U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Overview of Nuclear Reactor Technologies Program

FY13 NEUP Webinar

John E. Kelly
Deputy Assistant Secretary for Nuclear Reactor Technologies
Office of Nuclear Energy
U.S. Department of Energy

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Outline

- **Office of Nuclear Reactor Technologies (NE-7)**
  - Mission
  - Organization
  - Program Elements

- **Overview of each NE-7 Program Area**
  - Goals
  - Challenges
  - R&D activities
  - FY 2013 budget

Nuclear Reactor Technologies (NE-7) Overview

- **Mission: Keep current fleet operating safely and developing new nuclear technologies for deployment**
  - promote technologies that have greatest promise to enable new nuclear power
  - conduct R&D to maintain safe operation of existing fleet
  - honor commitments to other Federal agencies, International partners and universities
  - maintain unique capabilities and facilities to support future USG policy decisions and industry needs
  - Explore new high-risk, high-reward technologies

- **NE- 7 consists of three Offices (pending approval):**
  - NE-72: Light Water Reactor Technologies – Rebecca Smith-Kevern
  - NE-74: Advanced Reactor Technologies – Tom O'Connor
  - NE-75: Space and Defense Power Systems – Owen Lowe

- **Research activities are designed to address technical, cost, safety, and security issues associated with various reactor concepts**

Nuclear Reactor Technologies (NE-7) R&D Program Elements

- **Reactor Concepts RD&D includes four reactor technology sub-programs:**
  - Light Water Reactor Sustainability Program (LWRS)
  - Next Generation Nuclear Plant Demonstration Project (NGNP)
  - Advanced Small Modular Reactors (SMR)
  - Advanced Reactor Concepts (ARC)

- **Space Nuclear Power Systems**

Light Water Reactor Sustainability (LWRS)

- **LWRS Program Goals**
  - Develop fundamental scientific basis to allow continued long-term safe operation of existing LWRs (beyond 60 years) and their long-term economic viability
- **Benefits**
  - Current fleet provides >70% of non-greenhouse gas emitting electricity
  - Existing reactors reduce burden of new clean electricity that will need to come online
- **Key R&D areas**
  - Materials Aging and Degradation
  - Risk-Informed Safety Margin Characterization
  - Advanced Instrumentation and Controls
  - Systems Analysis and Emerging Issues (includes research to support post-Fukushima lessons learned)
- **FY 2013 Budget Request: $21M**

LWRS Challenges

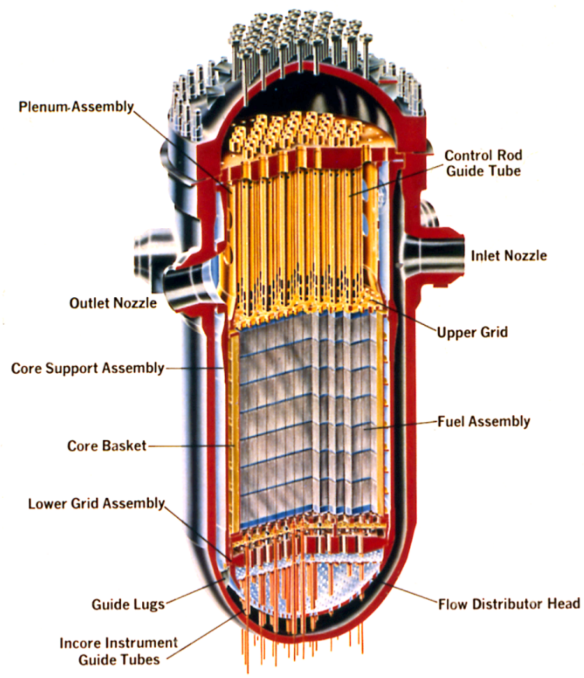
- **Extending reactor life to beyond 60 years will likely increase susceptibility and severity of known forms of materials degradation and potentially introduce new forms of degradation**

