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SMALL MODULAR REACTORS – A Southwest Energy Solution?

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Domestic Small Modular Reactor (SMR) Interest

- Value Proposition
  - Enhanced safety and security
  - Reduced capital cost before generating revenue makes nuclear energy accessible for more utilities/electrical coops/minimum grid
  - Shorter construction schedules due to modular construction
  - Improved quality due to replication in factory-setting
  - Meets electric demand growth incrementally
  - Meets base-load demand electricity demand and other needs (e.g., coal plant replacement, heating/cooling, water desalination)
- Market Drivers
  - Provides a solution to markets that have smaller electrical demand and infrastructure
  - Distributed Power Generation requiring less long distance transmission
  - Responds to markets where electricity demand is projected to increase incrementally
  - Modular construction would overcome skilled workforce issues
  - Require less capital outlay than for larger plants
  - Provide clean, base-load electricity to markets responding to climate and environmental goals

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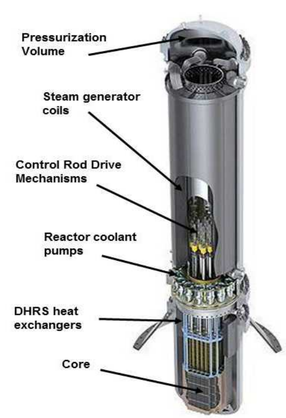
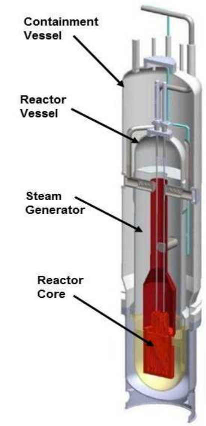
Small Modular Reactor Technology

Near-Term LWR Designs

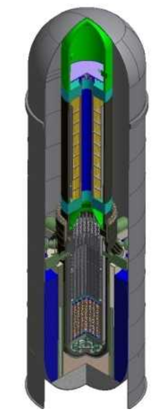
- Well Understood Technology
  - LWR based designs
  - Standard <5% UO2 fuel
  - Regulatory & operating experience
  - Prototype may not be required
  - Deployment by 2020



mPower (Babcock & Wilcox)
125 MWe



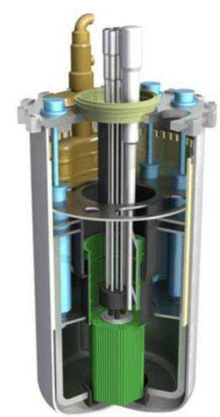
NuScale (NuScale)
45 MWe



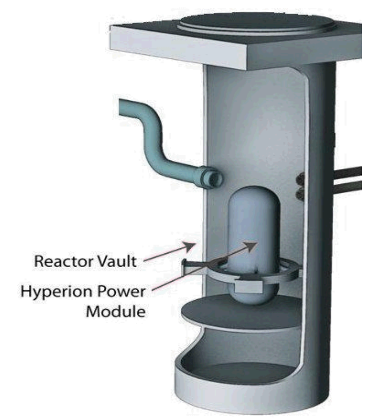
Westinghouse
~200 MWe

Longer-Term SMRs

- New Innovative Technologies
  - Mostly non-LWR based designs
  - Prototypes will be required
  - Deployment 15-20 years
- Broader Applications
  - Process heat applications
  - Transportable/mobile
  - Long-lived cores



