



U.S. DEPARTMENT OF
ENERGY

Nuclear Energy

Overview of Advanced Nuclear Power Technology and Global Plans

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Workshop on Isotope Federal Supply and Demand

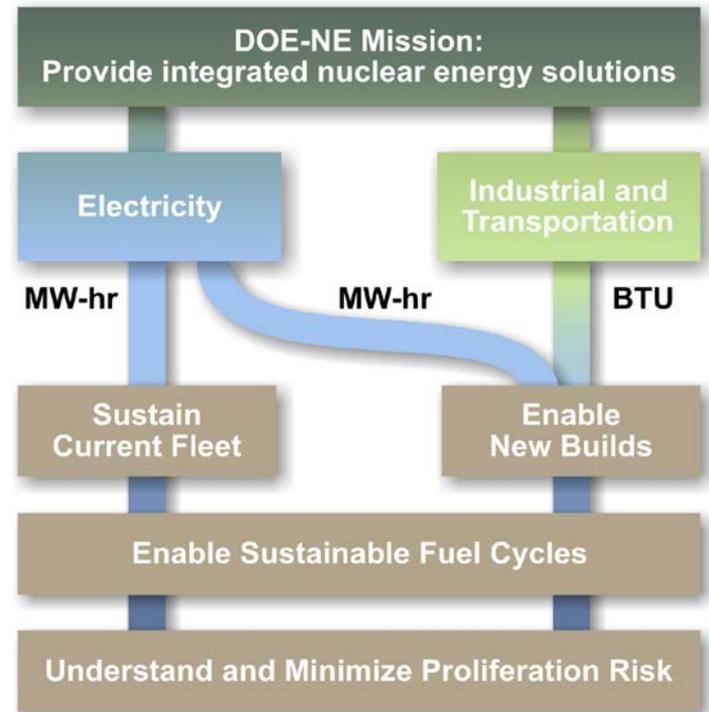
November 9, 2015



Nuclear Energy Roadmap Objectives

Nuclear Energy

- Develop technologies and other solutions that can improve the reliability, sustain the safety, and extend the life of current reactors
- Develop improvements in the affordability of new reactors to enable nuclear energy to help meet the Administration's energy security and climate change goals
- Develop sustainable nuclear fuel cycles
- Understand and minimize the risks of nuclear proliferation and terrorism





DOE Office of Nuclear Energy

Key Program Areas

■ Science and Technology Innovation

- Innovative Crosscutting Research
- Advanced Modeling and Simulation

■ Fuel Cycle Technologies

- Fuel Cycle R&D
- Used Nuclear Fuel Disposition

■ Nuclear Reactor Technologies

- Light Water Reactor Technologies
- Small Modular Reactors - technical support for licensing SMRs.
- Advanced Reactor Technologies

■ Idaho National Laboratory

- Facilities and security capabilities.



Advanced Test Reactor



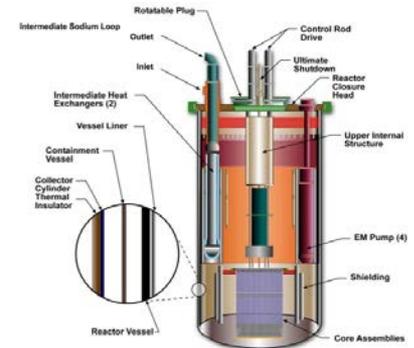
TRISO coated particle fuel



Advanced Reactor Technologies

■ R&D focused on Advanced, Small and Modular Reactor Concepts

- Fast Reactor Technologies
 - For actinide management and electricity production
 - Current focus on sodium cooled reactors
- High Temperature Reactor Technologies
 - For electricity and process heat production
 - Current focus on helium gas- and Fluoride High Temperature Reactors (FHRs) liquid salt-cooled reactors (Fluoride, Lithium, Beryllium salts)
- Advanced Reactor Generic Technologies
 - Common design needs for advanced materials, energy conversion, decay heat removal systems and modeling methods
- Advanced Reactor Regulatory Framework
 - Development of licensing requirements for advanced reactors
- Advanced Reactor System Studies
 - Advanced Test/ Demonstration Reactor Planning Study



