Nuclear Power Grids and Clean Energy

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AIAA Los Angeles/Las Vegas and ACS Southern California

Earth Day event

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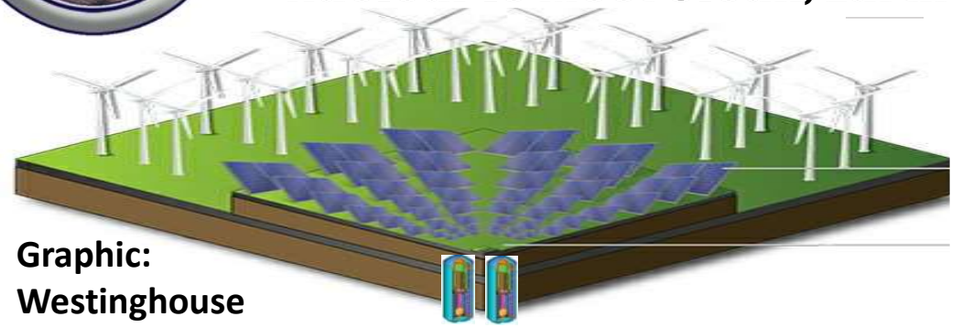
High Level Clean Energy Alternative Analysis:

Among *Carbon-Free* Solar, Wind & *Advanced* Reactor Power Systems

Nuclear Is Most Clean, Earth-Friendly, Safe, Abundant, Affordable & Reliable!

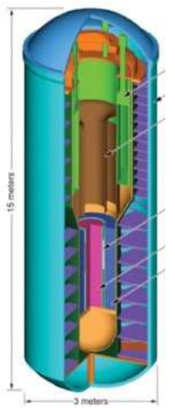


Graphic:
Westinghouse

For 225 MWe Power (Small City Size)

- **Wind = 60,000 acres**
- **Solar = 2,400 acres**
- **Reactors = 15 acres**

Decentralized Power Generation:	Solar	Wind	Nuclear
- Acres Required For 225 MWe Power	2,400	60,000	15
- Heat/Cool Buildings, Make Hydrogen, Purify Water	No	No	Yes
- Kill Wildlife (Birds, Animals, Insects, Plants, etc.)	Millions	Millions	~0
- Damage From Natural Disasters	Heavy	Heavy	Minor
- Vulnerabilities To Terrorism, EMP & Cyber Attacks	Huge	Huge	Minor
- Life Cycle of Units (years)	10-15	7-10	Up to 30
- Primary Manufacturing Source	China	China	USA
- Availability (Ave. Hours Per Day/Days Per Year)	0-12/100	0-24/180	24/365
- Est. Price of Power (Cents per KWh)	>15	>15	<07