- **Aging of Structures, Systems and Components (SSC) has potential to:**
  - Increase frequency of initiating events of certain safety transients
  - Create new and more complex transient sequences associated with previously-not-considered SSC failures
  - Increase severity of safety transients due to cascading failures of SSCs

- **R&D needed to provide tools, methods and data for understanding and predicting materials aging and degradation**
  - Will leverage related modeling and simulation efforts

LWRS – Nuclear Materials Aging and Degradation

- **Goals:**
  - Develop scientific basis for understanding and predicting long-term environmental degradation behavior of materials in nuclear power plants
  - Provide data and methods to assess performance of systems, structures, and components essential to safe and sustained nuclear power plant operations
  - Develop means to detect and characterize aging degradation processes



- **Key technical areas:**
  - Rx metals—looking at high fluence effects and cracking of nickel-based alloys
  - Concrete—developing monitoring tools
  - Cables—degradation and NDE tools

LWRS - Advanced Information, Instrumentation and Controls (IIC)

- **Current analog technology is not sustainable – need to modernize and improve IIC systems**
  - Replacements / upgrades are complex and costly
  - Regulatory uncertainty and a risk-averse industry reinforce the status quo of outdated and antiquated analog I&C
- **Digital instrumentation and control technologies will improve plant monitoring and reliability**
  - Develop advanced Centralized Online Monitoring (OLM) and Information Integration technologies
- **Implemented through a series of 20 planned pilot plant projects with industry**

From this…

…to this!

LWRS – Risk Informed Safety Margin Characterization (RISMC)

- **Support margins management decisions with the aim to improve economics, reliability, and sustain safety of current NPPs**
  - INL will develop and deploy methods and tools that support the quantification and management of safety margin and uncertainty

- **Goals of the RISMC Pathway:**
  - Develop and demonstrate a risk-assessment method coupled to safety margin quantification that can be used by NPPs to better understand and manage plant safety as components age and modifications are made
  - Create an advanced "RISMC toolkit" that enables more accurate representation of NPP safety margin

- **Margin Management Techniques**
  - Determine methods to model, measure, and maintain margins for active and passive components for normal and off-normal conditions
  - Develop techniques to conduct margins analysis, including methodology for carrying out simulation-based studies of safety margins

- **Simulation components of the RISMC Toolkit**
  - RELAP-7: systems code
  - RAVEN: simulation controller and scenario generation
  - GRIZZLY: component aging simulation

Next Generation Nuclear Plant (NGNP) Demonstration Project

NGNP Program Goals

- Expand benefits of nuclear power beyond electricity generation through a public-private demonstration project
  - Work with National Laboratories, industry, Nuclear Regulatory Commission, and international partners to demonstrate high-temperature gas-cooled reactor (HTGR) technology, producing electricity & process heat for industrial applications

Benefits

- HTGRs provide a zero carbon energy source for carbon intensive industrial applications such as petroleum refining and chemical processes
- Increases energy security by reducing the reliance on imported oil

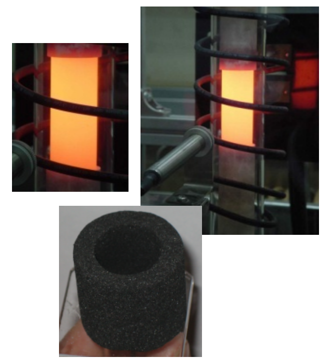
Key R&D areas

- HTGR fuel development and qualification
- Reactor materials
- Reactor analysis methods

