Small Modular Reactor
Beiträge zur Erhöhung der Sicherheit kerntechnischer Anlagen

Presented to

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Westinghouse

Outline

- Introduction and background Westinghouse SMR
  - Motivation
  - Benefits
  - Project update
- Westinghouse SMR Technology Overview
  - Plant layout
  - Overview on main systems
  - Modular construction
- Conclusion & Summary

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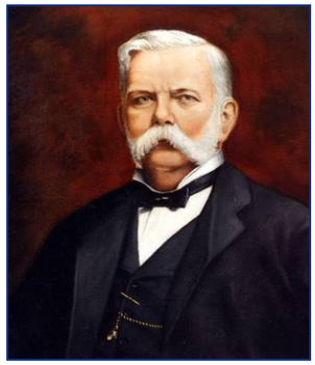
Westinghouse Electric Company
Global overview

- Westinghouse Electric Company provides fuel, services, technology, plant designs and equipment to utility customers in the worldwide commercial nuclear electric power industry
- More than 60 years of nuclear experience with the first commercial PWR in the US in 1957 (Shippingport)
- Nearly 50 percent of the nuclear power plants in operation worldwide, and nearly 60 percent in the United States, are based on Westinghouse technology
- **AP1000®** plant design: The first and only U.S. licensed large passive safety reactor
- State-of-the-art patented technologies and proprietary passive safety systems and technology
- We are only company operating under the name of George Westinghouse's original company



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Westinghouse's Global Vision with the Small Modular Reactor

Westinghouse will develop and deploy a safe, economic SMR to meet the needs of "existing" and "new to nuclear" customers around the world

- ✓ **Working within constraints**
  - Land, grid, cooling water, financing, distributed service territory
- ✓ **Offering clean energy**
  - Offset owner costs for infrastructure development: land, cooling, T&D
  - Generation diversity
  - Operational flexibility
- ✓ **Providing project certainty**
  - Reduced licensing risk
  - Short-construction durations
  - Cost predictability and certainty

A brighter future for nuclear…

- **Aging Fossil Plants**
- **District Heating**
- **Remote Markets**
- **Small Grid Markets**
- **Desalinization**
- **Process Heat**

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The Ameren Missouri & Westinghouse Partnership… supported by a strong industrial team

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Ameren MISSOURI

TECO TAMPA ELECTRIC · Exelon · Electric Cooperatives of Arkansas · FirstEnergy

Burns & McDonnell SINCE 1898 · SRNL · Dominion · KCP&L energizing life · FENOC FirstEnergy Nuclear Operating Company

aeci Associated Electric Cooperative, Inc. · MPUA Missouri Public Utility Alliance · EMPIRE SERVICES YOU COUNT ON · Association of Missouri Electric Cooperatives A Touchstone Energy® Cooperative

- ✓ Multiple seriously interested customers
- ✓ NexStart SMR Alliance will ensure that a license **moves forward**
- ✓ Submit a COLA for deploying the Westinghouse SMR at the Callaway Energy Center

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NexStart SMR ALLIANCE

Westinghouse SMR Technology Overview

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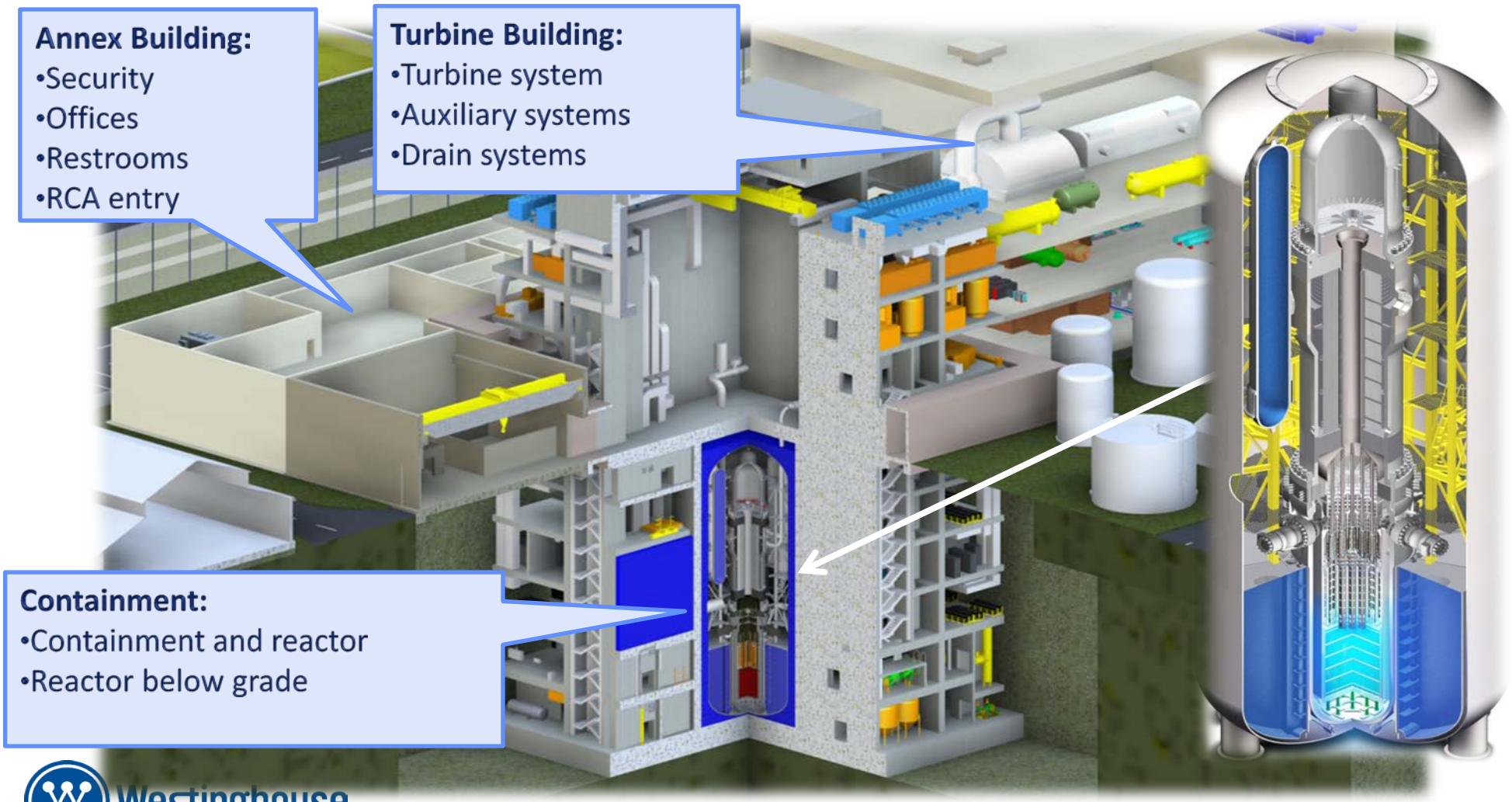
Small Modular Reactor Plant Layout

