U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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Nuclear Energy University Program (NEUP) Fiscal Year 2022 Annual Planning Webinar Advanced Reactor Materials (Subtopics IRP-RC-1)

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Office of Nuclear Energy
U.S. Department of Energy
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Advanced Reactor Technologies (ART) Program

Mission:

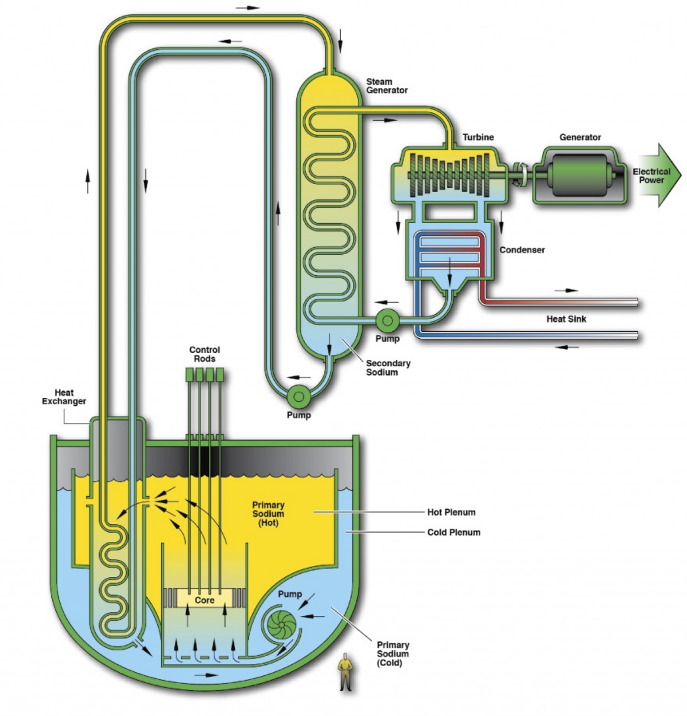
Identify and resolve the technical challenges to enable transition of advanced non-LWR reactor technologies and systems to support **detailed design, regulatory review and deployment** by the early 2030's

Objectives:

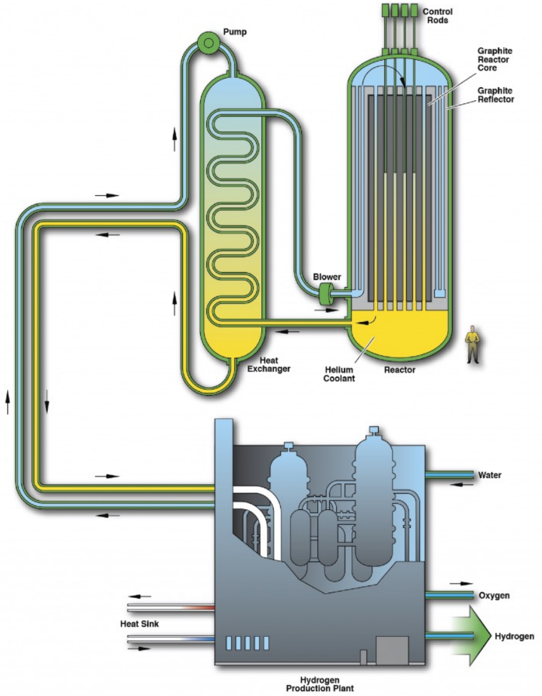
- Conduct focused research and development to **reduce technical barriers to deployment** of advanced nuclear energy systems
- Develop technologies that can enable new concepts and designs to achieve enhanced **affordability, safety, sustainability** and **flexibility** of use
- **Collaborate with industry** to identify and conduct essential research to reduce technical risk associated with advanced reactor technologies
- **Sustain technical expertise and capabilities** within **national laboratories** and **universities** to perform needed research
- Engage with Standards Developing Organizations (SDO's) to **address gaps in codes and standards** to support advanced reactor designs

