INL/MIS-25-86359-Revision-0

DOE ART-GCR Program Overview

July 2024

Changing the World's Energy Future

Gerhard Strydom

Idaho National Laboratory

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GAS-COOLED REACTOR
ADVANCED REACTOR TECHNOLOGIES PROGRAM

July 29, 2025

DOE ART-GCR Program Overview

INL/MIS-25-86359

Gerhard Strydom, PhD

Co-National Technical Director: ART-GCR (INL)

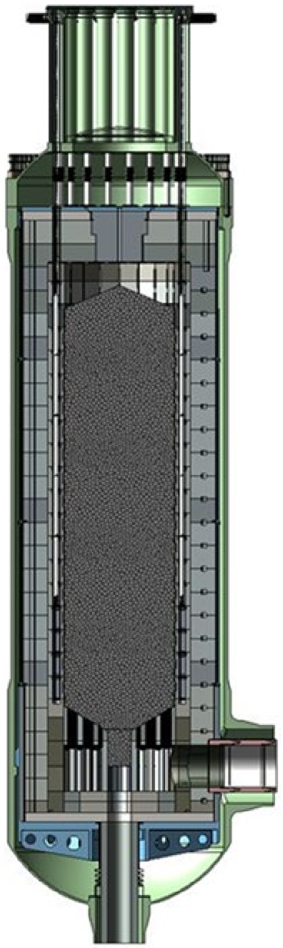
DOE ART-GCR Review Meeting

Hybrid Meeting at INL

July 29–30, 2025

ART-GCR Program Review: Goals

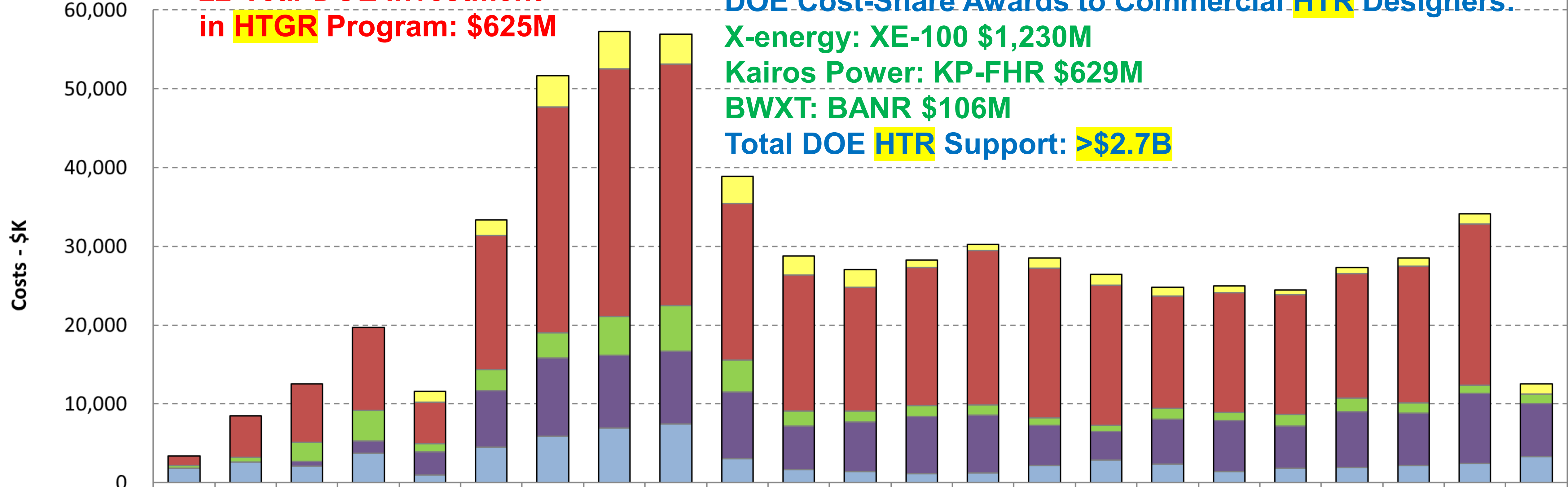
- Provide overview of Advanced Reactor Technologies Gas-Cooled Reactor (ART-GCR) and graphite programs objectives, status, and activities.
- Identify research areas and outcomes that will benefit stakeholders and clients (high-temperature gas-cooled reactor [HTGR] designers, suppliers, regulators; Department of Energy Office of Nuclear Energy [DOE-NE]; etc.).
- Identify remaining R&D gaps and future needs.



