EPRI Perspective on Common R&D Opportunities and Challenges for Microreactor Deployment

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Advanced Nuclear Technology

GAIN-EPRI-NEI Microreactor Workshop
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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

New York City: The Great Northeast Blackout, 1965

- 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

Advanced Reactors are Here

In this decade …

- Microreactors
- Non-light water reactors
- Light-water small modular reactors

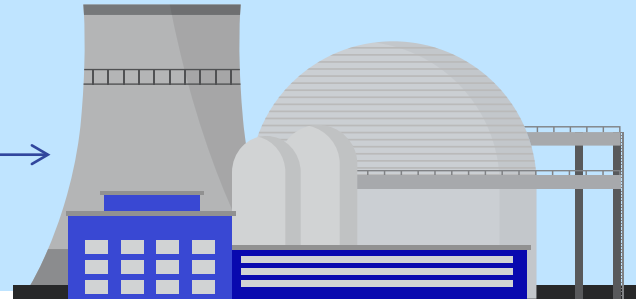
… will be deployed

The time to prepare for an advanced reactor future is now

ANT's Focus

MISSION

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

Energy Economics

Design and Engineering

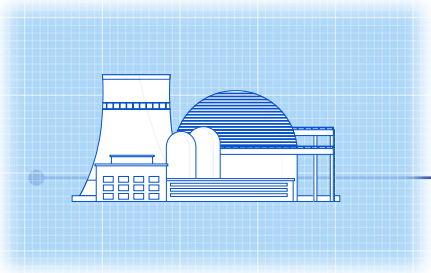
Technical Basis

Construction Optimization

Advanced Manufacturing

Commissioning

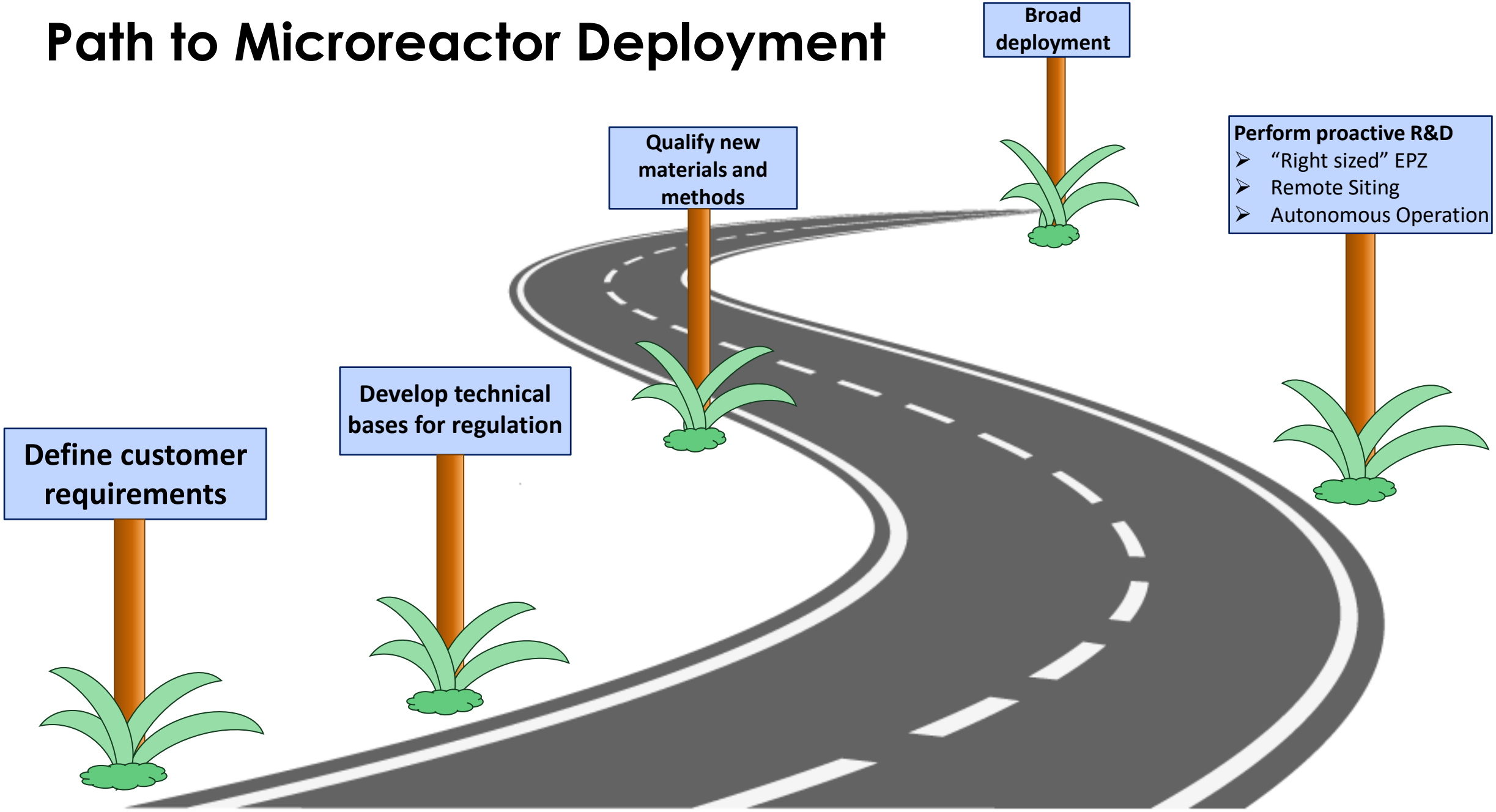
Initial Operations



From project initiation through initial operation

ANT is an extension of your team

Path to Microreactor Deployment



Cross-Cutting R&D Areas Supporting Microreactor Deployment

Security and Staffing
- Cyber security
- Physical security
- Staffing requirements

Engineering and Design
- Design codes and standards
- Seismic design
- Owner-operator requirements
