U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Update on DOE Small Modular Reactor Program

NRC Briefing on Small Modular Reactors

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

November 5, 2014

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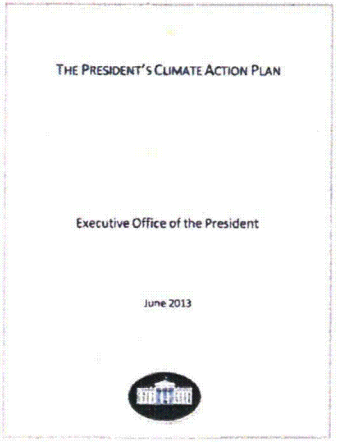
Nuclear Energy

SMRs Directly Support the President's Climate Action Plan

- **Clean energy goals cannot be met without significant contributions from nuclear power**
- **SMRs will complement large units giving utilities more nuclear power options**
  - Reduce capital cost and project risk
  - Improve passive safety technology
  - Potentially replace aging fossil plants
- **SMR deployment would create high-quality domestic manufacturing, construction, and engineering jobs**
- **SMR technology would give the US the opportunity to influence the safety, security, and safeguards of nuclear power globally**



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Licensing Technical Support Program is Cornerstone of DOE Effort

- **Public/Private projects**
  - Reduce regulatory and financial risk
  - Support design/engineering, testing, certification and licensing through cost sharing agreements
  - Accelerate commercial SMR development
  - Expect deployment in 2020's
- **Program began in 2012**
  - 6 year/$452 Million program
- **Agreements signed with mPower and NuScale teams and work is progressing**

SMR Small Modular Reactor

LICENSING TECHNICAL SUPPORT PROGRAM

NuScale

mPower

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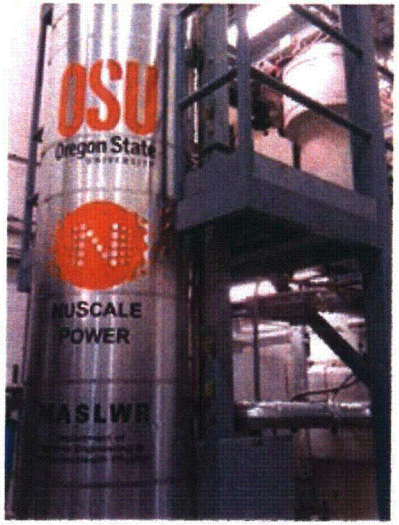
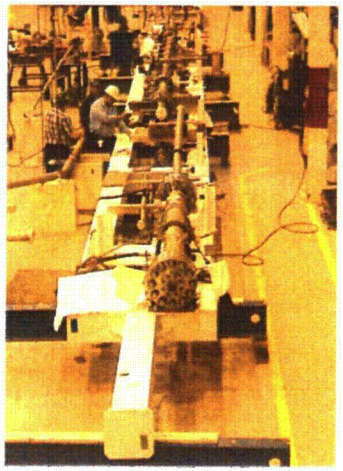
Engineering and Testing Infrastructure For Design Validation is Progressing



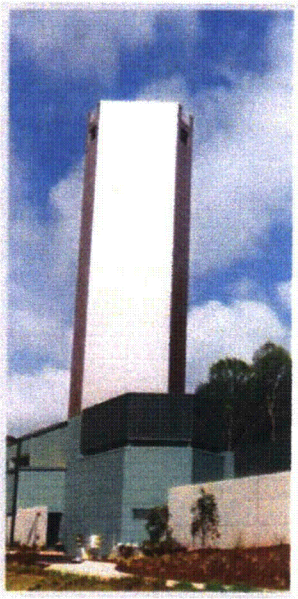
*MASLWR integral test facility continues to support **NuScale** design development and validation.*



Component prototype testing on reactor coolant pumps and control drive mechanisms

Bore hole drilling at Clinch River

***B&W mPower** Integrated System Test facility in Lynchburg, VA*



***NuScale** Control Room at Corvallis, OR*

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Additional DOE Efforts to Advance SMR Technology

- **SMR update to EPRI Utility Requirements Document**
- **Economic viability assessments**
  - Cost Comparison Study
  - Manufacturing Learning Study
  - Portfolio Analysis Study
  - SMR Business Case Study
- **Supporting EPRI aerosol deposition project**
- **Assessments of potential SMR sites**
  - Assessing Federal sites for potential SMR siting
  - Several States are also conducting feasibility studies
- **NNSA International Safeguards and Security Assessment**
  - LW-SMRs do not differ from conventional LWRs for the purposes of international safeguards and security

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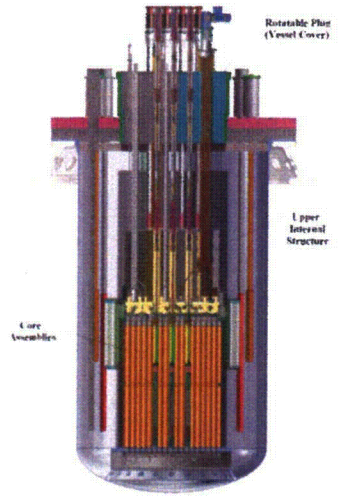
Advanced Small Modular Reactors

- **Industry designers continue to show significant interest in the development of Advanced SMRs**
  - Seven Advanced SMR concepts were submitted during the 2014 DOE Technical Review Panel process to identify advanced reactor R&D needs
  - Fourteen applications were received in response to a Funding Opportunity Announcement for cost-shared , industry-led R&D
  - Broad participation by industry in the United States Nuclear Infrastructure Council and Argonne National Laboratory sponsored Advanced Reactor workshop in early 2014

- **DOE and NRC are working to develop Advanced Reactor General Design Criteria**
  - Over eighty industry, university and national laboratory participants