Site Requirement:
Less than 6 ha, nuclear island 33,5 m x 33,5 m



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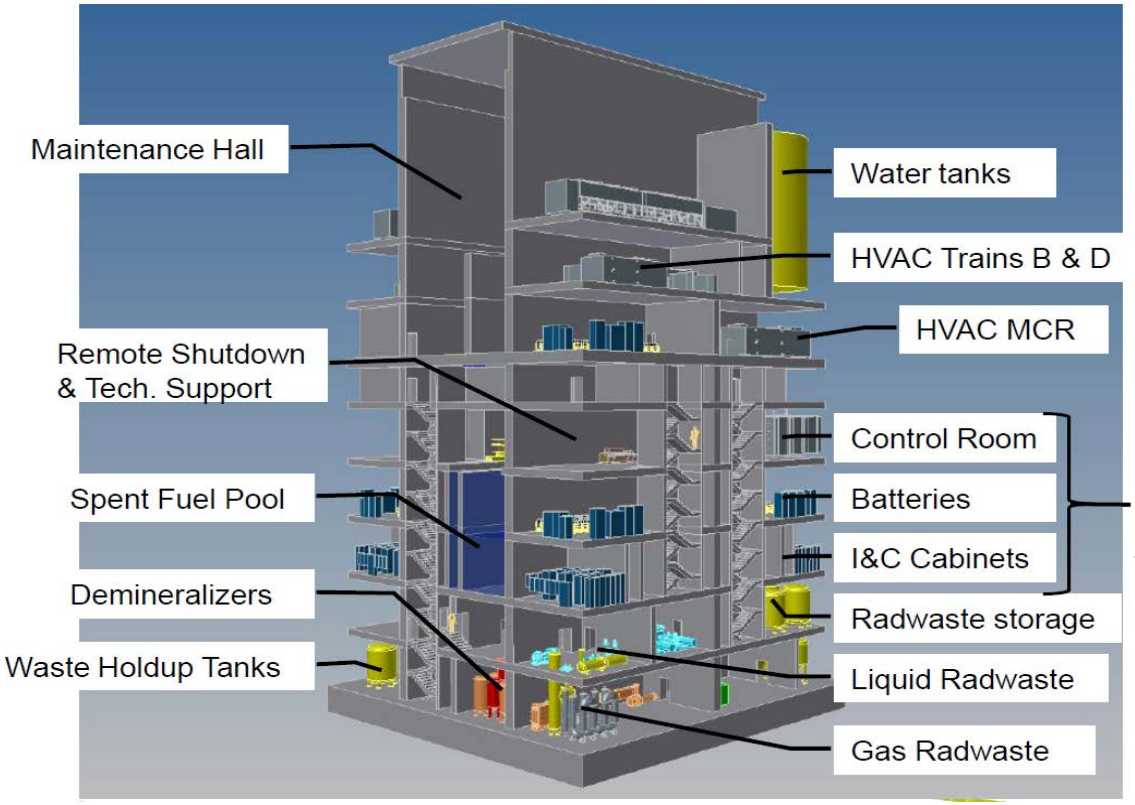
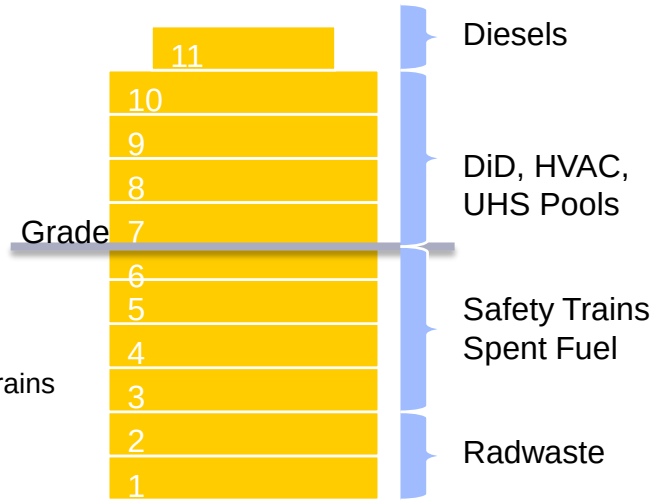
Westinghouse Small Modular Reactor Nuclear Island Layout