- Digital engineering

Operation and Maintenance
- Remote and/or autonomous operation
- Performance of novel components, configurations
- Inspection/NDE
- Operational experience and best practices

Materials and Manufacturing
- Material testing and qualification
- Fuel testing and qualification
- Fabrication and manufacturing methods
- Welding/joining technology
- Supply chain development and support

Safety Assessment and Licensing Basis
- Classification of SSCs
- Licensing basis events
- Defense in depth
- External hazards
- Reliability of novel components, configurations

Advanced Manufacturing & Materials

GOAL & VALUE

Identify, develop, qualify & implement more economical manufacturing, inspection & new materials that enable:

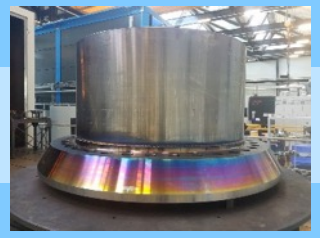
Higher Quality Components | Reduced Lead Times | Alternative Supply Chains | Cost Competitiveness | Enable Deployment

Advanced Manufacturing

Additive

PM-HIP

Mechanical Connections

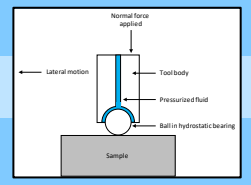


Advanced Welding

Advanced Cladding

Material Performance and Inspection

Mitigation Tech



Chemistry Control

Risk Informed Strategies

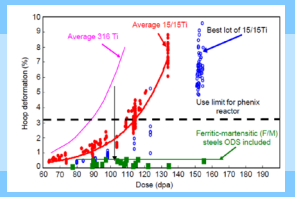
Advanced Sensors

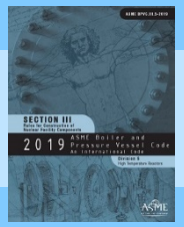
Enhanced Specs

New Materials Development

Degradation Mechanisms (MMMs/MDMs)

