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

Clean. Reliable. Nuclear.

GAIN-NEI
Fast Reactor Working Group Workshop

Argonne National Laboratory (ANL)

July 9-10, 2019

Brian K. Robinson

Office Nuclear Reactor Deployment

Advanced Reactor Technologies Program

Deputy Assistant Secretary for Reactor Fleet and Advanced Reactor Deployment (NE-5) - *Mission & Objectives*

- **Vision –** Be a catalyst for the commercialization of NE-sponsored research, development and demonstration products
- **Mission –** Integrate NE's research investments to achieve a productive and balanced portfolio of competitive and crosscutting RD&D and research infrastructure to enable expansion of the U.S. commercial nuclear industry
- **Objectives**
  - Full and effective integration of NE RD&D planning, execution and oversight
  - Systematic management of NE investments in research capabilities
  - Alignment of NE's RD&D programs with industry-identified technical and regulatory needs
  - Accelerate the introduction of innovative technologies into the marketplace (GAIN)

Office of Advanced Reactor Technologies - *Mission & Objectives*

Mission: Develop new and advanced reactor designs and technologies, that advance the state of reactor technology to improve competitiveness and support meeting Nation's energy, environmental, and national security goals. Conduct R&D on advanced technologies such as small modular reactors, fast reactors and high temperature reactors using helium or liquid salt coolants.

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
- 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
- Collaborate with industry to identify and conduct essential research to reduce technical risk associated with advanced reactor technologies

Office of Nuclear Reactor Deployment

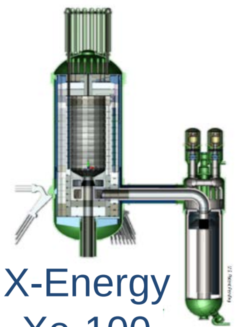
HEWD Proposed Appropriations

	FY 2019 Enacted	FY 2020 Request	HEWD Proposed
Reactor Concepts RD&D			
Advanced Small Modular Reactor R&D	100,000	10,000	100,000
Light Water Reactor Sustainability	47,000	30,150	55,000
Advanced Reactor Technologies	**111,500**	**75,000**	**105,000**
Versatile Advanced Test Reactor	65,000	100,000	65,000
Subtotal Reactor Concepts RD&D	323,500	215,150	325,000
Nuclear Energy Enabling Technologies			
Crosscutting Technology	50,000	17,400	45,000
Nuclear Energy Advanced Modeling and Simulation	31,000	30,000	40,000
Energy Innovation Hub for Modeling and Simulation	27,585	0	0
Nuclear Science User Facilities	44,000	27,600	40,000
Transformational Challenger Reactor	0	23,450	0
Subtotal NEET	152,585	98,450	125,000
Research and Development			
Integrated University Programs	5,000	0	5,000
STEP R&D	5,000	0	5,000
Total	**486,085**	**313,600**	**460,000**

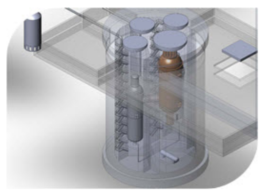
- **The House Energy and Water Development (HEWD) Appropriations Subcommittee bill proposed**
  - *$105,000,000 is for Advanced Reactor Technologies, of which $20,000,000 is for a new solicitation for at least two new public-private partnerships focused on advancing non-light water reactor designs towards demonstration phase, $25,000,000 is for MW-scale reactor research and development, $34,000,000 is for fuel and graphite qualification….*
- **The date for consideration by the full House has not been announced.**
- **The Senate has not announced a date for subcommittee markup.**

Examples: Advanced Reactor Industry Designs

Gas Reactors



X-Energy
Xe-100

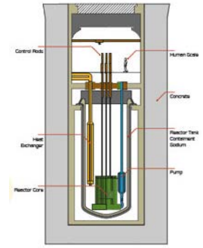


Framatome
SC-HTGR

Fast Reactors

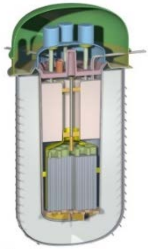
GE Hitachi
PRISM

TerraPower
TWR

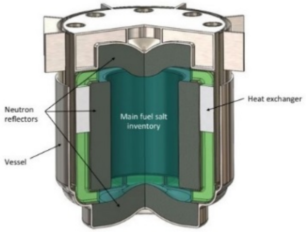


Advanced Reactor
Concepts LLC
ARC-100

Molten Salt Reactors

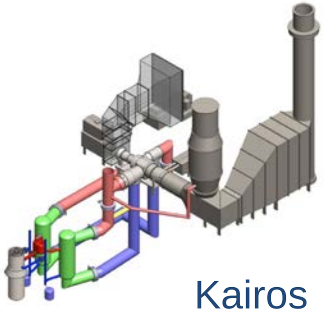


Terrestrial Energy
USA IMSR



TerraPower
MCFR

Elysium USA
MCSFR



Kairos
Power
UCB PB-
FHR

Office of Advanced Reactor Technologies
R&D Areas

Focus Areas:

- Fast Reactor Technologies
  - Demonstrate feasibility of advanced systems and component technologies
  - Methods and code validation to support design and licensing
  - Advanced alloy materials qualification for metal-cooled systems
- Gas Reactor Technologies
  - Advanced alloy and graphite materials qualification for high temperature gas-cooled systems
  - Scaled integral experiments to support design and licensing
  - TRISO-coated particle fuel development and qualification
- Molten Salt Reactor Technologies
  - Investigate fundamental salt properties
  - Materials, models, fuels and technologies for salt-cooled and salt-fueled reactors
- Cross-Cutting technologies
  - Advanced energy conversion (STEP)
  - Micro-reactors for remote applications

Office of Advanced Reactor Technologies
Completed & Planned Accomplishments

FY 2018 Accomplishments	FY 2019 Planned Accomplishments	FY 2020 Planned Accomplishments
Fast Reactor Technologies • Completed Mechanisms Engineering Test Loop (METL) • Continued modernization of U.S. fast reactor codes for potential licensing use • Developed external stakeholder access plan for legacy U.S. fast reactor operation and fuel testing databases • Continued ASME materials qualification efforts	• Initiate in-sodium testing of gear test assembly in METL and develop next experimental assembly • Continue to modernize and validate fast reactor safety codes for use in normal operation and transient analysis • Lead IAEA Coordinated Research Project on Fast Flux Test Facility Historical Safety Test Benchmark • Continue ASME material qualification efforts	• Continue in-sodium testing of industry-identified component experiments in METL. • Address NRC comments on historical metal fuel testing data qualification and complete the collection and qualification of historical data sets targeted by U.S. vendors. • Continue to modernize and validate fast reactor safety codes for use in normal operation and transient analyses. • Continue ASME material qualification efforts.
Gas Reactor Technologies • Continued advanced graphite creep (AGC) irradiations • Continued to develop methods and modeling capabilities • Established rupture properties and temperature limits for ASME code qualification of Alloy 617	• Resume computational activities including validation with experimental results and expanded analysis for severe accident heat removal • Continue graphite creep analysis • Continue ASME code qualification of Alloy 617 • Continue high-priority irradiation testing and examination of TRISO fuels.	• Continue experimental validation of models for normal operation and transient conditions. • Continue graphite irradiation and analysis. • Continue ASME code qualification of Alloy 617. • Continue high-priority irradiation testing and examination of TRISO fuels.
Molten Salt Reactor Technologies • Began to evaluate and develop salt chemistry instrumentation • Initiated fundamental salt chemistry investigations • Established a DOE salt chemistry database • Evaluated potential effects of volatiles • Developed the MSR modeling framework • Initiated materials qualification for structural components	• Continue development of chemical monitoring requirements, methods, and instrumentation • Define modeling framework for salt characterization • Continue fundamental salt chemistry investigations • Continue early qualification of materials for structural components	• Continue development of chemical monitoring requirements, methods, and instrumentation. • Establish modeling framework for salt characterization. Continue to collect fundamental data to understand fission product behavior in chloride salt-fueled systems. • Develop advanced instrumentation for monitoring fissile material inventory. • Investigate chemical control strategies.
Cross-Cutting Technologies • Identified use cases and requirements for micro reactor applications • Established sCO2 closed Brayton cycle (1MWe) test platform to support long-term R&D testing. • Develop a seal test rig for sCO2 power cycle.	• Complete technology roadmaps for micro-reactor applications • Develop heat exchanger design specification for coupling reactors to sCO2 power cycle • Continue work on printed circuit heat exchangers and intermediate heat exchanger alloys.	• Continue cross-cutting research and development R&D for micro-reactor applications. • Continue work on printed circuit heat exchangers, intermediate heat exchanger alloys and Brayton cycle plant analysis codes.

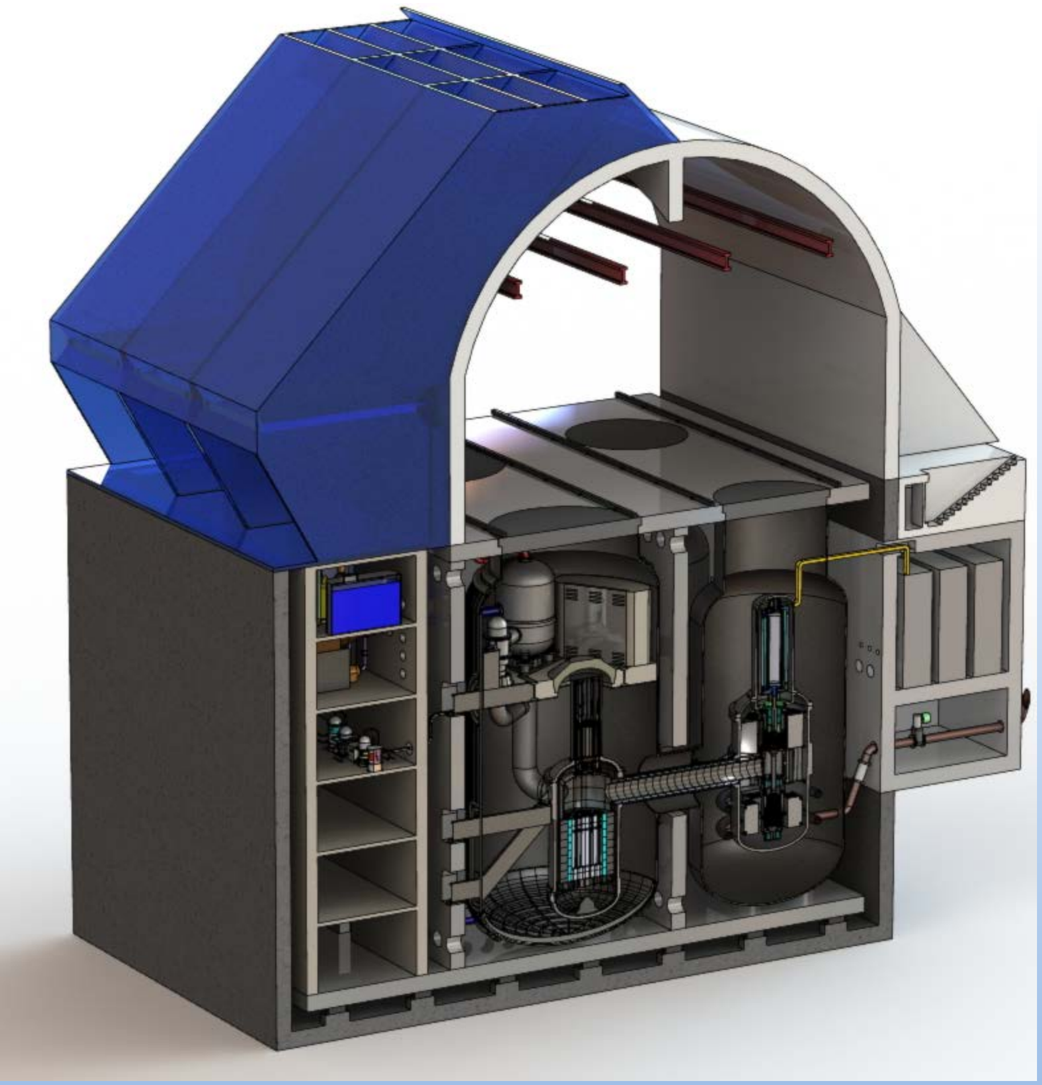
Questions?

