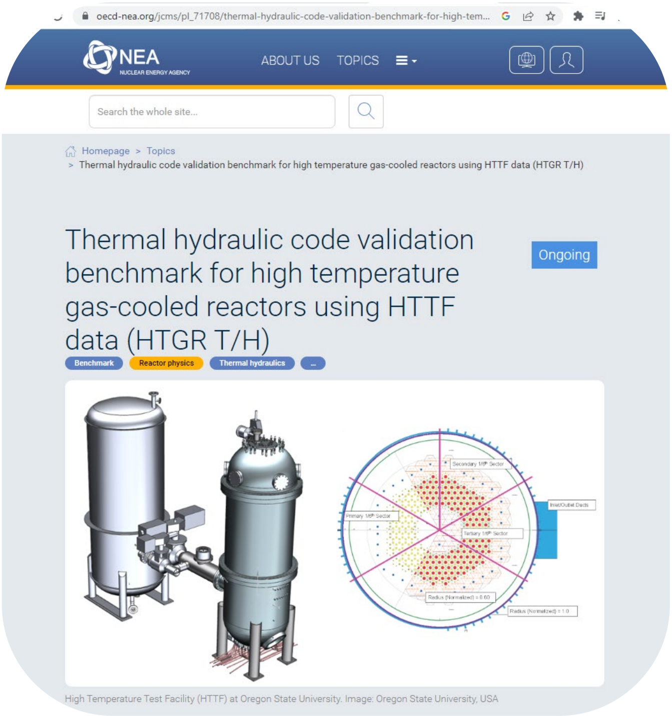
Test #	Procedure #	Test title	Phenomena
1	PG-01	Pre-Operation	Characterization
2	PG-02	Circulator and System Form Loss Characterization	Characterization
3	PG-06	Facility Gas Conditioning	Characterization
4	PG-07A	Primary Loop and RCST Volume Determination	Characterization
5	PG-08	Break Valve Characterization	Characterization
6	PG-09	Steam Generator Secondary Side Volume Determination	Characterization
7	PG-21	Lock Exchange Flow and Diffusion Test with 500°C average Gas Temp	DCC
8	PG-22	Lock Exchange Flow and Diffusion Test with 125°C average Gas Temp	DCC
9	PG-23	Lock Exchange Flow and Diffusion Test with 375°C average Gas Temp	DCC
10	PG-24	Lock Exchange Flow and Diffusion Test with 250°C average Gas Temp	DCC
11	PG-26	Low Power (<350kW) Double Ended Inlet-Outlet Crossover Duct Break, 2 Heaters	DCC
12	PG-27	Low Power (<350kW) Complete Loss of Flow, 2 Heaters	PCC
13	PG-28	Low Power (<350kW) Lower Plenum Mixing	Mixing
14	PG-29	Low Power (<350kW) Double Ended Inlet-Outlet Crossover Duct Break, Hybrid Heater	DCC
15	PG-30	Low Power (<350kW) Lower Plenum Mixing, Constant Temperature	Mixing
16	PG-31	Low Power (<350kW) Pressure Vessel Bottom Break with Restored Forced Convection Cooling	DCC
17	PG-32	Low Power (<350kW) Asymmetric Core Heatup	Heatup
18	PG-33	Zero Power Long Term Cooldown	Cooldown
19	PG-34	Low Power (<350kW) Asymmetric Core Heatup Full Hybrid Heater	Heatup
20	PG-35	Low Power (<350kW) Zero Power Crossover Duct Exchange Flow and Diffusion	DCC

Content

- Program Overview
- NSTF Facility Overview
- NSTF M&S and Validation Efforts
- HTTF Facility Overview
- HTTF Benchmark

Benchmark Information

- https://www.oecd-nea.org/jcms/pl_71708/thermal-hydraulic-code-validation-benchmark-for-high-temperature-gas-cooled-reactors-using-httf-data-htgr-t/h
- Code-to-code and code-to-data thermal-hydraulics code validation benchmark using available HTTF data
- Three exercises
  - Each exercise will include three problems
  - Three different code types, system codes (SYS), CFD codes, and system-to-CFD code couplings (COU)