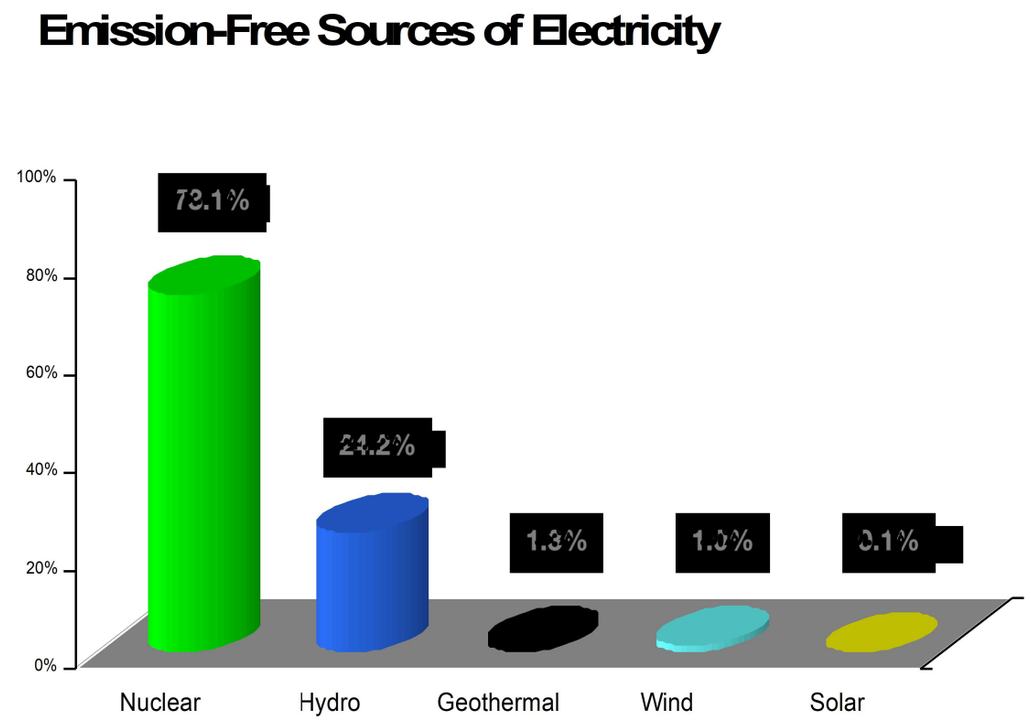


U.S./DOE SSTAR

Lead-Cooled, Mobile & Fixed Sites (25,000+ homes)

Always Up, Sealed, Underground, 30-yr. Fueled, Liquid-Lead Cooled, Walk-Away Safe, EMP Protected

Note that nuclear energy is by far the largest producer of CO2 emission free electricity in the US.

