SMALL MODULAR NUCLEAR REACTORS

Smaller and Smarter?

Presented to Engineers Joint Committee of Long Island

February 12, 2013

by

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Nuclear Science and Technology Department

BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

Outline of Presentation

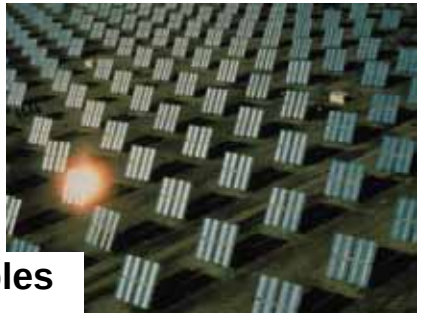
- **What are Small Modular Reactors (SMRs)?**
- **Why are they being promoted?**
- ***What are the design features of Integral Pressurized Water Reactors?***
- **What are the regulatory/technical concerns?**
- **What is the future for SMRs?**

Small Modular Reactors (SMRs)

- Less than 300 MWe
  - 45-300 MWe designs proposed
- Modular design
  - Factory built
- Integrated Pressurized Water Reactors (iPWRs)
  - NuScale
  - B&W (mPOWER)
  - Westinghouse
  - Holtec (SMR-160)
- Gas- or liquid metal - cooled designs

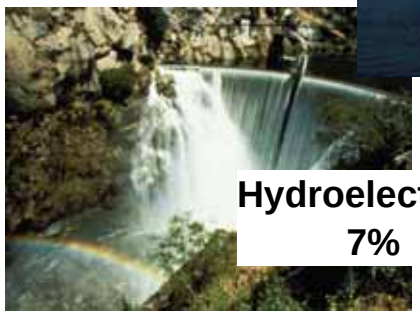
U.S. Electricity Sources

Oil
3%

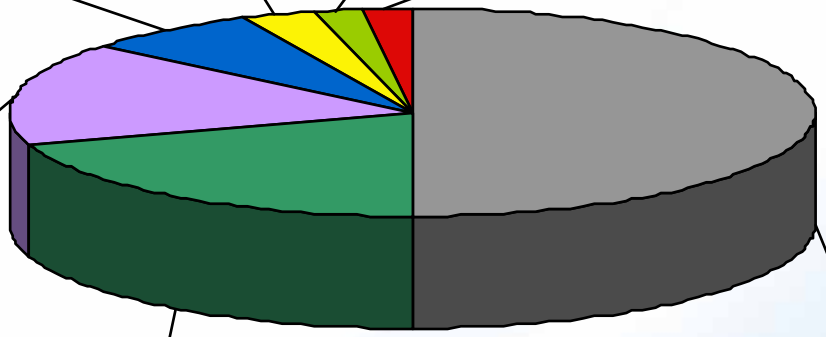


Renewables
2%

Other
2%

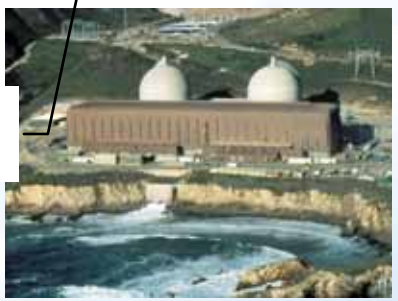


Hydroelectric
7%



Natural Gas
16%

Nuclear
20%



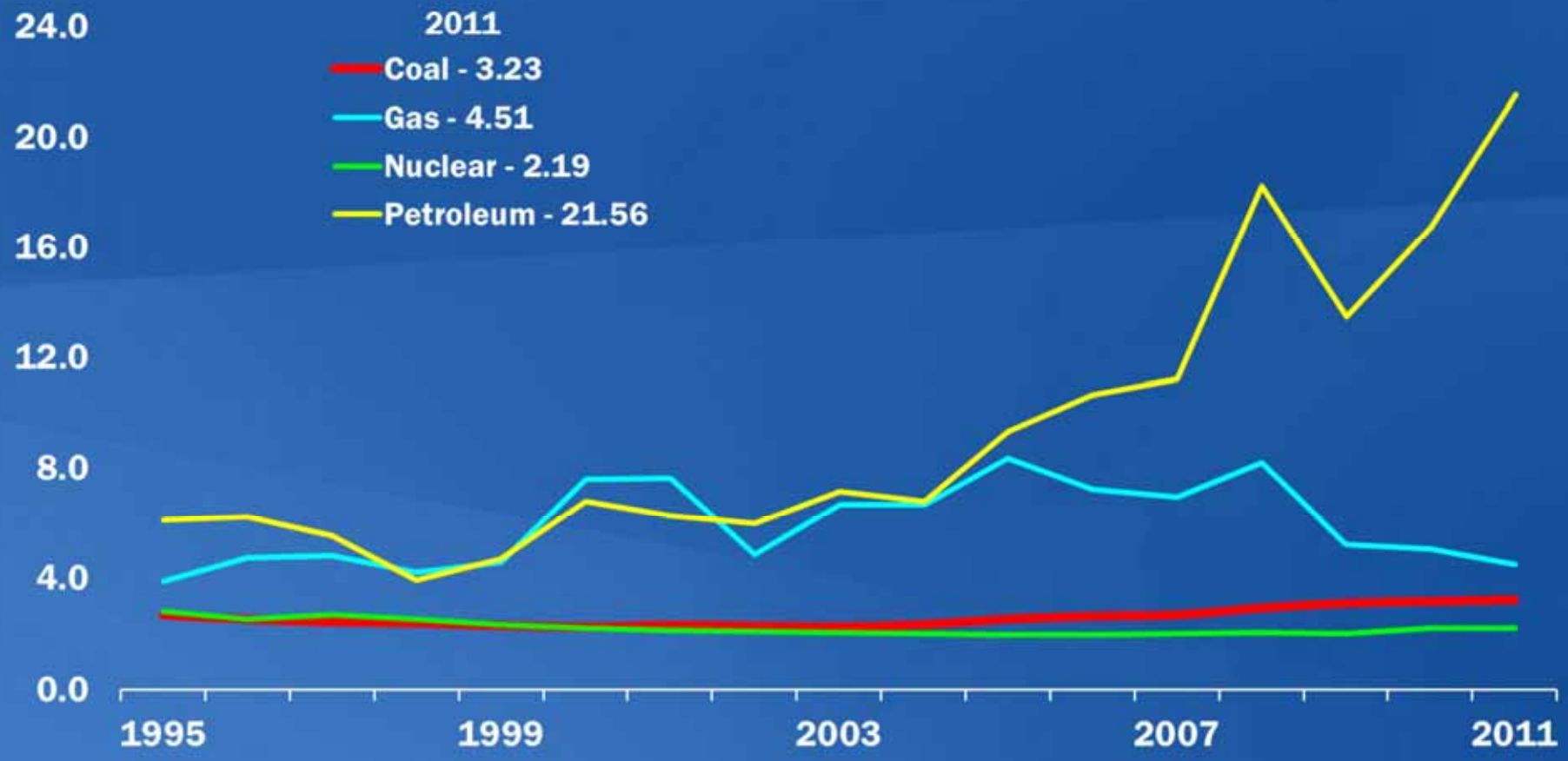
Coal
50%

WHY NUCLEAR?

- **Energy Security is National Security**
  - **Uranium is a domestic source of energy**
- **Competitive Costs**

U.S. Electricity Production Costs

1995-2011, *In 2011 cents per kilowatt-hour*



Production Costs = Operations and Maintenance Costs + Fuel Costs. Production costs do not include indirect costs and are based on FERC Form 1 filings submitted by regulated utilities. Production costs are modeled for utilities that are not regulated.

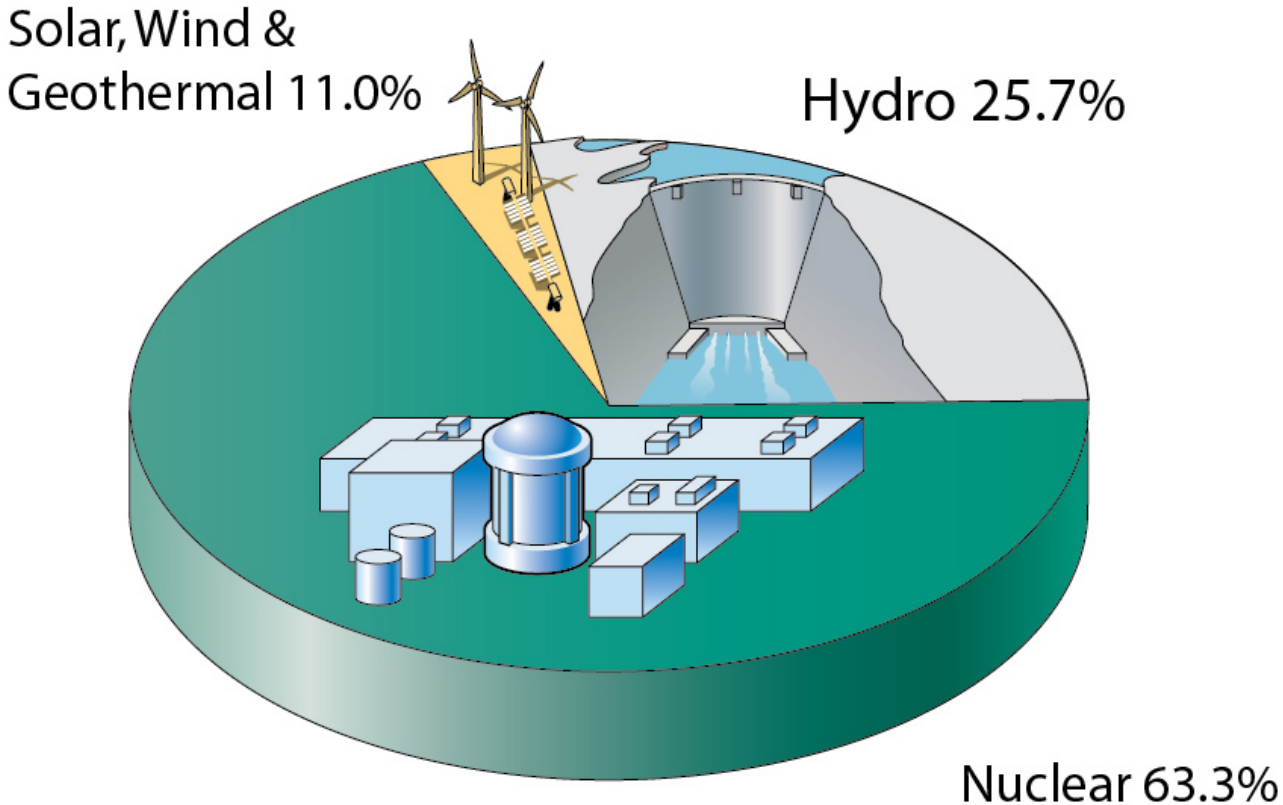
NEI

Source: Ventyx Velocity Suite
Updated: 5/12

WHY NUCLEAR?

- **Energy Security is National Security**
  - **Uranium is a domestic source of energy**
- **Competitive Costs**
- **No Climate-Change Releases**

Sources of Emission-Free Electricity 2011



WHY NUCLEAR?