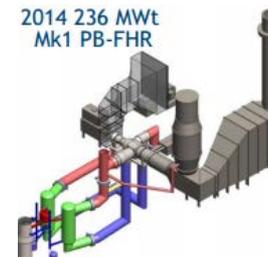
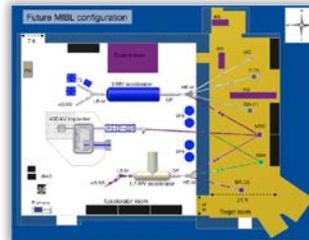
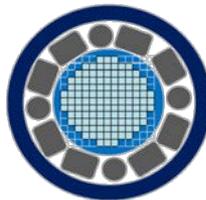
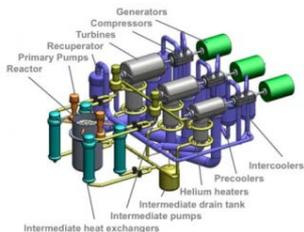
■ Supercritical Transformational Electric Power (STEP) Initiative:

- Integrating multi-office R&D projects
- Investigating commercialized Supercritical Carbon Dioxide (sCO₂) Brayton cycle energy conversion system



DOE Programs with Universities

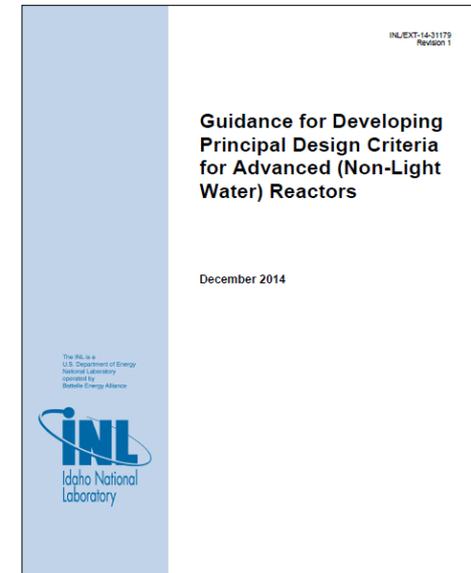
- **Integrated Research Projects in support of advanced nuclear technologies**
 - High-Temperature Salt-Cooled Reactor for Power and Process Heat (2011, MIT, Wisconsin, UC Berkeley) Fluoride High Temperature Reactor (FHR)
 - High Fidelity Ion Beam Simulation of High Dose Neutron Irradiation (2013, University of Michigan, DOE)
 - Integrated Approach to FHR Technology and Design Challenges (2014, MIT and Georgia Tech)





Reducing Regulatory Risk Licensing Initiative for Advanced Reactors

- **During 2012 DOE and NRC noted need for regulatory guidance for non-light water reactor designs**
 - Existing licensing guidance is written for light water reactors.
 - A regulatory framework is needed to support reasonable timelines for design certification and licensing.
- **NE and NRC initiated a joint project for development of General Design Criteria (GDC) for non-light water reactor concepts**
- **Key DOE actions of this initiative :**
 - Prepared draft Design Criteria / conducted workshops - March and July 2014
 - Completed Design Criteria – October 2014
 - Advanced Reactor Design Criteria (Applicable to FHRs)
 - Sodium Fast Reactor Design Criteria
 - Modular High Temperature Design Criteria
 - Issued a report to the NRC that proposed the draft Design Criteria and requested development of Regulatory Guidance – Dec 2014





Advanced Test/Demo Planning Study

■ **FY15 Omnibus Spending Bill**

“\$7,000,000 is for an advanced test/demonstration reactor planning study by the national laboratories, industry, and other relevant stakeholders of such a reactor in the U.S. The study will evaluate advanced reactor technology options, capabilities, and requirements within the context of national needs and public policy to support innovation in nuclear energy.”

■ **Nuclear Energy Advisory Council (NEAC) providing study advice.**

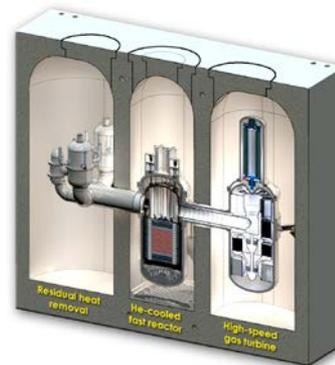
■ **The objective of the study is to provide options for a test and or demonstration reactor(s) to be built to support innovation and long term commercialization.**

■ **Draft report due in April 2016.**



Industry Collaboration

- DOE made multiple awards totaling \$15M in FY 2013 and FY 2014 for cost shared industry-led R&D to address specific technical R&D needs of advanced reactors
- With FY15 funding DOE will provide \$12M for cost-shared further development of two performance based advanced reactor concepts.
- These awards reflect DOE's interest in collaborating with industry and Congressional support for advanced reactor development.