DOE Investment in High Temperature Reactors: >$2.7B

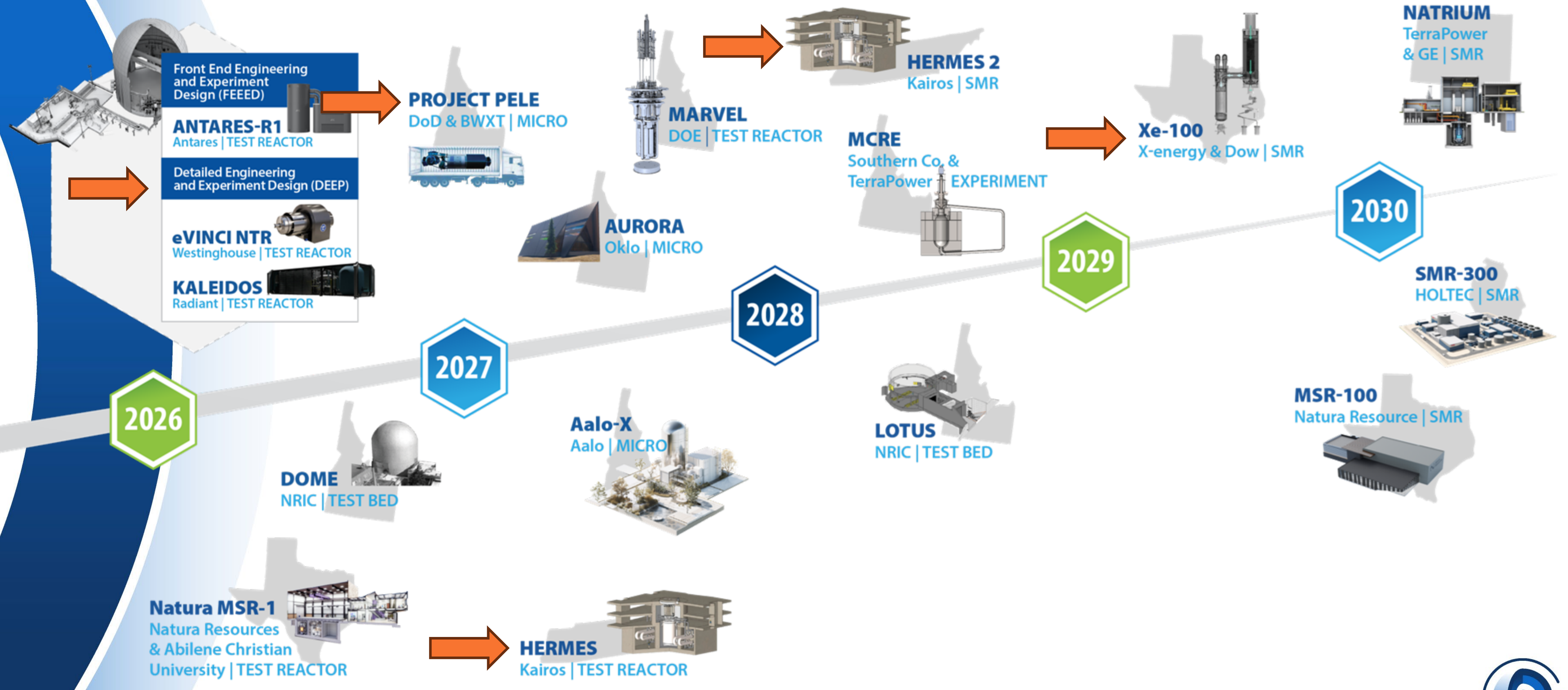
22-Year DOE Investment in HTGR Program: $625M

DOE Cost-Share Awards to Commercial HTR Designers:
X-energy: XE-100 $1,230M
Kairos Power: KP-FHR $629M
BWXT: BANR $106M
Total DOE HTR Support: >$2.7B