- **Energy Security is National Security**
  - **Uranium is a domestic source of energy**
- **Competitive Costs**
- **No Climate-Change Releases**
- **Proven Record**

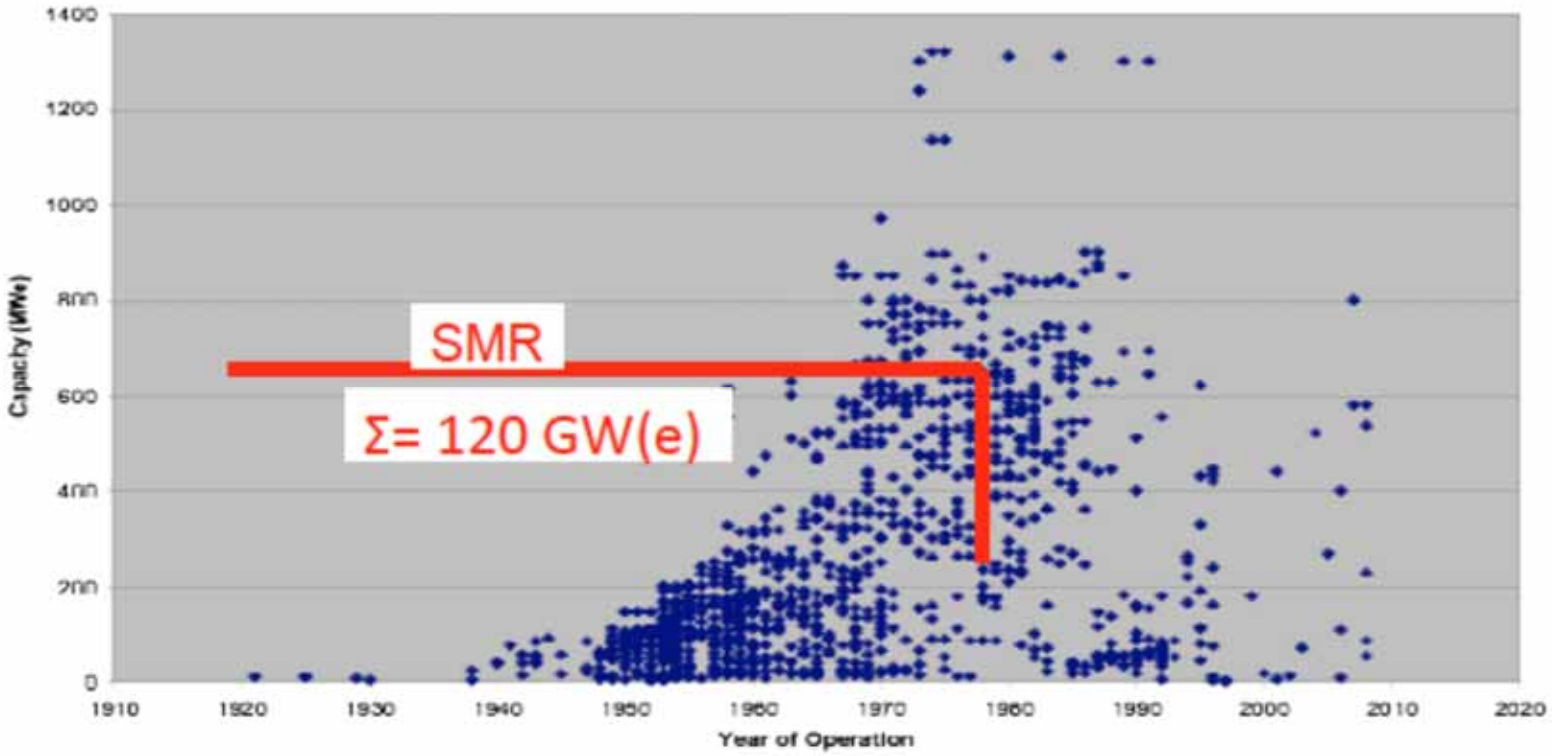
U.S. Nuclear Power Plants

Advantages of SMRs

- **Small size = small capital cost**
  - **U.S. utilities have trouble financing large projects**
  - **Build up capacity one small unit at a time**
  - **[BUT need to also be competitive on cost/kW installed]**
- **Small size =shorter construction time**
- **Small size attractive in certain markets**
  - **Remote locations**
  - **Small grids**
    - **Developing countries**
    - **Coal plant replacement**

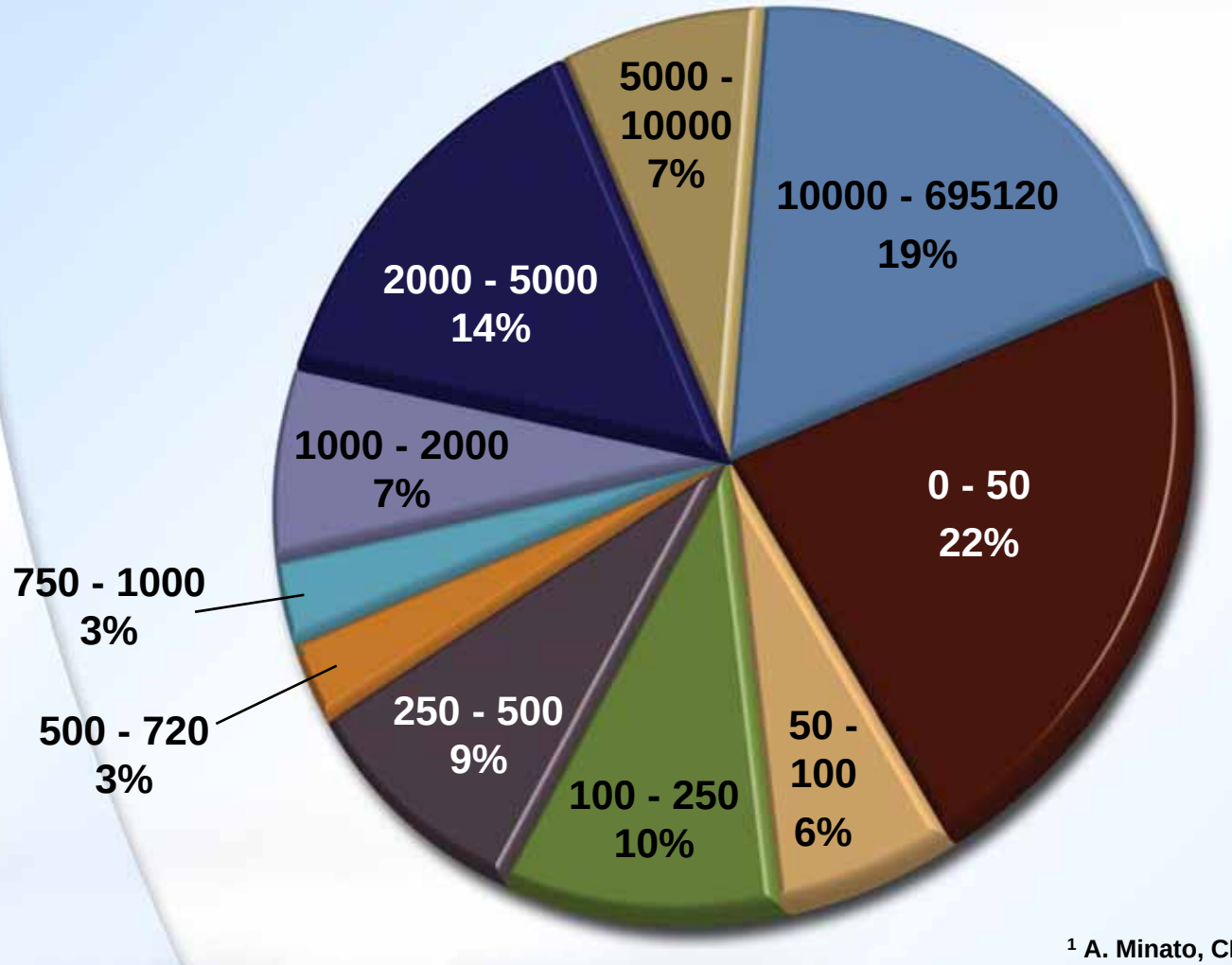
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Coal Plant Replacement



Most of the Emerging Export Market Opportunity is for Small to Medium Reactors (SMRs)

(1) Total Capacity of Electrical Generation in 226 Countries (MWe)



[1] A. Minato, CRIEPI

Right sized reactors take advantage of emerging nuclear and energy system trends.

Advantages of iPWRs

- **Small size = innovative design = low $/kW?**
- **Factory built**
  - **Improved quality due to replication in factory**
  - **Transported via standard methods**

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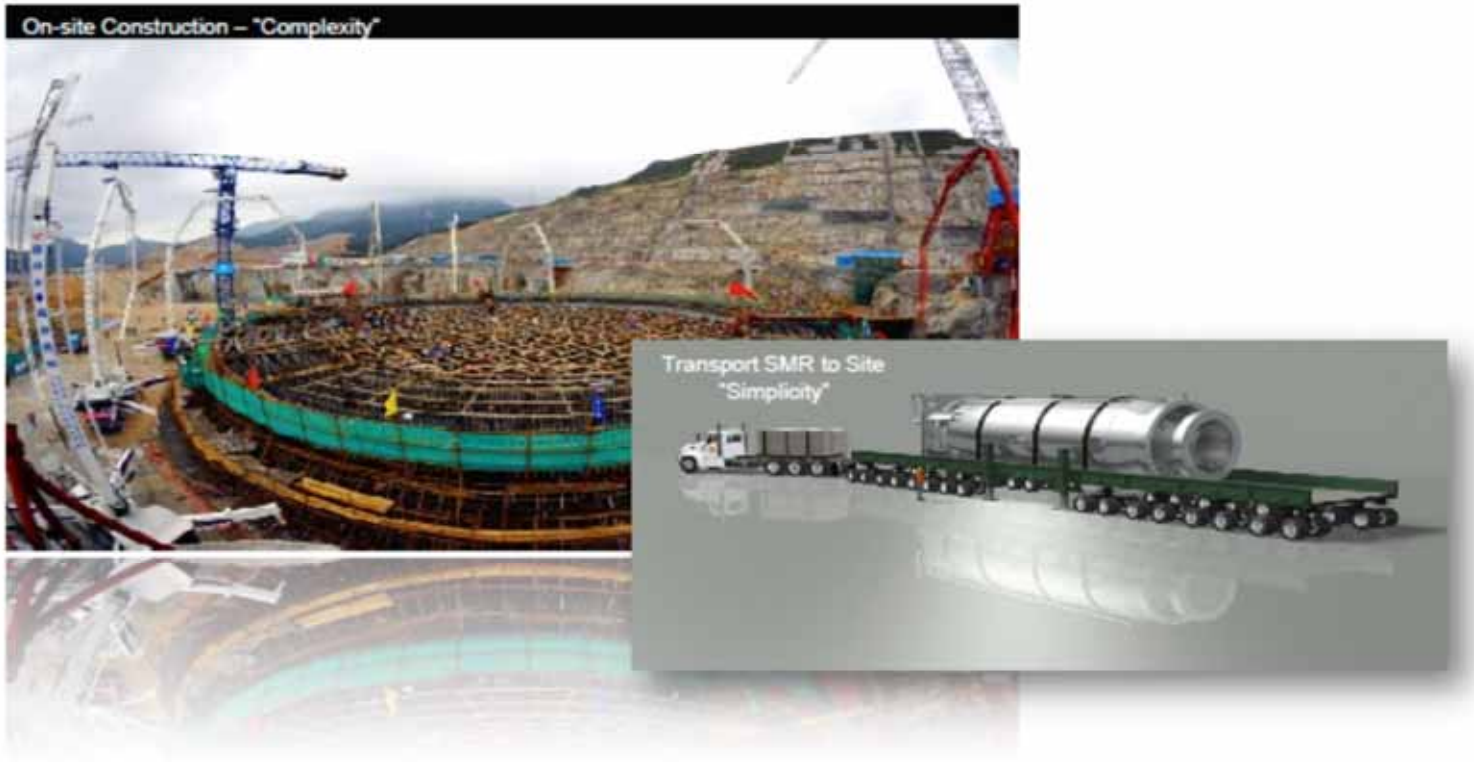
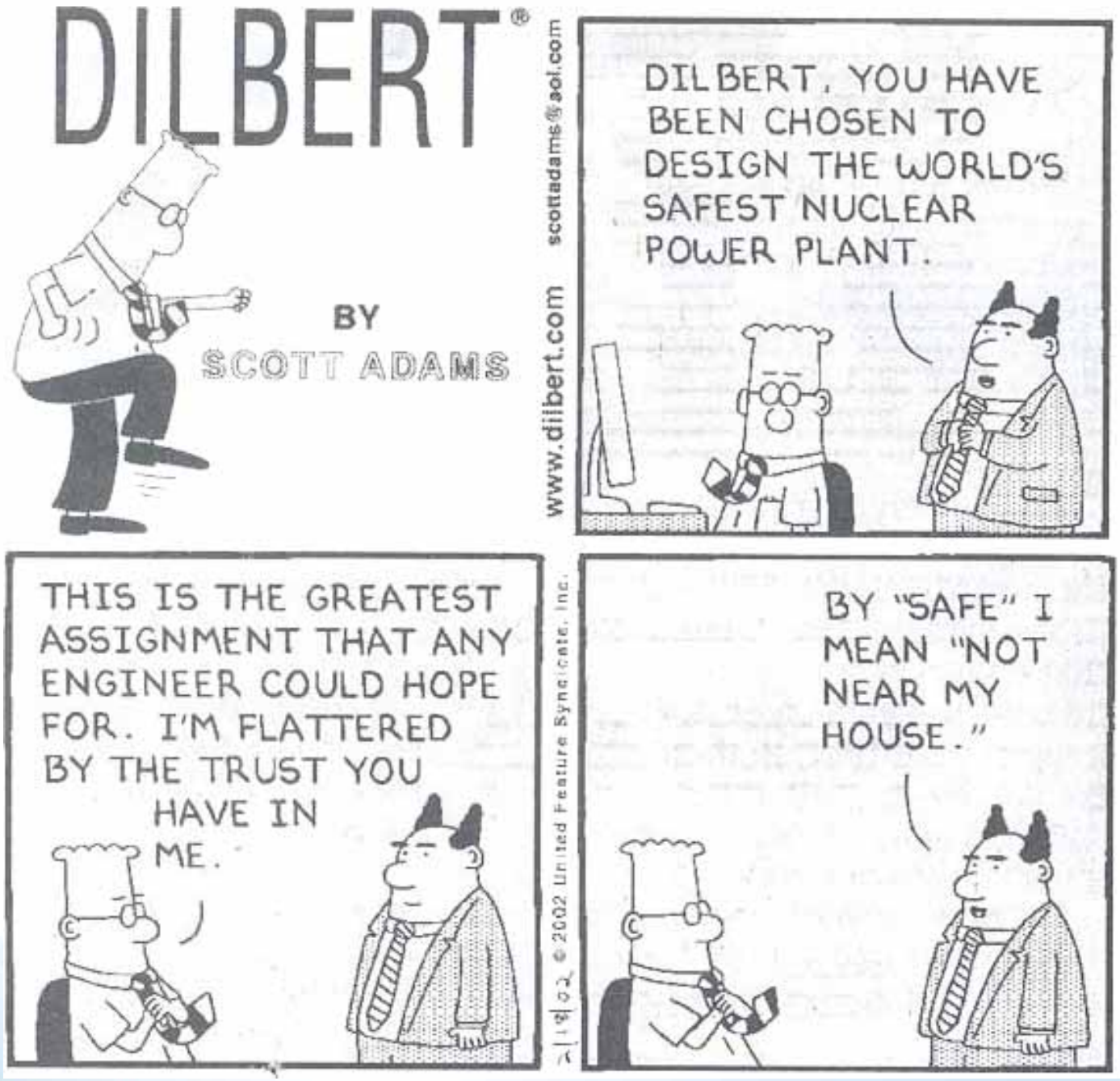
"Complexity" Versus "Simplicity"