Compartments isolate safety system components for enhanced safety and security

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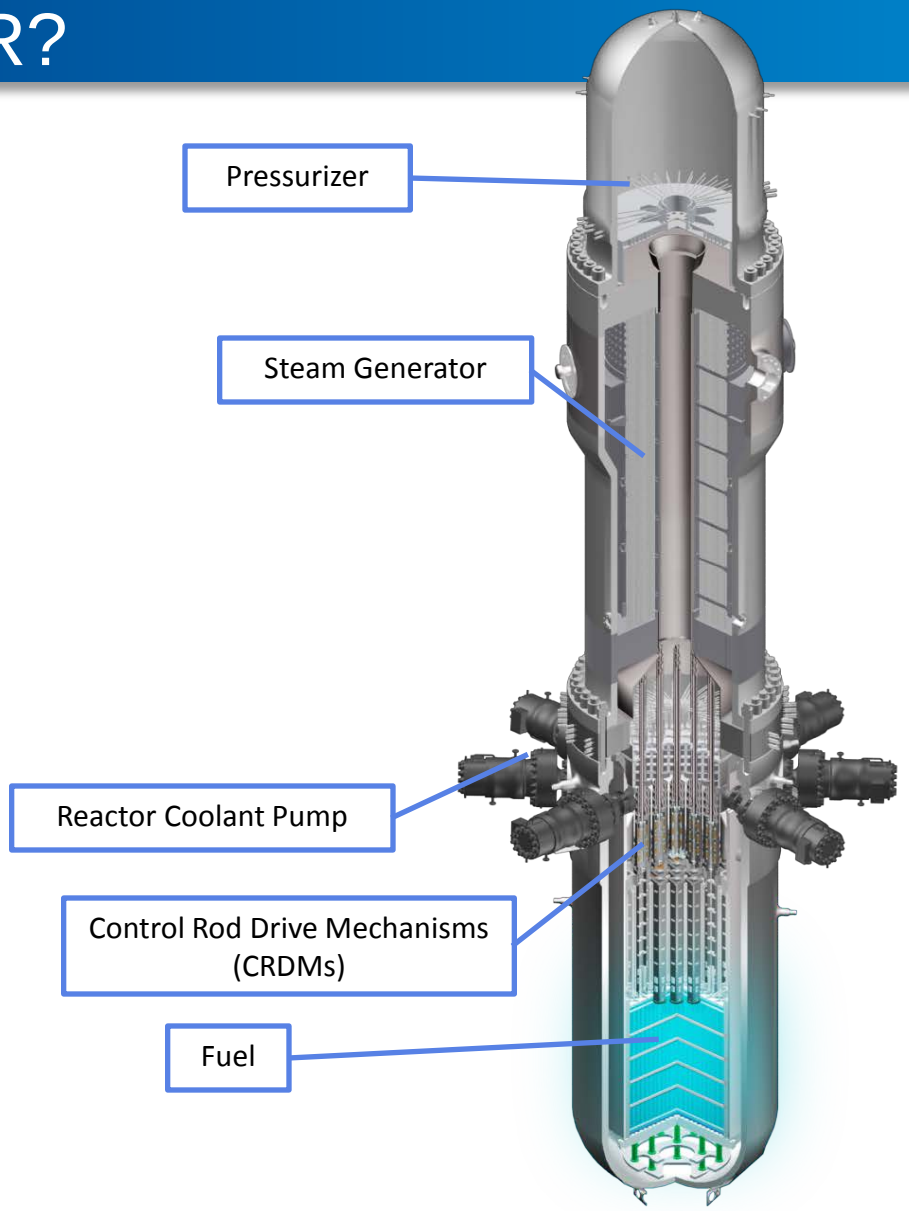
Small Modular Reactor
What is the Westinghouse SMR?

- An integral pressurized water reactor—single >225 MWe reactor
- Standalone unit; no shared systems
- Innovative packaging of proven components
- The highest levels of safety with fewer accident scenarios
- Leverages **AP1000®** plant passive safety system designs
- Compact reactor coolant system and containment



An engineered, economic solution for today's clean energy challenges

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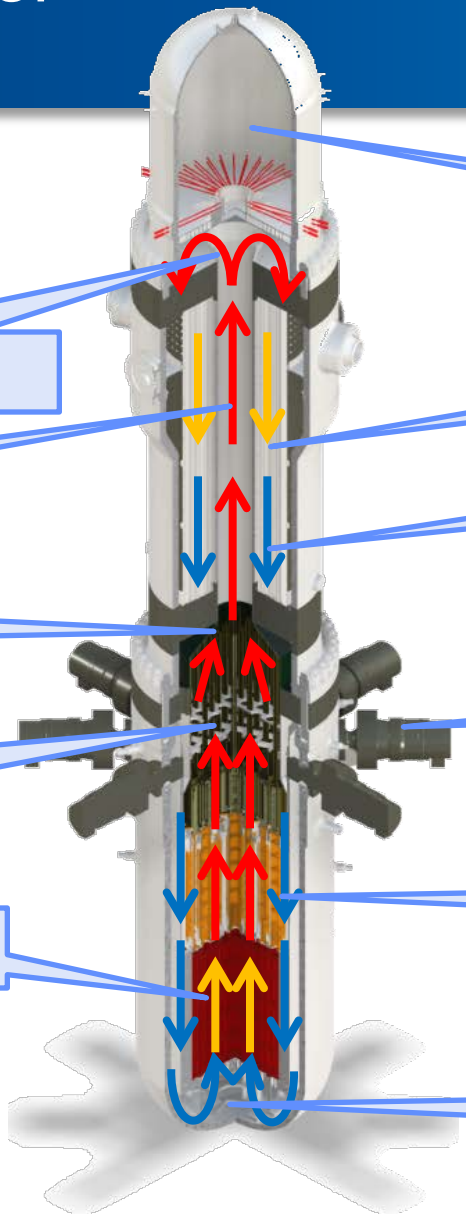
Small Modular Reactor Coolant Flow Path



Pressurizer

Flow Turn

Steam Generator

Hot Leg

Cold Leg

Transition Cone

Reactor Coolant Pumps

Upper Plenum (Reactor Vessel Internals)