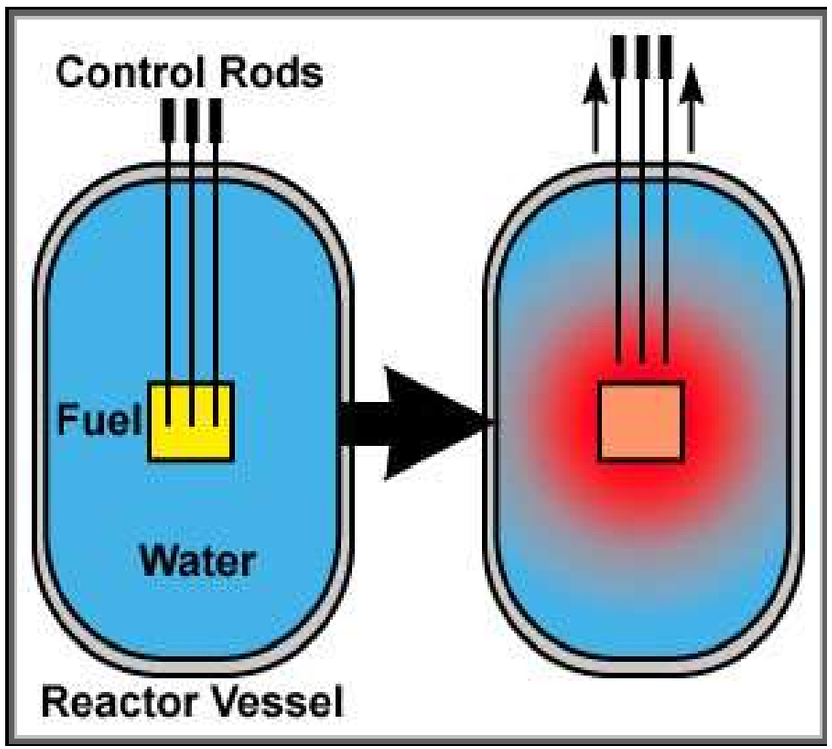


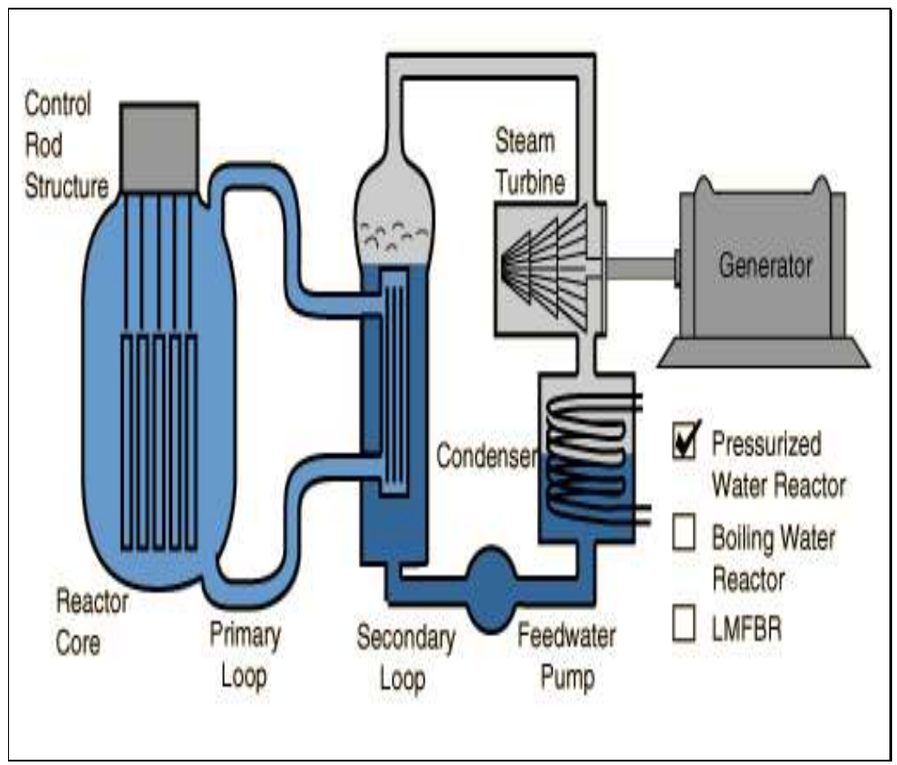
Source: Energy Information Administration

What is the trajectory leading to the current state of nuclear energy development?

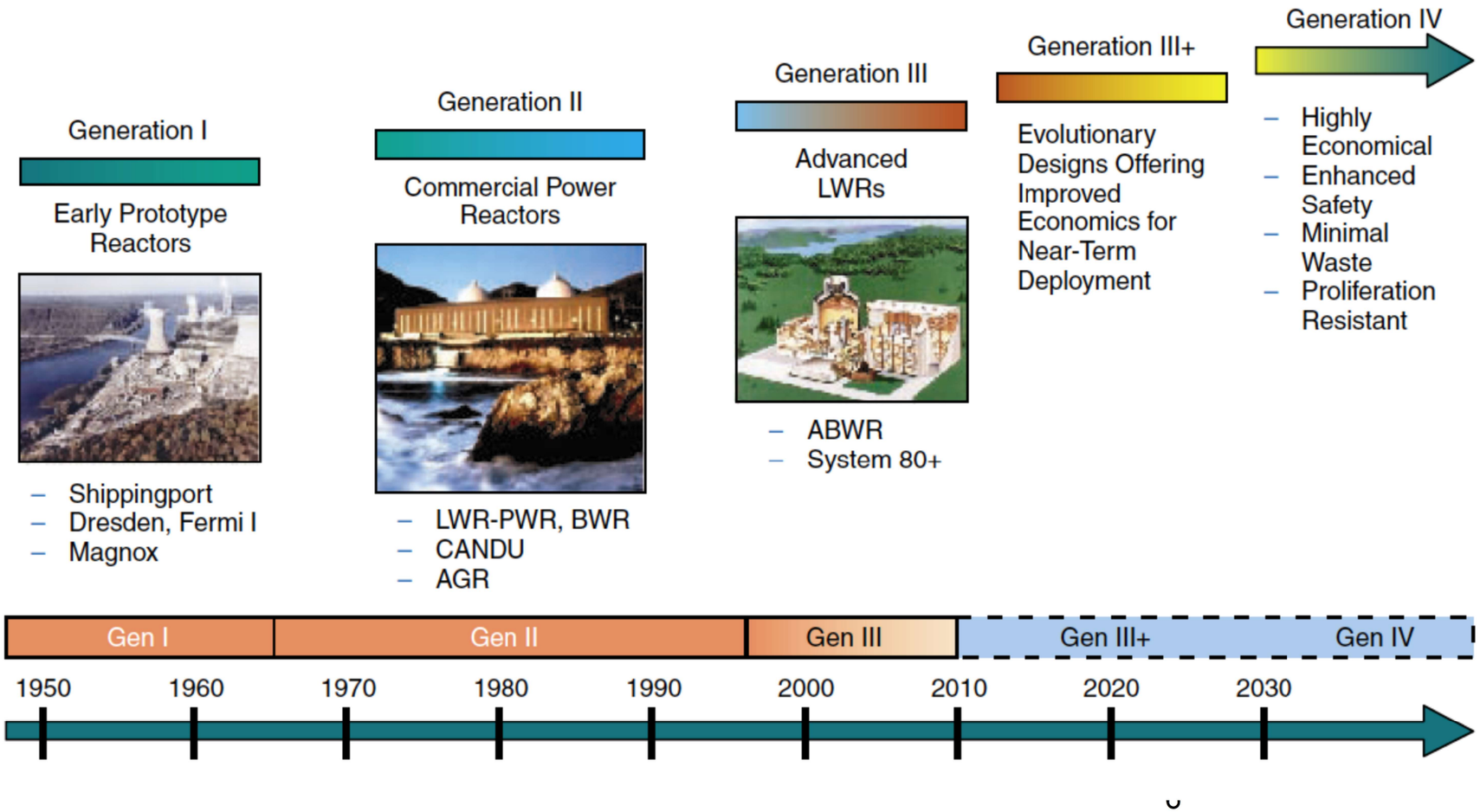
- First introduced in the 1940s in the Manhattan Project
- Next step: Naval propulsion
- Then Eisenhower's Atoms for Peace plan led to commercialization and globalization
- Economics drove designs to larger and larger sizes
- Four generations of reactor designs with progressively reduced accident risk and improved safety
- But what about reactor accidents?
  - Three Mile Island
  - Chernobyl
  - Fukushima Daiichi
- Where are we now: considering small and very-small (micro-reactors) as we go forward into the next phase of nuclear energy

