Introduction and Kickoff

Andrew Sowder
Sr. Technical Executive, Advanced Nuclear Technology

Innovation Network for Fusion Energy (INFUSE) Workshop
December 1, 2020
Electric Power Research Institute...Born in a Blackout

- Mission: advancing safe, reliable, affordable and environmentally responsible electricity for society

- Independent, nonprofit center for collaborative public interest energy and environmental research

- Major offices in Palo Alto, CA, Charlotte, NC, and Knoxville, TN
  - Laboratories in Knoxville, Charlotte and Lenox, MA
  - In-country presence around the world

- International membership and reach:
  - International members > 25% of EPRI research (~50% for nuclear)
  - EPRI members generate > 90% of the electricity in the United States (100% of US nuclear)
  - EPRI programs engage > 75% of nuclear operators globally

New York City: The Great Northeast Blackout, 1965
A Research Portfolio Spanning Entire Electricity Sector

**Generation**
- Advanced Coal Plants, Carbon Capture and Storage
- Combustion Turbines
- Environmental Controls
- Major Component Reliability
- Materials and Chemistry
- Operations and Maintenance
- Power Plant Water Management
- Renewable Energy

**Nuclear**
- Advanced Nuclear Technology
- Chemistry, Low-Level Waste and Radiation Management
- Equipment Reliability
- Fuel Reliability
- Long-Term Operations
- Materials Degradation/Aging
- Nondestructive Evaluation and Material Characterization
- Risk and Safety Management
- Used Fuel and High-Level Waste Management

**Energy & Environment**
- Environmental Sciences: Air and Multimedia
- Strategic Analysis and Technology Assessments
- Environmental Sciences: Groundwater and Land Management
- Workforce and the Public: Health Assessment and Safety
- Environmental Sciences: Water and Ecosystems

**Power Delivery and Utilization**
- Distribution Utilization
  - Distribution
  - Energy Utilization
  - Information, Communication, and Cyber Security

- Transmission
  - Grid Operations and Planning
  - Transmission and Substations
EPRI Focus on Advanced (Fission) Reactors

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Evolving Technologies, Markets, and Missions for Nuclear

GEN I & II
Early demonstrations through GW-scale commercial fleets
- Diversity of designs
- Diversity of vendors
- Diversity within vendors
- Limited standardization
- Aggressive build rates
- Evolving regulations

GEN III/III+
Evolutionary designs, GW-scale +
- Convergence on ALWRs
- Passive safety
- Standardization
- Integration with licensing
- Emergence of SMRs
EPRI and European utilities establish LWR-centric requirements

Advanced Reactors
Beyond large LWRs: GEN IV, non-LWRs, IwSMRs
- Aggressive cost and schedule targets
- Competitiveness via new missions and customers
- Focus on innovation, tension with standardization?
- Evolving regulatory frameworks
EPRI launches AR Owner-Operator Requirements

Microreactors
MWe-scale expands technology options
- Heat pipe cooling
- Remote deployment
- New markets
- Competition with diesel
Advanced Nuclear Technology (ANT) Program Focus

Accelerating the deployment of nuclear power around the world

Informing Resource Planning  
Driving Innovation  
Reducing Deployment Costs  
Supporting Plant Startup

Training  
Siting and Owner Requirements  
Design and Engineering  
Technical Basis  
Advanced Manufacturing  
Commissioning  
Initial Operations

From project initiation through initial operation

ANT is an extension of your team
Expanding AR Community Engagement in EPRI

Full ANT Members

Advanced Reactor Supplemental Members

New in 2020
Renewed ANT Program for the Next Generation Plants

Needs of New Plants

- Flexible
- New Materials
- Resilient Supply Chain
- Reduced Construction Costs
- Efficient Startup

Focus Areas

- Advanced Reactors
- Advanced Reactor Material Development
- Advanced Manufacturing
- Engineering and Construction Innovation
- Commissioning and Initial Operations
Advanced Manufacturing

Goal: Identify, develop, qualify and implement more economical manufacturing technologies that enable:

- Higher Quality Components
- Reduced Lead Times
- Alternative Supply Chains
- Cost Competitiveness

Additive Manufacturing

- 316L LPBF Code Case & Data Package (submitted to ASME August 2020)
- Additive Manuf. Roadmap for Nuclear Applications (Q3 2020)
- DED-AM Component Demonstration

Advanced Manuf. Demonstration Project

- PM-HIP
- EB Welding
- DLC
- Heat Treat

Advanced Welding Techniques

- Adaptive Feedback Welding
  - ANT + WRTC
- Modular In-Chamber EBW
Engineering and Construction

Goal: Identify, develop, qualify engineering and construction technologies that enable:

- Reduced Cost • Increased Quality • Improved Efficiency

Automated Technologies
- 3D Scanning of Embedded Items in Concrete
- Digital Twin for Structure Life Cycle
- Smart Structural Monitoring

Engineering Solutions
- Siting Guide
- URD
- Design
- Field Guides

High Strength Concrete and Reinforcement
- Experimental Testing and NDE
- Concrete Optimizations
Commissioning and Initial Operations

**Goal:** Ensure a smooth transition from construction to commissioning, and then to initial operations by:

- New Plant Startup
- Lessons Learned
- Technology Transfer

**New Plant Technical Assistance**

Develop detailed guidance for all phases of a new plant project: Project Initiation, Pre-construction, Commissioning and Initial Operations.