ART Program Includes Advanced Reactor Materials R&D Activities

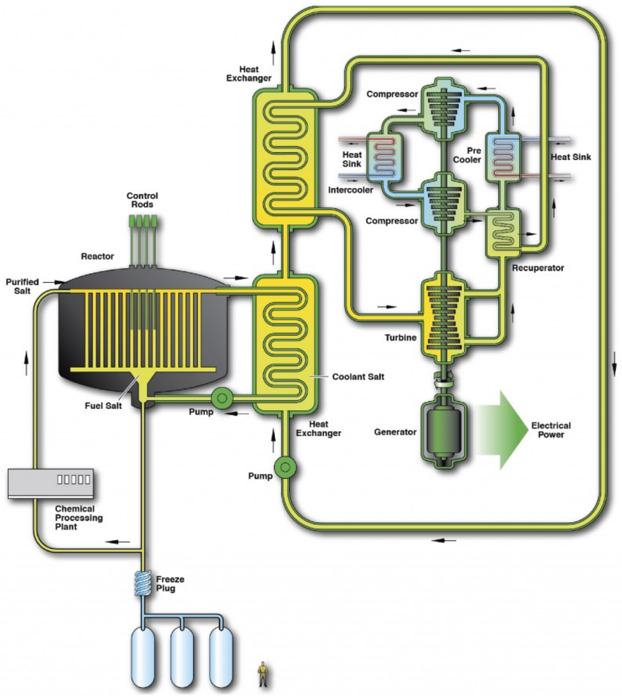
- Development and qualification of graphite and advanced alloys for advanced reactor systems
- Three advanced reactor systems to watch by 2030



Sodium Fast Reactor



Very High Temperature Reactor



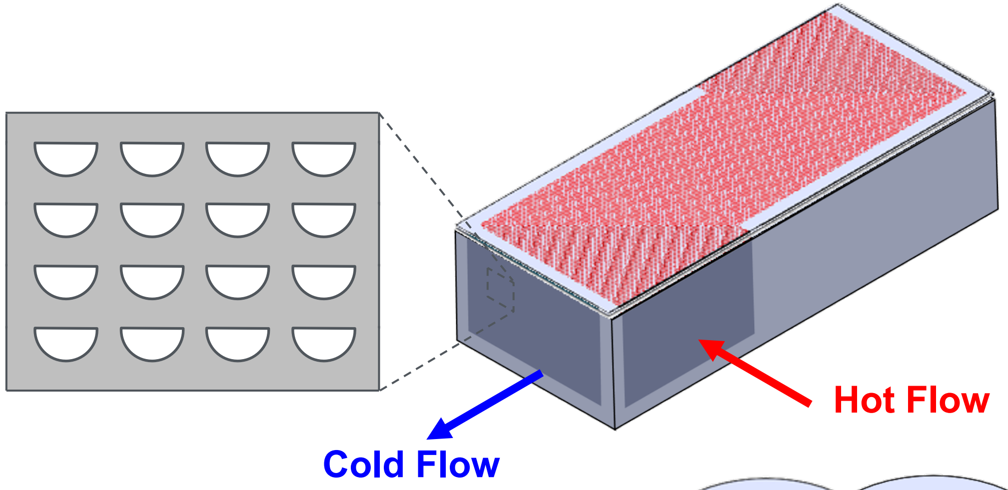
Molten Salt Reactor

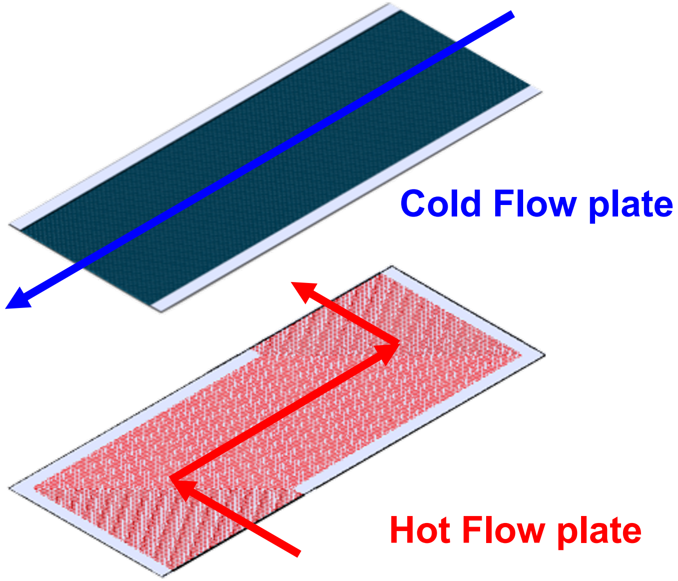
FY22 Integrated Research Project (IRP)