Downcomer

Core

Lower Plenum

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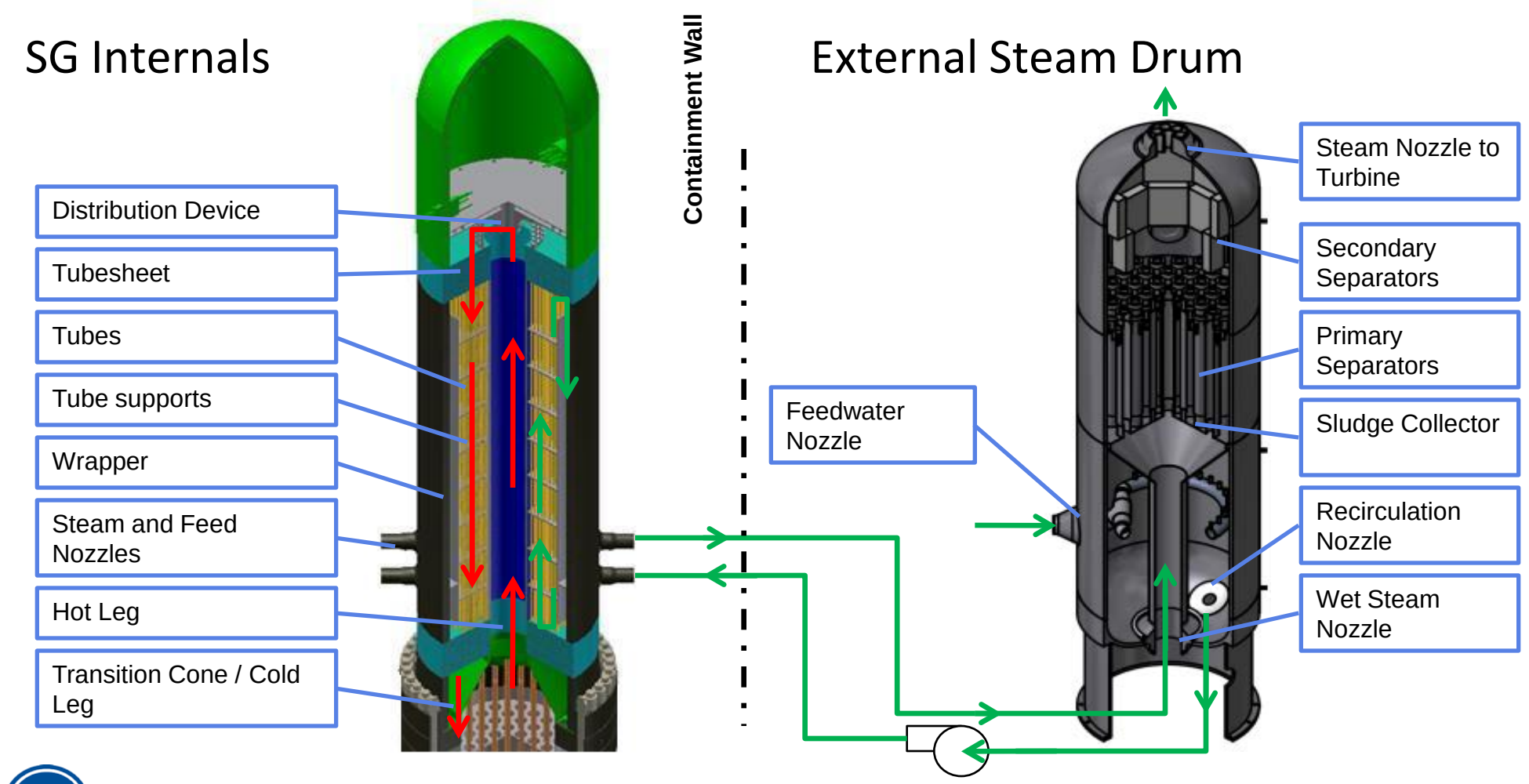
Small Modular Reactor Steam Generator



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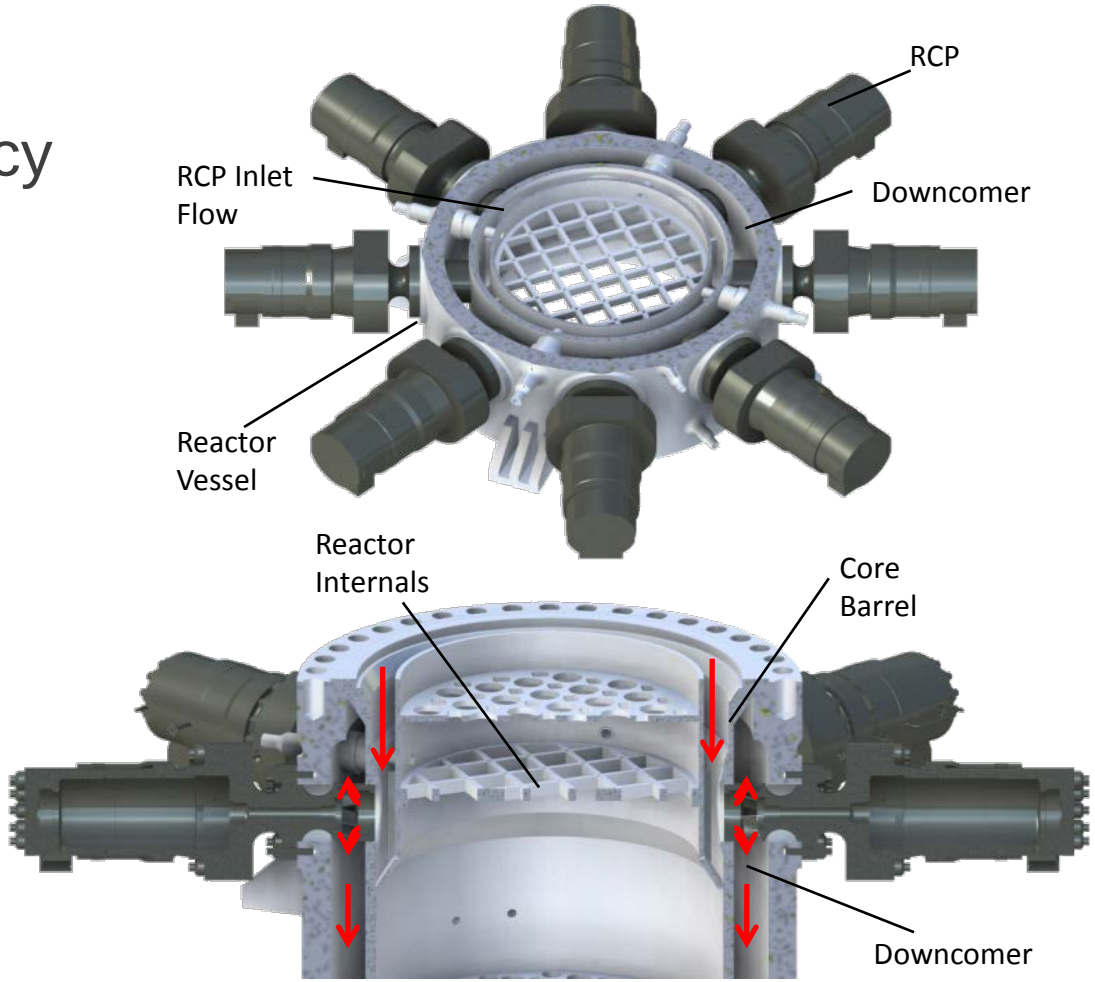
Westinghouse Small Modular Reactor
Reactor Coolant Pumps Overview