- **DOE is supporting R&D for Advanced SMRs in several areas**
  - Advanced fuels - TRISO coated particle fuel qualification
  - Advanced materials and graphite qualification
  - Advanced design and testing of compact reactor components
  - In-service inspection technology/techniques
  - Supercritical CO_2 energy conversion systems
  - Advanced high temperature instrumentation



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NRC Actions are Very Important for SMR Program

- **Extensive and ongoing pre-application engagement with SMR vendors**
- **Design Specific Review Standard development**
- **Standard Review Plan revisions (NUREG-0800)**
- **Regulatory Guide 1.206 update**
- **Engagement on design and risk-informed approaches**
  - Source Term calculations
  - Appropriately sized Emergency Planning Zones (EPZs)
  - Treatment of multiple modules at a site
  - Staffing requirements for operations and security
- **Readiness assessment in SECY-14-0095**

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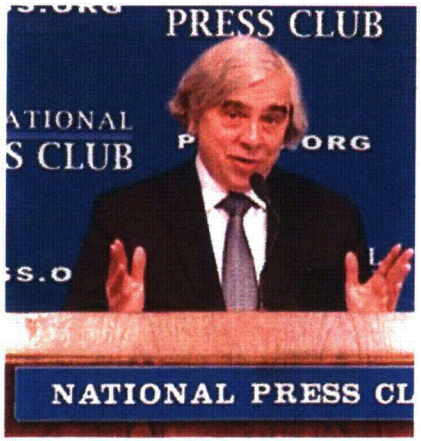
Summary

- **Nuclear Power is important for the U.S. All-of-the-Above Energy Strategy**
- **DOE stands behind continued SMR development and sees the market emerging in the 2022-2025 timeframe**
- **We will continue to support efforts that improve SMR market potential domestically and internationally**



"All-of-the-Above is not merely a slogan, but a clear-cut pathway to creating jobs and at the same time reducing carbon emissions, which recently stood at their lowest level in 20 years…

President Obama has made clear that he sees ***nuclear energy*** *as part of America's low carbon energy portfolio.* ***And nuclear power is already an important part of the clean energy solution here in the United States."***

~ Secretary of Energy, Dr. Ernest Moniz,
National Press Club, February 19, 2014

Industry Perspective on Small Modular Reactors

November 5, 2014

Ricardo (Ric) Pérez

Senior Vice President, Tennessee Valley Authority

Chairman, NEI Small Modular Reactor Working Group

Three key perspectives:

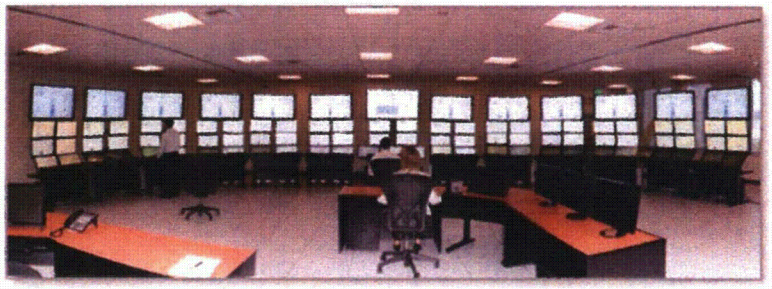
- ✓ Clear need for the SMR option
- ✓ SMR industrial capabilities available
- ✓ Need for a predictable regulatory path forward

There is a need for SMRs

- SMR projects target the delivery of reliable, carbon-free electricity to variable and diverse markets
- SMRs may provide replacement power for retiring generation and complement renewables
- SMRs offer potential for improved safety and innovation

NuScale 1/3-scale test facility

Corvallis, Oregon



NuScale Control Room Simulator

Sustaining development and licensing investment requires a predictable regulatory framework

- SMR development and investments on target to submit NRC applications in 2015 and 2016
- NRC priority/resources needed on key issues before applications are submitted
- Apply lessons learned from new plant projects

Full height Integrated Systems Test Facility
Bedford, Virginia

CRDM Prototype Testing
Euclid, Ohio

Images used by permission of Generation mPower LLC

Summary

- Utilities want SMR options in the next decade
- Successful large reactor programs provide a regulatory/policy roadmap
- Continue efforts to resolve issues and provide SMR regulatory clarity
  - Emergency planning
  - Application and review standards

Clinch River Site
Oak Ridge, Tennessee

Market Considerations and Projections for SMRs

November 5, 2014

Anthony Ianno, Managing Director,
Investment Banking, Morgan Stanley

Overview of Investors' Views

- Although existing nuclear is valued for fuel diversity and environmental advantages, it is economically challenged in many markets
- Completion of new nuclear units under construction is critical to test the new NRC licensing regime

Overview of Investors' Views (Cont'd)

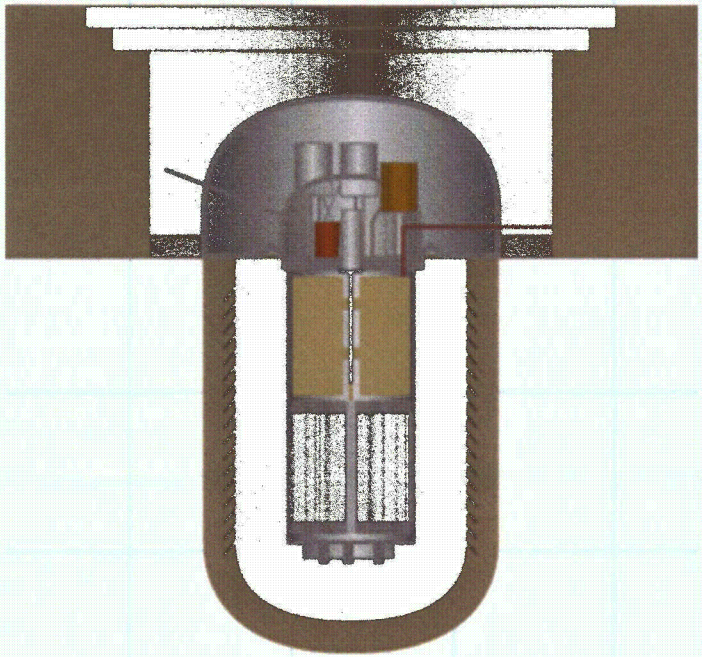
- Rate base treatment or long-term power agreements required to finance new nuclear construction
- Competitive markets do not support development of new nuclear power generating facilities