The idea behind energy from nuclear fission is relatively straightforward





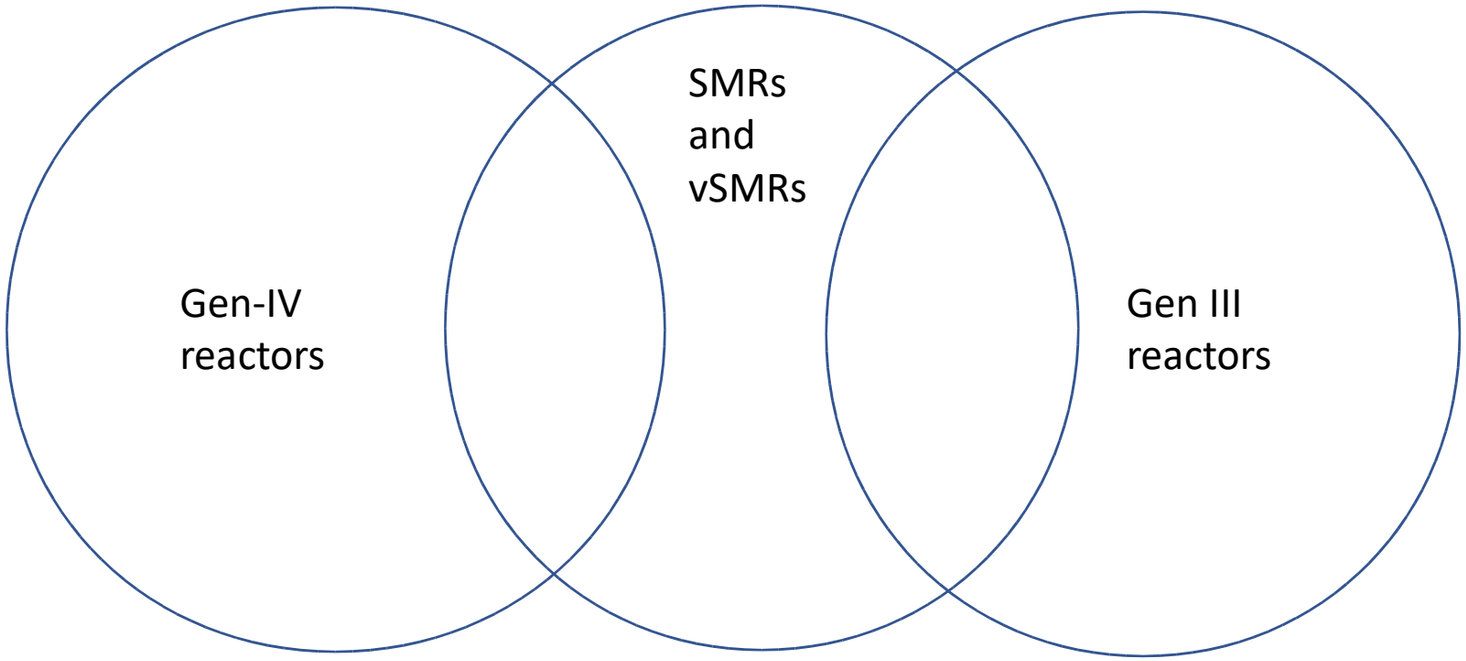
The 4 generations of reactor development