- Seal-less pump design
- Driven with variable frequency drives (VFD)
- Mounted horizontally to reactor vessel below closure flange
- Internally circulating reactor coolant removes pump heat via heat exchanger to plant component cooling water system



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Westinghouse Small Modular Reactor Internal Control Rod Drive Mechanism Design

- Current PWR loop designs have external CRDMs
- The internal CRDMs eliminate an accident scenario
- Three-coil, magnetic jack based on **AP1000®** plant design with modifications:
  - ***High-temperature*** **coil winding design**
  - **Sealed, stainless steel coil stack housing**
  - **Sealed power conduit with leak detection**
- Testing program under way

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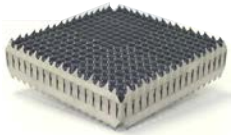
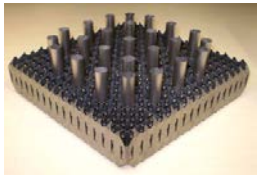
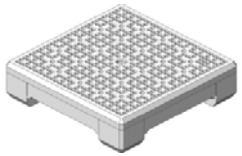
Small Modular Reactor Fuel Design Sketch







Top Mounted Core Instrumentation

Inconel Top Grid

RFA2 Mid-Grid
- Enhanced strength
- Enhanced fretting margin
- ZIRLO™ Material

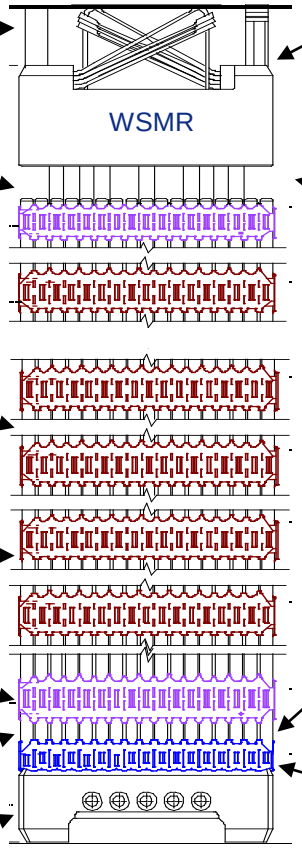
***Optimized ZIRLO™* Cladding**

IFBA, ZrB_2 Integral Fuel Burnable Absorber

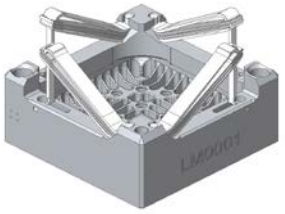
Inconel Bottom Grid

Oxide Coated Cladding

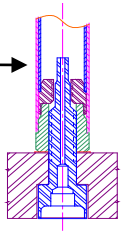
Low Profile Debris Filter Bottom Nozzle (LP DFBN)



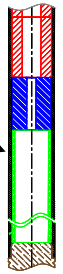
Westinghouse Integral Nozzle (WIN)
- No potential for loose parts
- One piece casting



Skeleton structure
- Enhanced dimensional stability
- ZIRLO thimble tubes
- Thick thimble tubes
- Tube-in-tube dashpot design
- Anti-bowing design prevents IRI



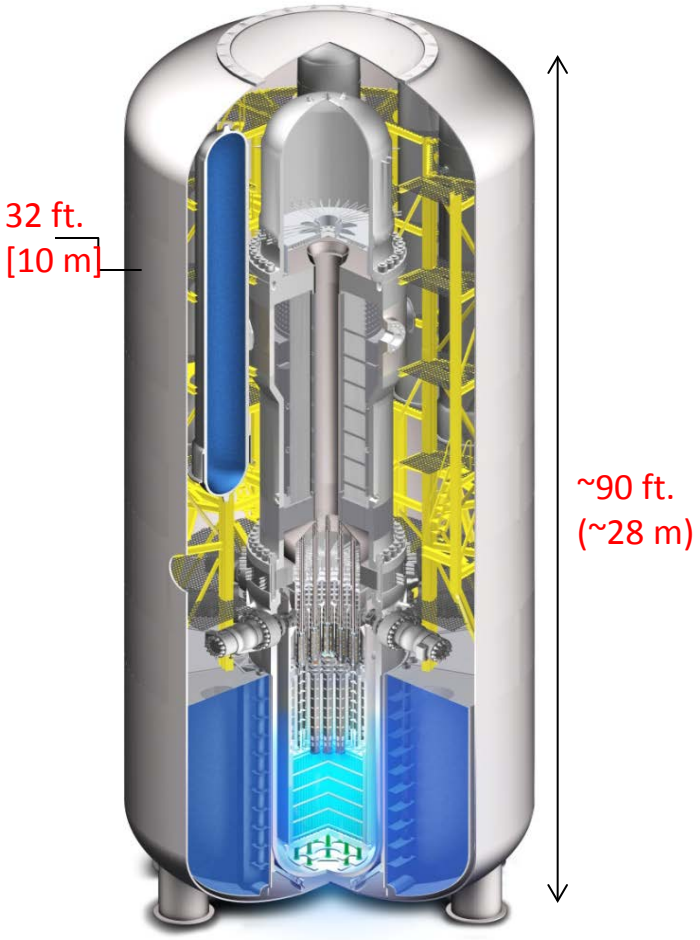
Stand-off Piece/Bottom Plenum



Protective Grid (P-Grid)

Based on proven 17x17 RFA design

Westinghouse Small Modular Reactor Plant Design



Specifications	
Thermal Output	800 MWt
Electrical Output	>225 Mwe
Passive Safety Systems	No operator intervention required for 7 days
Core Design	17x17 Robust Fuel Assembly 8.0 ft. Active Length < 5% Enriched U235 89 Assemblies Soluble Boron and 37 Internal CRDMs 24-Month Refueling Interval
Reactor Vessel Size	Outer Diameter: 11.5 ft. Height: 81 ft.
Upper Vessel Package	280 Tons
Containment Vessel Size	Outer Diameter: 32 ft. Height: 91 ft. Fully Modular Construction
Reactor Coolant Pumps	8 External, Horizontally-Mounted Pumps Sealless Configuration
Steam Generator	Recirculating, Once-Through, Straight-Tube
Pressurizer	Integral to Vessel
Instrumentation and Control	Ovation®-based Digital Control System