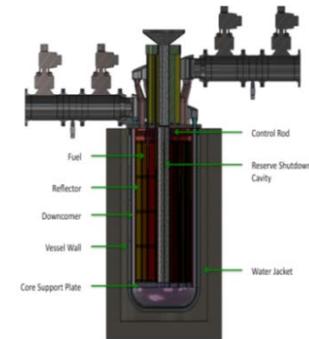


General Atomics EM2



Increasing Industry Interest in Advanced Reactors

- **U.S. Nuclear Infrastructure Council - Advanced Reactor Summit in Feb 2015**
- **Nuclear Energy Institute - advanced reactor industry group initiated in Feb 2015**
- **Nuclear Innovation Alliance - 2014 to facilitate development and licensing.**
- **Various companies * have started up with express interest in advanced reactors:**
 - Advanced Reactor Concepts LLC (Sodium Fast Reactor)
 - Gen4 Energy (Lead Fast Reactor)
 - X-Energy (High Temperature Gas Reactor)
 - TerraPower (Sodium Fast Reactor/ Molten salt reactor)
 - Terrestrial Energy (Molten Salt Reactor)
 - Thorcon Power (Molten Salt Reactor)
 - Transatomic Power (Molten Salt Reactor)
 - FLiBe Energy (Molten Salt Reactor)



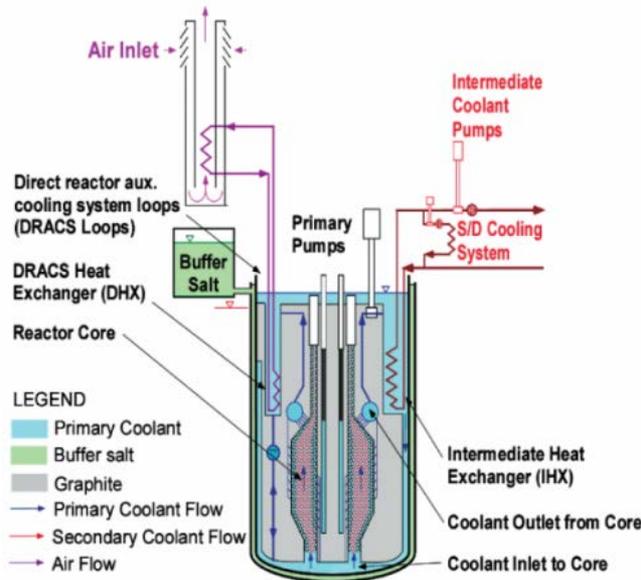
Gen4
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- **NRC-DOE Advanced Reactor Development and Licensing Workshop**

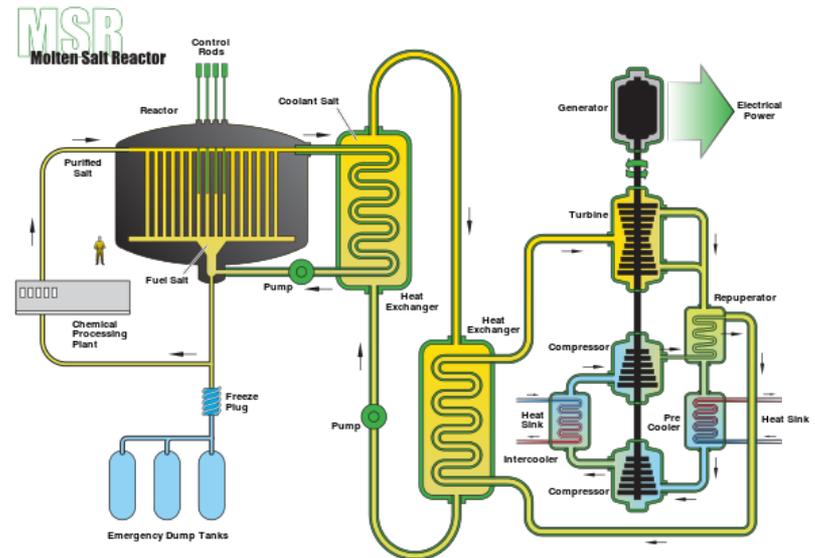
* This is not a complete listing of new startup companies.



- Isotope enrichment technology may be necessary in some advanced reactors.
- Fluoride Salt Cooled High Temperature Reactors (FHRs) (fixed solid fuel) and Molten Salt Reactors (MSRs) (fuel dissolved in the salt) use salt with enriched Lithium.