Clean. **Reliable.** **Nuclear.**

Innovation is Key to Reviving Nuclear Power in U.S.

- **Power cost competitive with natural gas**
- **Compatibility with renewables**
- **Take advantage of technologies and materials from other industries**
- **Better use of nuclear fuel resources**
- **Greatly reduced waste**

EM² is a Modular, Gas-Cooled, "Convert and Burn", Fast Reactor



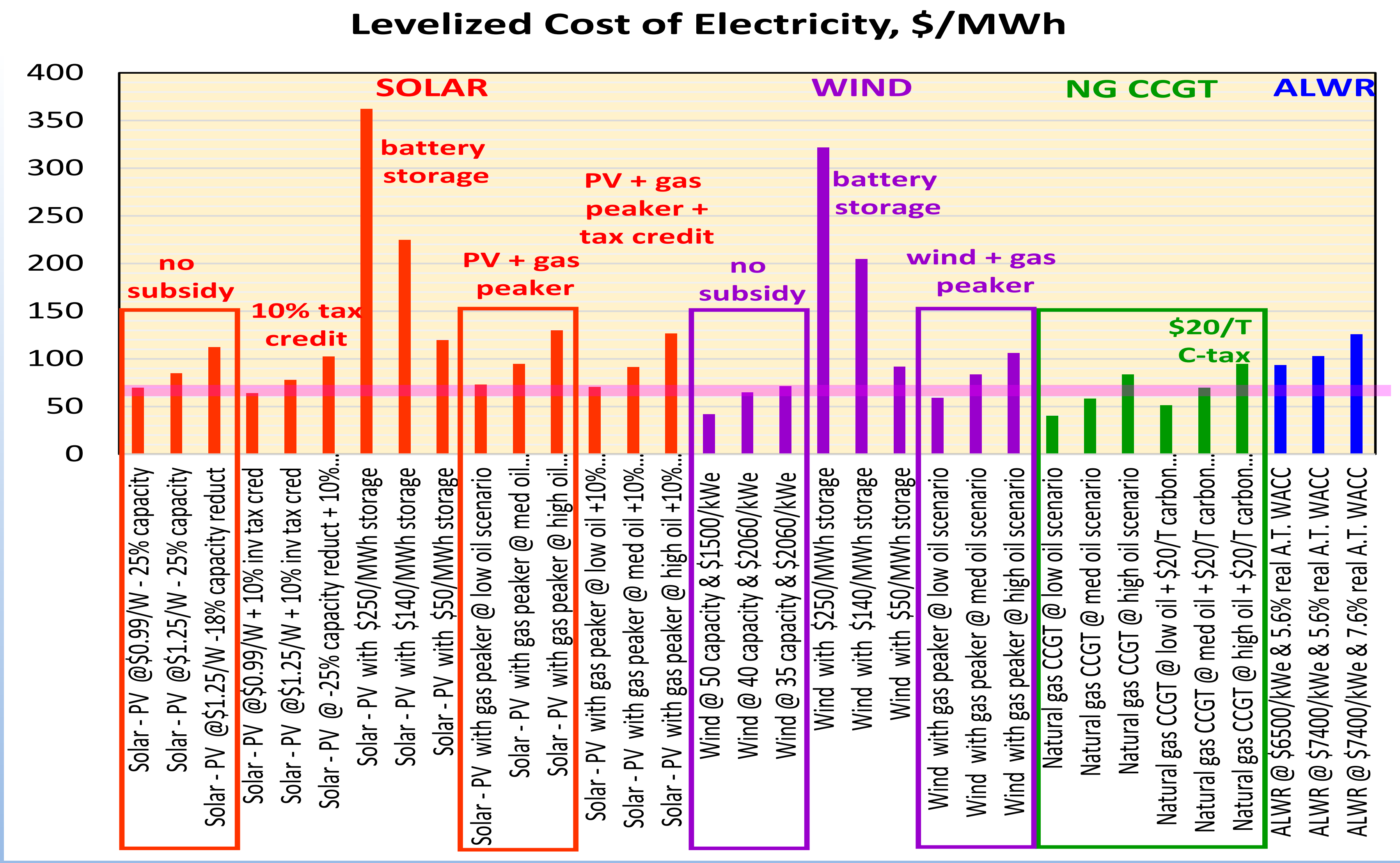
Two reactor systems on one seismically isolated module

Specifications:

- 265/240 MWe per module for water/dry cooling
- 500 MW_t reactor power
- Variable speed direct gas turbine
- Electronically coupled to grid
- Seismically isolated
- Passively safe – NRC licensable
- 30 year core life
- Free-standing containment

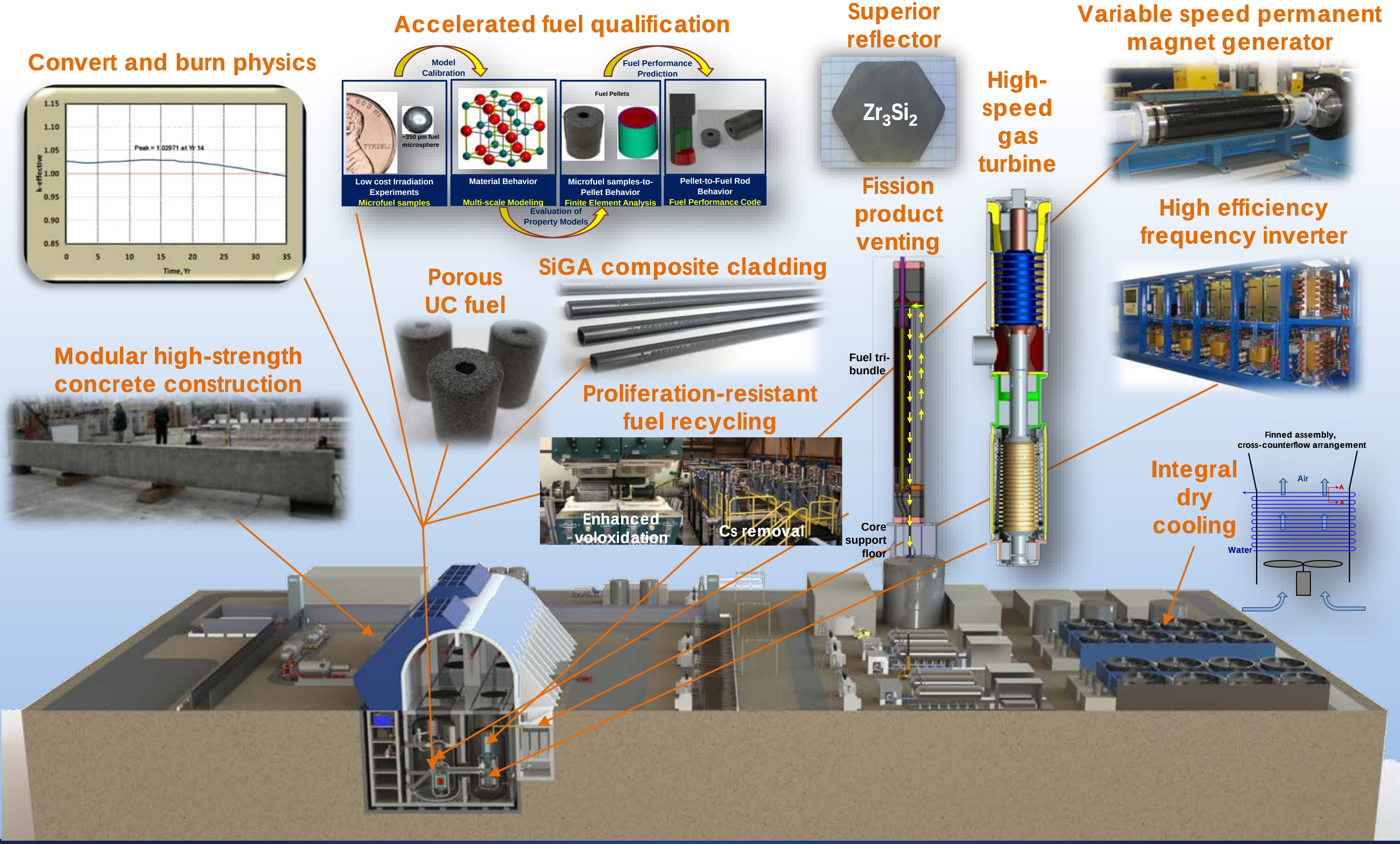
GENERAL ATOMICS

Investigation of Generation Options for 2020 – 2030 Suggests Competitive LCOE Might Be $60/MWh



GENERAL ATOMICS

To Meet Goals for EM², We Re-invented Everything from the Concrete to the Generator