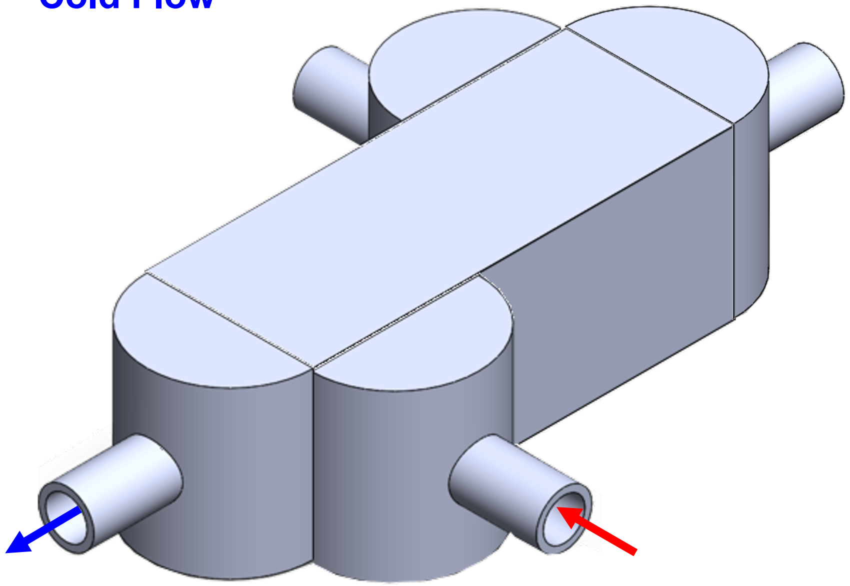
- IRP-RC-1: Development of Enabling Fabrication Technology for Compact Heat Exchangers for Advanced Reactors
  - Compact heat exchangers (CHXs) offer the potential for significant improvement in efficiency and reduction in cost for advanced reactors systems
  - Their use is appropriate with all coolants currently being investigated for such systems by advanced reactor developers (gas, liquid metals & molten salt)
  - Also appropriate for supercritical CO_2 for advanced energy conversion systems and even water for small modular or large integrated PWRs