Financing Implications for SMRs

- Investors will focus on total production cost including operating cost and risk-adjusted return on capital costs in appraising economic viability
- SMRs are considered a new technology with technological risk
- Construction and regulatory risks will need to be addressed

Financing Implications for SMRs (Cont'd)

- Investors will require protection against potential disallowances or write offs
- Mechanisms like DOE Loan Guarantee required to assure debt financing
- Incentives for Equity Investors would also be necessary since loan guarantees only addresses debt financing



Small Modular Reactors

Technology and Deployment Choices

Alexander Glaser

Department of Mechanical and Aerospace Engineering
and Woodrow Wilson School of Public and International Affairs
Princeton University

Briefing for the U.S. Nuclear Regulatory Commission
Rockville, Maryland, November 5, 2014

Source: terrestrialenergy.com

Revision 4b

Princeton Project on Small Modular Reactors

funded by the MacArthur Foundation, Carnegie Corporation of New York, and the Princeton Carbon Mitigation Initiative

SCOPE OF PROJECT

Review and analyze proposed SMR designs and their associated nuclear fuel cycles

Examine the implications of a large-scale deployment of SMRs with a particular focus on resource requirements and proliferation risks

(Research supported by neutronics calculations for notional SMRs)

OUTLINE OF THIS TALK

Part I: Technology Choices for SMRs

Part II: Siting and Deployment Choices for SMRs

PART I: Technology Choices for SMRs

Integral Pressurized Water Reactors

("Leveraging the First-to-Market Advantage")

Most Concepts Considered Today Are Based on Standard Light-water Reactor Technology

Design	Company	Power	Status
mPower	Babock & Wilcox	2 x 180 MWe	Detailed design
NuScale	NuScale Power	12 x 45 MWe	Detailed design
W-SMR*	Westinghouse	225 MWe	Basic design
HI-SMUR (SMR-160)	Holtec	145 MWe	Basic design
SMART	KAERI	100 MWe	Licensed
KLT-40S	OKBM, Russia	2 x 32 MWe	Under construction

*Project currently suspended

(Babcock & Wilcox (mPower) and NuScale Power have been selected by DOE's cost-sharing program)

General Observations About Integral Pressurized Water Reactors

Technology is mature

(compared to all other SMR concepts currently being considered)

Characteristics compared to existing gigawatt-scale light-water reactors

Significantly higher uranium/fuel demand (55–65%)
(and respective increase in volume of spent fuel)

Significantly higher demand for enrichment capacities

Comparable attractiveness of spent fuel for reprocessing or diversion
(total plutonium production increases by 30–40%, but lower concentration in spent fuel)

A. Glaser, L. Berzak Hopkins, M. V. Ramana, "Resource Requirements and Proliferation Risks Associated with Small Modular Reactors," *Nuclear Technology*, 184, October 2013, pp. 121–129

PART I: Technology Choices for SMRs

Reactors with Lifetime Cores

("Offering the Nuclear Battery")

Early Interest in SMRs was Often Motivated by the Vision of Lifetime-Core Reactors

A 2007 IAEA report discussed 30 reactor concepts without on-site refueling

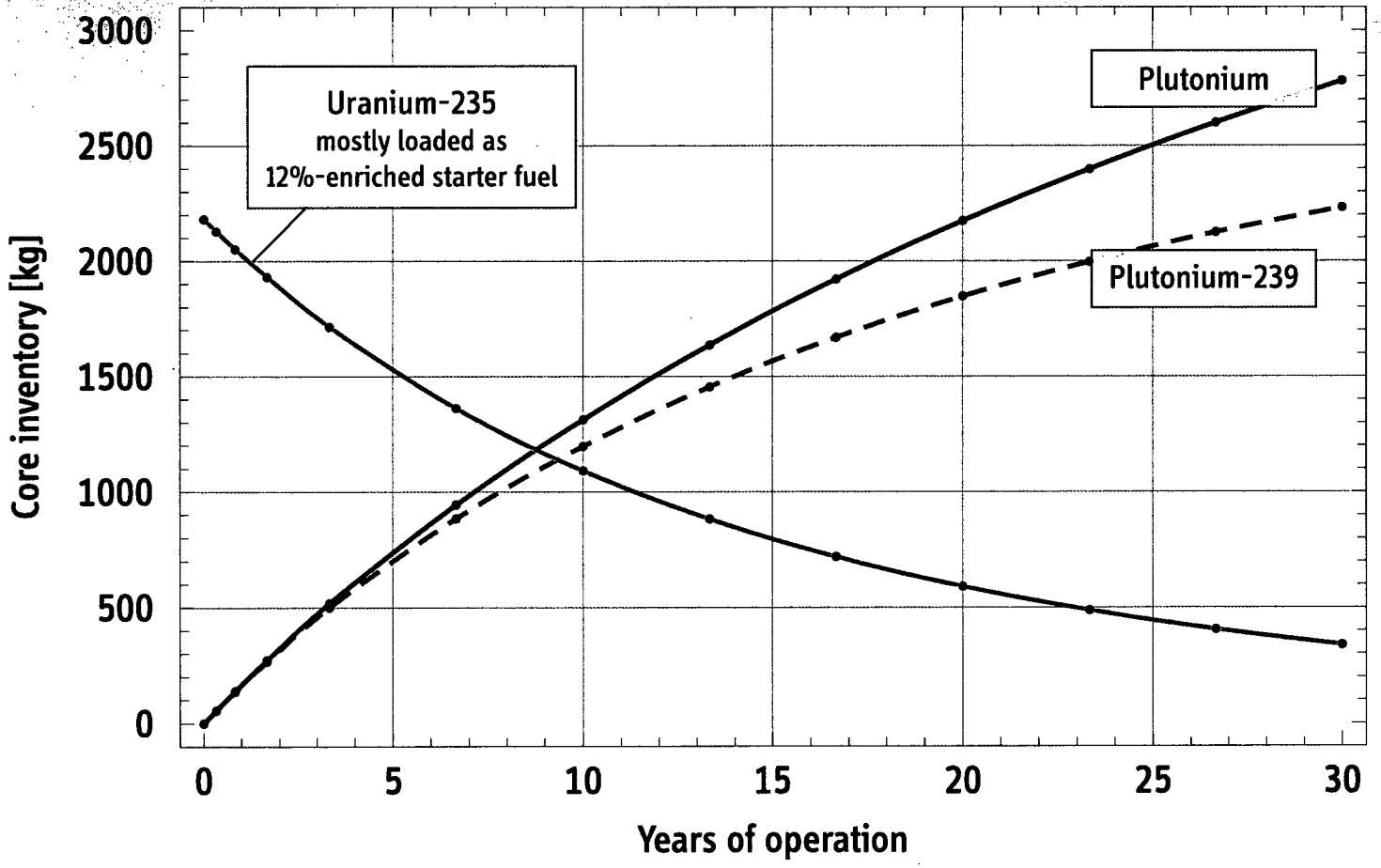
but very few projects in this category retain (some) momentum today