AR Materials Development





Materials Qualification

Materials Challenges for Advanced Reactors

- **Code Qualification**
  - Only 6 ASME/JSME Code Qualified alloys for high temperature service
  - Additional Alloys Under Consideration

Can take **10 years** to fully qualify a new alloy

Just because the material is Code Qualified doesn't mean it is approved for Nuclear Service (*or optimized*)

- **Environmental Effects**
  - Owner/Operator has the responsibility to demonstrate to regional regulator that the effects on structural failure modes are accounted for in their specific reactor design

What's Required for Regulatory Approval:

- Irradiation data
- Corrosion due to coolant
- Thermal performance—embrittlement over time

Limited data exists for all the above

Still Not Done

Additional, critical data and understanding required for informed fabrication and design of AR components

- Optimized fabrication processes
- Weld data

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

Austenitic Stainless Steels

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

Ferritics-Martensitics and Low Alloy Steels

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

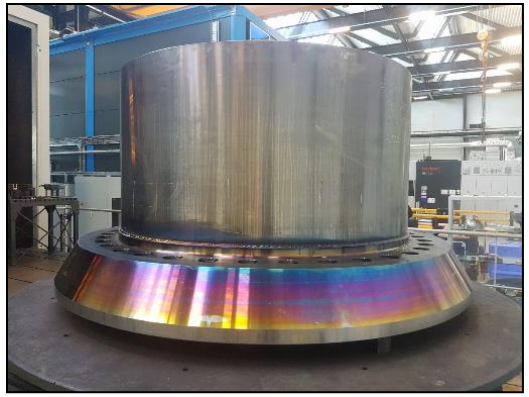
Nickel-Based Alloys

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

AR Materials Development Industry Coordination Workshop Planned for June

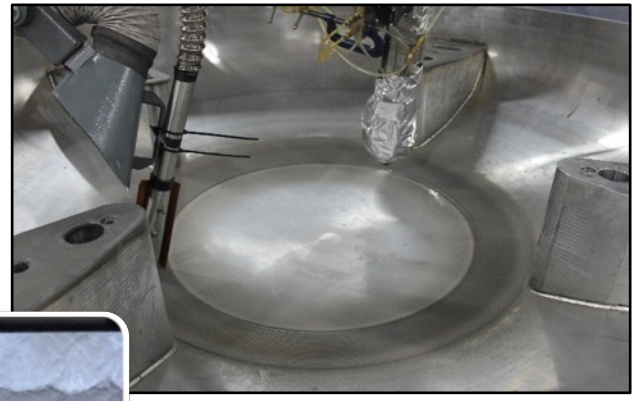
Advanced Manufacturing Techniques

- Eliminate Long Lead Forgings
  - Traditionally 2-5 year lead time
  - PM-HIP components produced in 6-12 months
  - Goal to reduce to 40% of costs
- Powder Metallurgy - Hot Isostatic Processing
  - Produces near-net shaped components
  - Eliminates 1000's of hour of machining
- Electron Beam Welding (EBW)
  - 10x reduction in typical weld times, compared to conventional welding processes and methods.
  - Demonstrate EBW for fabricating reactor sections
- Diode Laser Cladding
  - Reduces cladding material by > 50%
  - No machining required after application
- Advanced Machining
  - Reduces machining time by up to 4X