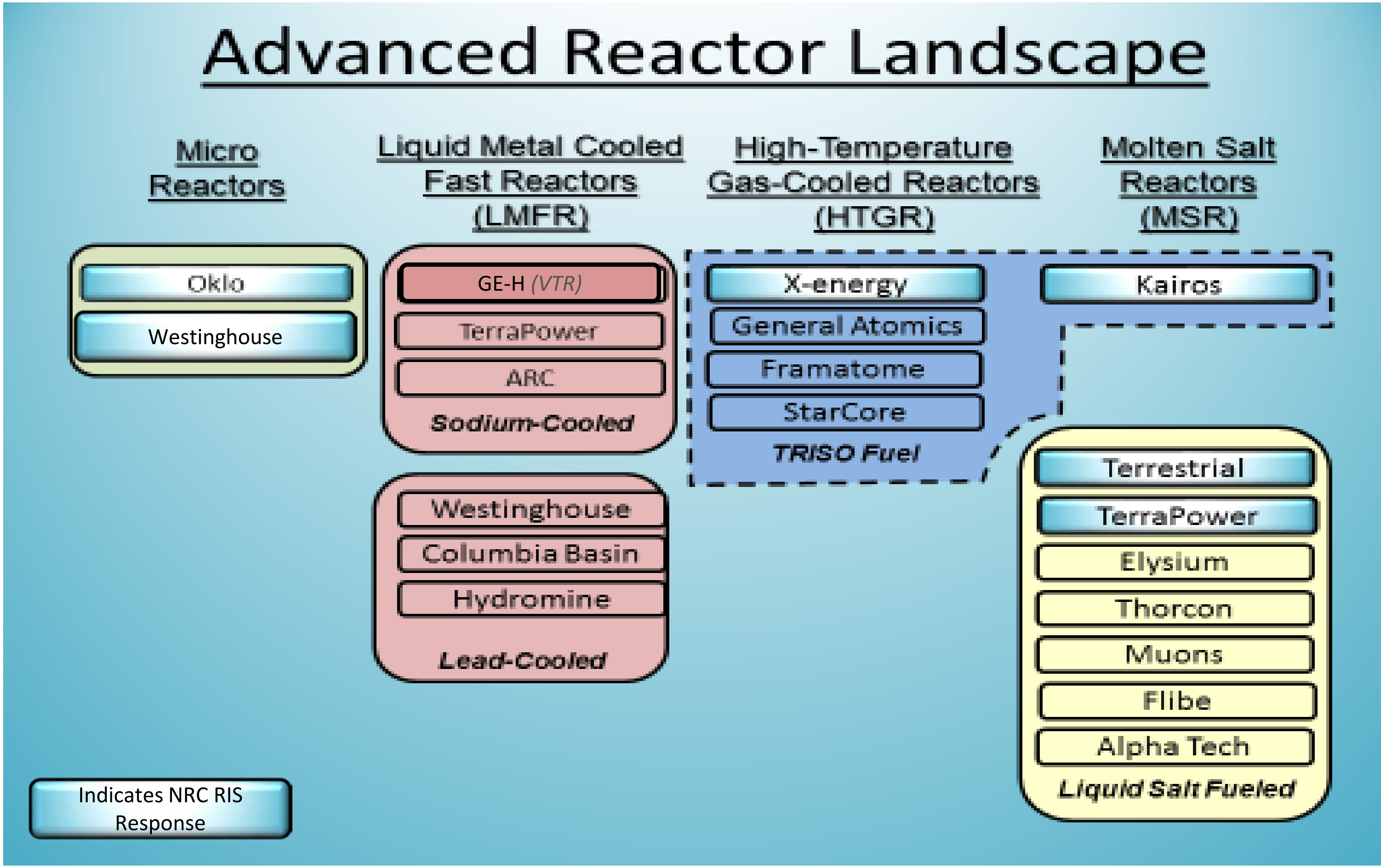


GENERAL ATOMICS

U.S. Nuclear Regulatory Commission's Preparation Activities for Non-Light Water Reactor Licensing

Jan Mazza

Project Manager, U.S Nuclear Regulatory Commission


Advanced Reactor Landscape
Micro Reactors
Liquid Metal Cooled Fast Reactors (LMFR)
High-Temperature Gas-Cooled Reactors (HTGR)
Molten Salt Reactors (MSR)
Oklo
Westinghouse
GE-H (VTR)
TerraPower
ARC
Sodium-Cooled
Westinghouse
Columbia Basin
Hydromine
Lead-Cooled
X-energy
General Atomics
Framatome
StarCore
TRISO Fuel
Kairos
Terrestrial
TerraPower
Elysium
Thorcon
Muons
Flibe
Alpha Tech
Liquid Salt Fueled
Indicates NRC RIS Response

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Notable Congressional Drivers

- Nuclear Energy Innovation Capability Act (NEICA)
    - ❖ Focus on DOE Activities
- Nuclear Energy Innovation and Modernization Act (NEIMA)
    - ❖ Focus on NRC Activities
- Nuclear Energy Leadership Act (NELA)
    - ❖ Focus on Commercialization via U.S. Government

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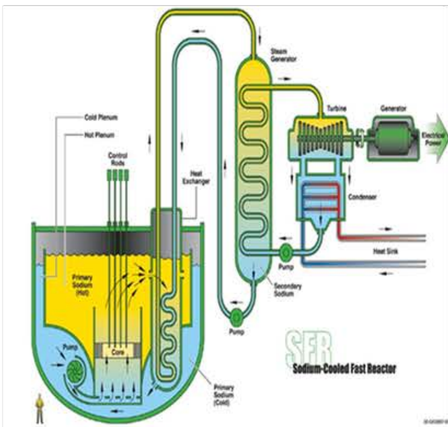
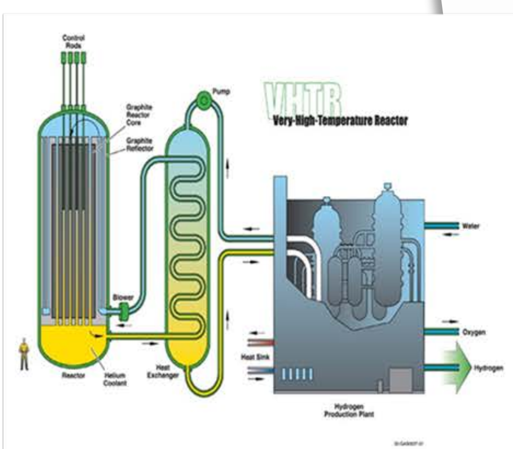
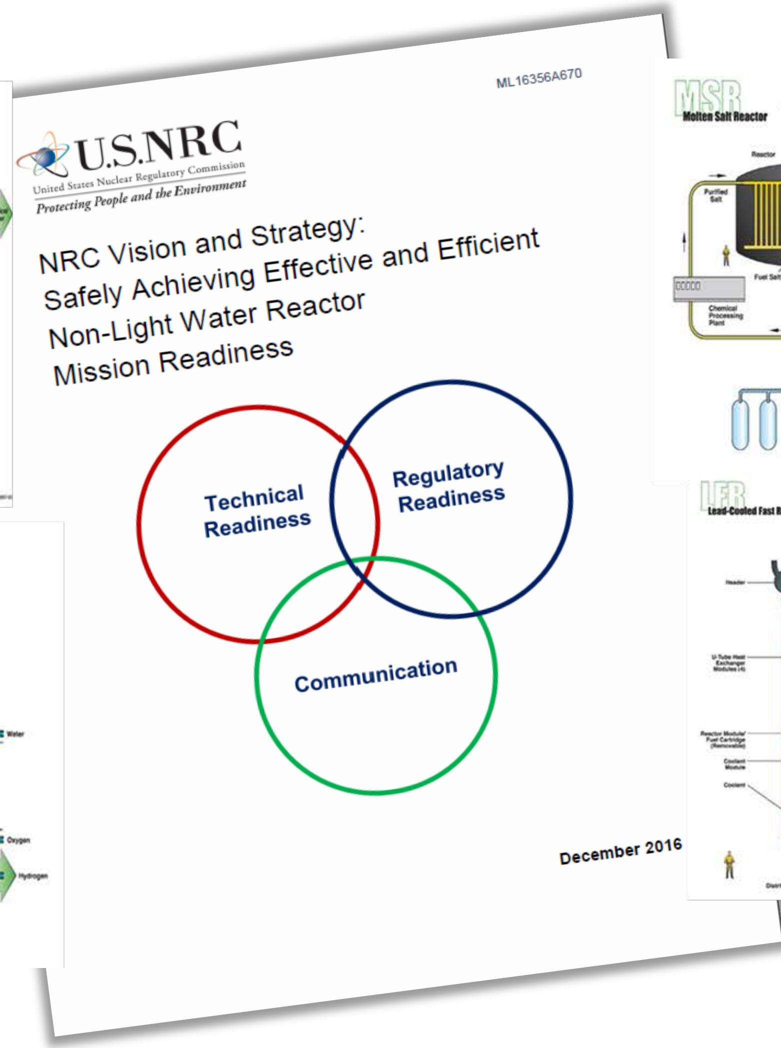
Advanced Reactor Program






ML16356A670

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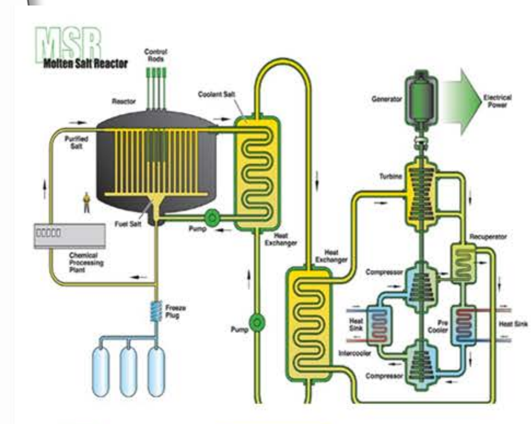
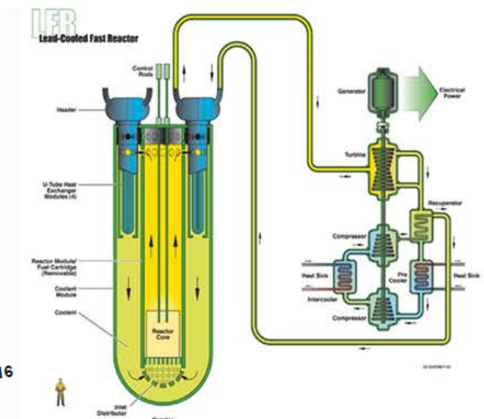
NRC Vision and Strategy:
Safely Achieving Effective and Efficient
Non-Light Water Reactor
Mission Readiness