Design	Company	Power	Status
Gen4 Module (G4M)	Gen4 Energy (USA)	25 MWe	Conceptual design
4S	Toshiba (Japan)	10 MWe	Detailed design
EM^2	General Atomics	200 MWe	Conceptual design

Status of Small Reactor Designs Without On-Site Refuelling, IAEA-TECDOC-1536, International Atomic Energy Agency, January 2007

SMRs with Lifetime Cores Can Have Significant Inventories of Fissile Material

Neutronics calculations for a notional design, 200 MWe, 30-year core life, 300 days per year



A. Glaser, L. Berzak Hopkins, M. V. Ramana, "Resource Requirements and Proliferation Risks Associated with Small Modular Reactors," *Nuclear Technology*, 184, October 2013, pp. 121–129

General Observations About (Small) Reactors with Lifetime Cores

Characteristics compared to existing gigawatt-scale light-water reactor

Significantly decreased resource demand
(when operated as a break-even breeder, e.g. with a fast-neutron spectrum)

In principle, compatible with once-through operation
(but large plutonium inventory in spent fuel potentially "attractive" for reprocessing)

Overall proliferation risks strongly depend on design choices and fuel-cycle architectures

Significant technology gaps remain

(especially with regard to irradiation performance of fuels and materials)

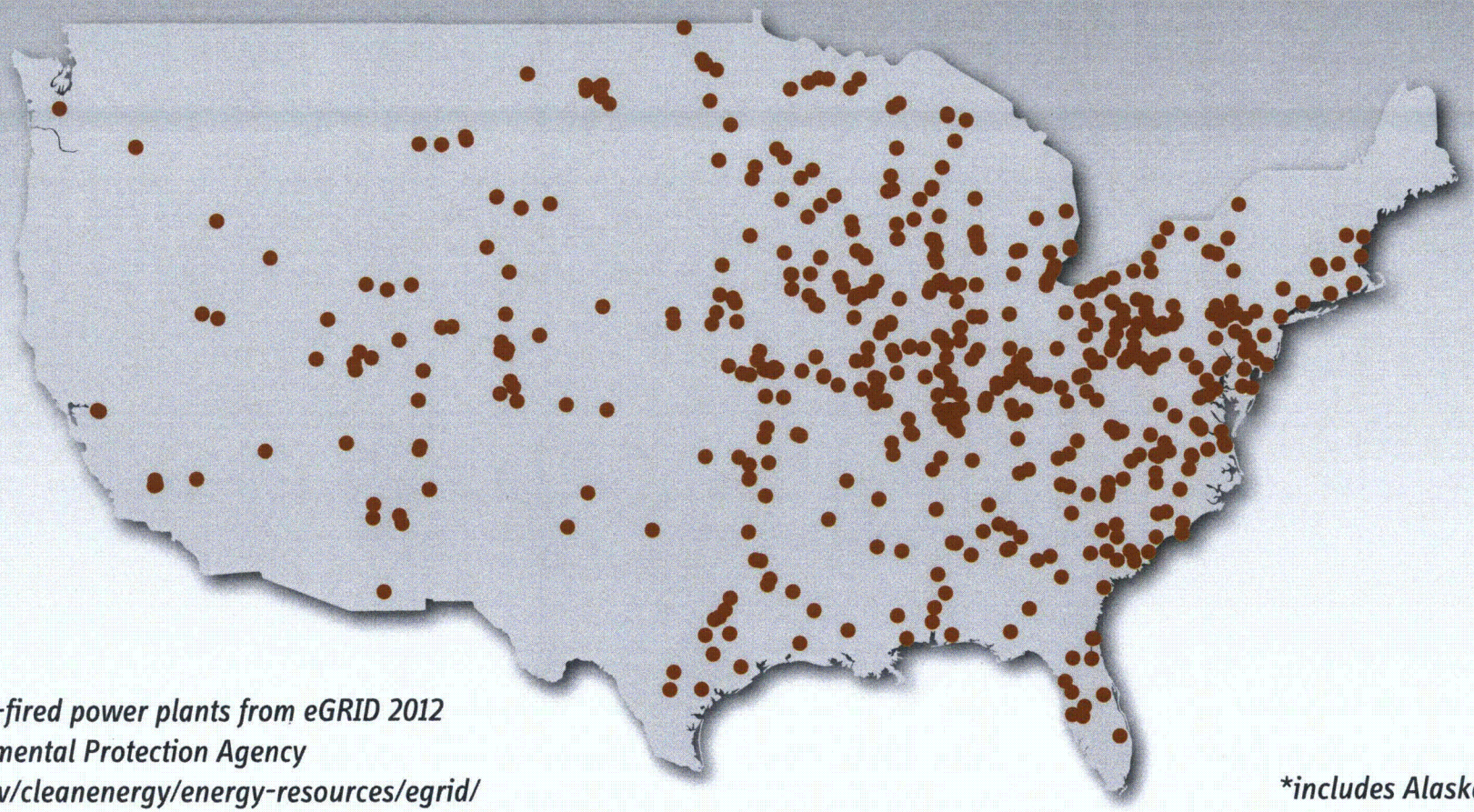
PART II

Siting and Deployment Choices

Could Small Modular Reactors Be Deployed at Sites That Previously Hosted Coal-fired Plants?