Lower RPV Flange Shell Mockup
Electron Beam Weld
~6 ft (1.82m) diameter

Completed in 47 minutes

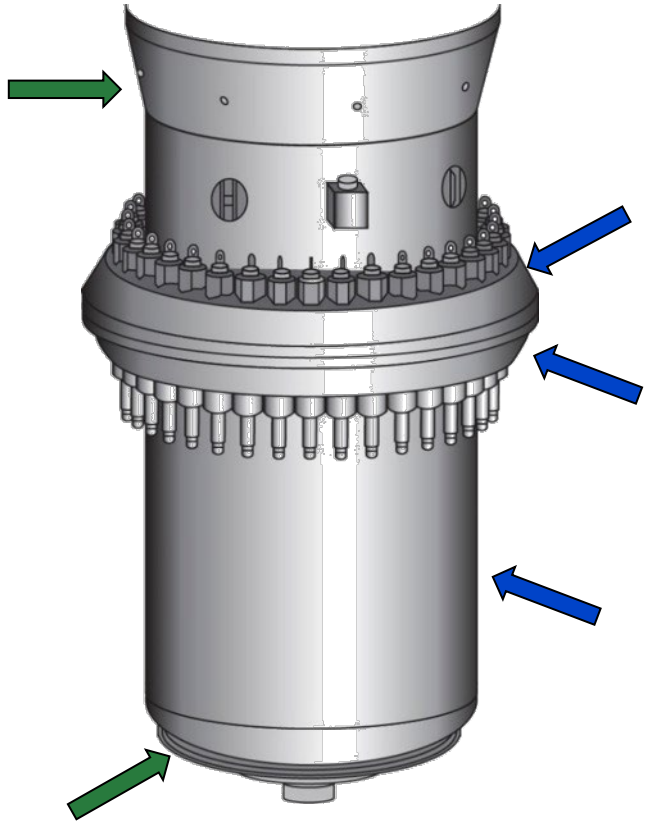


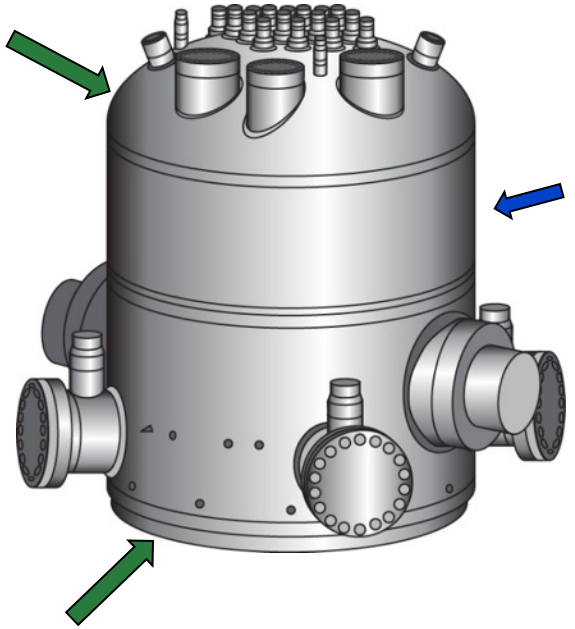
Goal = Accelerate Commercial Deployment of Small Modular Reactors

SMR Advanced Manufacturing Project

Objectives

- Rapidly accelerate the deployment of SMRs
- Develop/Demonstrate new methods for manufacture & fabrication of a RPV in **< 12 months**
- Eliminate **40%** from the cost of an SMR RPV
- Primary Advanced Methods:
  - Powder Metallurgy-Hot Isostatic Pressing (PM-HIP)
  - Electron Beam Welding
  - Diode Laser Cladding





Representative Model of NuScale Power Reactor Pressure Vessel
Copyright NuScale Power

DOE Project DE-NE0008629

EPRI ELECTRIC POWER RESEARCH INSTITUTE

U.S. DEPARTMENT OF ENERGY

NUCLEAR AMRC

NUSCALE Power for all humankind

Technical Reports:
3002015814: Progress Report (Year 1)
3002019335: Progress Report (Year 2)

SMR Advanced Manufacturing Project

Mockup Fabricated from Forgings & Assembled via Electron Beam Welding

NUCLEAR AMRC

Circumferential Welds Completed in < 60 minutes

SMR Advanced Manufacturing Project

Lower RPV Assembly

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