5

Advantages of iPWRs

- **Small size = innovative design = low $/kW?**
- **Factory built**
  - **Improved quality due to replication in factory**
  - **Transported via standard methods**
- **Meets electric demand incrementally**
- **Enhanced safety**
  - **Passive safety**
  - **No large piping**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BY "SAFE" I MEAN "NOT NEAR MY HOUSE."
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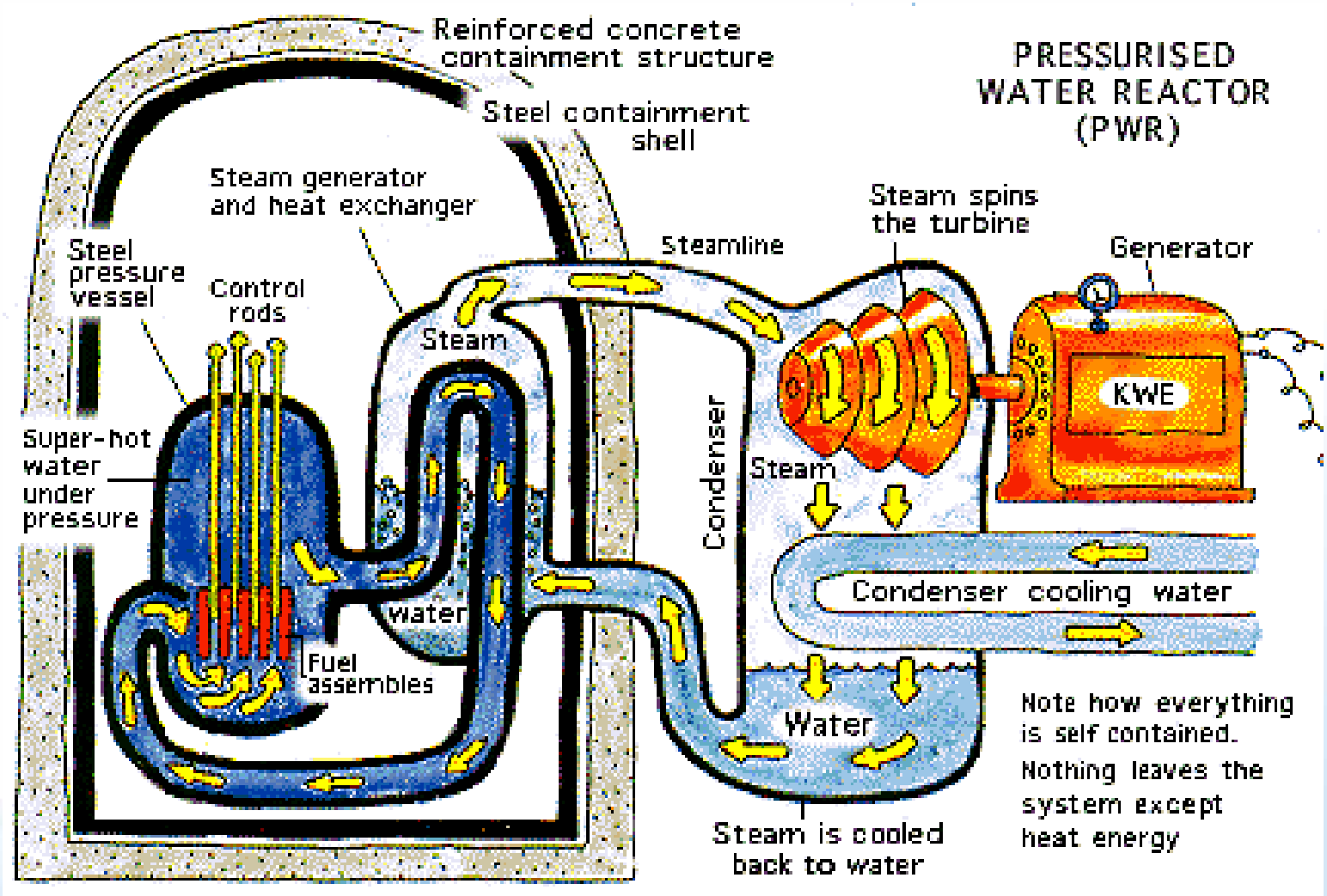
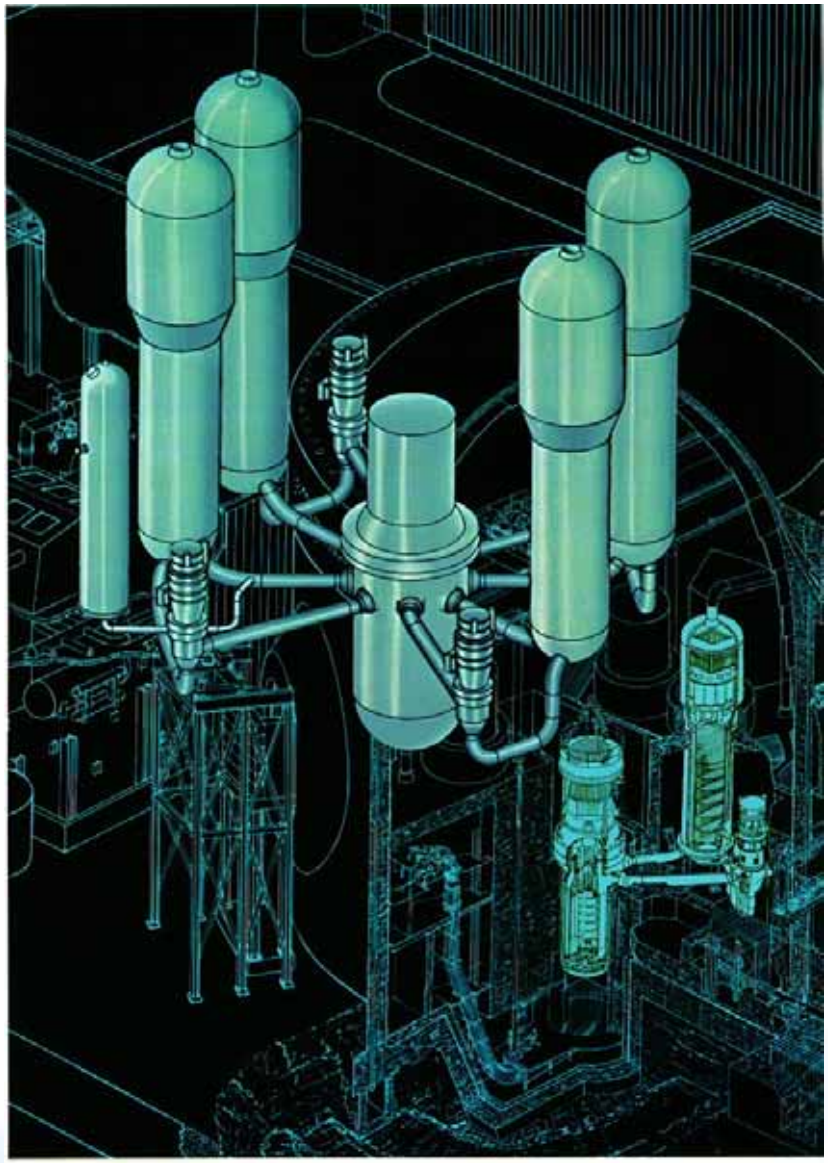
Advantages of iPWRs

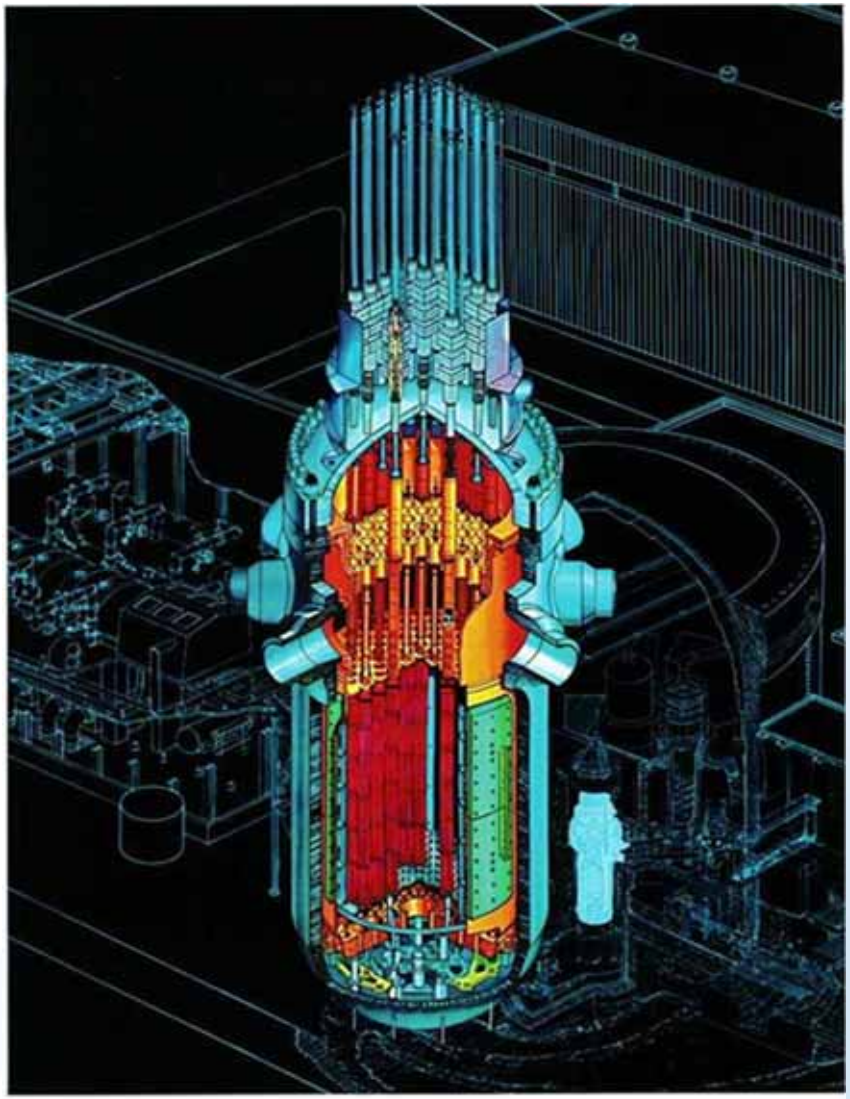
- Small size = innovative design = low $/kW?
- Factory built
  - Improved quality due to replication in factory
  - Transported via standard methods
- Meets electric demand incrementally
- Enhanced safety
  - Passive safety
  - No large piping
- Based on existing PWR technology