In the United States, 560 coal sites (1370 generators) with an installed capacity of 330 GWe*

250 sites (with about 600 generators and a cumulative capacity of 115 GWe) could be considered candidate sites for SMR deployment (pre-1980 and 40–500 MWe)



Data on coal-fired power plants from eGRID 2012
U.S. Environmental Protection Agency
www.epa.gov/cleanenergy/energy-resources/egrid/

**includes Alaska and Hawaii*

Siting Small Modular Reactors

Coal-fired power plants are generally closer to urban areas

No U.S. nuclear power plant has population of more than 300,000 within 10 miles of the plant whereas 30% of U.S. small/old coal plants have population of more than 300,000 within that range

But large numbers of coal-plants are still in relatively remote areas

60% of U.S. small/old coal plants have population of less than 100,000 within 10 miles
(compared to 75% of all U.S. nuclear power plants)

This corresponds to about 150 sites with 70 GWe (i.e., hypothetically 200–300 SMRs)

Many opportunities to site SMRs at locations similar to typical nuclear sites

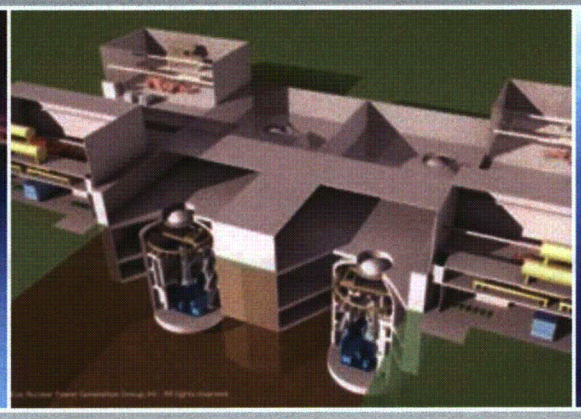
(Moreover, 62 additional sites with operating nuclear power plants)

Based on population data from the United States 2010 Population Census; Digital Map and Geospatial Information Center, Princeton University

Proposed Deployment Modes for SMRs

on barges, underground, underwater

FNPP, Rosatom



mPower, B&W

Flexblue, DCNS

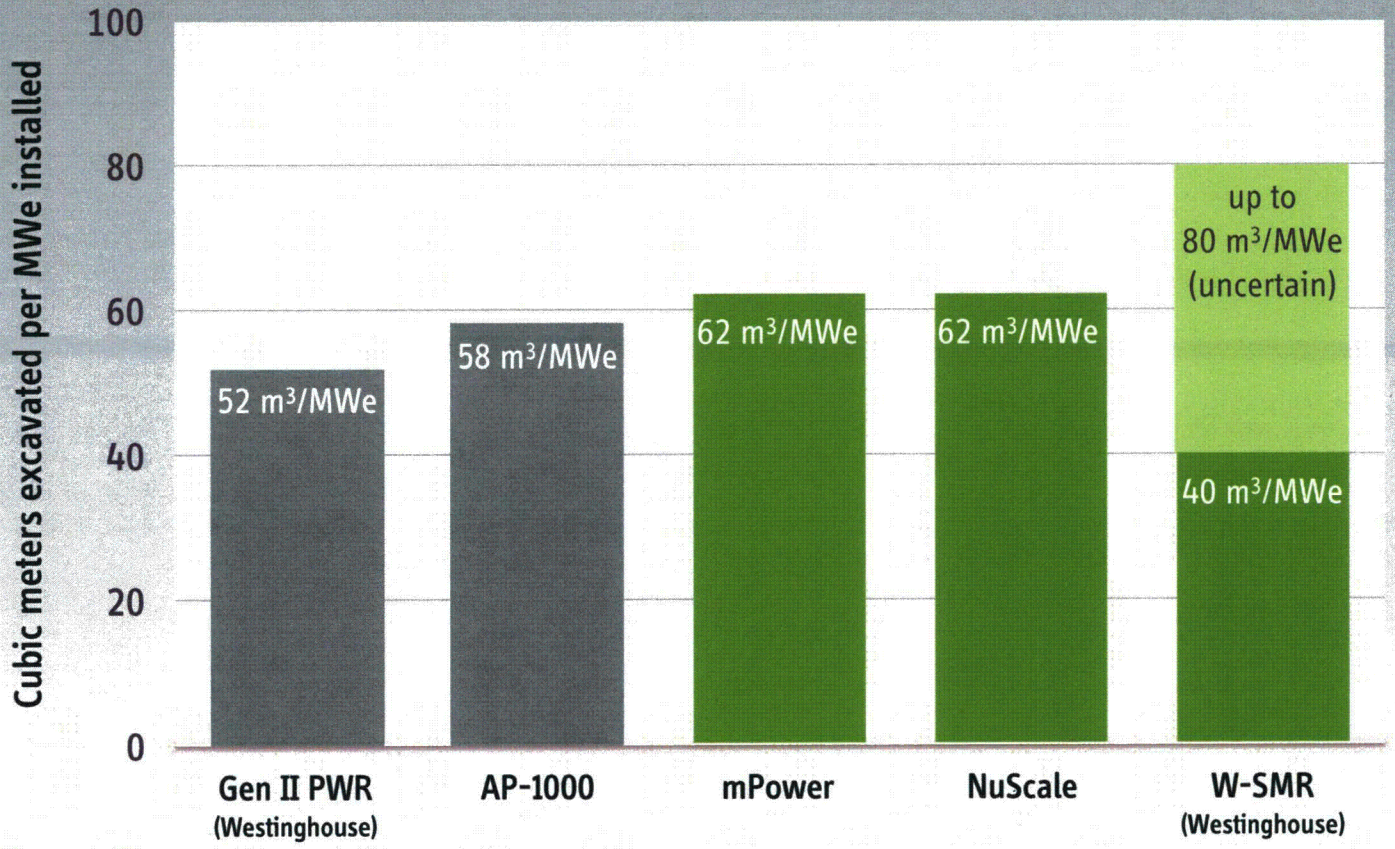
Essentially all SMR designs currently considered for near-term deployment in the United States would be built underground