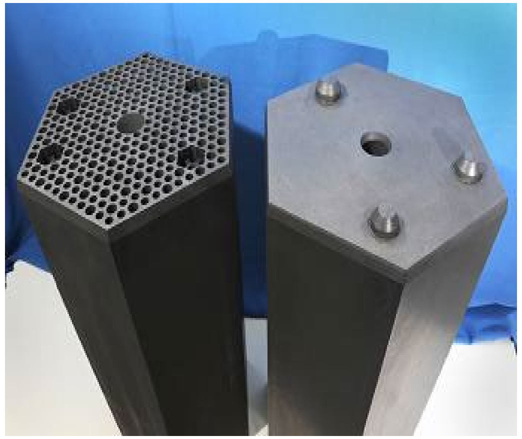


	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25
PM/Campaign Mgmt	0	0	0	0	1,404	1,952	3,903	4,727	3,812	3,460	2,473	2,252	940	751	1,265	1,431	1,149	863	545	771	983	1,279	1,285
Fuels	1,256	5,270	7,426	10,542	5,241	17,038	28,681	31,476	30,612	19,863	17,217	15,778	17,603	19,597	18,996	17,811	14,243	15,140	15,206	15,786	17,423	20,536	0
Metals	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	1,727	1,277	1,025	1,200
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	7,114	6,587	8,848	6,720
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	1,883	2,207	2,460	3,300
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	27,281	28,477	34,148	12,505

Test and Demonstration Projects Under Development



DOE ART-GCR Program Areas



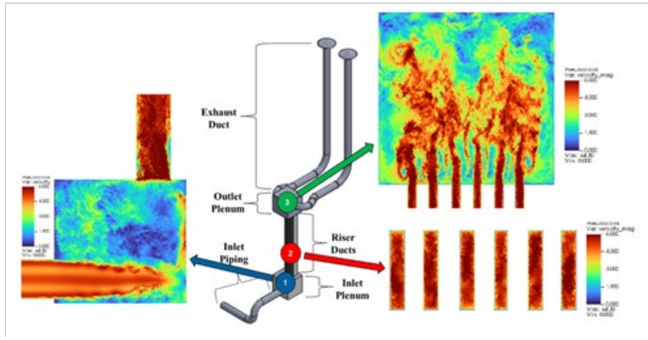
Graphite qualification

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

Metals

- Achieve American Society of Mechanical Engineers (ASME) codification of alloys and design methods for high-temperature use in pressure vessels, heat exchangers, and other primary circuit components.

Experimental and simulation methods



- Develop prismatic and pebble-bed HTGR core analysis methods.
- Verify and validate codes utilizing domestic and international experimental datasets, code-to-code benchmarks, and uncertainty analyses.

ART-GCR Program: Graphite

Capsule Irradiation
- HDG-1 Irr
- HDG-2 Design
- HDG-2 Sample order

PIE
- AGC-4 Disassembly
- Sample Transport
- AGC-4 PIE
- Irradiation Behavior

50% to 65% of program funding

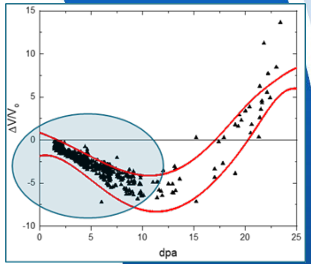
Characterization
- Baseline
- Modeling
- Licensing ASME
- HT Mech Testing
- ASTM Dev
- Irradiation Damage
- Oxidation
- Graphite Microstructur
- Oxidation Properties
- Carbon Lab Upgrade
- Oxidation Resistance
- Split Disc
- Thermal Creep

Data
- NDMAS
- Graphite Analysis Tool
- University Collaborations
- Vendor Collaboration
- IAEA/EDF Collaboration
- N. Graphite Specification
- Supply Chain

ASME
- Irrdiation Response
- Design Rules
- Molten Salt
- Oxidation
- Definition of Failure
- RIM
- Composites

ART-GCR Program: Graphite

Will Windes (INL)
AGC (Graphite) Lead



Completed Advanced Graphite Creep (AGC)-4 post-irradiation examination (PIE)

- Data package report containing all AGC-4 results will be published in August.

Completed high-dose graphite (HDG)-2 design (almost there…)

- Several lessons learned from AGC-4 and HDG-1 have been incorporated.
- Estimate much finer temperature control (+/- 35℃).
- Added ET-10 grade (Kairos Hermes) and ceramic composites to planned tests.