PWR Concept

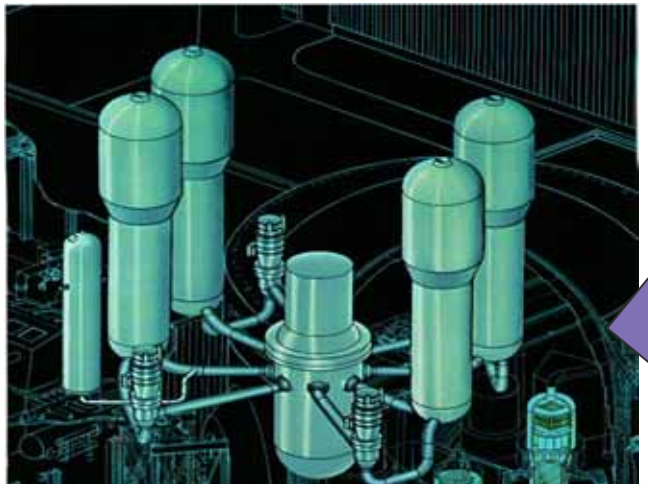

Reinforced concrete containment structure
Steel containment shell
PRESSURISED WATER REACTOR (PWR)
Steam generator and heat exchanger
Steam spins the turbine
Steamline
Generator
Steel pressure vessel
Control rods
Steam
KWE
Super-hot water under pressure
Condenser
Steam
Condenser cooling water
water
Fuel assemblies
Water
Note how everything is self contained.
Nothing leaves the system except heat energy
Steam is cooled back to water