FY 2013 Budget Request: $21.1M

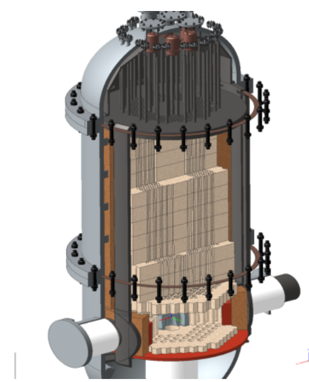
NGNP - Analysis Methods R&D

- **R&D focused on developing practical tools to analyze neutronics, thermal-hydraulics, and safety**
  - Experimental planning and phenomena (Scaling, experimental design, fundamental phenomena identification and PIRT)
  - Modeling and simulation of core phenomena (neutronics, thermal-hydraulics, and multiphysics)
  - Plant simulation and safety analysis, (source term, uncertainty and sensitivity analysis, licensing approaches)



Graphite/Air Reaction Rate Testing

ANL Facility to Validate Reactor Cavity Cooling System Behavior



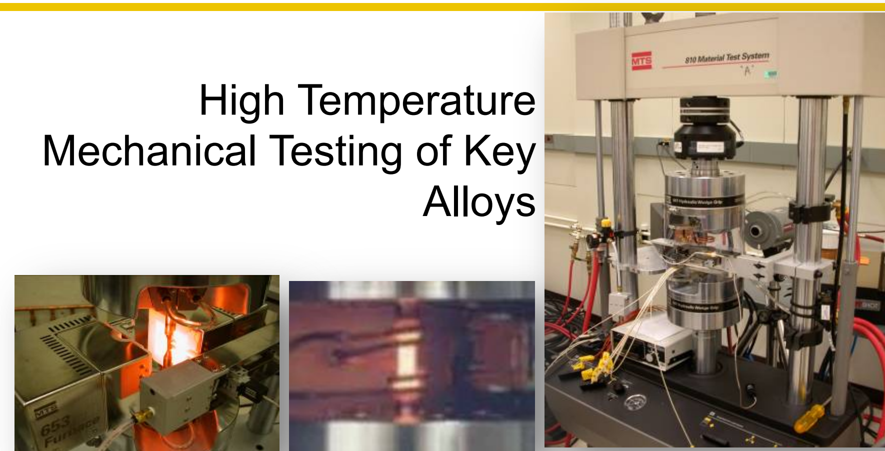
OSU's High Temperature Test Facility to Model Depressurized Cooldown

INL's Matched Index of Refraction (MIR) Facility to Study 3-D Flow Effects in Plena

NGNP – Materials R&D

- **R&D on graphite, ceramics, composites and high temperature structural materials**
  - Improved NDE techniques
  - Graphite recycling and long-term oxidation
  - Irradiation damage/high temperature/moisture effects
    - heat exchanger, steam generator, pressure vessel
  - Predicting component lifetimes
  - ASME code development

High Temperature Mechanical Testing of Key Alloys

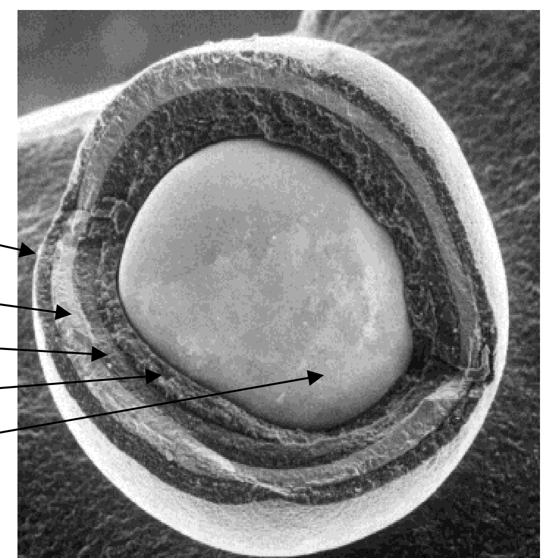


Graphite Characterization Labs at INL and ORNL

NGNP – Fuels R&D

- **R&D to design and fabricate high performance fuels with very low failure rates**
  - Establish credible fission product transport mechanisms and mechanistic source term under normal, off-normal, and accident conditions
  - Improved quality control techniques for fabrication
  - Develop innovative fuel designs for higher outlet temperatures and increased fuel margins relative to existing concepts