GE PRISM
320 MWe



Hyperion
25 MWe

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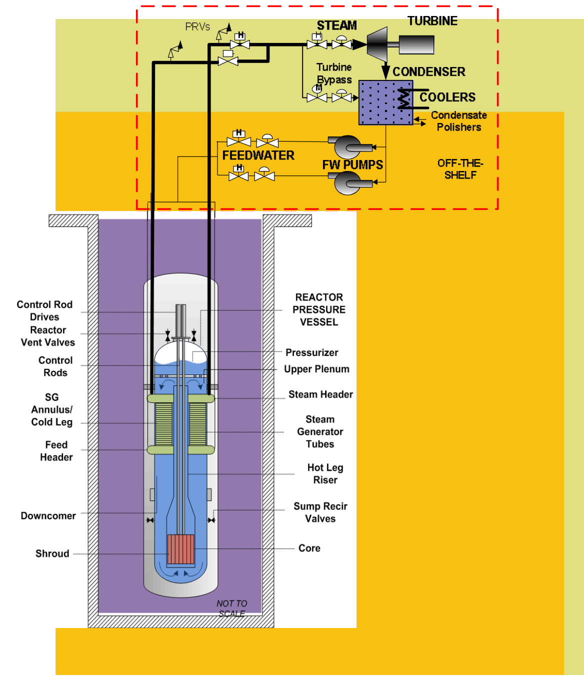
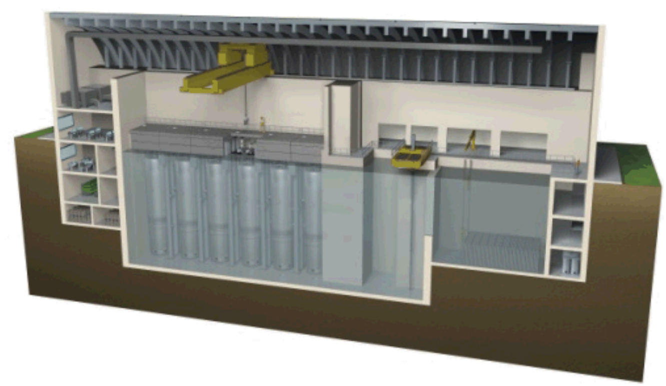
The SMR Safety Case

- Primary system components in a single vessel
- Increased coolant inventory in primary reactor vessel
- Increased pressurizer volume
- Smaller radionuclide inventory
- Cooling of core and vessel by natural convection
- More effective heat removal
- Lower power heat decay
- Below-grade reactor vessel and spent fuel pool
- Enhanced resistance to seismic events





Schematics Courtesy of NuScale Power, Inc.

Southwest Perspective

- Eliminate Fresh Water Evaporative Cooling
  - Fresh Water Needs for a Nuclear Plant – ~10,000 gal/MW-Day installed
  - Dry heat rejection means loss of efficiency ~10%
- Develop <50 MWe at less that $2000/kWe installed
  - Skid Mounted delivery
  - No “Stick-Built” Construction
- Island Southwest from National Grid
  - Secure energy
  - Installations and region
- Solutions?
  - Supercritical CO2 closed Brayton Cycles with Dry Heat Rejection, 40% efficiency – no water
  - Smart Integrated Micro-Macro Grids

Mitamba Power Station, South Africa, 6x660 MWe

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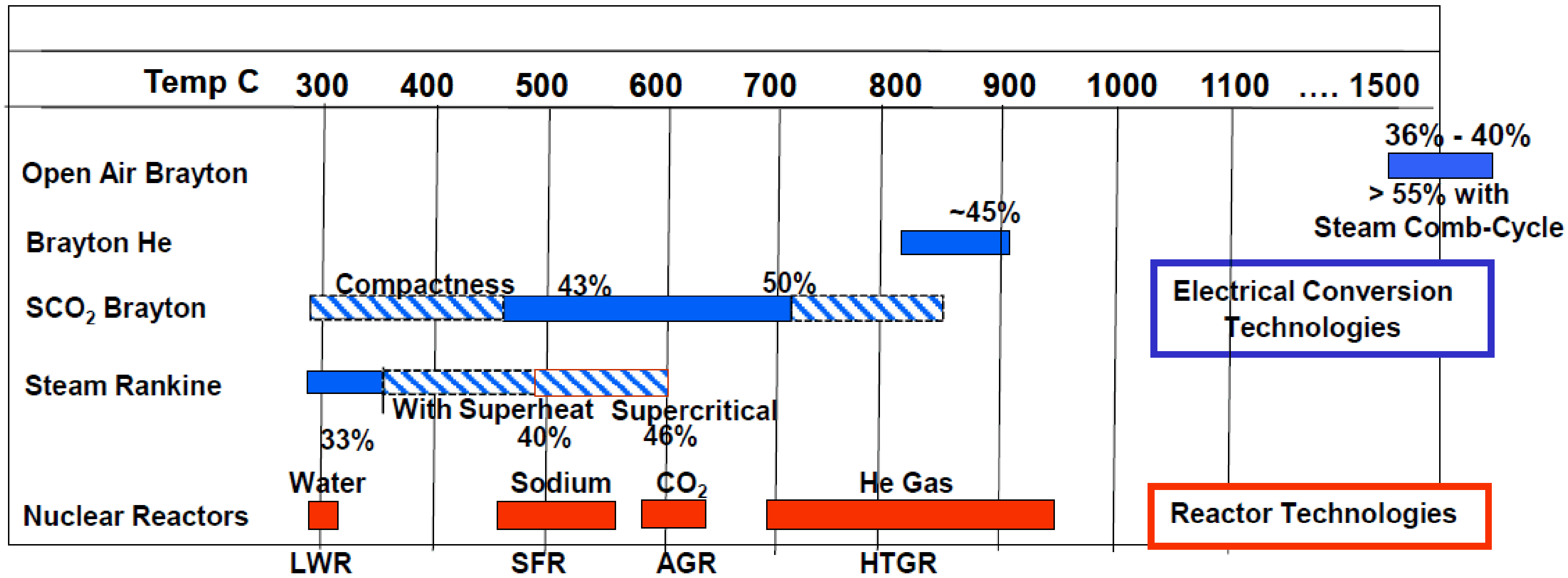
Supercritical S-CO_2 Brayton Cycle