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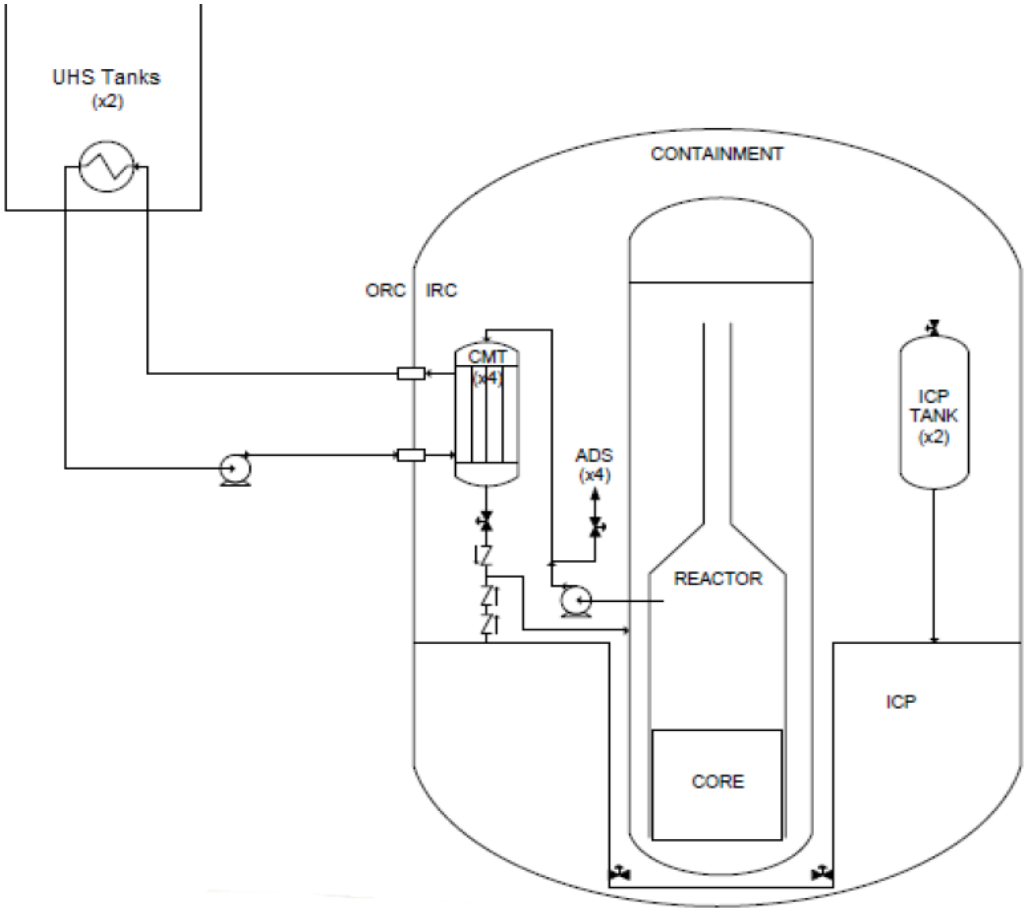
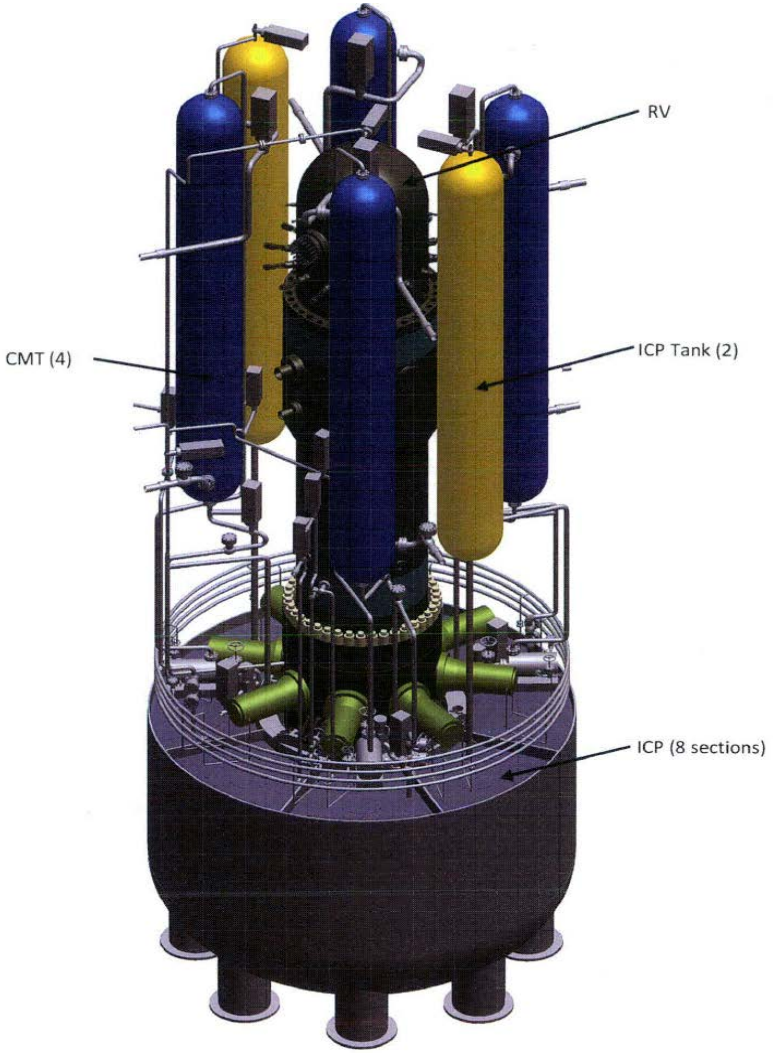
Small Modular Reactor
Overview on Main Systems