Idea is not new but has attracted new attention since 9/11

C. W. Forsberg and T. Kress, Underground Reactor Containments: An Option for the Future?, CONF-970649-3, 1997
W. Myers and J. M. Mahar, Underground Siting of Small Modular Reactors: Rationale, Concepts, and Applications, ASME Symposium, 2011

Excavation Volumes for Underground Siting

(Based on the Containment Size of Different Reactor Types)



Per megawatt installed, underground siting of SMRs is not necessarily easier than for typical gigawatt-scale power reactors

Values for SMRs are estimates by Ali Ahmad (Princeton University, October 2014)

Underground vs Aboveground Siting

Underground siting may have important advantages ... but also some drawbacks

Enhanced protection against aircraft impact and (possibly) earthquakes
(versus accessibility in emergencies or resistance to flooding)

Additional costs of underground siting are highly uncertain, somewhere between 20–60%

SMRs already challenged to compete with large reactors on levelized cost of electricity

Benefits of agreeing early on "standard" deployment modes

Standardization can "enhance plant safety, improve the efficiency and reduce the complexity and uncertainty in the regulatory process"

Nuclear Power Plant Standardization, Policy Statement
Nuclear Regulatory Commission, 10 CFR Part 50, 52 FR 34884, Washington DC, September 1987

Summary

Technology and Deployment Choices for SMRs

(Summary)

Technology Choices for SMRs

Current focus is on light-water reactor concepts for SMRs

Risk of technology lock-in by giving preference to first-to-market projects

Reactor design choices and fuel-cycle architectures determine resource requirements and proliferation risks of SMRs

Siting and Deployment

Many sites available in the United States that are comparable to typical nuclear sites
(with regard to population density near the plant)

Underground vs aboveground siting involves tradeoffs between security, safety, and economics

U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

Briefing on Small Modular Reactors

November 5, 2014

Mark Satorius

Executive Director for Operations

Deborah Jackson

Deputy Director, Division of Advanced Reactors and Rulemaking

Agenda

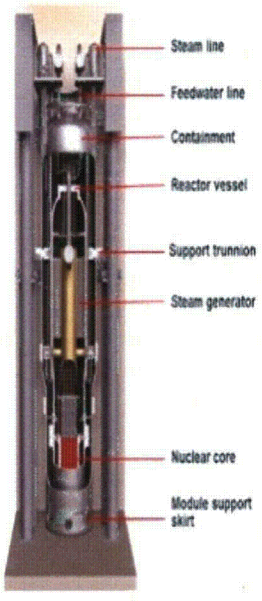
- SMR Licensing
- Guidance
- Policy

Stewart Magruder
Chief, SMR Licensing Branch

Pre-Application Interactions Facilitate More Effective Reviews

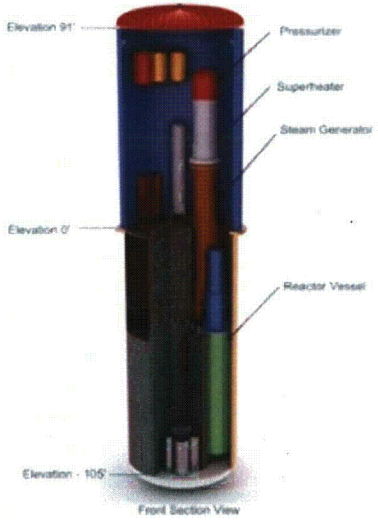
- Meeting frequently with SMR designers on technical topics
- Identified licensing, policy, and technical issues
- Developing Design Specific Review Standards (DSRSs)