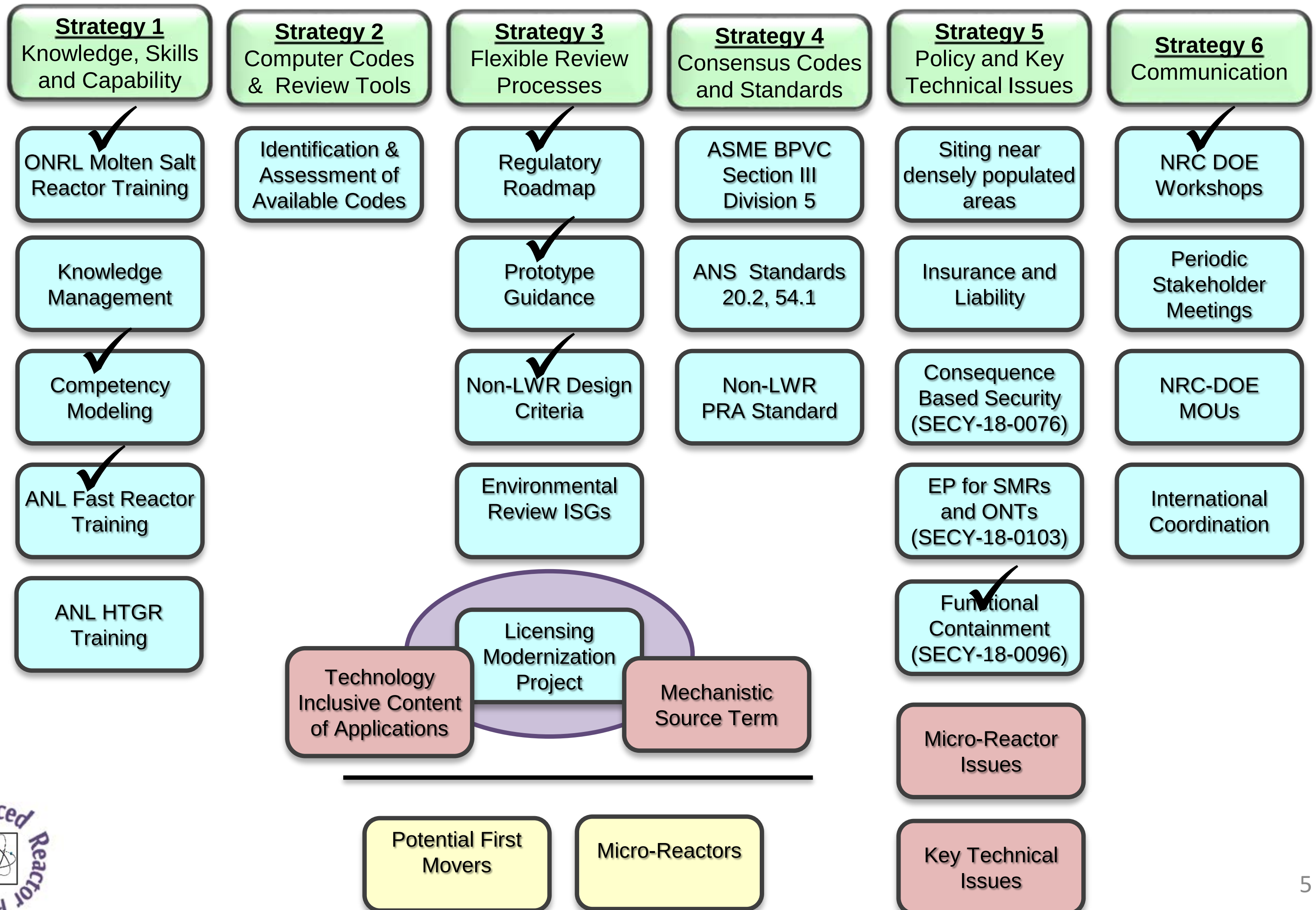
December 2016



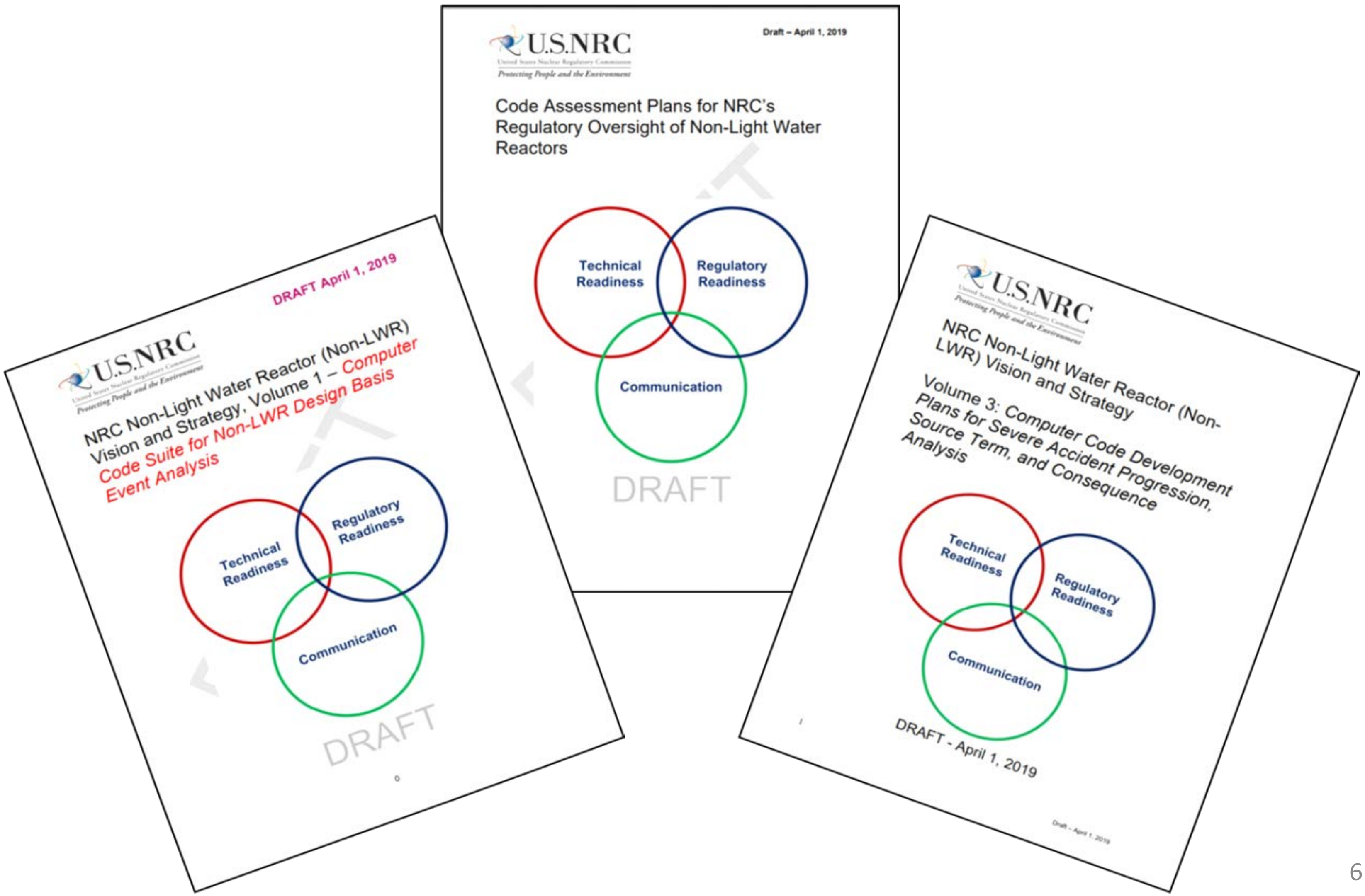


Advanced Reactor Program

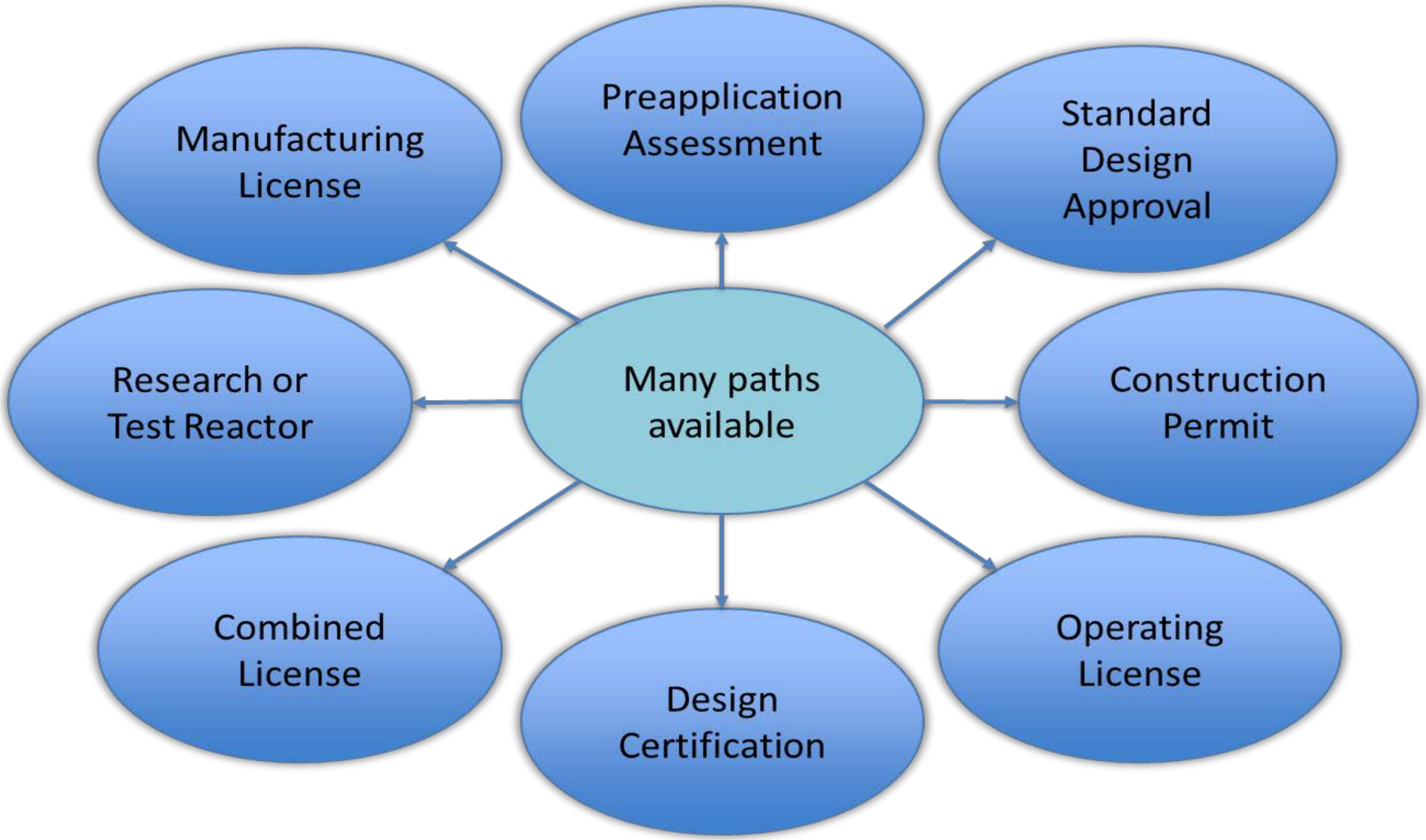
Strategies & Contributing Activities



STRATEGY 2 –Computer Codes

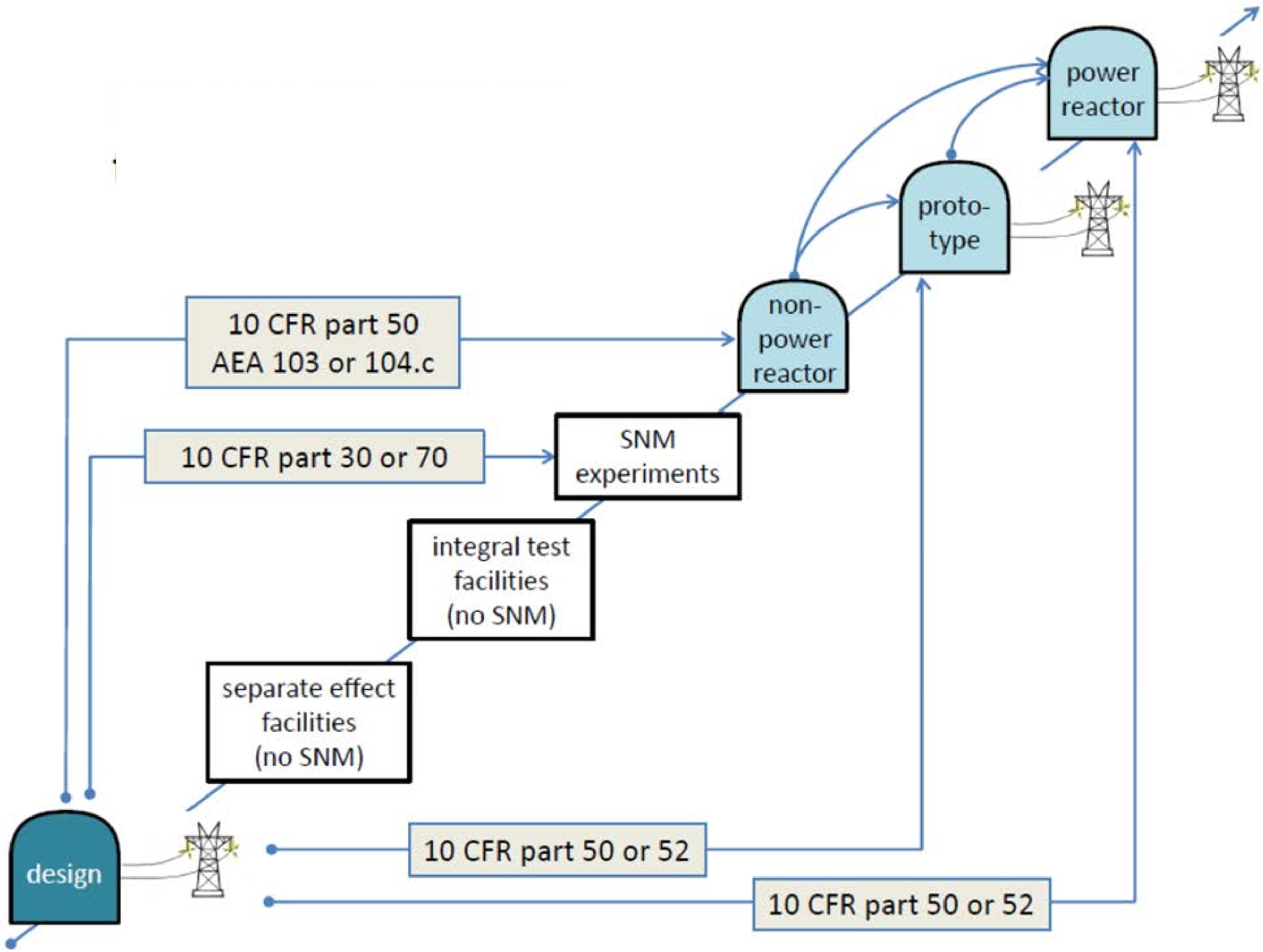


STRATEGY 3
Regulatory Review Roadmap for Non-LWRs



Clarifying Flexible Review Processes

STRATEGY 3 - Potential Licensing Pathways



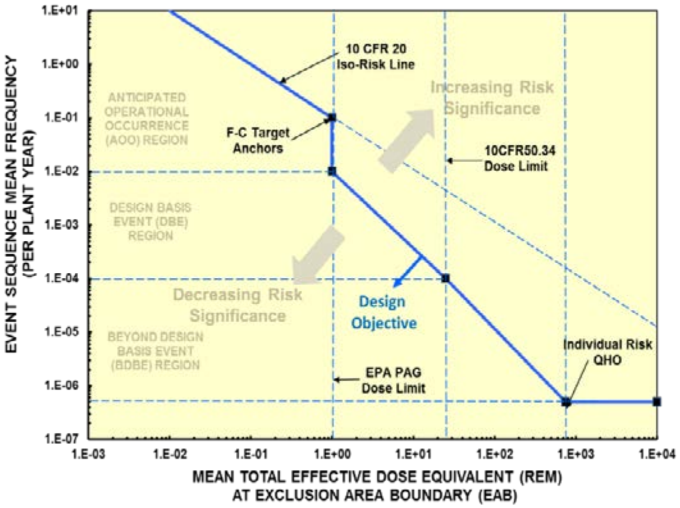
STRATEGY -3 Licensing Modernization Project

- Nuclear Energy Institute Technical Report (NEI 18-04) "Modernization of Technical Requirements for Licensing of Advanced Non-Light Water Reactors"