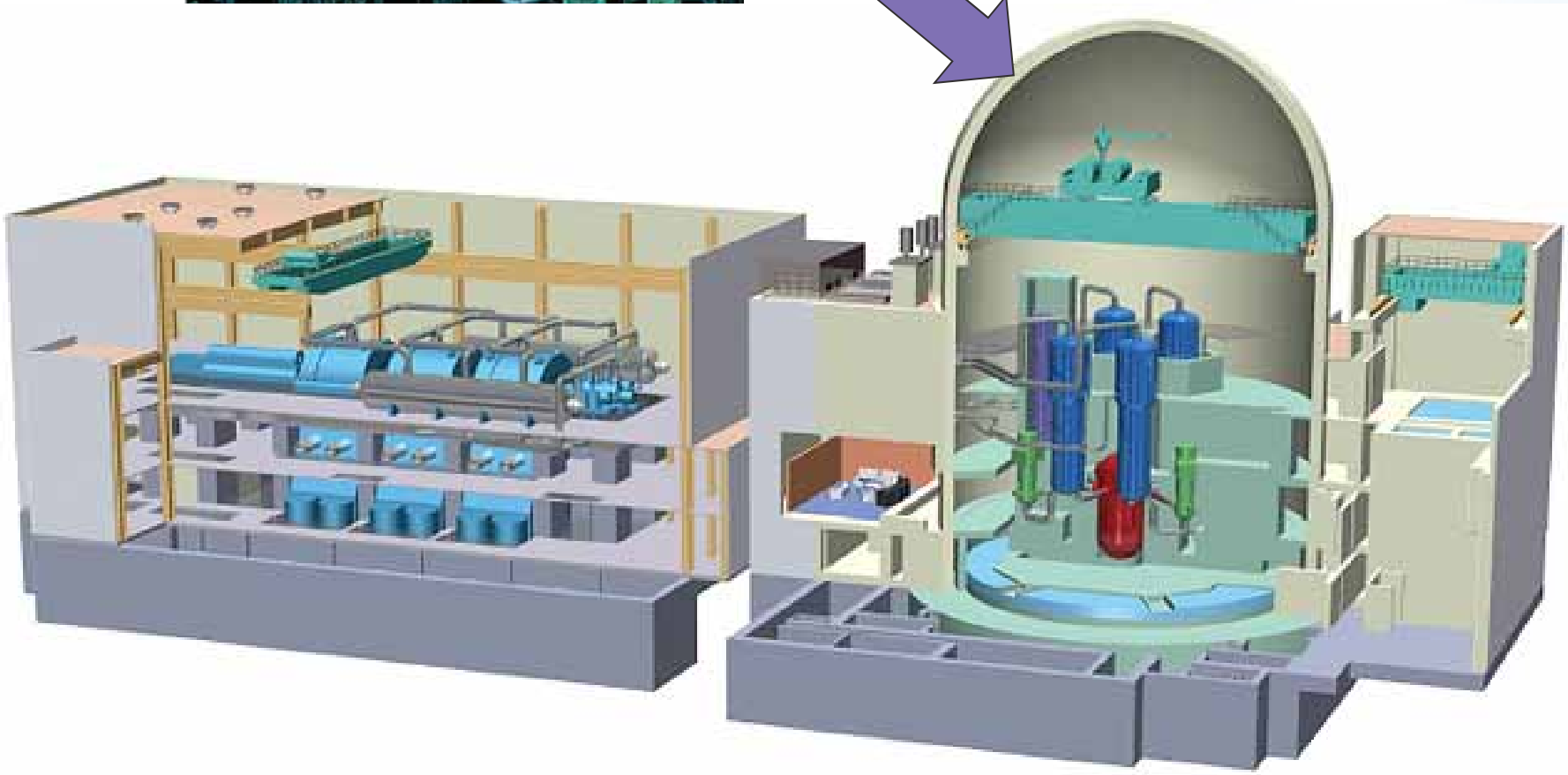


Westinghouse NUCLEAR STEAM SUPPLY SYSTEM

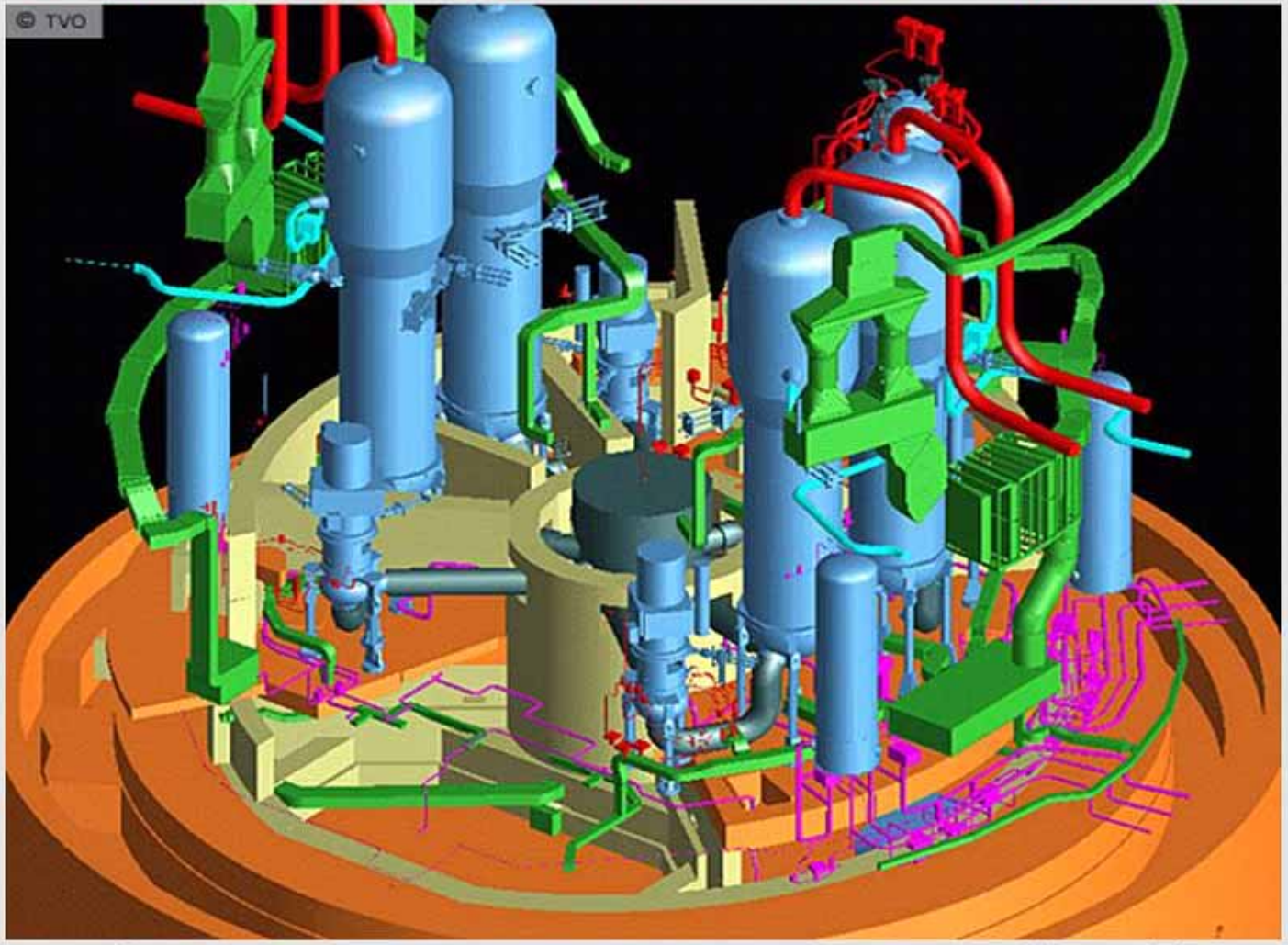


Westinghouse NUCLEAR REACTOR



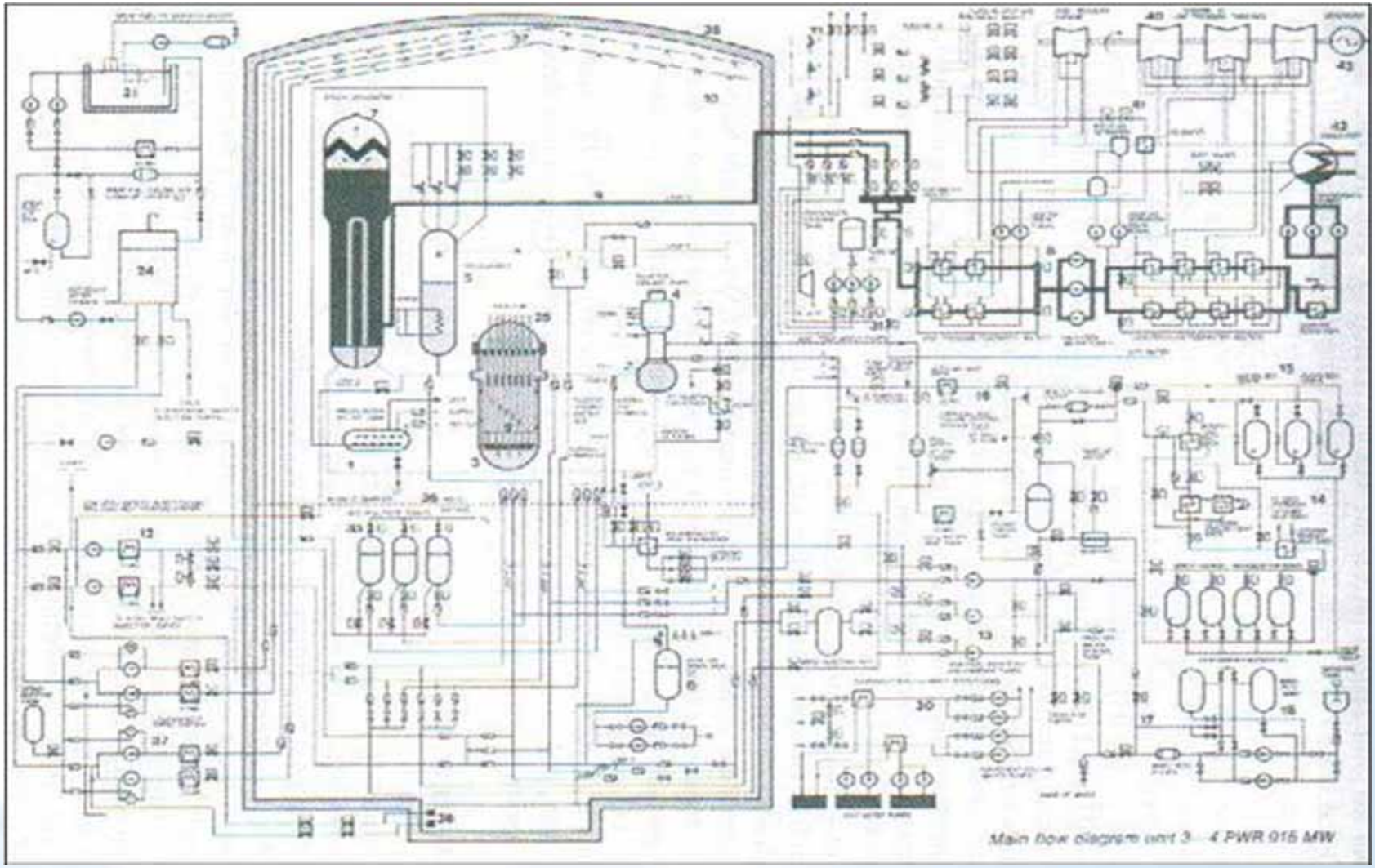


European Pressurized Water Reactor (EPR) …



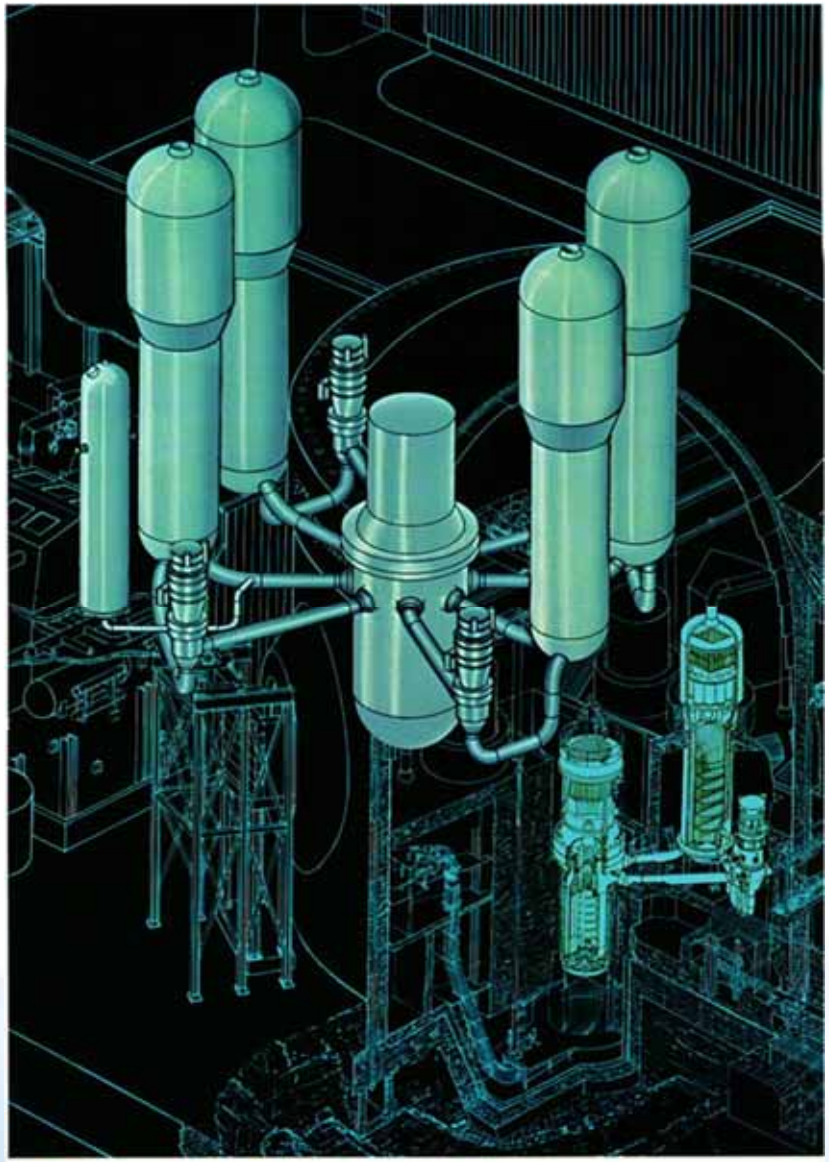
Source: areva.com

Figure: 6-1

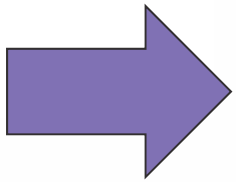

Main flow diagram unit 3 - 4 PWR 915 MW

NPPs In Finland

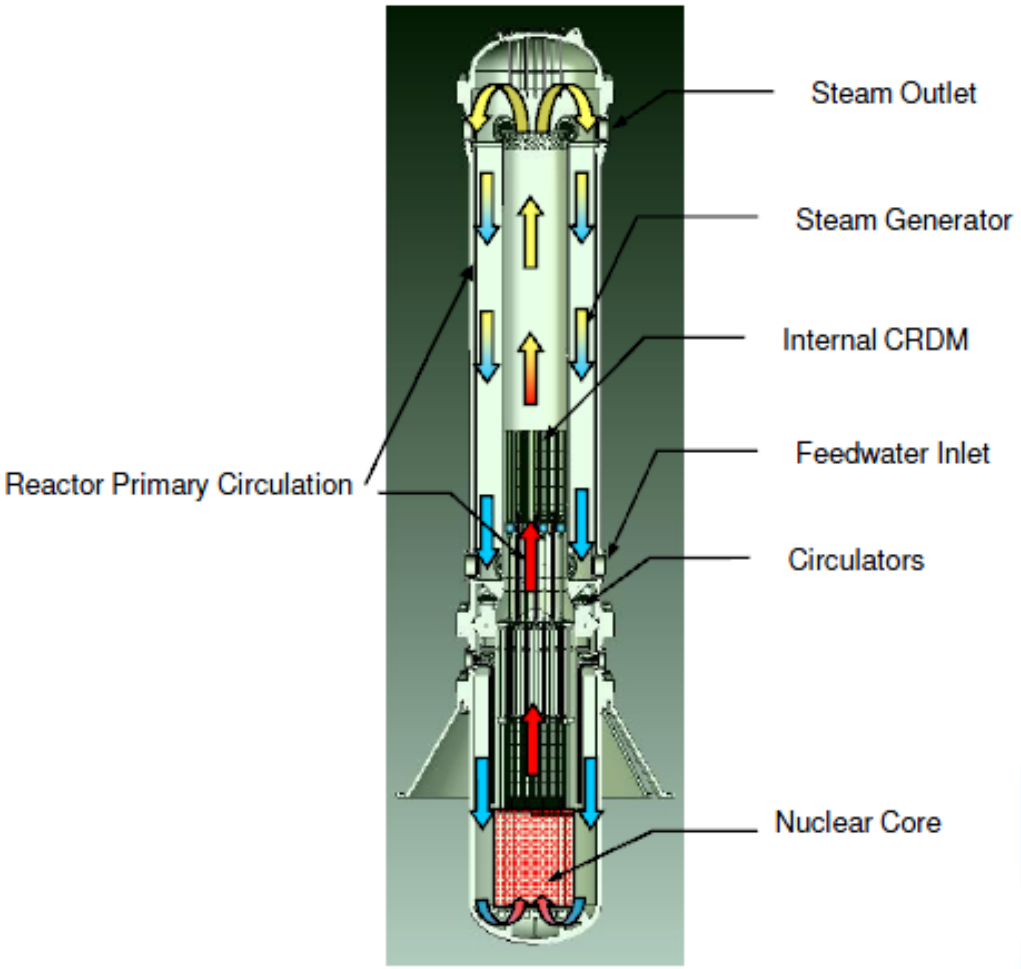
Smaller and Smarter?