Generation IV Reactors

- **Gas Cooled Fast Reactor (GFR)**
- **Very High Temperature Reactor (VHTR)**
- **Supercritical Water Cooled Reactor (SCWR)**
- **Sodium Cooled Fast Reactor (SFR)**
- **Lead Cooled Fast Reactor (LFR)**
- **Molten Salt Reactor (MSR)**

Small modular reactors (SMRs) versus micro reactors/vSMRs



SMRs are generally smaller than 300 MW and:

- ***employ modular construction techniques***
- ***major components can be shipped from factory fabrication locations to the plant site by rail or truck***
- ***include designs that simplify plant site activities required for plant assembly***

vSMRs or Micro Reactors are generally in the 1-50 MW range:

- ***Provide even greater flexibility such as transportability***
- ***Further improved safety and security***
- ***Highly decentralized power production***

MICROREACTORS:

Small reactors **BIG** potential

Plug-and-play reactors able to produce 1-20 megawatts of thermal energy used directly as heat or converted to electric power

FEATURES:

- *Factory Fabricated*
- *Transportable*
- *Self-Regulating*

BENEFITS:

Small Size

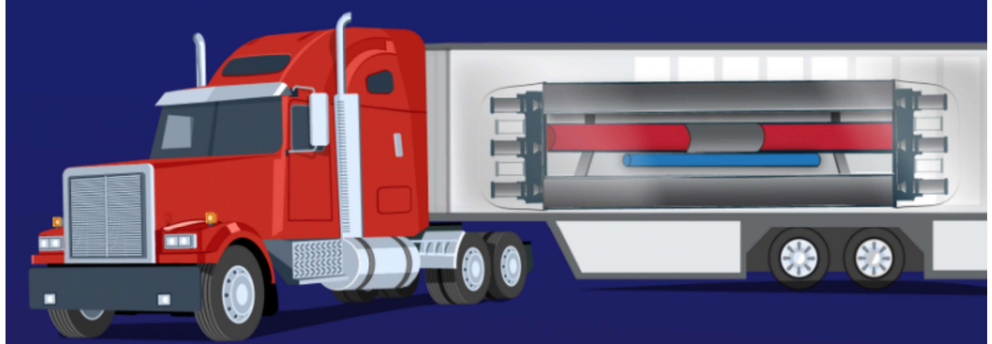
Fits on the back of a semi-truck and can be deployed to remote locations and military bases for reliable heat and power.

Simple Design

Fail-safe and self-regulating designs that require fewer components, maintenance and operators.

Fast On-site Installation

Can be connected and generating power within a week of arriving on site.