  - Risk-Informed Performance-Based Guidance for Non-Light Water Reactor Licensing Basis Development

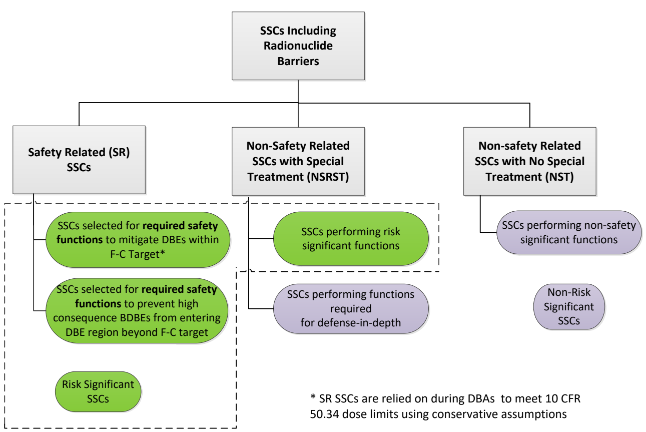
- NRC issued Draft Regulatory Guide (DG-1353) for public comment on May 3, 2019
  - Endorses NEI 18-04 with some clarifications
  - One acceptable method

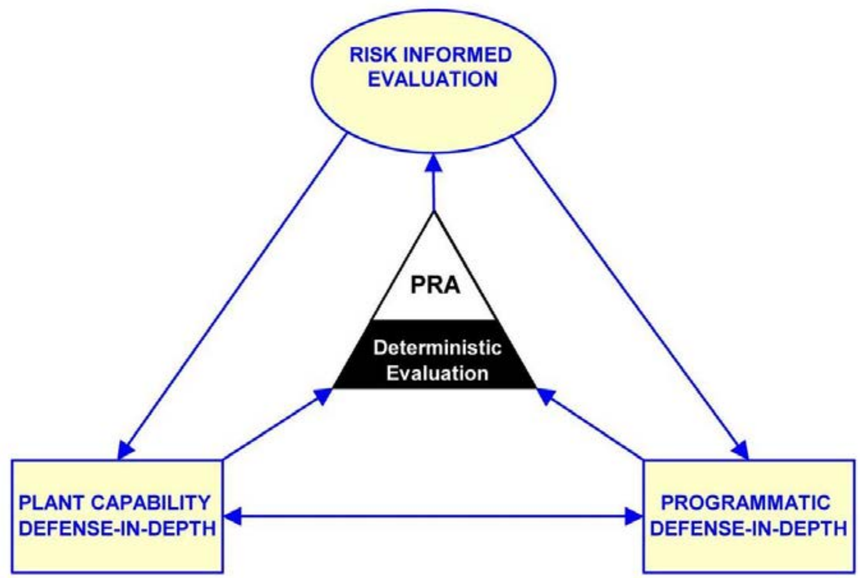
- The industry has conducted several pilots of LMP and more are planned

STRATEGY 3 - LMP Goals



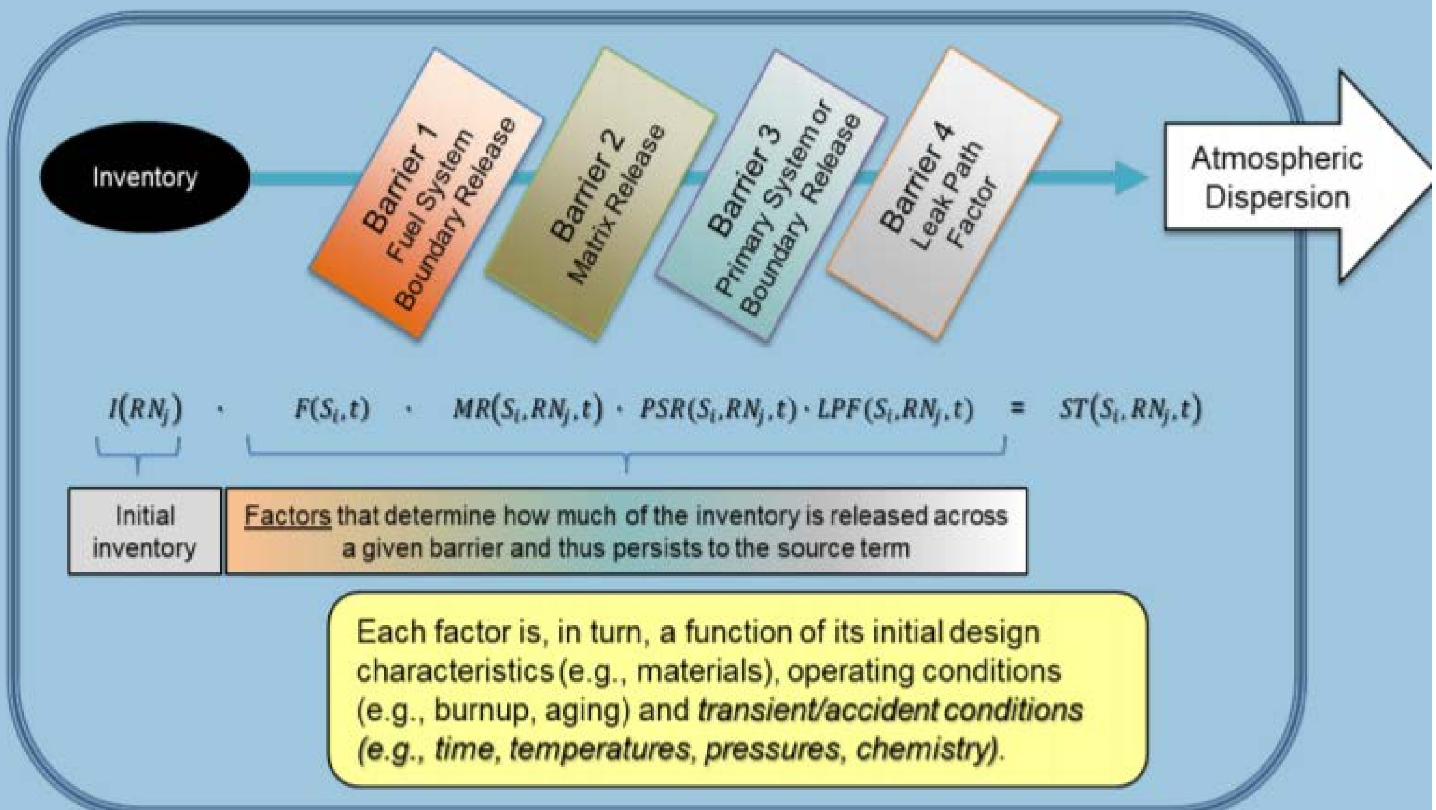
- Selection of Licensing Basis Events
- Structures, Systems, and Components Classification
- Defense in Depth Assessment