Westinghouse NUCLEAR STEAM SUPPLY SYSTEM



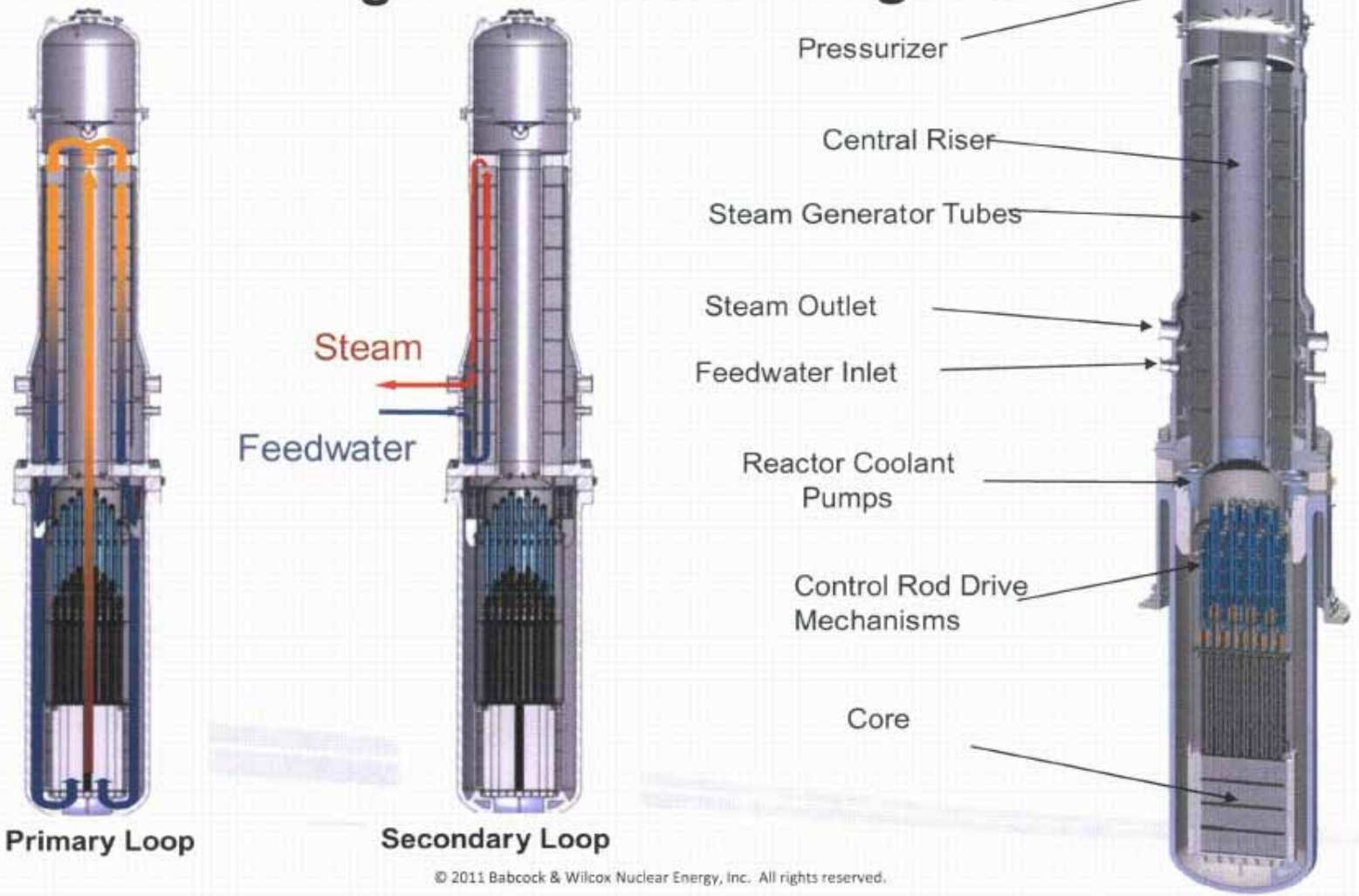
General Features of mPower



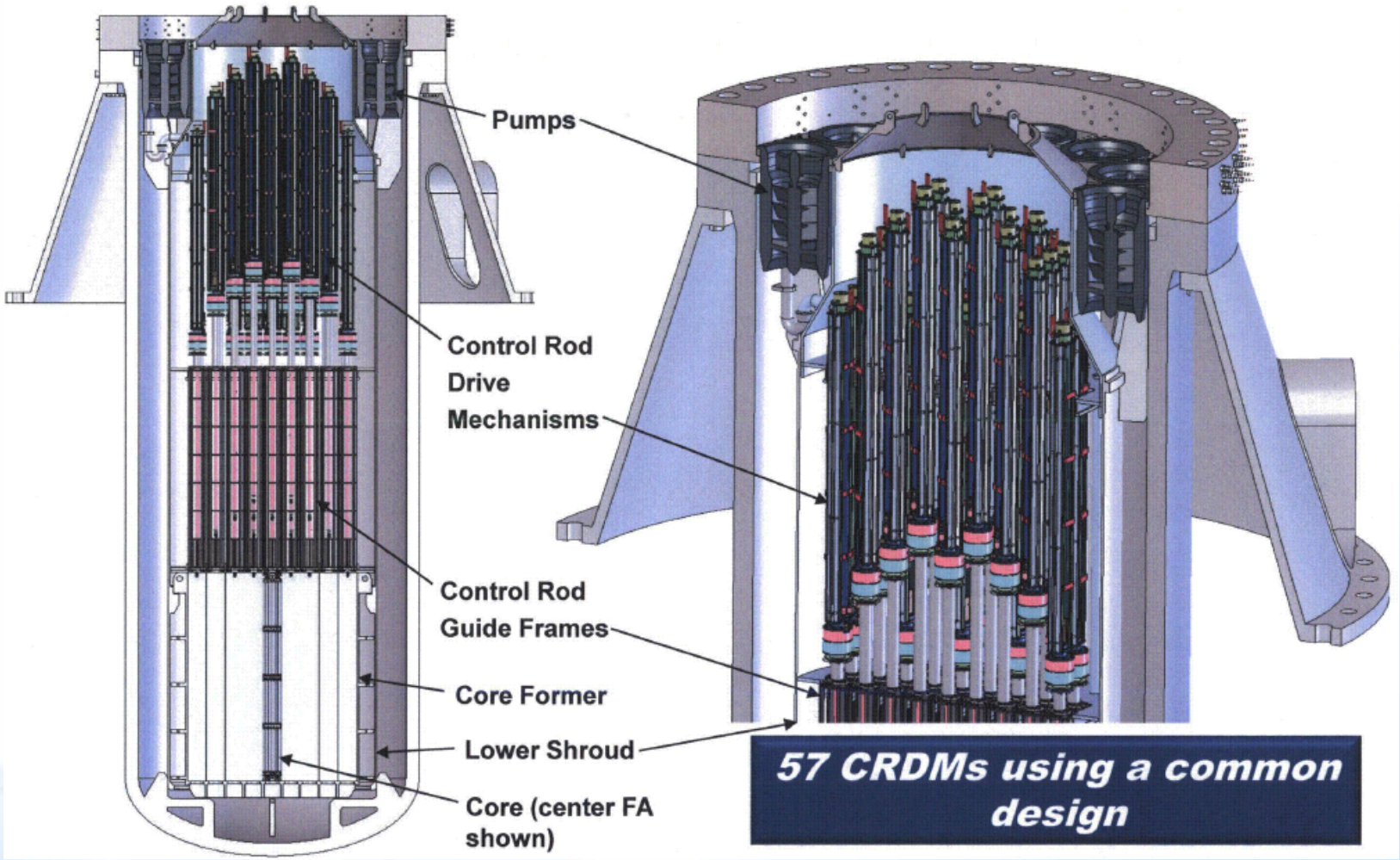
- ~125 MWe
- Internal steam generator
- Standard PWR fuel
- Large primary coolant inventory
- Small penetrations into primary coolant system at top of RPV
- Diverse, redundant internal CRDMs
- No boron in primary coolant
- 4-year fuel cycle

generation
mPower

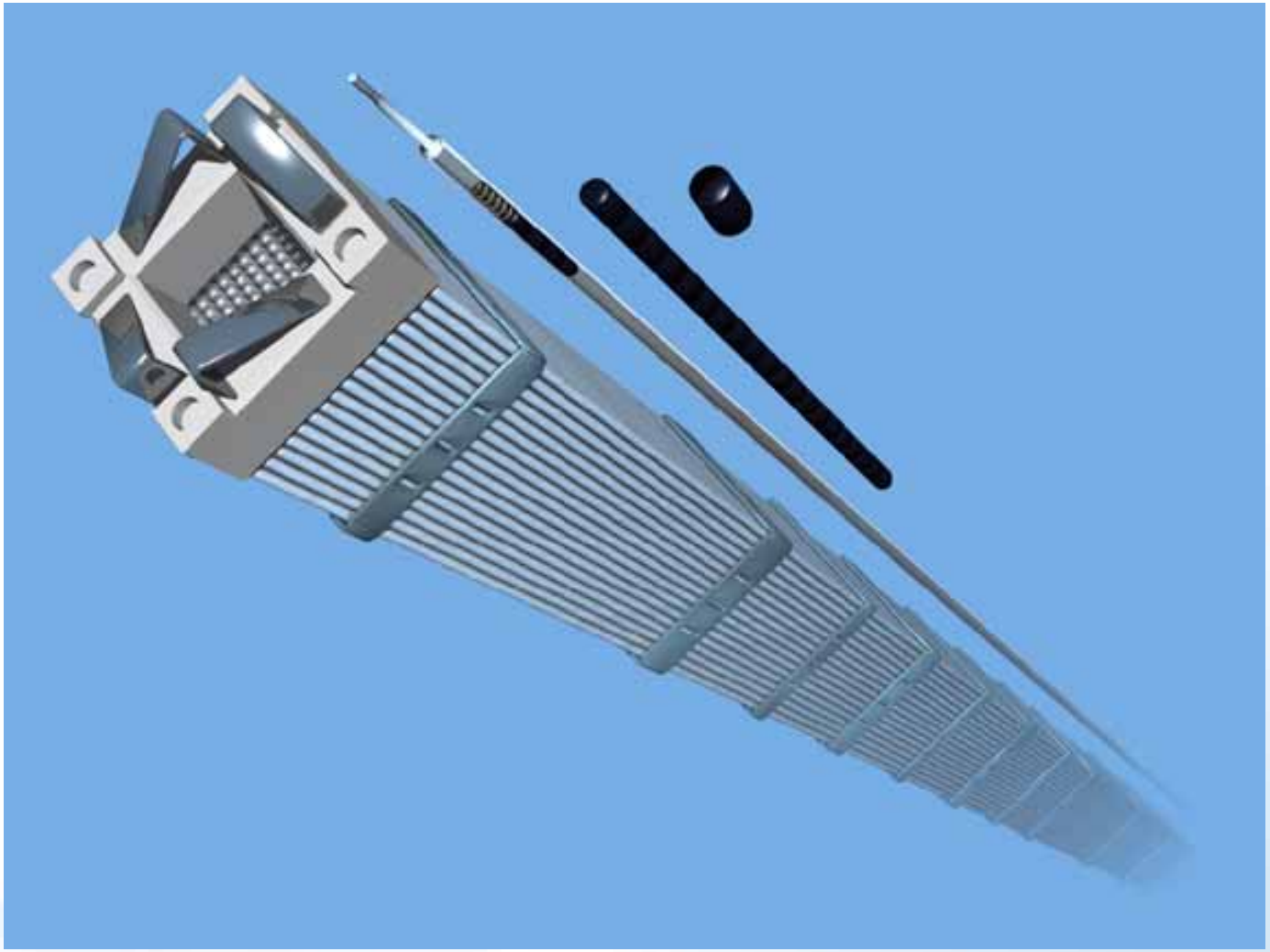
Integral Reactor Arrangement

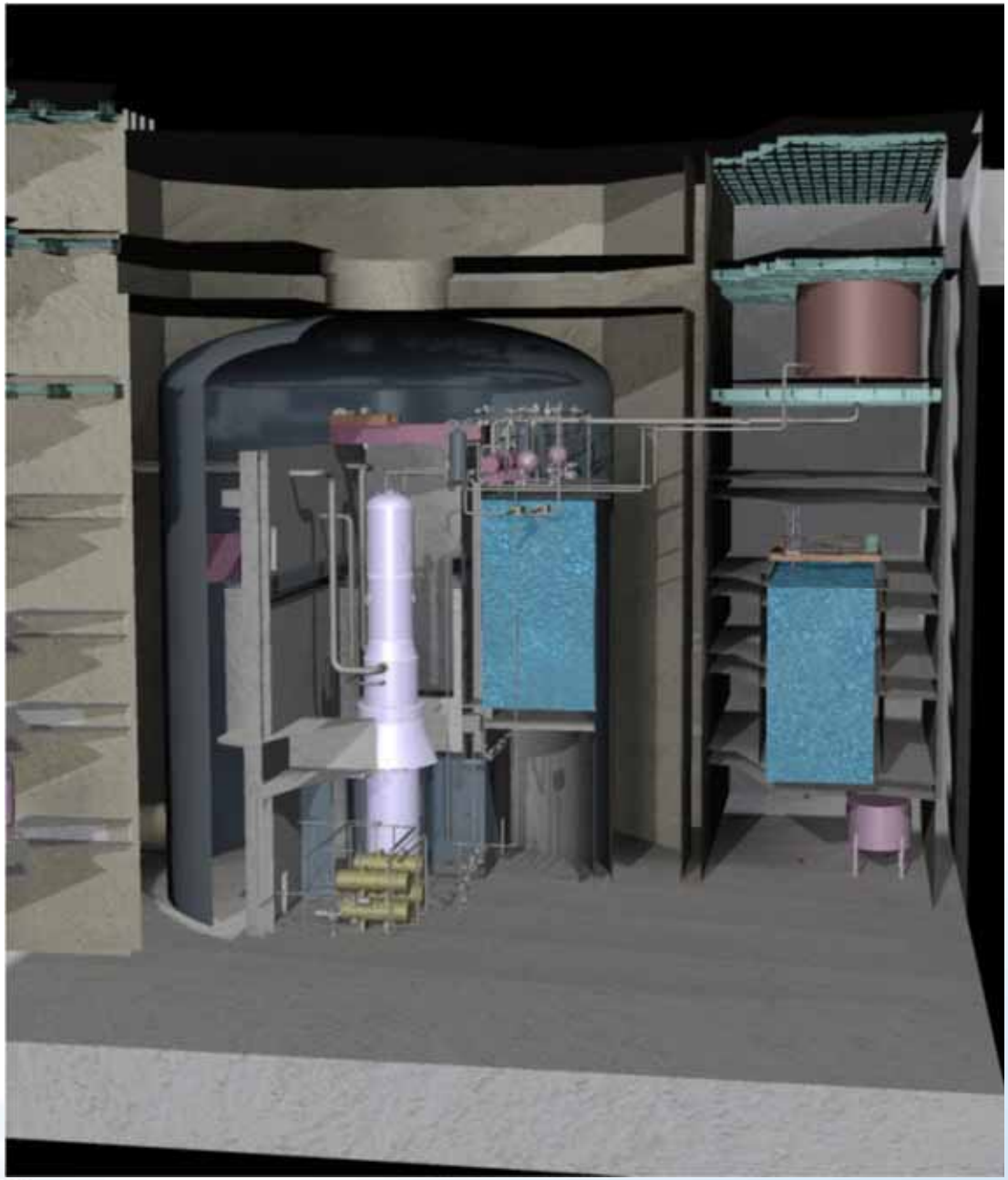


Lower Vessel



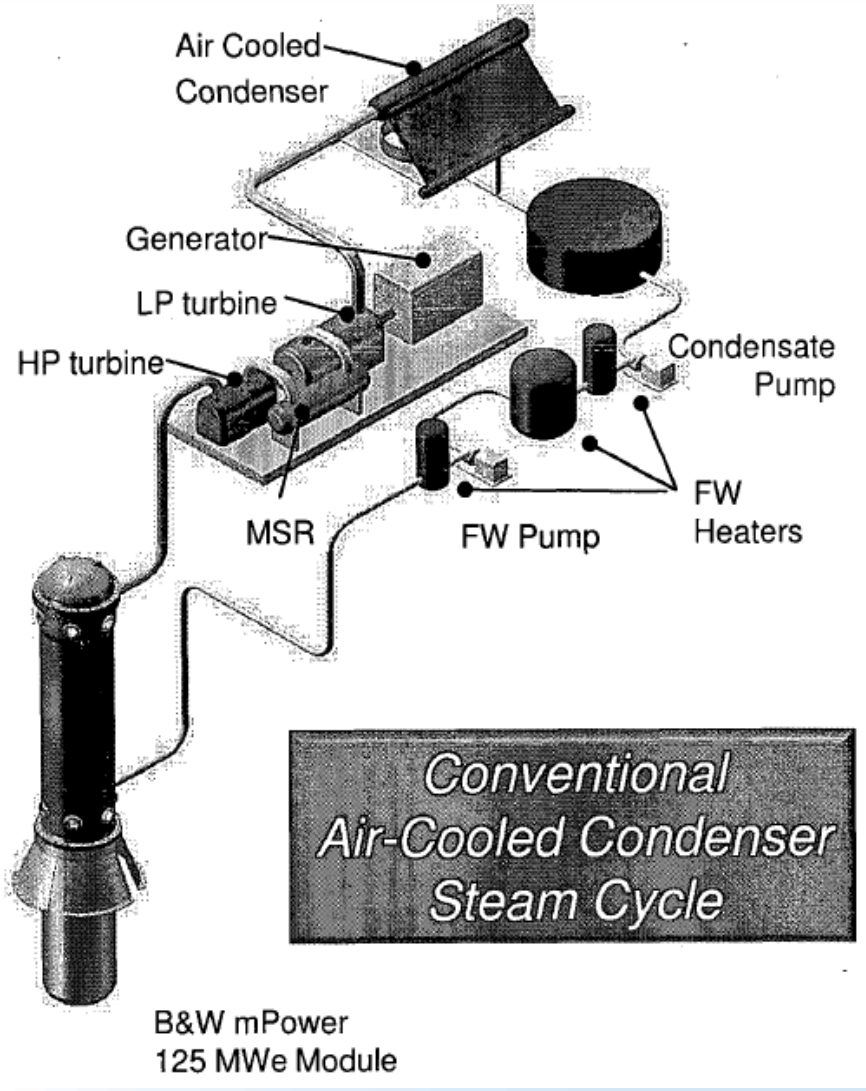
PWR Fuel Element





Balance of Plant

- Conventional steam cycle
- BOP operation not credited for design basis accidents
  - Reactor can be cooled without feedwater flow to the steam generator
  - All fuel can be cooled for a minimum of 72 hours without any BOP system
- Air or water condensers