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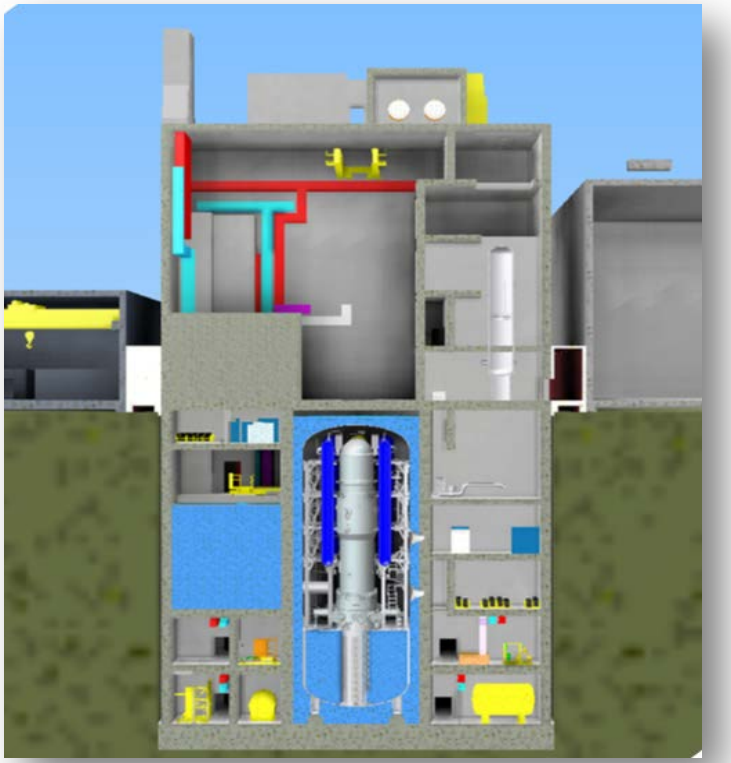
Small Modular Reactor Safety Systems

- **Reactor shutdown**
  - Control rods
  - Boric acid injection from core makeup tanks (CMTs)
- **Reactor decay heat removal**
  - Steam Generator with gravity feed from steam drum
  - Core Makeup Tank closed circuit cooling to Ultimate Heat Sink (UHS) tank
- **Reactor inventory addition**
  - Core Makeup Tank injection
  - In-Containment Pool (ICP) injection
  - Long-term recirculation
- **Containment heat removal**
  - Convection and condensation of steam inside containment
  - Heat transfer through Containment wall to an external pool
  - External pool automatically refilled by UHS tanks



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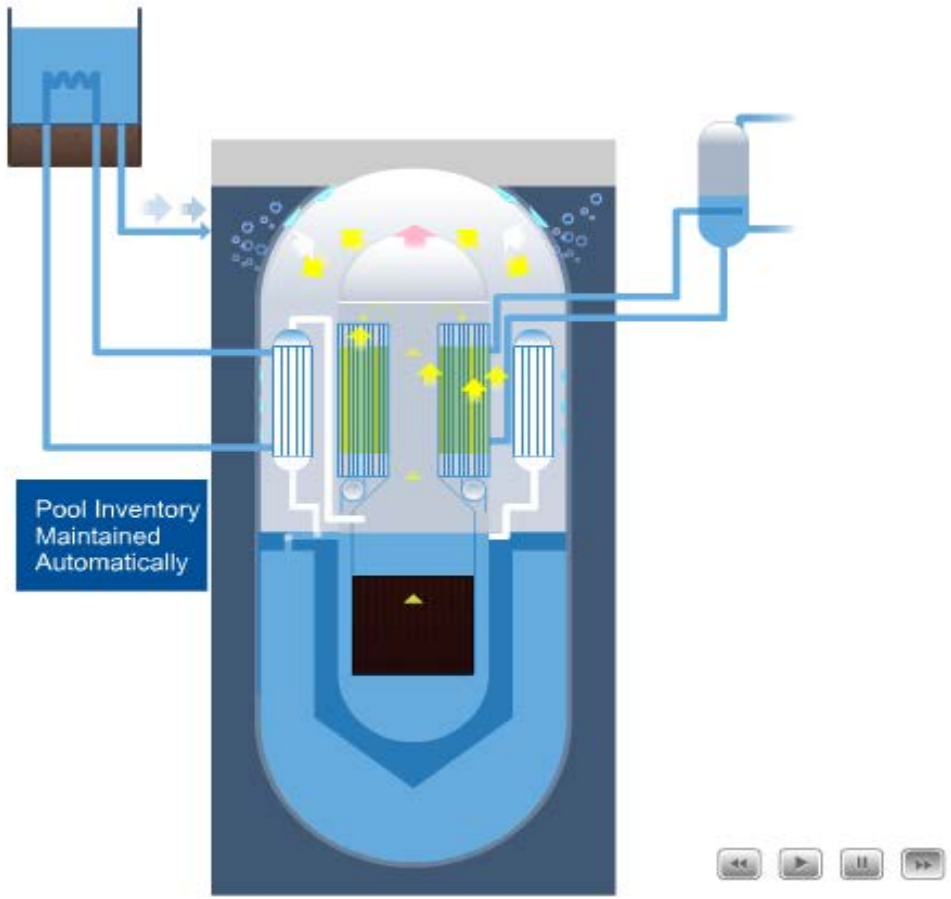
Westinghouse Small Modular Reactor (SMR) Safety Animation



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Small Modular Reactor
Leveraging Passive Safety in our Design

- **7 Days of Passive Heat Removal with Onsite Inventory**
  - Capability to add additional water inventory for indefinite cooling
- **100% reliance on natural forces**
  - Evaporation, condensation, gravity