STRATEGY 3 - Fundamental Safety Functions

Recent NRC activities related to advanced reactors (e.g., functional containment performance criteria, possible changes to emergency planning & security, and DG-1353) recognize the limitations of existing LWR-related guidance, which requires a return to first principles such as fundamental safety functions supporting the retention of radionuclides



STRATEGY 3 - Micro Reactors

- Department of Energy/Department of Defense interest
- Pushing the envelope further
  - Emergency Planning
  - Minimal Security
  - Minimal Staffing
  - Remote/Autonomous Operations
  - Reduced Environmental Impacts
  - Siting
  - Oversight
  - Transportation (Portable)
- Need to scale review to consequences

STRATEGY 4 - Codes and Standards

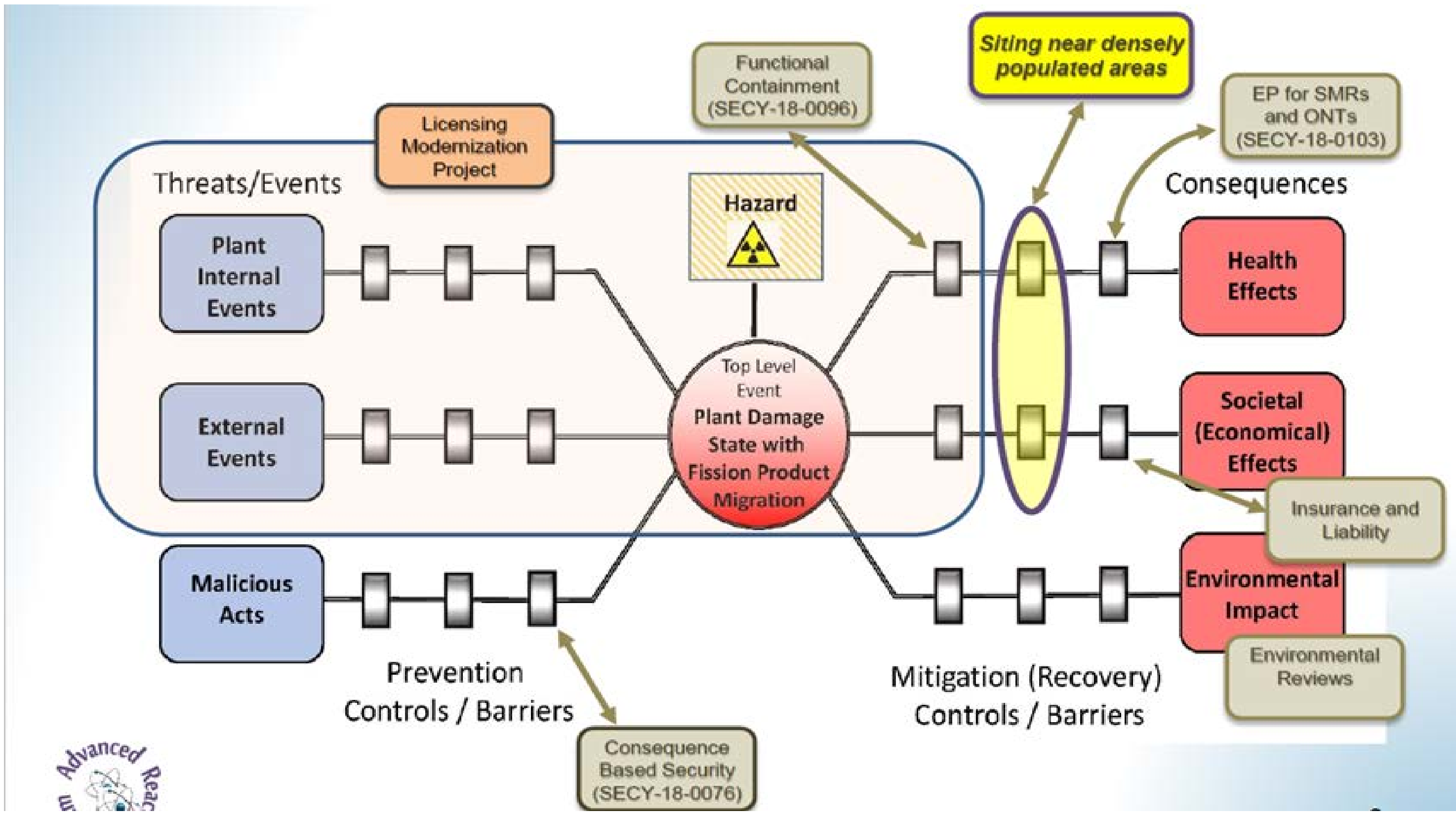
- ASME BPVC, Section III, Division 5
- ASME/ANS RA-S-1.4 (Non-LWR PRA Standard)

Slides from 6-27-2019 Stakeholder Meeting (ML19179A181)

STRATEGY 5 - Resolving Key Policy Issues Early

- Emergency preparedness for small modular reactors and other nuclear technologies
- Consequence based physical security
- Functional containment performance criteria
- Population-Related Siting Considerations for Advanced Reactors

STRATEGY 5 - Resolving Key Policy Issues Early



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Making Progress

(Quotes from November 27, 2018 Memo on Third Way Website)

The ability and willingness of the NRC to become more adaptive is crucial to continued investment in the diverse array of advanced nuclear technologies under development in the U.S.

Takeaways

NRC has a reputation for being rigid and inhospitable to innovation. For companies that are reimagining the design of a nuclear reactor, that makes it pretty tough to attract investment. But based on Third Way analysis, NRC has made major progress over the past few years to modernize its structure and processes to better accommodate advanced reactor developers. While licensing a new nuclear reactor will always be challenging, these steps are a positive indicator that NRC is willing to adjust in order to keep up with fast-evolving technologies.

"I'm encouraged by the current Commission and its dedication to efficiency and innovation. Change can start at the top, but it also must permeate to all levels of staff, if it is to have lasting and practical impact. I'm confident it can be done, but it will indeed require transformation."

As Dr. David Hill, Chief Technology Officer of Terrestrial Energy USA, has remarked, "Terrestrial Energy USA has been delighted with the amount of preparatory work the US NRC has done to ready itself to license the IMSR [Integrated Molten Salt Reactor] in the USA."

Conclusion

Through its transformative and collaborative efforts, the NRC is becoming more transparent, communicative, and flexible in its approach to the regulatory process and interactions with advanced reactor developers. Advanced reactor industry stakeholders are engaged with the Commission, and have acknowledged its willingness to adapt and innovate in its procedures. Although further adjustments are necessary, the NRC has endeavored to ensure its efforts to accommodate advanced reactor technologies in the regulatory process are feasible, effective, and holistic.

Summary

- NRC is executing its Vision and Strategy -
  – Transitioned from strategic planning to execution of implementation action plans to prepare for anticipated applications
- Planning for the broad range of designs under development, including various numbers, types and timing of applications
- Significant outreach and close coordination with external stakeholders
- Expanded NRC staff organizational capacity

Questions?

References

- NRC Vision and Strategy (ML16356A670)
- Implementation Action Plans (IAPs) (ML17165A069 and ML17164A173)
- Regulatory Review Roadmap including prototype guidance (ML17312B567)
- RG 1.232, "Guidance for Developing Principal Design Criteria for Non-Light Water Reactors" (ML17325A611)
- SECY-19-0009, "Advanced Reactor Program Status" (ML18346A075)
- SECY-18-0076, "Option and Recommendations for Physical Security for Advanced Reactors" (ML18052B032)
- SECY-18-0096, "Functional Containment Performance" (ML18114A546)
- SECY-18-0113, "Proposed Rule: Emergency Preparedness for Small Modular Reactors and other New Technologies," (ML18134A086)

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References Cont.

- NEI-18-04, "Risk-Informed Performance-Based Guidance for Non-Light Water Reactor Licensing Basis Development," (ML18271A172)
- DG 1353, "Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Approach to Inform the Content of Applications," (ML18264A093)
- Code Assessment Plans for NRC's Regulatory Oversight of Non-Light Water Reactors (ML19093B266)
- NRC Non-LWR Vision and Strategy, Volume 1—Computer Code Suite for Non-LWR Design Basis Event Analysis," dated April 1, 2019 (ADAMS Accession No. ML19093B322)
- NRC Non-LWR Vision and Strategy Volume 3—Computer Code Development Plans for Severe Accident Progression, Source Term, and Consequence Analysis," dated April 1, 2019 (ADAMS Accession No. ML19093B404)
- https://www.thirdway.org/memo/against-all-expectations-the-modernization-of-the-nuclear-regulatory-commission

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Fast Reactor R&D Overview

Robert Hill
ART Fast Reactor – National Technical Director
Argonne National Laboratory

Industry FRWG/DOE Fast Reactor Workshop
July 9, 2019

Office of Nuclear Energy – Mission Pillars

- Advance nuclear power to meet the nation's energy, environmental, and national security needs.
- Resolve technical, cost, safety, security and regulatory issues through research, development and demonstration.