Fabrication of Microchannel CHX

- **Photochemical etching**
- **Stacking**
- **Diffusion bonding**





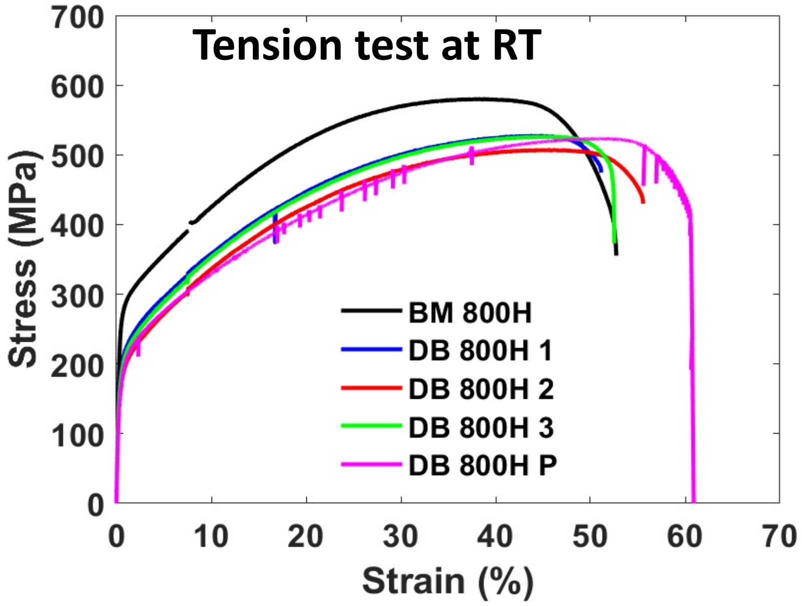


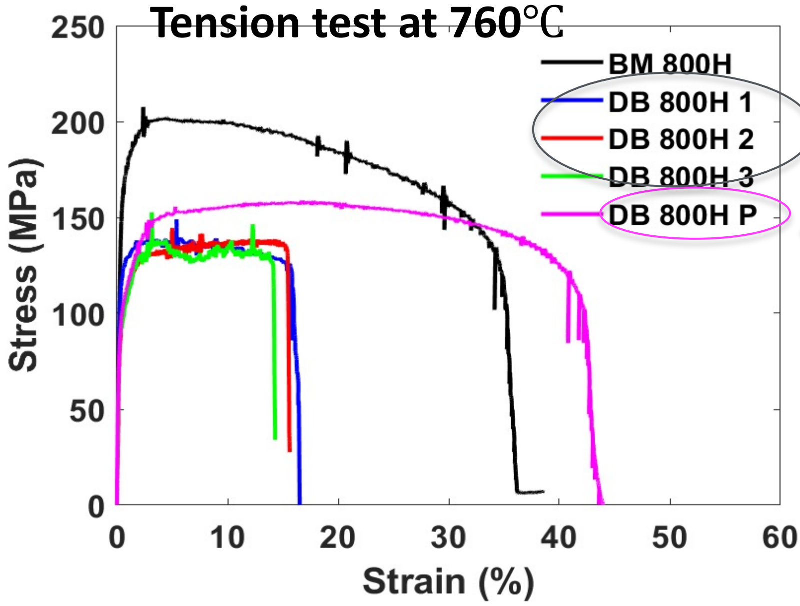
Animation courtesy of Allen, U Michigan

Technical Issues

- Microchannel CHXs fabricated by the diffusion bonding of multiple layers of etched stainless steel sheets, 316L, have been successfully commercialized for applications in petrochemical processing
- Efforts to apply this technology to fabrication of nuclear components for operations at 750ºC or above from high temperature alloys have proven to be challenging
  - Creep and cyclic properties of multi-layer stacks of diffusion bonded Alloy 800H or Alloy 617 produced to date have been significantly degraded compared to their wrought counterparts
  - Failure tends to occur at the bond-lines with limited ductility
  - These properties are critical for high temperature reactor operations
  - Current acceptance criteria based on tensile properties and microstructural characterization are not able to identify poor-performing diffusion-bonded interfaces in terms of creep and cyclic properties, particularly for the long design lifetimes of these microchannel CHXs

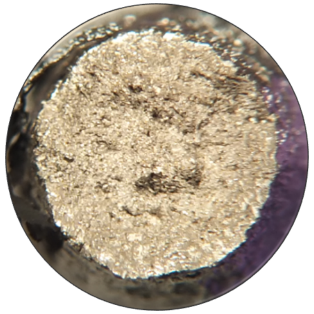
Results from FY17 IRP Project, “Advancements towards ASME nuclear code case for compact heat exchangers”





Tensile load perpendicular to bond lines

Tensile load parallel to bond lines



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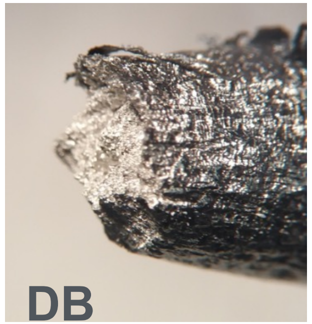
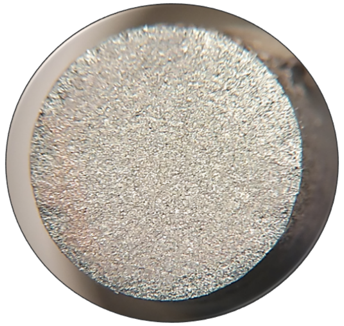
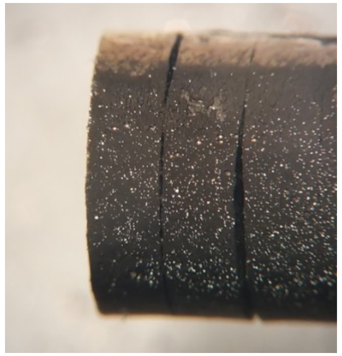


Ductile Tensile Failure





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Debonding at bond lines

- Test specimens fabricated from Alloy 800H diffusion bonded stack

Results courtesy of Hassan, NCSU

IRP Scope

- Proposals are sought for an integrated research project (IRP) that will determine the scientific basis of process/property relationships for successful diffusion bonding of high temperature alloys that are qualified or being qualified for nuclear construction in Section III Division 5 of the ASME Boiler and Pressure Vessel Code

IRP Goals

- Improvement of creep, fatigue, and creep-fatigue properties of diffusion-bonded materials for CHXs to near-wrought values
- Develop predictive capability that will dramatically decrease the iterative development of processing pathways for additional high temperature alloys of interest
- Develop acceptance criteria for diffusion bonding processes that adequately reflect the performance metrics for nuclear applications for incorporation in nuclear Codes and Standards
- Validate the acceptance criteria by the testing of a diffusion-bonded structural component under creep and cyclic loading to provide evidence of the improved bonding technique and the appropriateness of the acceptance criteria
  - The test article will need to be fabricated using the optimized diffusion bonding process developed as part of the IRP and incorporate microchannels typical of a CHX
  - A simplified component for testing is acceptable if the objectives of the demonstration can be achieved

Benefits, Capabilities and Collaboration

- Establishing an IRP to investigate the issues described in this Call would significantly augment the existing ART programmatic content and address a recognized need in a very useful manner
- The university community has well established strengths that directly address the topics identified (structure-properties relations, characterization, materials joining, process modeling, high temperature material behaviors, mechanical properties testing, etc.)
- With industry and Federally Funded Research and Development Centers (FFRDCs), the universities could form a powerful team that could make a great deal of progress towards resolving these issues in a three-year period
- Potential for interactions with existing CHX manufacturers is strong and would be very valuable to the overall IRP effort

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