Clean. Reliable. **Nuclear.**

U.S. DEPARTMENT OF **ENERGY** | *Office of* **NUCLEAR ENERGY**

*Source: U.S. Energy Information Administration

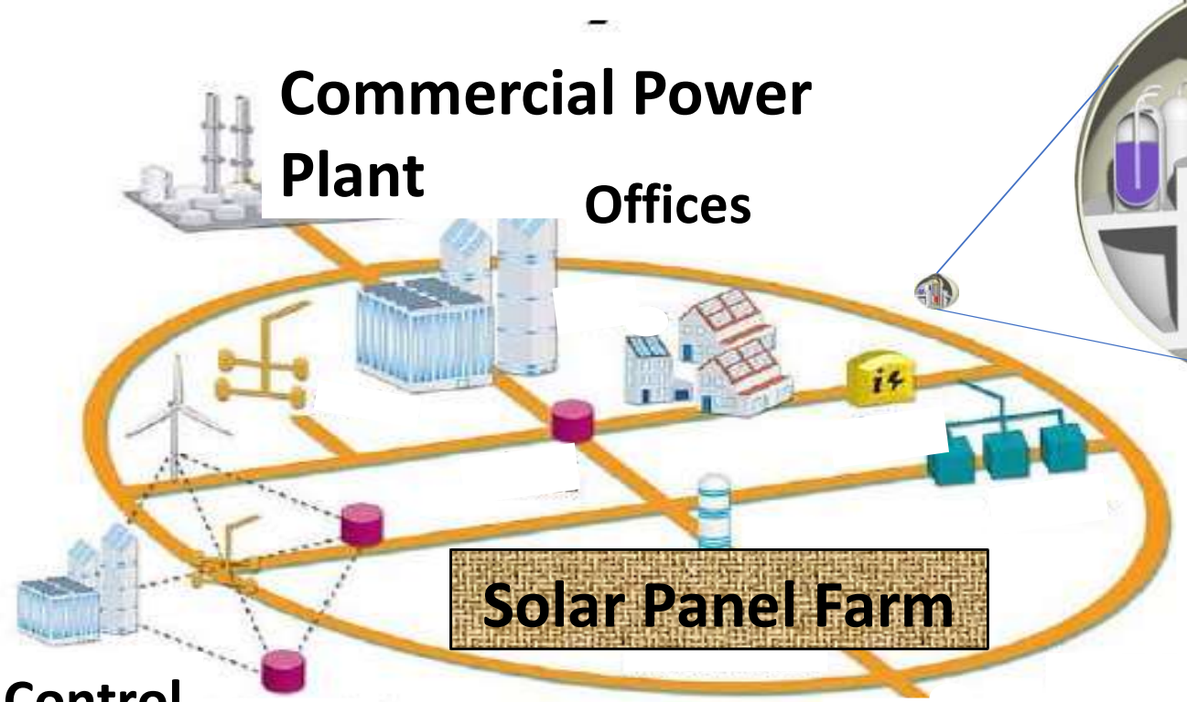
According to DOE, the Benefits of Small Modular Reactors (SMRs) include:

- **MODULARITY. ...**
- **LOWER CAPITAL INVESTMENT. ...**
- **SITING FLEXIBILITY. ...**
- **GREATER EFFICIENCY. ...**
- **SAFEGUARDS & SECURITY / NONPROLIFERATION. ...**
- **U.S. INDUSTRY, MANUFACTURING, AND JOB GROWTH. ...**
- **ECONOMIC DEVELOPMENT.**

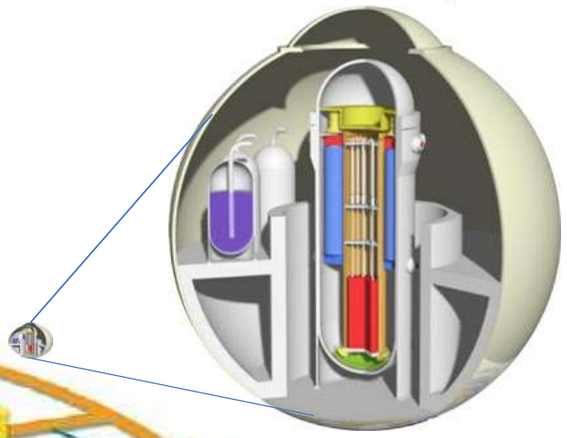
Conceptual View Of A MicroGrid With Micro Reactor Power System

Some Desired System Features

Sealed, Underground, EMP-Terrorist-Protected, Safe, No Emissions, Turn-Key, Leased, Refueling For Decades, Air-Plant-Land-Animal-Friendly