Existing Fleet

Advanced Reactor Pipeline

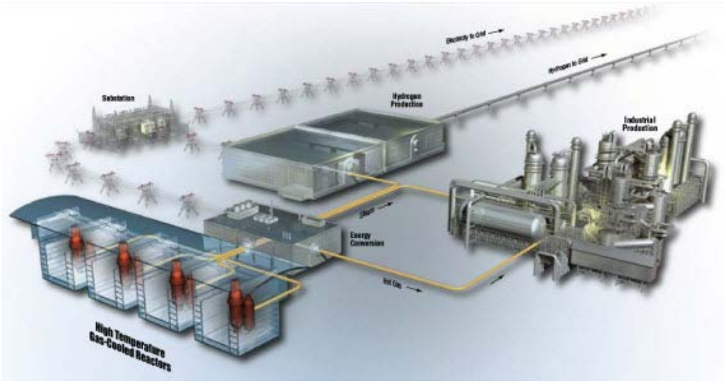
Fuel Cycle Infrastructure

Global Competitiveness



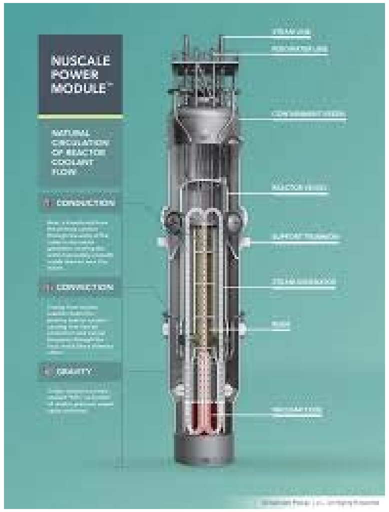

DOE-NE ADVANCED REACTORS PIPELINE

REACTOR TYPES
Light-Water Based SMRs e.g. NuScale
High-Temperature Reactors • Prismatic & pebble bed designs • Helium Cooled • Molten Salt Cooled Emphasis: TRISO fuel and Graphite qualification
Liquid Fueled Reactor (Molten Salt) • Fast-, thermal- and hybrid-spectrum designs
Fast Spectrum Reactors • See next viewgraph

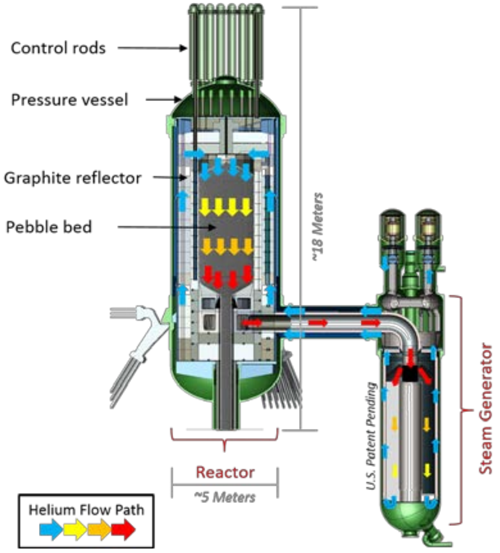


AREVA - HTGR

12 X 50 Mwe *"© NuScale"*



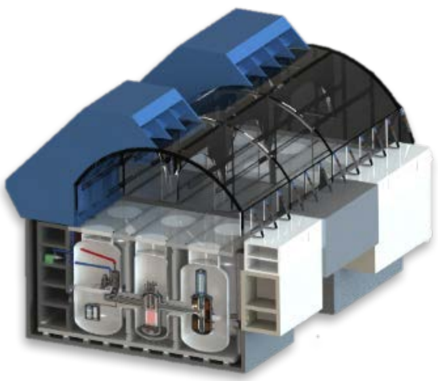
Xe-100 Pebble-Bed Reactor (200 MWth)



ADVANCED REACTOR EXAMPLES

Different Advanced Reactor Designs Being Developed By Industry

Gas Fast Reactors

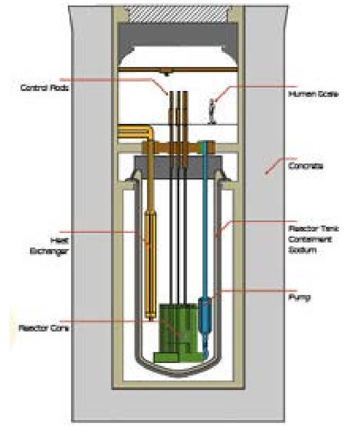


GA Gas-cooled
Fast Reactor

GE Hitachi
PRISM

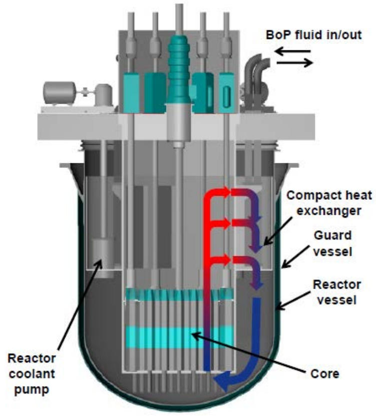
Sodium-Fast Reactors

TerraPower
TWR



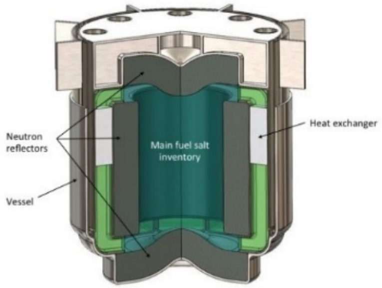
Advanced Reactor
Concepts LLC
ARC-100

Lead-Fast Reactors



Westinghouse LFR

Molten Salt Fast Reactors



TerraPower
MCFR

Elysium USA
MCSFR

Office of Advanced Reactor Technologies

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

DOE ART Program - Fast Reactor R&D – Priorities

- For the commercial deployment of fast reactor technology, <u>two recurring challenges are identified</u>
  - For advanced fuel cycles, capital investment in reactors is the dominant cost (cost reduction is also vital for electricity production)
  - A pathway must be established for non-LWR licensing
- Therefore, ART Fast Reactor work activities have focused on:
  - Research, development, and demonstration of <u>innovative cost reduction and performance enhancing</u> technologies (e.g., new configurations, materials, energy conversion, etc.)
  - Clarifying fast reactor <u>licensing criteria and</u> science-based approach for <u>demonstration</u> of regulatory compliance – NRC engagement and resolution of regulatory issues

Engagement with Industry

In FY17, DOE-NE established the Gateway for Accelerating Innovation in Nuclear (GAIN) initiative to provide developers with access to technical, regulatory and financial support

U.S. industry self established advanced reactor working groups. The Fast Reactor Technology Working Group consists of diverse concepts:

- **SFR – Oklo, General Electric, TerraPower, Advanced Reactor Concepts**
- **LFR – Westinghouse, Columbia Basin Consulting Group, Hydromine**
- **GFR – General Atomics**
- **MCFR – Elysium, Southern/TerraPower, Flibe**

Group requests are generally broad in scope and identify capabilities useful for multiple technology options

Fast Reactor Industry Technology Working Group

Program Request from the Fast Reactor TWG:

- **Fast Test Reactor**
- **Legacy Data Management**
  - Fuel QA data, CREDO operations database
- **Fuels**
  - Irradiation testing, >5% LEU source, TREAT testing
- **Modeling and Simulation**
  - Access to existing and advanced DOE tools, validation data, software QA, source term modeling, fuels performance
- **Nuclear Data**
- **Education and Training**
- **Separate and Integral Effects Test Facilities**
  - Component testing (e.g., METL), materials, structural, TH, energy conversion, decay heat removal, coolant and fuel handling

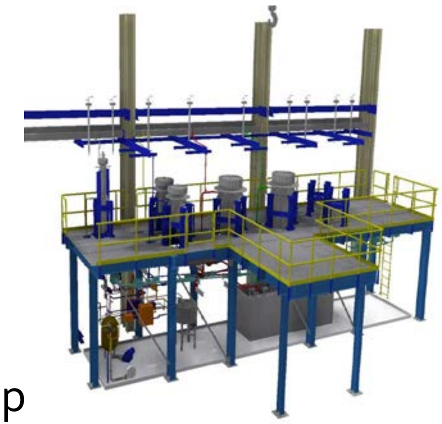
Consistent with current ART directions, but with expanded scope

High Level Activities and Key Milestones

- **Technology Development – intermediate-scale sodium loop, compact heat exchanger, knowledge preservation**
  - 2019 – First test article in the METL components testing loop
  - 2020 – METL operations with multiple test vessels
  - 2020 – Conclude fundamental heat exchanger experiments (transition to compact heat exchanger testing)
- **Methods Modeling and Validation – databases, qualification of data and tools, studies on old/new validation experiments**
  - 2018 – Launch of IAEA CRP on FFTF passive safety test
  - 2019-21 – Execute external access plan for fast reactor databases
  - Continue addressing licensing and safety gaps identified in 2014
- **Advanced Materials – ASME code qualification of modern alloys, and life extension of existing materials**
  - 2021 – Complete G91 extension to 60 year design life in ASME rules
  - 2023 – Submission of initial ASME code case for Alloy 709

Mechanisms Engineering Test Loop (METL)

- **To test small or intermediate scale advanced liquid metal components and instrumentation in sodium:**
  - Gear Test Assembly for Compact Refueling Machine
  - Westinghouse Thermoacoustic Sensor Testing
  - Thermal-Hydraulic Experimental Test Article (THETA)



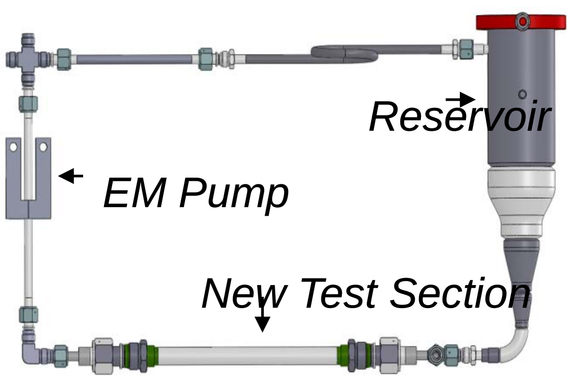
- **METL consists of:**
  - ~3,000 kg of reactor-grade sodium – to be purified in cold trap
  - Two 18 inch test vessels and two 28 inch test vessels (Phase I)
  - Max system temperature = 1000°F (except for 28 inch test vessels – 1200°F)
  - Test vessels can be isolated from main loop

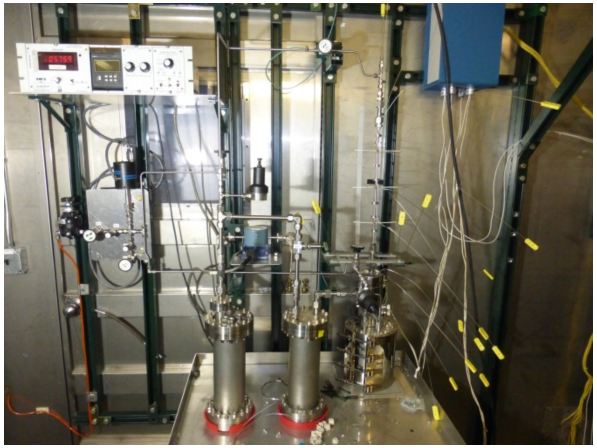
- **Will provide much needed U.S. infrastructure (both personnel and hardware) to test liquid metal systems and components**