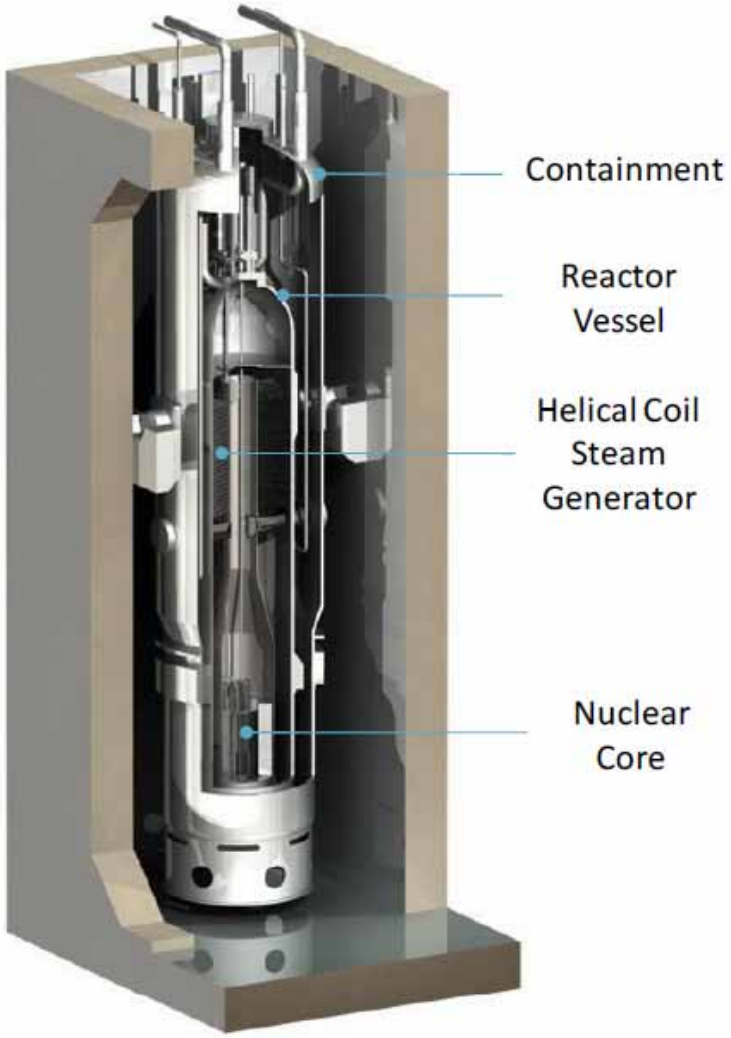


General Features of NuScale iPWR

- **45 MWe per module**
- **Natural circulation cooling (no pumps, pipes, valves)**
  - **Eliminates some accident scenarios**
  - **Improves economics**
- **Two steam generators and pressurizer inside reactor pressure vessel**
  - **No primary piping breaks can cause loss-of-coolant accident**
- **Secondary cooling circuit utilizes simple off-the-shelf turbine-generator**

Reactor Vessel and Containment

- **Containment is in reactor pool**
- **Modules separated by a wall in the reactor pool (which also provides the containment support)**
- **Containment is maintained in a partial vacuum**

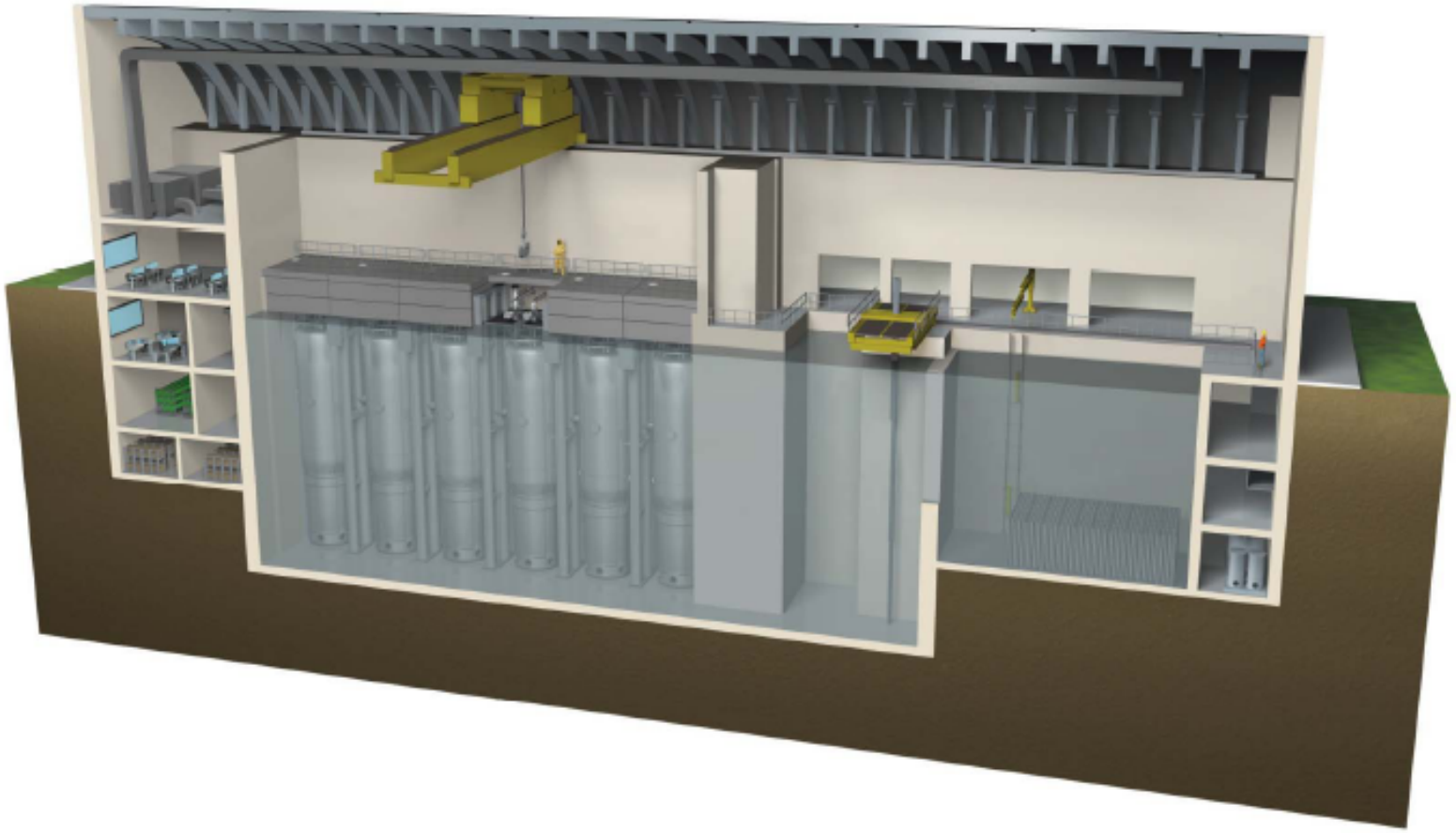


Reference: NuScale Power Overview of NuScale Design Slides, April 2, 2009

Other Features

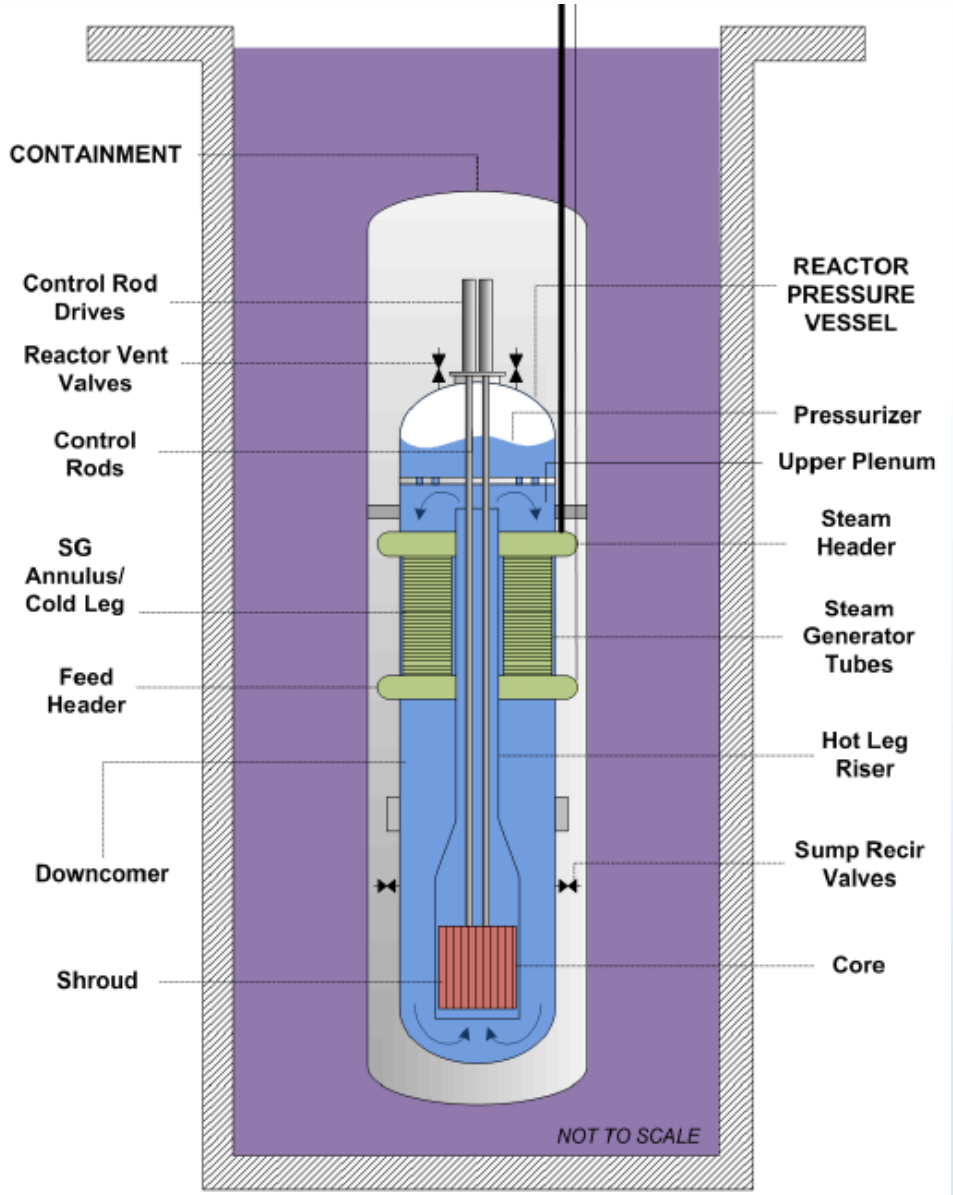
- **Nuclear steam supply system is factory built**
  - **Prefabricated and shipped by rail, truck, or barge**
- **Large natural heat sink**
  - **Simplifies and enhances safety case**
- **Below grade reactor**
  - **Enhances security and safety**
- **Up to 12 modules at one site**