Engaged in Productive Discussions with SMR Designers

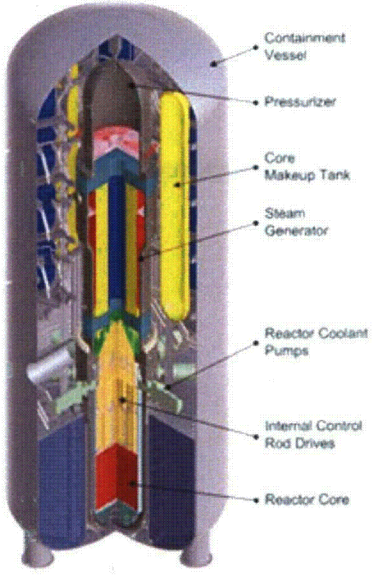


NuScale

mPower



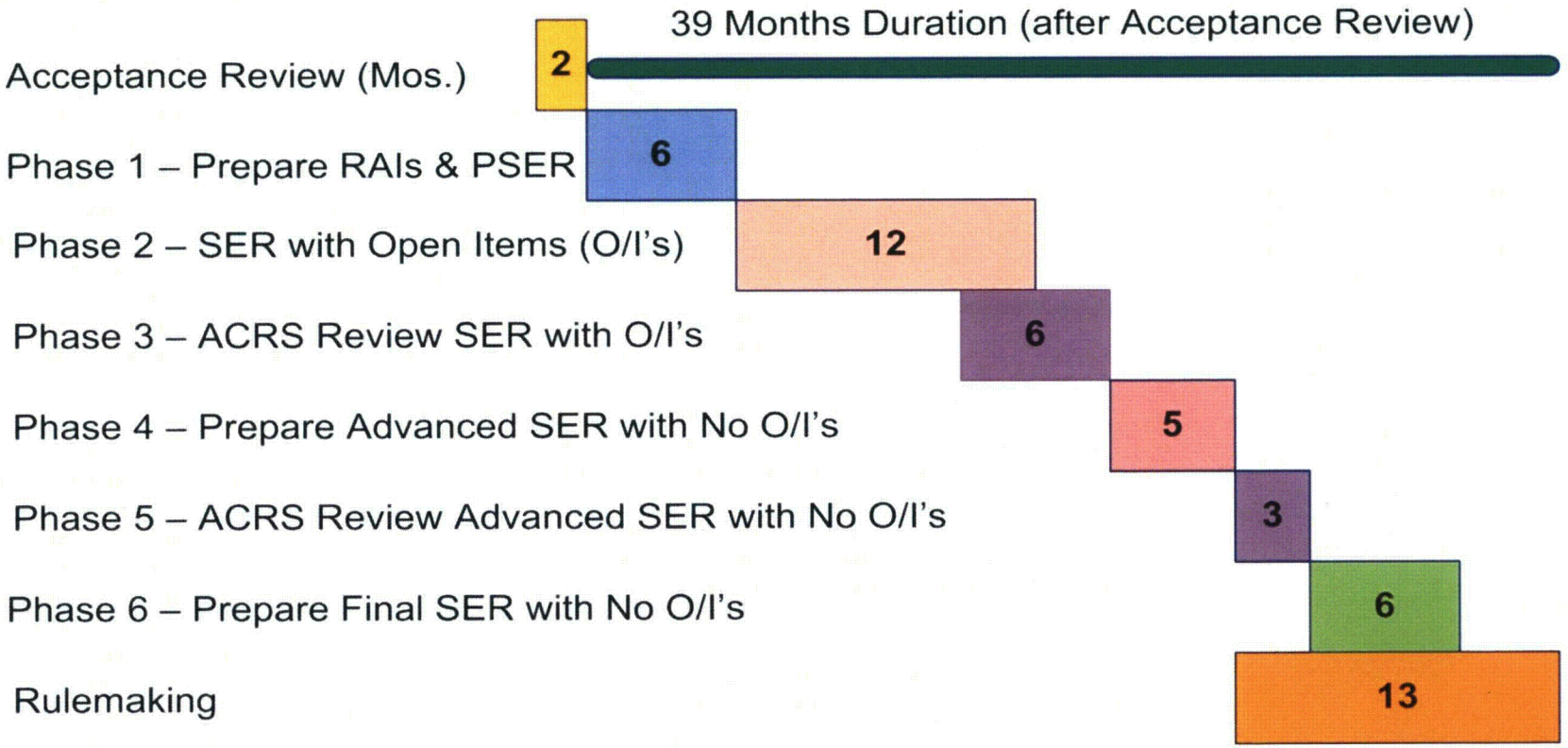
Holtec SMR-160



Westinghouse SMR

Baseline Review, Optimal Scenario

Baseline SMR Design Certification Review Schedule



Optimal Scenario Requires Satisfying Key Assumptions

1. Requests for additional information answered in a timely manner
2. DSRS complete before docketing
3. Positions developed on all critical issues

Additional Key Assumptions

4. Safety Evaluation Report with Open Items complete before phase 3
5. Use of Design Acceptance Criteria is minimized

Actively Observing TVA Early Site Permit Preparations

- **Informative site visits**
- **Effective public meetings**

Diane Jackson at the Clinch River Site

NRC Leading Collaboration with International Partners

- **Established forum for SMR regulators**
- **Goal is to identify and address key regulatory challenges**

INPRO Dialogue Forum on SMRs

Forum Objectives

- Share regulatory experience among forum members
- Document and disseminate the results of discussions
- Interact with key stakeholders

Forum Will Address Important Issues

- Emergency Planning Zone size
- Defense in depth
- Grading approaches to reviews

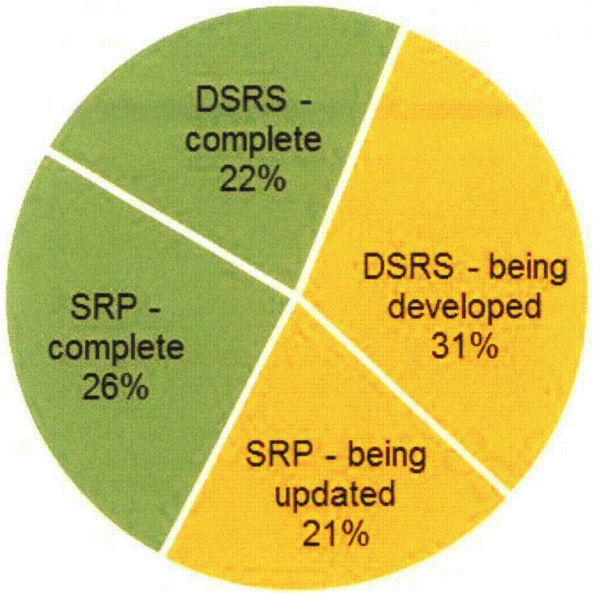
Joseph Colaccino
Chief, New Reactor Rulemaking and Guidance Branch

Completed Guidance to Support SMR Related Application Reviews

- mPower Draft DSRS
- Introduction to Standard Review Plan (SRP) for SMR reviews
- Pre-application readiness assessment guidance
- Interim Staff Guidance for light water reactor reviews

Optimizing Pre-Application Engagement – NuScale DSRS

- **Composition:**
  - **137 DSRS sections**
  - **119 SRP sections**
- **All DSRS and SRP sections complete by end of 2015**