Completed Vendor Irradiation Capsule (VIC) design

- Irradiation capsule specifically designed for commercial HTR vendors.
- Latest VIC meeting (June 2025) engaged with several manufacturers and designers who expressed interest in qualifying their graphite and composite materials.

ASTM/ASME progress

- Wrapping up initial Design Code rule changes with several papers on probabilistic design challenges.
- Developing new graphite wear testing methods in inert helium and molten salt, and at high temperatures.

ART-GCR Program: HTGR Modeling Methods

David Reger (INL)
Methods, Modeling, and Validation Lead

US-Japan BLC-CNWG

NEA Nuclear Energy Agency

GEN IV International Forum
Expertise | Collaboration | Excellence

IAEA International Atomic Energy Agency

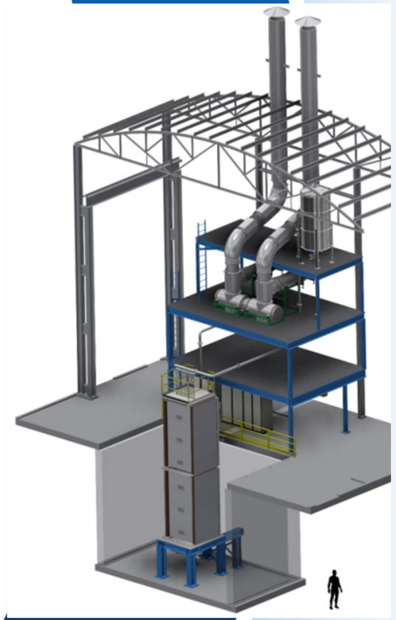
FUEL
GRAPHITE
MATERIALS

Validation Data
Modeling Insight

Validation Data
International Visibility
Expertise

GAS-COOLED REACTOR
ADVANCED REACTOR TECHNOLOGIES PROGRAM

METHODS



Methodologies
Expertise
Validation Data

Code Development
Code Validation

Models Distribution

NRIC National Reactor Innovation Center

NEAMS
NUCLEAR ENERGY ADVANCED MODELING & SIMULATION PROGRAM

Expertise
Validation Data

U.S. REACTOR VENDORS

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

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

ART-GCR Program: HTGR Modeling Methods

- International collaborations provide valuable data for Nuclear Energy Advanced Modeling and Simulation (NEAMS)-developed HTGR simulation codes: NEXSHARE data platform (International Atomic Energy Agency [IAEA]),* bilateral agreement with the Japan Atomic Energy Agency (JAEA) Civil Nuclear Working Group (CNWG),** Generation-IV Forum (GIF) Computational Validation Methods Benchmarks (CMVB), Organization for Economic Cooperation and Development (OECD) / Nuclear Energy Agency (NEA) benchmarks.***
    - Updated models for High Temperature Test Reactor loss of forced cooling (LOFC) experiments as part of NEA benchmark—shared with DOE by the Nuclear Regulatory Commission (NRC). (*The only prismatic HTGR LOFC data worldwide!*)
    - GIF: Idaho National Laboratory (INL) leads two out of the five work packages (WPs) and collaborates in all WPs, where unique neutronics, source term, and thermal fluid experimental datasets are being shared.
- Domestic datasets being used for validation:
    - Compared results for NEA High Temperature Test Facility (HTTF) benchmark to validate system and computational fluid dynamics (CFD) codes.
    - Nearing completion of reactor cavity cooling system (RCCS) experimental program at Natural Convection Shutdown Heat-Removal Test Facility (NSTF) at Argonne National Laboratory.

Outcome: *Validated high-fidelity, modern codes that industry and NRC can use for comparisons against legacy tools for safety, margin, and uncertainty assessments.*

* https://nucleus.iaea.org/sites/connect/NEXPublic/SitePages/Home.aspx
** https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_128404.pdf
*** 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

ART-GCR Program: Metals

Mike McMurtrey (INL)
Metals Lead

Improve and simplify high-temperature design methodology for advanced reactor developers

- Qualify and incorporate Alloy 709 into ASME Code as high-temperature construction material for sodium-cooled fast reactor (SFR), HTGR, and molten-salt reactor (MSR) applications with 100,000-hour Code Case by 2026.

- Continuing development of new ASME Class B rules and limited deformation data generation for all Division 5 Class A materials.