Cross-sectional view of 6 modules



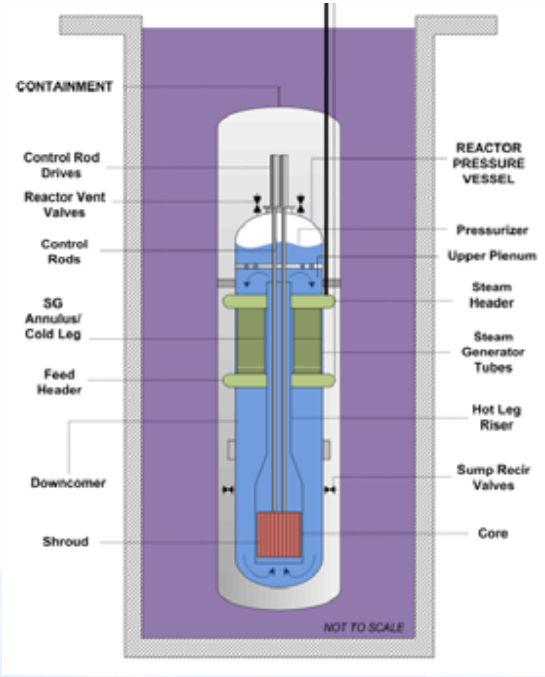
Normal Cooling

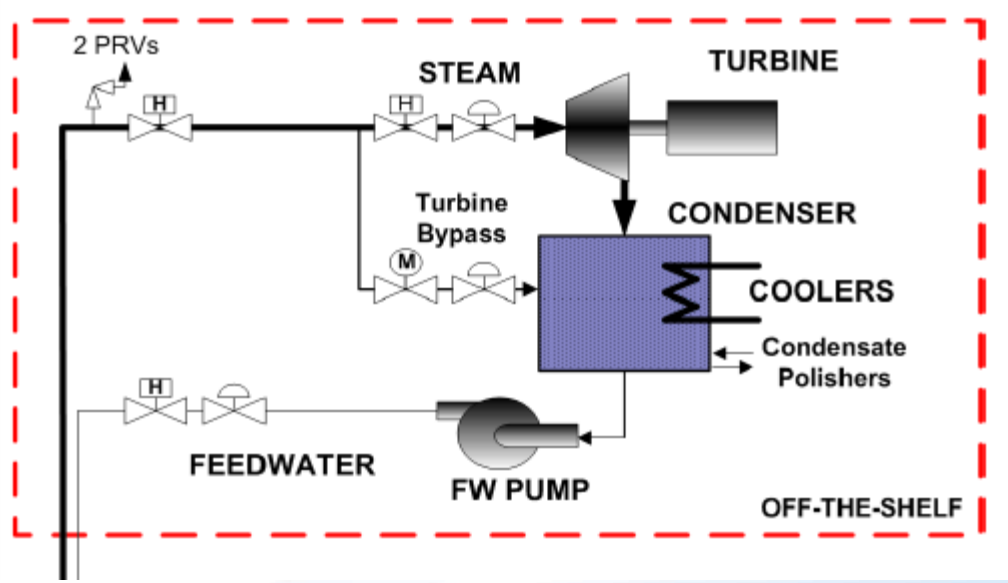
- Helical coil OTSG
- Two tube banks
  - 536 tubes / bank
  - ~1.6 cm OD
  - Avg length 30 m
- FW inlet header and steam outlet header



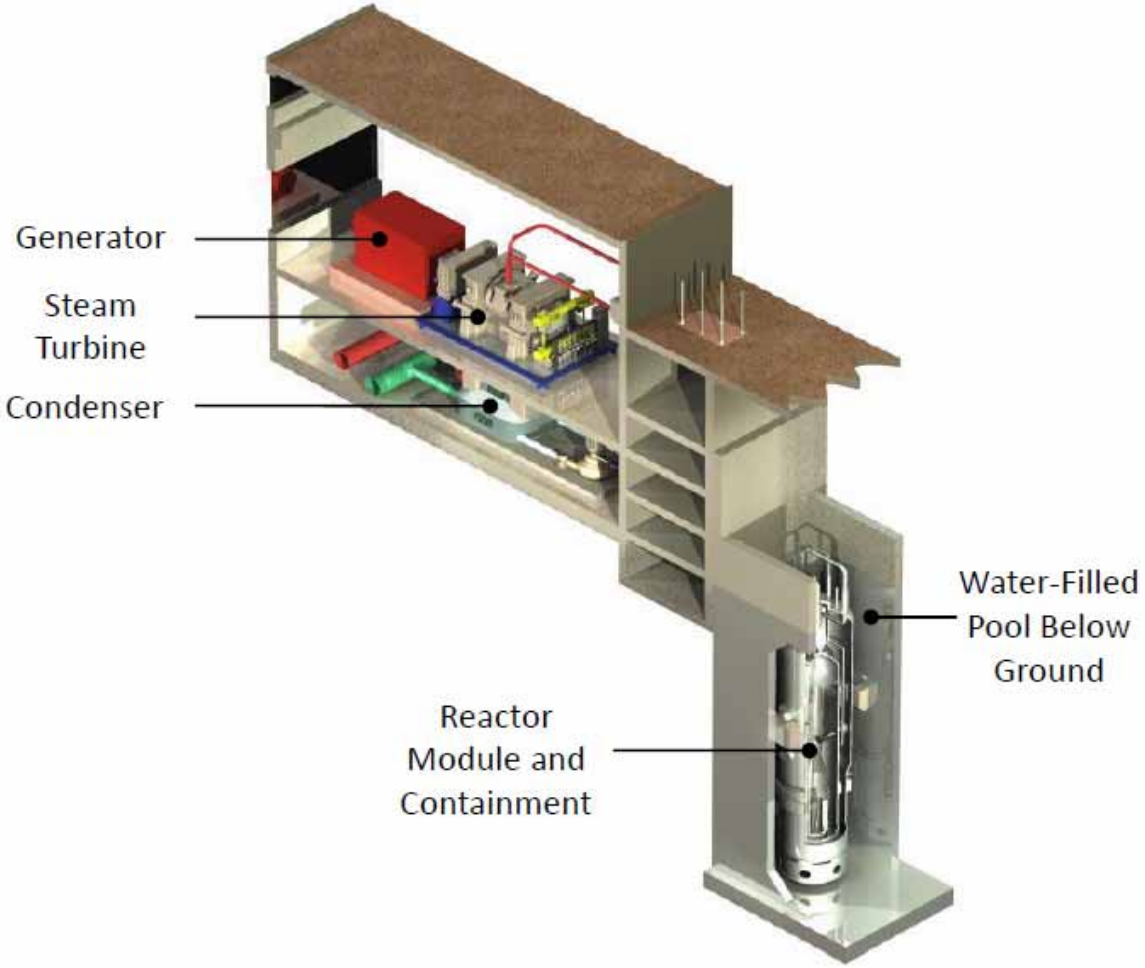
Simplified Steam System

- Superheated steam
- No feedwater heaters
- “Off-the-shelf”
- 100% steam bypass



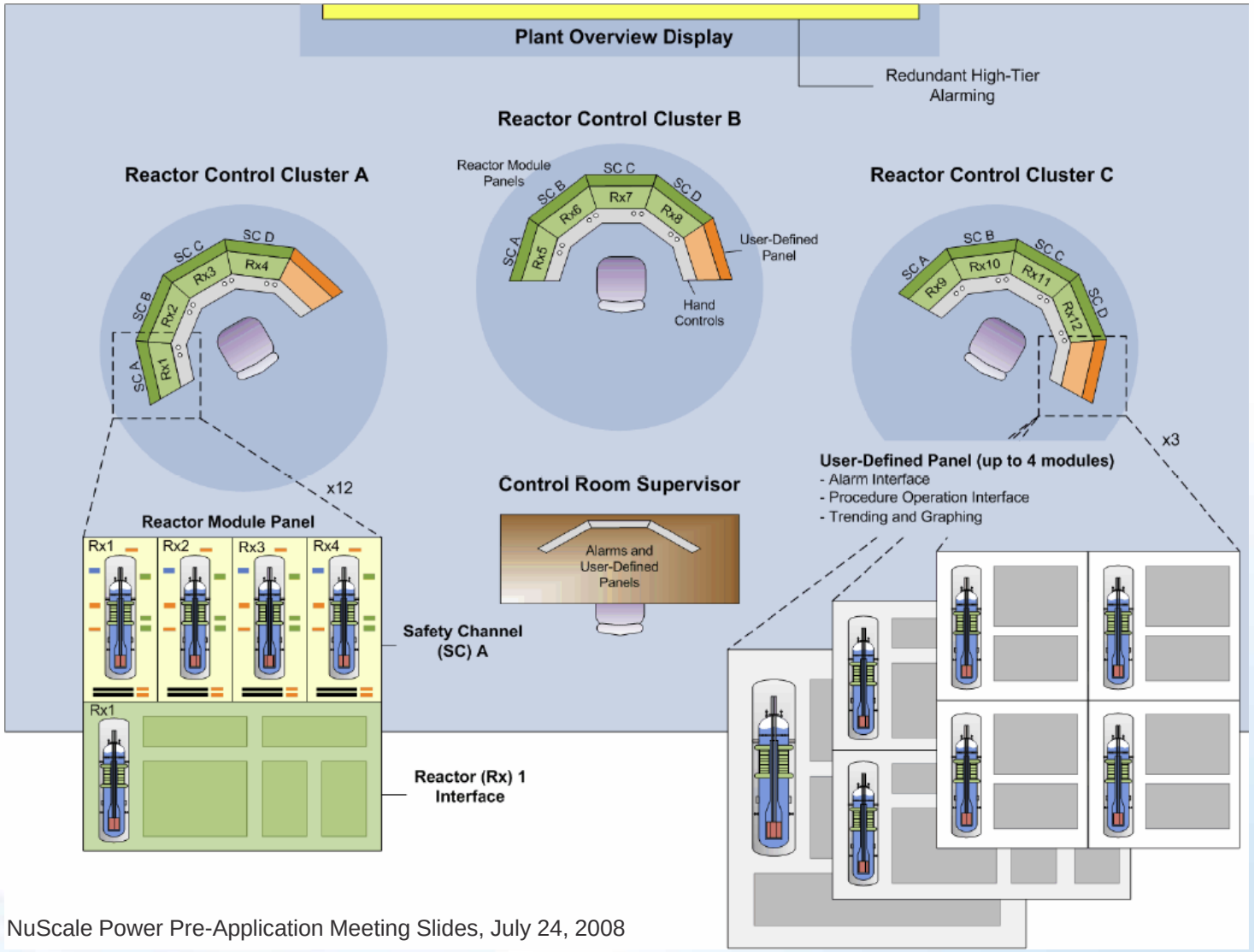


NuScale Module



Reference: NuScale Power Overview of NuScale Design Slides, April 2, 2009

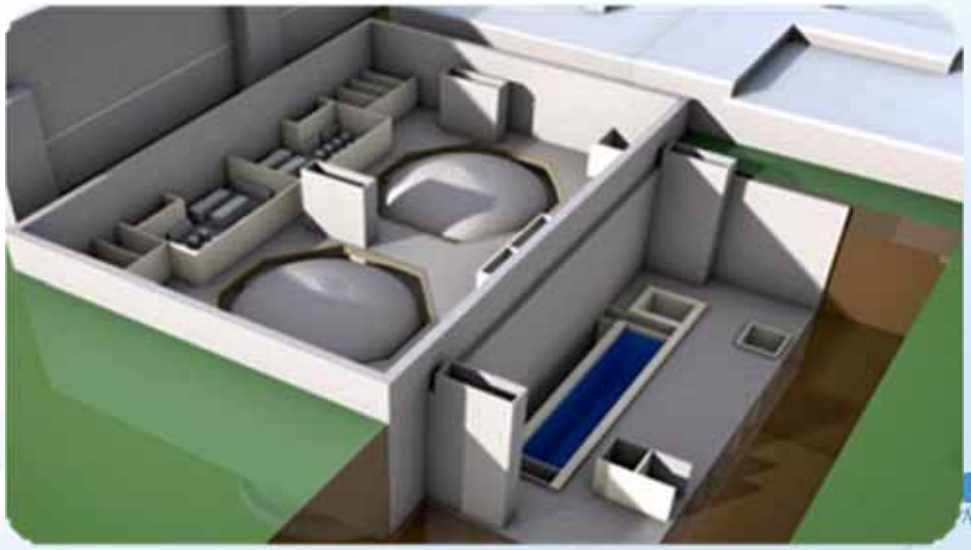
Multi-Module Control Room Layout



Reference: NuScale Power Pre-Application Meeting Slides, July 24, 2008

Policy/Technical Issues

- **Control Room Staffing Levels**
  - **Multiple units in one room**
- **Source Term**
- **Emergency Planning**
- **Seismic Issues**



Who's Onboard?

- **Industry/Utilities**
  - **mPower: TVA/Bechtel…**
  - **West: Ameren Missouri, Burns&McDonnell, GD Electric Boat…**
  - **NuScale: Fluor, Curtiss Wright**
- **Nuclear Regulatory Commission**
  - **New licensing requirements**
- **Department of Energy**
  - **$450M in support of SMR development**

The Future?

- Promising technologies
- Lots of competition
- Regulatory hurdles
- Technical hurdles