Moving Aggressively to Complete Additional Guidance

- NuScale DSRS
- Staff acceptance review Office Instruction

Application Guidance Updated and Expanded

- **Combined license application Regulatory Guide (RG 1.206)**
  - **Utilizing industry developed standard format and content**
  - **Providing new guidance for applicants that use DSRS**
  - **Enhancing guidance on the Final Safety Analysis Report**

Continued Updates Tied to Submittal Dates

- **Finalize prior to receipt of SMR related application:**
  - **DSRS**
  - **SRP sections referenced by DSRS**
  - **Draft of RG 1.206 for use and comment**

Anna Bradford

Chief, Advanced Reactor and Policy Branch

Significant Work Has Been Accomplished

SECY-10-0034: Potential Policy, Licensing, and Key Technical Issues for Small Modular Nuclear Reactor Designs
SECY-11-0024: Use of Risk Insights to Enhance the Safety Focus of Small Modular Reactor Reviews
SECY-11-0079: License Structure for Multi-Module Facilities related to Small Modular Nuclear Power Reactors
SECY-11-0098: Operator Staffing for Small or Multi-Module Nuclear Power Plant Facilities
SECY-11-0112: Staff Assessment of Selected Small Modular Reactor Issues Identified in SECY-10-0034
SECY-11-0152: Development of an Emergency Planning and Preparedness Framework for Small Modular Reactors
SECY-11-0156: Feasibility of Including Risk Information in Categorizing Structures, Systems, and Components as Safety-Related or Non-Safety Related
SECY-11-0178: Insurance and Liability Regulatory Requirements for Small Modular Reactor Facilities
SECY-11-0181: Decommissioning Funding Assurance for Small Modular Nuclear Reactors
SECY-11-0184: Security Regulatory Framework for Certifying, Approving, and Licensing Small Modular Nuclear Reactors
Commission Memo: Current Status of the Source Term and Emergency Preparedness Policy Issues for Small Modular Reactors (5/30/13)
Commission Memo: Update Regarding Recommendations for Use of Risk Insights for Small Modular Reactor Reviews (1/30/14)
Commission Memo: Status of Mechanistic Source Term Policy Issue for Small Modular Reactors (06/20/14)
SECY-14-0095: Status of the Office of New Reactors Readiness to Review Small Modular Reactor Applications

Progress on Selected Policy Issues

- ☐ Mechanistic Source Term
- ☐ Emergency Planning Zone
- ☑ Control Room Staffing
- ☑ Security

Mechanistic Source Term (MST) Approaches are Already Being Evaluated

- SMR designers are interested in using MST approaches
- We anticipate more detailed information from industry
- May require a policy decision from the Commission

Emergency Planning Zone (EPZ) Size Will Need Commission Input

- Staff discussed a "scalable" EPZ approach in SECY-11-0152
- NEI submitted a white paper and public meetings have been held
- A new SECY paper is being developed

Guidance Is In Place for Control Room Staffing

- Applicants may propose different staffing levels than currently required in regulations
- NUREG-0711 was updated in November 2012

Guidance Is In Place for Control Room Staffing (cont'd)

- **The need for a long term approach will be further evaluated**

NuScale Control Room Simulator

Security Can Be Handled Under NRC's Requirements

- Industry is taking security into account in their designs
- SMR vendors may propose new approaches to security

Security Can Be Handled Under NRC's Requirements (cont'd)

- **The staff has determined that current security requirements are adequate**

B&W Site Schematic

Strategically Planning for Non-Light Water Reactors

- Issued comprehensive Report to Congress
- Implementing proactive joint, two-phase initiative with DOE
- Commented on proposed safety design criteria for sodium fast reactors

Strategically Planning for Non-Light Water Reactors (cont'd)

- Issued Next Generation Nuclear Plant assessments
- Increasing international engagement

Summary

- Staff has made significant progress and identified policy issues for future Commission consideration
- NRC is engaging in strategic international interactions
- Our preparations ensure the NRC continues to be ready to review SMR applications when they arrive

Acronym List

- ACRS – Advisory Committee on Reactor Safeguards
- DAC – Design Acceptance Criteria
- DOE – Department of Energy
- DSRS – Design Specific Review Standard
- EPZ – Emergency Planning Zone

Acronym List (cont'd)

- FSAR – Final Safety Analysis Report
- INPRO - International Project on Innovative Nuclear Reactors and Fuel Cycles
- ISG – Interim Staff Guidance
- LWR – Light Water Reactor
- MST – Mechanistic Source Term

Acronym List (cont'd)

- NEI – Nuclear Energy Institute
- NGNP – Next Generation Nuclear Plant
- NRO – Office of New Reactors
- O/I – Open Items
- OI – Office Instruction
- PSER – Preliminary Safety Evaluation Report

Acronym List (cont'd)

- RAI – Request for Additional Information
- RG – Regulatory Guide
- SER – Safety Evaluation Report
- SMR – Small Modular Reactor
- SRP – Standard Review Plan
- TVA – Tennessee Valley Authority

Status of Technical and Policy Issues

Issue	No Further Action	Path Forward
Prototype Reactors	✓	
Licensing of Multi-Module Facilities	✓	
Manufacturing License	✓	
Defense-In-Depth	✓	
Key Design Issues	✓	
Control Room Staffing	✓	
Operational Programs	✓	
Installation During Construction	✓	
Facilities Using Process Heat	✓	

B1

Status of Technical and Policy Issues (cont'd)

Issue	No Further Action	Path Forward
Security and Safeguards	✓	
Aircraft Impact	✓	
Decommissioning Funding	✓	
Multi-Module Risk		Revising SRP Ch. 19
Mechanistic Source Term		Assessing Industry's Proposals
Emergency Preparedness		Developing SECY Paper
Annual Fees		Proceeding with Rulemaking
Insurance and Liability		Future Rulemaking, If Needed