1000 micron coated fuel particle



Advanced SMR R&D

Advanced SMR R&D Program Goals

- Develop advanced SMR technologies with emphasis on technologies that:
  - are manufactured in a factory and shipped to the site
  - offer simplified operation and maintenance for distributed power applications
  - achieve greater levels of safety and resilience, flexibility of use, sustainability and construction or operational affordability

Benefits

- Inherent/passive safety features
- Increased flexibility
- Lower initial construction costs

Key activities

- Develop innovative concepts that utilize advanced technologies to achieve expanded functionality; Materials, Instrumentation, Control, Human, Machine Interface (ICHMI)
- Evaluating technologies that further reduce costs; Economic Analysis
- DELTA (Pb) loop on-line
- SMR site suitability and screening tools

FY 2013 Budget Request: $18.5M

Advanced SMR R&D Focus Areas

- **Instrumentation, Control, Human, Machine Interface (ICHMI)**
  - Evaluate advanced SMR R&D concepts and identify technology gaps/challenges
  - Place emphasis on passive safety and on coordination of multiple modules to meet demands of single grid or energy system
  - Develop approaches integrating personnel and automation to maximize productive safe operations of SMRs

- **Component and Technology Development**
  - Establish key long-term design needs for advanced SMR R&D materials; long-term degradation mechanisms such as creep and creep-fatigue damage, thermal aging and corrosion
  - Develop high-temperature materials qualification and validation data for commercial materials alloys 617 and 800H

- **Safety and Licensing**
  - Identify various types of emerging SMR technologies and key attributes to consider when developing a licensing support plan. Develop guidance for performing an initial "regulatory gap analysis"

- **Economic, Analysis and Evaluation**
  - Develop an economic model that can examine individual effects of modular construction and factory fabrication for FOAK to NOAK deployment

Advanced Reactor Concepts (ARC)

- **ARC Program Goals**
  - Develop and refine future reactor concepts that could dramatically improve nuclear power performance, including sustainability, economics, safety and proliferation resistance
  - Reduce long-term technical barriers for advanced nuclear energy systems focusing on fast reactors, fluoride-cooled advanced high-temperature reactors and energy conversion systems

- **Benefits**
  - ARC R&D is focused on advanced reactor concepts that can:
    - Resolve key feasibility and performance challenges
    - Reduce fabrication, construction and operating costs, and
    - Explore and develop supercritical CO2 Brayton thermal cycle for improved conversion efficiency and reduced plant size

- **R&D Focus Areas**
  - Liquid metal-cooled fast reactors
  - Liquid fluoride salt-cooled reactors
  - Advanced energy conversion technologies, eg. supercritical CO2 Brayton cycle