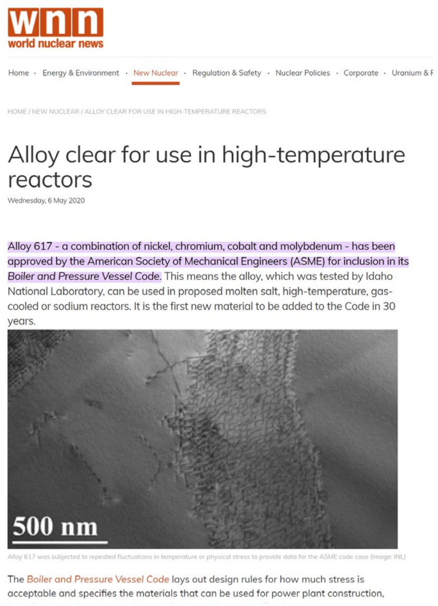
- Develop and implement high-temperature design methodology needed for advanced reactor designs into the ASME Code to improve and simplify the design process:
  - Continued expansion of Class B to include additional materials/welding options.
  - Further development of alternative creep-fatigue design methodologies.

Tensile Tests

Future Program Focus Areas to Enable HTGR Deployment: Materials

Codification of graphite and metallic alloys

- The data we generate in ART-GCR (baseline, irradiation, mechanical properties, etc.) is useful to industry in licensing discussions, but the *really* useful outcome occurs when we codify existing and new materials into ASME or another authority. HTGR developers can then use these materials directly (e.g., as we did for Alloy 617). This takes many years of collecting data and building consensus in the code committees on methodology.



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HOME / NEW NUCLEAR / ALLOY CLEAR FOR USE IN HIGH-TEMPERATURE REACTORS

Alloy clear for use in high-temperature reactors

Wednesday, 6 May 2020

Alloy 617 - a combination of nickel, chromium, cobalt and molybdenum - has been approved by the American Society of Mechanical Engineers (ASME) for inclusion in its *Boiler and Pressure Vessel Code.* This means the alloy, which was tested by Idaho National Laboratory, can be used in proposed molten salt, high-temperature, gas-cooled or sodium reactors. It is the first new material to be added to the Code in 30 years.

Alloy 617 was subjected to repeated fluctuations in temperature or physical stress to provide data for the ASME code case (Image: INL)

The *Boiler and Pressure Vessel Code* lays out design rules for how much stress is acceptable and specifies the materials that can be used for power plant construction,

Capabilities at National Labs

- We should continue to support creating and preserving the capabilities required to generate data for new materials (e.g., the Graphite "Vendor Irradiation Capsule). In the larger context, unique and very expensive facilities such as Advanced Test Reactor (ATR) and the Materials and Fuels Complex (MFC) hot cells at INL are national assets that our program used, and will use, extensively. They are examples of facilities that no commercial designer can afford to build, maintain, and staff.

Future Program Focus Areas to Enable HTGR Deployment: Methods

Harvesting/leveraging HTGR demonstration projects

- Demonstration and Operation of Microreactor Experiments (DOME): The first three projects funded to be tested/demonstrated in DOME are all tristructural isotropic (TRISO)-fueled systems, and are at least partly taxpayer funded. The startup testing, first critical, and operational test data are very valuable for the HTGR community and could be used to design code validation benchmarks for reactor developers and the NRC.

Harvesting international and Nuclear Energy University Program (NEUP) data

- We can perform *verification* of new simulation tools developed by the NEAMS program via relatively cheap code-to-code benchmarks, but *validation* benchmarks are much more critical and valuable (and expensive), since code performance is compared with actual reactor or experimental data sets.
- We should continue to assess international data sets (IAEA, GIF) and the domestic NEUP landscape for HTGR-relevant projects that we can use for validation.

ART-GCR Leadership

Matt Hahn (DOE-NE)
Federal Program Manager

Gerhard Strydom (INL)
National Technical Director

Travis Mitchell (INL)
Program Manager

Will Windes (INL)
AGC (Graphite) Lead

David Reger (INL)
Methods, Modeling, and Validation Lead

Mike McMurtrey (INL)
Metals Lead

Courtney Otani (INL)
NDMAS and Gen-IV Handbook Lead

Thank You

Gerhard Strydom

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