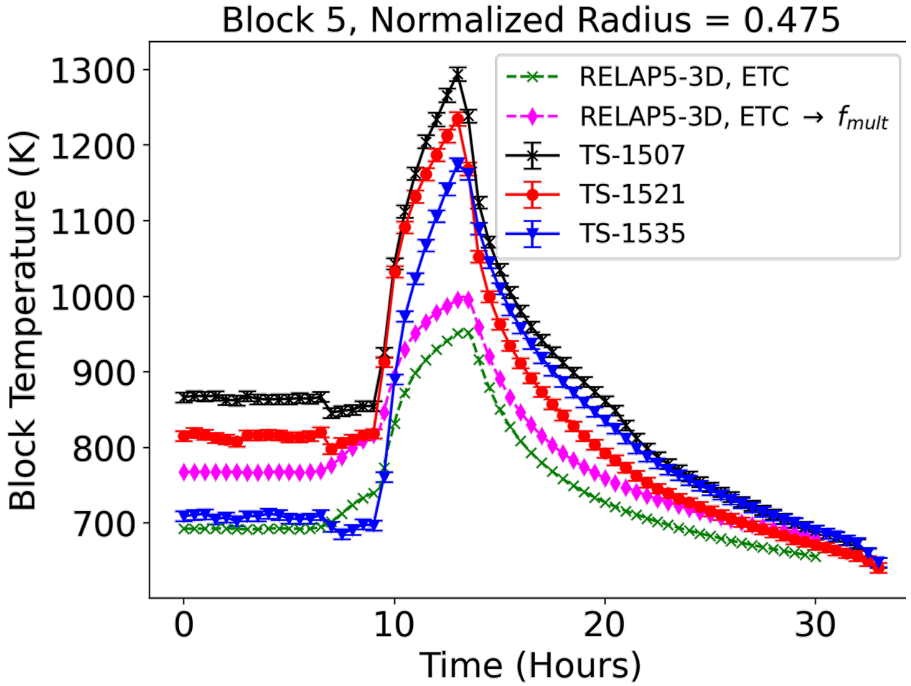
Mid 2022

Mid - End of 2025

	t0												t0 + 1 Year												t0 + 2 Years											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Draft Specifications																																				
Computations																																				
Exercise 1																																				
Exercise 2																																				
Exercise 3																																				
Final Publication																																				

PG-27 transient modeling

- Used conditions at 60 hours as t=0
- Transient temperature rise is always under-predicted
  - Under-predicted by 28-48%
- Peak temperatures are too low, even in locations where initial temperatures were too high
- Uncertainty in the heat capacity of the blocks is relatively low, so heat capacity is not the driving factor
- Temperature drop from 5-10 hours is likely due to increase in coolant flow rate in that time period. We do not model that flow increase

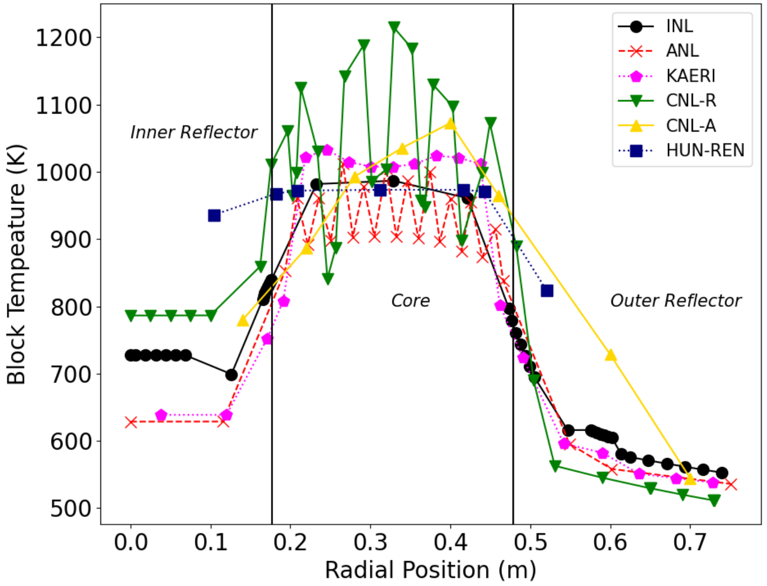


Measured|Standalone ETC|ETC + friction calibration temperature rise

	Inner Ring	Middle Ring	Outer Ring
Block 7	480|305|327	552|324|232	505|300|272
Block 5	487|297|317	504|306|317	453|263|232
Block 3	424|284|304	426|286|295	322|232|202

Benchmark results help understand code performance for gas-cooled reactors

- Code-to-code comparison: comparable predictions of behavior in the core but significantly different temperatures in the inner reflector
- international collaboration: United States, Canada, South Korea, and Hungary



Comparison of core ceramic block temperatures at the core midplane in HTTF during a full-power steady state as calculated by several institutions

HTGR T/H Benchmark Problem 2, Exercise 1A
Participants: Robert F. Kile, Aaron S. Epiney (Idaho National Laboratory), Thanh Hua, Ling Zou (Argonne National Laboratory), Sung Nam Lee (Korea Atomic Energy Research Institute), Geoff Waddington, Tariq Jafri, Xianmin Huang (Canadian Nuclear Laboratories), Zsombor Bali, Gustáv Mayer (HUN-REN Centre for Energy Research)

29

Conclusions

- The NSTF (Natural Convection Shutdown Heat Removal Test Facility) and HTTF (High Temperature Test Facility) play crucial roles in validating software for high temperature gas cooled SMRs.
  - NQA-1 qualified licensing data for industry.
  - 38 accepted tests for NSTF and 20 for HTTF.
  - Initial validation efforts for CFD and system codes.
- More data are available trough the NEUP program and the other branches of the ART-GCR program.
- Synergies between the GIF VHTR-CMVB NEXSHARE and NEA Benchmarks.

Acknowledgments

- **INL**
  - Gerhard Strydom, Ryan H. Stewart, Zachary M. Prince, Vincent M. Laboure, Javier Ortensi, Sebastian Schunert, Aaron S. Epiney, Sunming Qin, Cody J Perman, Joshua Hanopy, Ishita Trivedi, Robert Kile, Mustafa K. Jaradat, Jacob A. Hirschhorn, Ryan T. Sweet, Yifeng Che, Joshua J. Cogliati
- **ANL**
  - Darius D. Lisowski, Qiuping Lv, Matt Jasica, Mitch Farmer, Art Vik, John Woodford, Ooi, Zhiee Jhia, Jun Fang, Emily Shemon.

GAS-COOLED REACTOR

ADVANCED REACTOR TECHNOLOGIES PROGRAM

Thank you for your attention, Questions?

Paolo Balestra

paolo.balestra@inl.gov / +1 208-526-4532

U.S. DEPARTMENT OF ENERGY