**New Products**

Guidance and Best Practices for Construction Tests

Analysis of Recent Startups

**Existing Needing Updates**

Startup Program Guidelines

Establishing a Maintenance Program for New Builds

Source: IAEA Nuclear Energy Series No. NP-T-2.10
The Nuclear Family Tree
Advanced Reactors in Context

- Small Modular Light Water Reactor (SMR)
- Gas-cooled Fast Reactor (GFR)
- Lead-cooled Fast Reactor (LFR)
- Sodium Fast Reactor (SFR)
- Supercritical-water-cooled Reactor (SCWR)
- Molten Salt Reactor (MSR)
- High-temperature Gas-cooled Reactor (HTGR)
Fission Offers a **Unique** Bundle of Energy Attributes (Fusion Too!)

- energy dense
- dispatchable
- non-emitting
- scalable

Other low carbon options co-dependent on maturity of auxiliary technologies.
Advanced Reactors

Goal: Enable and accelerate commercialization of advanced reactors by:

Aligning Design Attributes with End-User Needs • Increasing Understanding • Addressing Technology Gaps

Requirements & Guidance

Owner-Operator Requirements

Safety-in-Design

Strategic Analysis and Technology Assessment

Economics and Markets

Expanded Flexibility Concept

Technology Development and Transfer

TRISO Fuel Qualification

AR Material Gap Analysis
### Austenitic Stainless Steels

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>316H SS</td>
<td>Extend BPV-III Div 5. Code properties to include time dependent behavior (Creep, Creep fatigue)</td>
</tr>
<tr>
<td></td>
<td>Development and demonstration of cladding (Mo rich) for protection</td>
</tr>
<tr>
<td>316FR SS</td>
<td>Code qualification properties for ASME Code Sec III Div 5 for 316FR including time dependent properties</td>
</tr>
<tr>
<td>Type 15-15Ti SS</td>
<td>Verification of swelling resistance</td>
</tr>
<tr>
<td></td>
<td>Development of code properties for 15-15Ti material design</td>
</tr>
<tr>
<td>Alumina Forming SS</td>
<td>Demonstration of adequate resistance to irradiation/swelling at expected high dpa</td>
</tr>
<tr>
<td></td>
<td>Development of processing and joining of alumina forming austenitic stainless steels</td>
</tr>
<tr>
<td>D9 Stainless Steel</td>
<td>Development of for ASME Code Sec III Div 5 properties (including time dependent properties) for D9</td>
</tr>
<tr>
<td></td>
<td>Development of swelling behavior at long times under realistic conditions – demonstrate adequacy</td>
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### Ferritics-Martensitics and Low Alloy Steels

<table>
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<tr>
<th>Material</th>
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<tbody>
<tr>
<td>Ferritic-Martensitic--9Cr</td>
<td>Demonstration of adequate resistance to swelling at high fluence range.</td>
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<td></td>
<td>Time dependent properties for ASME Code Sec III Div 5.</td>
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<tr>
<td></td>
<td>Development of fabrication and effective joining methods</td>
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<tr>
<td>Ferritic-Martensitic--12Cr</td>
<td>Demonstration of adequate resistance to swelling at high fluence range.</td>
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<tr>
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<td>Time dependent properties for ASME Code Sec III Div 5.</td>
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<tr>
<td></td>
<td>Development of fabrication and effective joining methods</td>
</tr>
<tr>
<td>Ferritic Martensitic</td>
<td>Validation of commercial reliability – Properties sensitivity to heat treatment/local microstructures</td>
</tr>
<tr>
<td></td>
<td>Response to fabrication processes – welding practices</td>
</tr>
<tr>
<td>LAS</td>
<td>Time dependent and fatigue properties for ASME code Sec III Div 5</td>
</tr>
</tbody>
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### Nickel-Based Alloys

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<tbody>
<tr>
<td>Hastelloy N</td>
<td>Demonstration of radiation tolerance of Hast N variants (Proper understanding of chemistry→ microstructure properties</td>
</tr>
<tr>
<td></td>
<td>Development of properties for ASME Code Sec III Div 5 certification</td>
</tr>
<tr>
<td>800H and 617</td>
<td>Summary Document of Properties</td>
</tr>
</tbody>
</table>

### Summary Document of Properties

- **AR (Gen IV) Material Gap Analyses Published 2019 - 2020**
  - **Downloadable at EPRI.com for Free**

- **Identify candidate materials for major AR families:**
  - SFRs - 3002016949
  - HTGRs/GFRs - 3002015815
  - LFRs - 3002016950
  - MSRs - 3002010726

- **Review available data for implementation into designs**

- **Outline development and validation programs**
Economics and Competitiveness of Advanced Nuclear


Key drivers influencing deployment:

- Competition (technology)
- Capital costs
- Revenue
- Regional factors
- Energy and environmental policies

Cumulative nuclear additions through 2050 (GW) across a range of sensitivities (horizontal axis) and nuclear capital costs (dots)

Fusion and fission look the same to current capacity expansion models.