Field of Use Explored for S-CO2 Brayton Technology

- Light Water Reactors (1000 MWe)
- Sodium Fast Reactors (500 MWe)
- High Temperature Gas Reactor (750 MWe)
- Molten Salt Reactor (1000 MWe)
- Small Modular Reactors (50 MWe)
- Maritime Propulsion (100-250 MWe)
- Concentrated Solar Power (10-150 MWe)
- Geothermal (50-150 MWe)
- Fossil Energy (500-1000 MWe)
- Advance Coal Combustion/Carbon Sequestration (500 MWe)
- Space Nuclear Propulsion
- Solar Electric Propulsion (250 KWe)

Power Conversion and Nuclear Reactor Outlet Temperature Ranges



S-CO_2 Power Conversion Operating Temperatures Matches all Advanced Reactor Concepts

LWR – compactness, condensing cycle appear promising

LWR- highly efficient with S-CO2 Condensing Power Cycles

Pursuing DoD Reactor Project

- **Not effective to approach each branch independently, need a DoD-wide initiative analogous to mission-critical weapon or support systems that Congress authorizes and appropriates for**
  - **DoD has multiple missions in multiple environments, CONUS islanding is only one.**
  - **Development to first deployment could easily be $0.5B and up.**
- **A systematic approach is needed to guide to military reactor development**
  - **Define missions and deployment "environments"**
  - **Define system functional requirements**
  - **Power levels and cycling requirements**
  - **Lifetime and availability constraints**
  - **Costs / Economics, etc**
- **Identify / define candidate system concept and technology options**
  - **Evaluate options against requirements**
  - **Performance**
  - **Technical maturity**
  - **Technical development risk**
  - **Cost and schedule**
- **Select Reactor Concept**

1. Establish Evaluation Criteria & Metrics
2. Reduce Options to short list
3. More detailed evaluations
4. Reduce to Primary and Backup System Options
5. Develop preliminary designs
6. Formalize development plans

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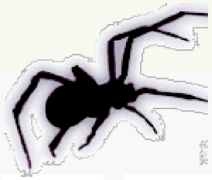
SMRs for DoD Installations

- Integrate SMRs with Renewable Energy SPIDERS
- Benefits to DoD
  - Energy Security
  - Reduction of GHG Emissions
  - Reliable Energy Source
    - Electrical power for operations
    - Hydrogen for synthetic fuels production
    - Solid waste disposal (carbon source)
    - Personnel comfort (heating and cooling)
    - Other (e.g., water desalination)
  - Owned, Operated, and Regulated by Others
- Challenges
  - Fukushima Effect
  - FOAK Costs
  - Perceived Legacy Costs

Smart Power Infrastructure Demonstration for Energy Reliability and Security JCTD



CIRCUIT LEVEL DEMONSTRATION

- Renewables
- Storage
- Energy Management

FT CARSON MICRO-GRID

- Large Scale Renewables
- Vehicle-to-Grid
- Smart Micro-Grid
- Critical Assets
- CONUS Homeland Defense Demo
- COOP Exercise