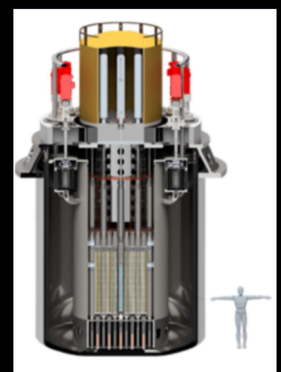


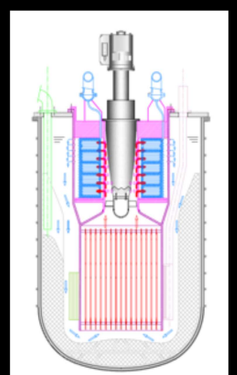
Generic MicroGrid Layout



Buried Micro Reactor Concept


HOLOS

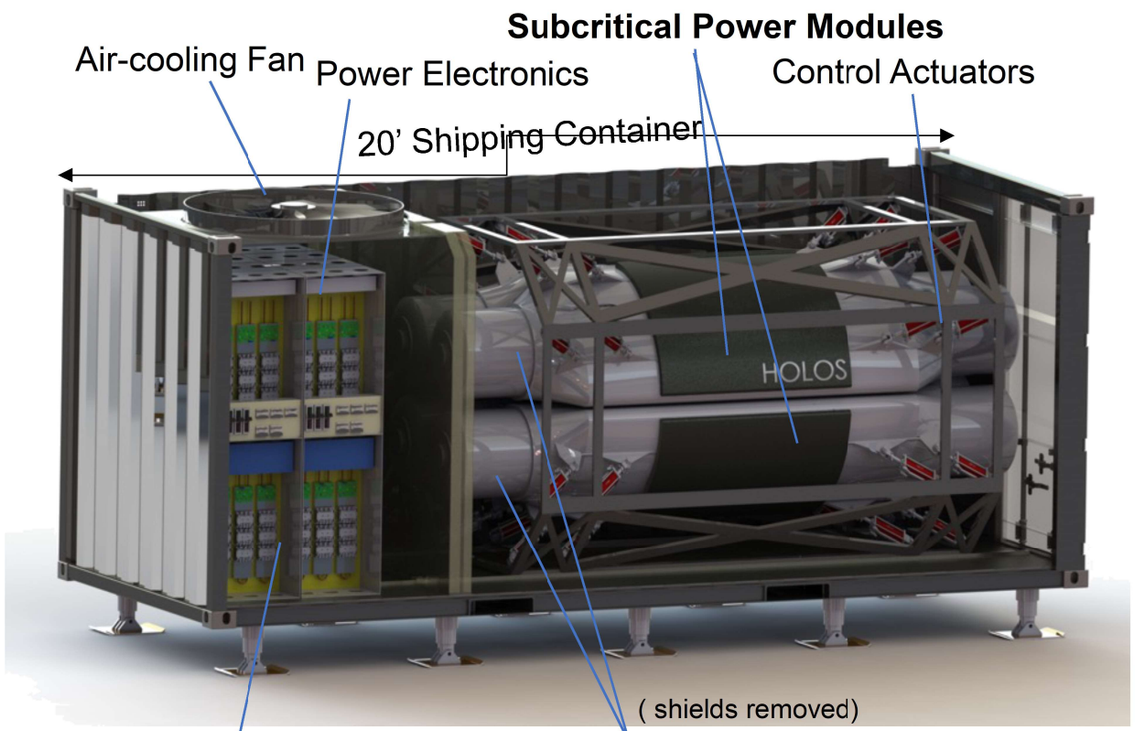





eVinci™

Holos-Gen

Holos-QUAD 3 MWe generator in a 20’ Shipping Container



Video clip:
http://www.holosgen.com/holos-titan-generator/

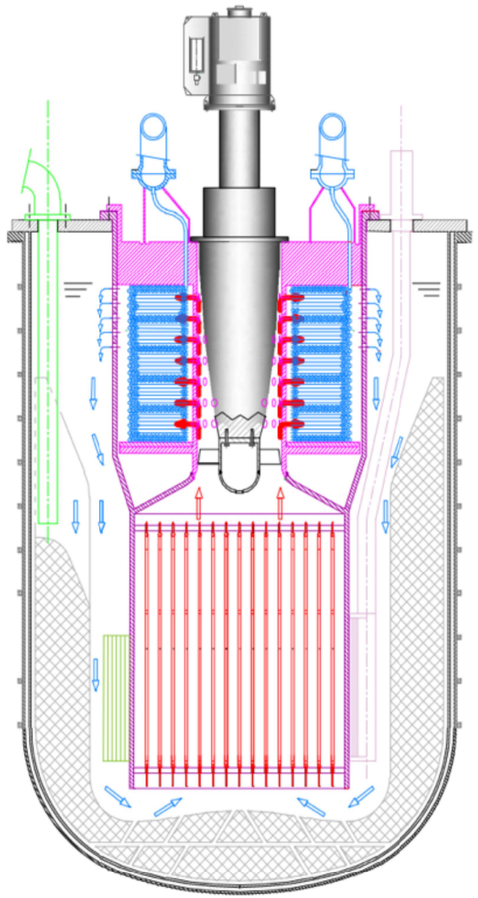
Parameter	Description
Reactor Type	High Temperature Gas Reactor
Coolant	Various configurations: Helium, CO2, Air
Ultimate Heat Sink	Environmental air
Electric Power Output [MWe]	Various Configurations: 31-102-203-604-804
Fuel Type	TRISO
Fuel Enrichment	≤ 19.75%
Fuel Cycle [EFPY]	Various Configurations: 3, 8, 12 years
Load Following	Real time
Passive Decay Heat Removal	Natural air convection
Dimensions	20' - 40' Transport ISO Container
Transportability	To and from deployment site (shielded transport with spent fuel cartridges)