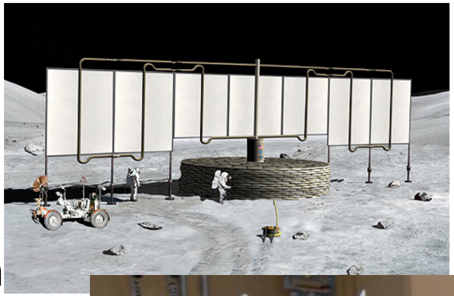
- **FY 2013 Budget Request: $12.4M**

ARC Key R&D Activities

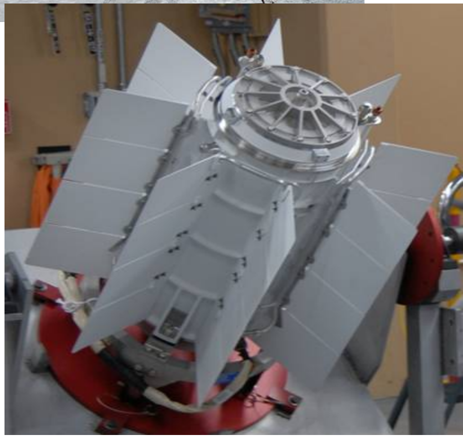
- **Reactor Concept Development**
  - Evaluate and compare alternative coolants and develop optimal integrated reactor system designs
- **Initiation of Mechanisms Engineering Test Facility Project**
  - Establish a platform for testing of innovative systems and components in high temperature liquid sodium
- **Advanced Materials**
  - Advanced structural alloy development and testing
  - Support development of codes and standards
- **Advanced Energy Conversion Systems**
  - Supercritical CO2 Brayton cycle machinery performance, Computational Fluid Dynamics modeling, corrosion chemistry
- **Construction of a Liquid Salt Test Loop**
  - Re-establish high-temperature fluoride-salt technology
  - Investigate phenomena specific to liquid salt including core heat transfer, corrosion, and fluidic diode performance

Space Nuclear Power Systems

- **Space Nuclear Power Systems Program Goals**
  - Design, develop, build and deliver radioisotope power systems for space exploration and national security applications
  - Support research, development and design of fission power systems for space exploration and national security needs



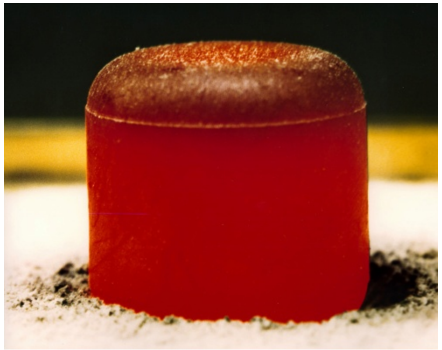
- **Benefits**
  - Enable customer missions in locations and environments wh other power systems such as chemical batteries and solar power systems do not work
  - Directly support NASA missions to explore the moon, mars, outer plants and beyond



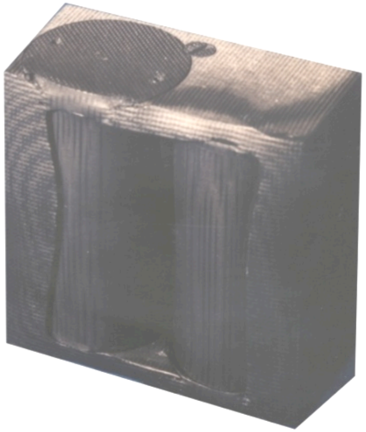
- **Key R&D Areas:**
  - Develop materials for use in the extreme environments of space applications
  - Improve the efficiency of thermoelectric couples

Space and Defense Power System R&D Challenges

- **Innovative Heat Source Fuel Forms**
  - New and innovative methods of formulating ceramic heat sources that would be enveloped by geometry and heat output of current designs and lead to enhanced safety performance



- **Replacement Materials for Aeroshells**
  - Alternate materials for aeroshell module that protects fuel during potential atmospheric reentry events, to meet or exceed ablation resistance, thermal conductivity, and structural strength of current material



- **Improved Thermoelectrics**
  - High efficiency thermoelectric couples with hot side temperature of 1000 C to obtain a target efficiency between 20-30% and stability to support an operable life of 10 years

NRT FY13 NEUP Work scope

- **RC-1: Computational Methodologies**
- **RC-2: Advanced Technologies, Development and Demonstration**
- **RC-3: Advanced Structural Materials**
- **RC-4: Materials Aging and Degradation: Accelerated Test Techniques and Validation**
- **RC-5: Risk-Informed Safety Margin Characterization (RISMC): Advanced Mechanistic 3D Spatial Modeling and Analysis Methods to Accurately Represent Nuclear Facility External Event Scenarios**
- **RC-6: Instrumentation, Information, and Control: Online Monitoring Technologies for Standby Safety Systems**
- **RC-7: Radioisotope Power Systems Applied R&D**
- **MS-RC-1: Reactor Concepts R&D**
- **MS-RC-2: Radioisotope Power Systems RD&D**