CAMP SMITH ENERGY ISLAND

- Entire Installation Smart Micro-Grid
- Islanded Installation
- High Penetration of Renewables
- Demand-Side Management
- Redundant Backup Power
- Makana Pahili Hurricane Exercise

TRANSITION

- Template for DoD-wide implementation
- CONOPS
- TTPs
- Training Plans
- DoD Adds Specs to GSA Schedule
- Transition to Commercial Sector
- Transition Cyber-Security to Federal Sector and Utilities

VIRTUAL SECURE ENCLAVE CYBER-SECURITY

- Use of Sandia developed Energy Surety Microgrid conceptual designs at Ft. Carson and Camp Smith
- Sandia designated Deputy Technical Manager to OSD Power Surety Task Force

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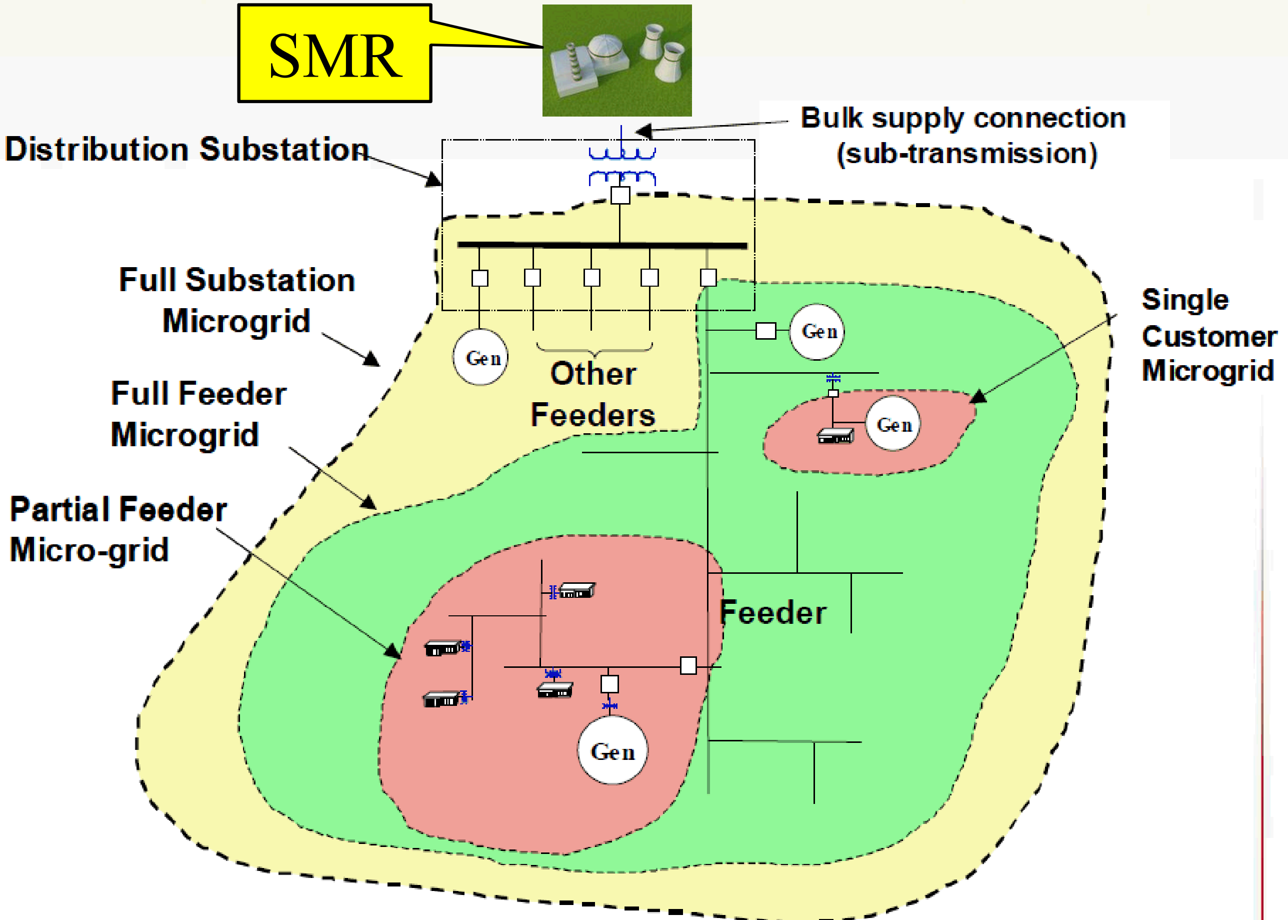
Use Renewable and Distributed Generation to Support DoD Microgrids and the Smart Grid