Fluoride Salt Cooled High Temperature Reactor



Molten Salt Reactor



Isotopes for Advanced Reactors

■ Lithium-7 in Fluoride Salt Cooled High Temperature Reactors

- FHR's and MSR's will use salt coolants such as FLiBe (Fluoride, Lithium, Beryllium)
- Use of FLiBe requires enrichment of Li-7 to 99.995%
- Enrichment is necessary to support reactor physics needs
- Promising methods in terms of economics and effectiveness include:
 - Crown ether solvent extraction (ORNL proposed study to use Couette columns to facilitate process)
 - Magnetically activated and guided isotope separation
- Supply chain not stable, China and Russia are the sole producers of Li-7 enriched material
- DOE/ ORNL currently maintains 2250 kg of Li-7 enriched FLiBe salt. More would need to be fabricated if a test/ demo reactor is built.

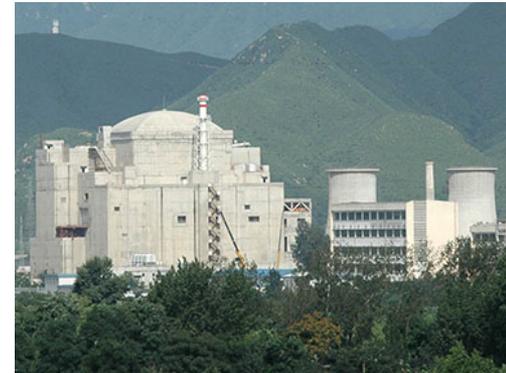
Isotopes for Advanced Reactors

■ Chlorine-37 for Molten Salt Reactors

- Chloride salt based MSR's are being proposed by TerraPower and other companies
- Chloride salts are advantageous in improving actinide burning and breeding
- Chlorine consists of two stable isotopes Cl-35 (75.8%) and Cl-37 (24.2%)
- Chlorine-35 has a larger neutron absorption cross section than Cl-37.
- Chlorine-35 may activate and become Cl-36 which is long lived (301,000 years) and emits an energetic beta particle (709keV).
- Therefore, use of isotopically separated chlorine is the preferred option for chloride-based fuel salts



- R&D focused on liquid metal-cooled fast reactors and gas or salt-cooled high temperature reactors
- Fast Reactor examples
 - **China** - CEFR (operating test sodium fast reactor (SFR))
 - **Japan** – Joyo (test SFR awaiting restart), Monju (demo SFR awaiting restart)
 - **Russia** – BOR-60 (operating test SFR), MBIR (test SFR under construction), BN-800 (operating demo SFR), BREST (proposed test lead-cooled fast reactor)
 - **Korea** – Prototype Generation IV SFR (proposed demo SFR)
 - **France** – ASTRID (proposed demo SFR)
 - **India** – PFBR (demo SFR under construction)
- High Temperature Reactor (HTR) examples
 - **Japan** – HTTR (test gas-cooled HTR awaiting restart)
 - **China** – HTR-PM (proposed demo pebble-bed gas-cooled HTR), Fluoride salt -cooled HTR (proposed solid fuel salt-cooled test HTR), molten salt-cooled reactor (proposed liquid fueled salt-cooled HTR)



China Experimental Fast Reactor (CEFR)



High Temperature Test Reactor (HTTR)



US Advanced Reactor Collaborations

■ Multi-lateral collaborations

- Generation-IV International Forum
 - 13 Members, 6 Reactor Types
 - U.S. signatory to Very High Temperature Reactor (VHTR) and Sodium Fast Reactor (SFR) System Arrangements
 - Observer status on Molten Salt Reactor (MSR) and Lead Fast Reactor (LFR) Systems
- SFR Trilateral Agreement (US, Japan, France)



■ Bilateral collaborations

- Japan - R&D on fast reactors and HTRs, advanced materials, fuel, modeling and simulation,
- France - Reactor and safety analysis for the ASTRID SFR, transmutation fuels, advanced fuel cladding
- Russia - Multi-purpose fast research reactor (MBIR) International User Center, High temperature gas reactors (HTGRs), and SMRs
- China - Fast Reactor Safety, helium and liquid salt cooled HTRs
- Korea – Work for others and I-NERI projects in support of SFRs

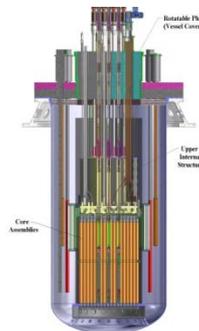




Summary

Nuclear Energy

- DOE is pursuing advanced reactor technology as a means to support future energy needs.
- Advanced reactors are supported through program R&D, industry led R&D and regulatory efforts.
- Advanced reactors will need further development before deployment.
- Isotope need is primarily for salt cooled reactors such as FHRs or MSR.



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