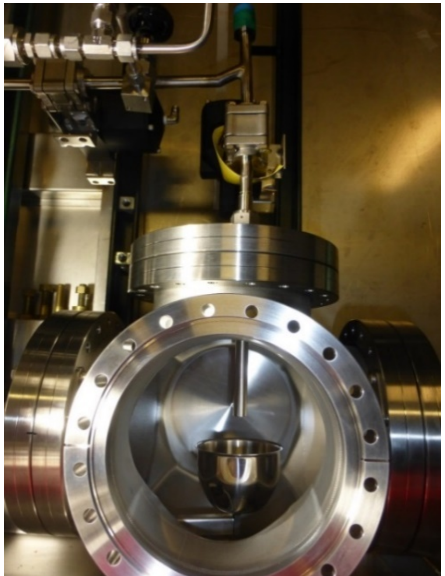
METL – piping insulated with jacket (FY18)

Compact Heat Exchanger Development – Key Phenomena

- Three experiment facilities have been assembled and used to obtain data essential for reliable design of sodium-to-carbon dioxide heat exchangers connecting intermediate sodium circuit to supercritical CO2 system
  - Sodium Freezing and Remelting
  - Sodium Draining and Refilling
  - Sodium Plugging
- Without the data and an understanding of the phenomena in the tests, heat exchanger design constraints (e.g., a reliable safe value for the minimum sodium channel size) will not be known







SFR Safety Testing Databases

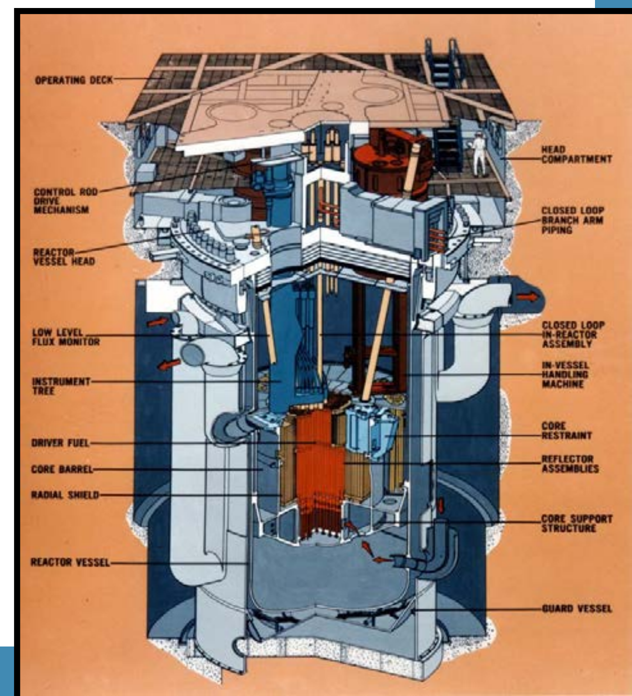
- **EBR-II Safety Test Database**: ~80 experiments from comprehensive shutdown heat removal, BOP, and inherent control testing program. — Completed
- **FFTF Passive Safety Testing Database**: Unprotected loss-of-flow transient tests, including core restraint system and GEM response. — Completed
- **TREAT Test Database**: Meta- and numerical data from ~800 one-of-a-kind tests as the basis of present knowledge of transient fuel behavior. — Completed
- **SFR Component Reliability Database**: Based on combination of original CREDO data and revisited EBR-II, FFTF, and FERMI run logs. — Completed
- **EBR-II and FFTF Metal Fuel Irradiation Databases**: Pin-by-pin fuel irradiation history, profilometry micrographs, gamma scans, x-sections. — Ongoing
- **Out-of-pile Metal Fuel Test Database**: Data from Whole Pin Furnace and Fuel Behavior Testing Apparatus to characterize margins to fuel failure for metal-alloy SFR fuel as part of IFR program. — Ongoing

New IAEA CRP on FFTF

Loss of Flow Without Scram Test #13

- Four year Coordinated Research Project (CRP)
  - LOFWOS Test #13:
    - Demonstrated effectiveness of GEMs as shutdown device
    - Limited free bow core restraint system
  - Benchmark specification developed by Argonne and PNNL
- 1st Research Coordination Meeting:
  - Hosted by IAEA in Vienna, Oct. 22-25, 2018
- CRP led by Argonne and PNNL

Participants:	
CIAE (China)	NRG (Netherlands)
INEST (China)	IBRAE (Russia)
NCEPU (China)	IPPE (Russia)
XJTU (China)	CIEMAT (Spain)
CEA (France)	KTH (Sweden)
HZDR (Germany)	EPFL (Switzerland)
KIT (Germany)	PSI (Switzerland)
IGCAR (India)	Argonne (USA)
ISSSA (India)	US NRC (USA)
NINE (Italy)	Texas A&M (USA)
Uni. of Rome (Italy)	TerraPower (USA)
JAEA (Japan)	PNNL (USA)
KAERI (Korea)	



Code Qualification for Alloy 709

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Background:

- Alloy 709 (20Cr-25Ni) is an austenitic stainless steel with significant time-dependent strength advantage over 316H stainless steel as a SFR construction material
- Enhanced time-dependent strengths of Alloy 709 with respect to 316H can reduce commodity requirements, and thereby decrease the capital cost of the reactor plant
- Can also permit structural components to withstand higher cyclic and sustained loading, leading to higher safety margins, and the prospect of eliminating costly add-on hardware instituted in past designs, and other design innovations and simplifications

Status:

- Qualification efforts for ASME Division 5 Code Case for 100,000 h and 760C are ongoing
- Tests include tensile, creep, fatigue, and creep-fatigue

Alloy 709 plates fabricated from 45,000 lb commercial heat

Grade 91 ASME Code Extension: Thermal Aging Effect on Yield and Tensile Strengths for Long Service Life

U.S. DEPARTMENT OF ENERGY

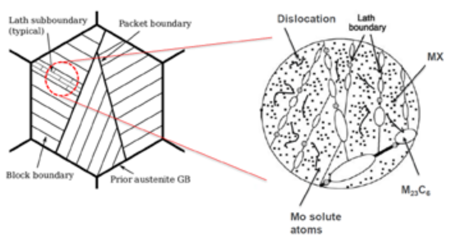
Nuclear Energy

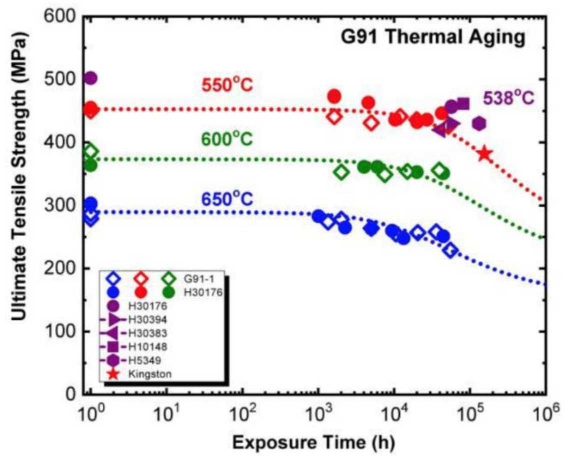
Application:

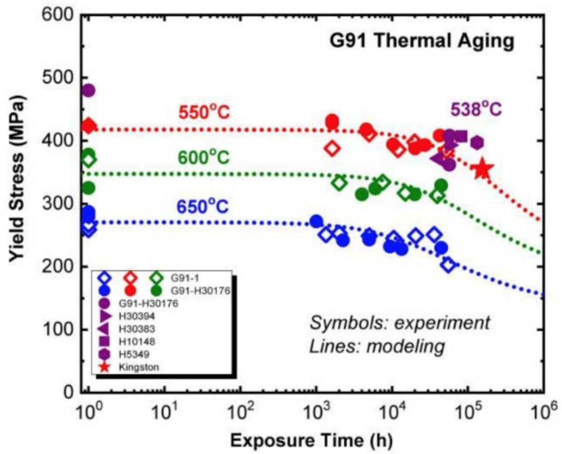
- Seismic design rules are based on tensile properties
- Characterization of yield and tensile strength reductions due to thermal aging for long design lifetime is necessary

Results:

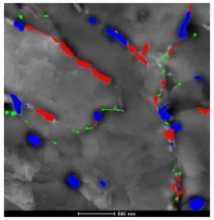
- Developed a mechanistic model that is related to microstructural aging mechanisms, and supported by data out to about 135,000 hours, for the long-term yield and tensile strengths of Grade 91, accounting for thermal aging effects
- Used as the basis for developing ASME Division 5 thermal aging factors to 500,000 h

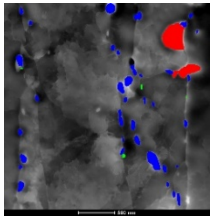


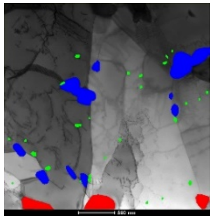


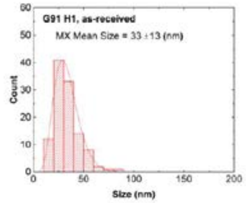


In-situ tensile testing at Beamline 1-ID at Advanced Photon Source, ANL









Detailed characterization of microstructure evolution due to aging

Service exposed Grade 91 steel

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Summary

- **Industry interest in Advanced Reactor options has increased**
  - Wide variety of technology options being promoted
  - Legislation for industry-led R&D and innovation R&D

To support near-term commercialization, R&D efforts are focused on

1) **technology innovations for cost reduction**
2) **key licensing challenges**

- **Recent progress and accomplishments technology R&D items focused on innovations for performance improvement (cost reduction)**
  - METL sodium loop operation in 2018
  - First Test Article (GTA) testing completed in March 2019
  - Alloy 709 austenitic alloy ASME code qualification and welding for SFR
  - Supercritical CO2 technology and heat exchanger R&D
- **Recent progress and accomplishments on licensing R&D items focused on safety analysis tools/validation and advanced fuels**
  - Advanced modeling tools being developed and validated
  - Knowledge preservation in databases (e.g., FFTF benchmark proposal)
  - R&D on fabrication and irradiation performance of advanced metal alloys

METL Status

- **Initial fill of sodium into METL in May 2018.**
  - **15 55-gallons drums were heated and transferred to the sodium dump tank.**
- **Sodium was transferred from the dump tank and into the main loop in September 2018 and sodium purification was initiated.**
- ***https://www.osti.gov/biblio/1492054-mechanisms-engineering-test-loop-phase-status-report-fy2018-update-fy2017-report***
- **Gear Test Assembly (GTA) was fully assembled, water and air tested, and moved to B308 for commission**
  - ***First test article into METL December 2018***
- ***After insertion and initial checkout, it was operated for ~9,800 simulated core assembly removal and insertion cycles under load (Feb-Mar 2019)***
  - ***In process of removal for cleaning in inert enclosure***
- **Thermal Hydraulic Test Article (THETA) will use two test vessels to model pool stratification**
  - ***Complete design/fab in FY19 with startup in FY20***