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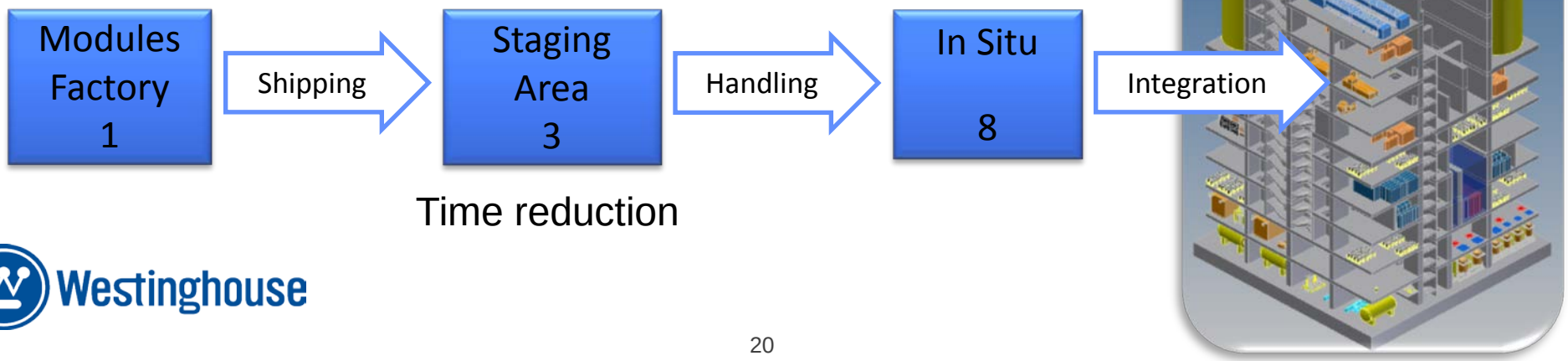
Westinghouse Small Modular Reactor
Modular Construction

- Traditional large scale reactor economies of scale can be countered through application of modular construction techniques
- SMR maximizes modular design in all aspects of plant
- Modular design drives work normally completed at the construction site to the factory where quality is better controlled, overall cost are reduced and schedule certainty increased
- Modules are designed for road and rail transport to site and scalable to other forms of transport



SMRs Compete Favorably with other Clean Electricity Technologies

SMR Technology*	LCOE $/Mwh	Capacity Factor
SMR LEAD Plant	90	90%
SMR FOAK-1	84	90%
SMR FOAK-4	71	90%

Clean Technology**	LCOE $/Mwh	Capacity Factor
Wind	96	33%
Solar PV	153	25%
Solar Thermal	242	20%
Geothermal	98	91%
Biomass	115	83%

LCOE – Levelized Cost of Energy

* Energy Policy Institute of Chicago, University of Chicago, "Small Modular Reactors - Key to Future Nuclear Power Generation in the U.S.," November 2011.

** U.S. Energy Information Administration, Annual Energy Outlook 2012, June 2012, DOE/EIA-0383(2012).

All estimates are in 2010 $

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Westinghouse Small Modular Reactor Economic Benefits

- **Ease of Licensing**
- Shift from active to passive safety systems
- Smaller source term
- Integral on-site used fuel management
- **Ease of Financing**
- Smaller capital cost
- Shorter development time to first revenue
- Lower risk-adjusted weighted average cost of capital
- **Ease of Deployment**
- Simplified on-site assembly
- Shorter deployment times
- Better matching to electricity demand

SMRs have the potential to be a very attractive economic option… but it will take a joining of the industry beyond vendor companies to include regulators and customers in order to achieve a plant that can be standardized and factory-built

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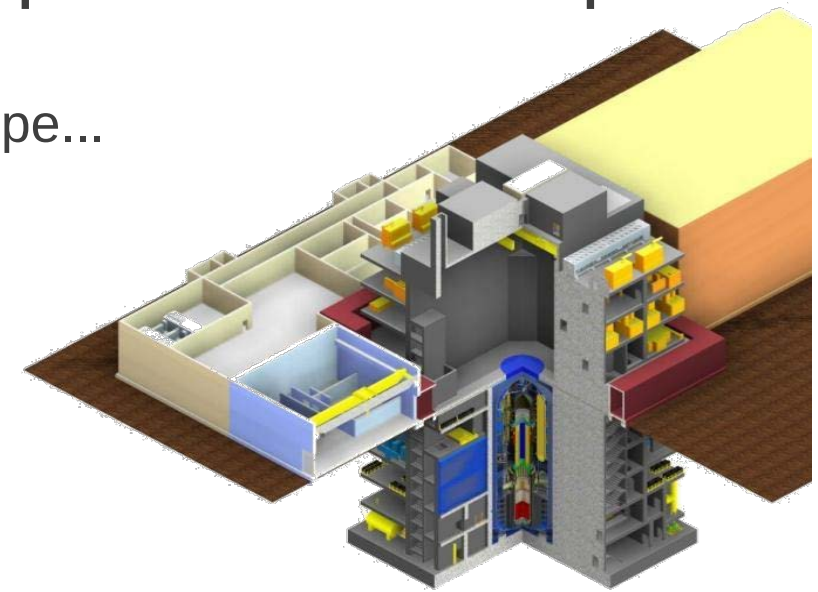
Westinghouse Small Modular Reactor Conclusions

- The Westinghouse SMR is a **simpler**, **safer**, **passive** design based on proven PWR technology
- **Passive safety** without operator action needed combined with traditional safety systems generate a **highest level of safety**
- **Modular construction** techniques, combined to the overall simplification of the plant, results in **simpler** construction and **shorter** construction **schedule**
- Westinghouse SMR is self-reliant, self-contained and fail safe, and thus highly robust against extreme external events…with a **positive** contribution to **public**
- Westinghouse **SMR** fits perfectly to **multiple** grid **requirements** in the US as well as in Europe...

Nuclear is part of Europe's future!



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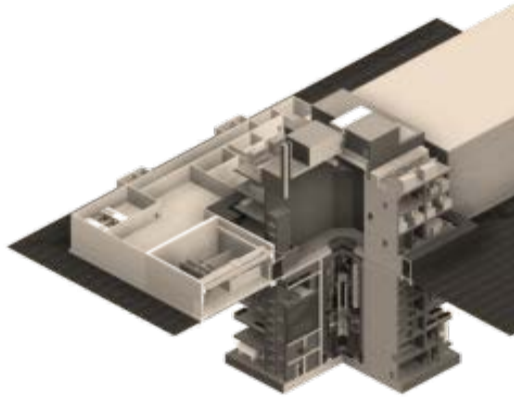
Westinghouse Small Modular Reactor Questions?



www.westinghousenuclear.com/smr

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