- Small combustion and μ-turbines
- Fuel cells
- IC engines
- Small hydro and wind
- Solar electric and solar thermal
- Energy storage (batteries, flywheels,…)
- Plug in hybrid vehicles
- Small nuclear power



Ref. EPRI

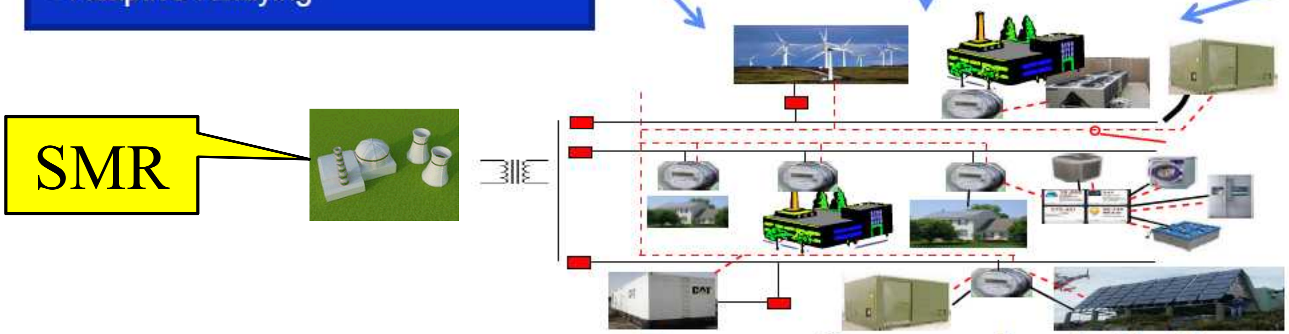
Residential	Less than 10-kW, single-phase
Small Commercial	From 10-kW to 50-kW, typically three phase
Commercial	Greater than 50-kW up to 10MW

JCTD Elements and Example Technologies

Cyber-Security
- Virtual Secure Enclave
- Live Action Network
- Secure Distributed Monitors
- Situational Awareness

Smart Grid
- Advanced Metering Infrastructure
- Substation & Distribution Automation
- Two-Way Communications & Control
- Adaptive Relaying

Islanded Micro-grid
- Load Control Systems
- Islanding Control System
- Energy Management System
- Seamless Grid Synchronization



Energy Secure Installation

Demand Side Management
- Energy Efficiency Technologies
- Dynamic Voltage Regulators
- Smart Sockets
- Automated Load Shedding

Backup Power
- Vehicle-to-Grid
- Fuel Cells
- Batteries

Renewable Integration
- Photovoltaic
- Wind
- Biofuel

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Key SMR Safety Assurance Research Needs

- Emergency Planning Zone
  - Technical basis needed for EPZ requirements for smaller cores
  - Preliminary source term and PRA being developed at SNL as the technical basis for this type of analysis
- Operations & Staffing
  - Current NRC regulations based on 1-2 large cores; modular designs with smaller cores need to be examined
  - INL evaluating multi-module facilities operations and staffing issues
  - Reduce water usage
  - Emergency Planning for beyond Design Basis
  - Loss of Off-Site Power
- Physical Security
  - Below-grade and smaller cores may reduce physical security and staffing costs
  - SNL applying Integrated Safety, Operations Security and Safeguards (ISOSS) principles to address adequate staffing issues

Conclusions

- SMR Benefits:
  - Support energy security, climate change mitigation, & economic growth goals
    - Nuclear power remains a key element of the U.S. energy strategy and portfolio; benefits higher than risks
  - Regain technical leadership and innovation
  - Improve U.S. manufacturing capability and supply chain infrastructure
  - Create high-quality manufacturing, construction, and engineering jobs
  - Become global leader in SMR technology based on mature nuclear infrastructure and NRC certified designs
- Challenges:
  - Define the business case for < 200 MWe baseload plants
  - Demonstrate/validate enhanced safety features
  - Prove economy of mass production
  - Identify Owners/Operators willing to support DoD and commercial requirements

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