Notes:
1: 1x 20’ ISO container **1 – 3 MWe**
2: 1x 40’ ISO container **10 – 13 MWe**
3: 2x 40’ ISO containers **20 MWe**
4: 4x 40’ ISO containers **60 – 80 MWe**

The Hydromine LFR-TL-X is derived from a larger reactor known as the LFR-AS-200.

A series of very small modular reactors (vSMRs).
TL stands for Transportable Long-lived reactor
X (= 5, 10 or 20) is the electrical power in MWe.)

- Very long-life core
- Transportability in an upright position
- among the most compact (>1MWe/m3 primary volume), and passively-safe advanced reactors under current development.



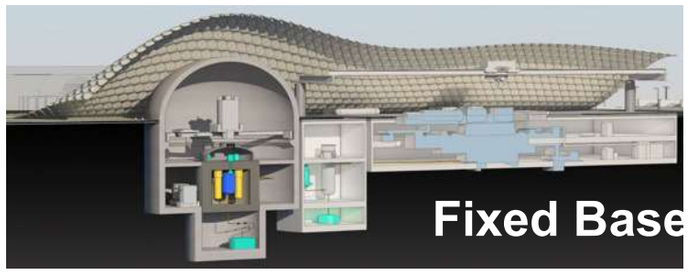
Scheme of LFR-TL-5, LFR-TL-10, LFR-TL-20

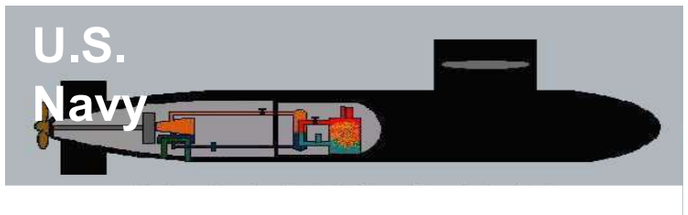
MAJOR TECHNICAL PARAMETERS	
Parameter	**Value**
Technology developer, country of origin	Hydromine Nuclear Energy S.à.r.l., Luxembourg
Reactor type	Liquid metal cooled fast reactor (pool type)
Coolant/moderator	Lead/none
Thermal/electrical capacity, MW(t)/MW(e)	15/5; 30/10; 60/20
Primary circulation	Forced circulation
System pressure (MPa)	Atmospheric, non-pressurized
Core inlet/exit temperatures (°C)	360/420
Fuel type/assembly array	LEU, cylindrical cassette
Number of fuel assemblies	N/A
Fuel enrichment (%)	19.75
Fuel burnup (GWd/ton)	40
Fuel cycle (months)	≥100
Main reactivity control mechanism	Ex-core, reversed-flag type, rotating staff moves absorbers closer to or away from the core
Approach to engineered safety systems	Active +passive
Design life (years)	30
RPV height/diameter (m)	3.5/2
Seismic design	0.5g peak ground accelerations
Distinguishing features	Active + passive walkaway safety. No intermediate loops. Simple, compact primary system: about 1 m^3/MW(e) compact reactor building.
Design status	Conceptual design

GRID Independence Is Possible With Fixed Or

Transportable Micro Nuclear Power Systems

- Think: "Giant Battery"—Internally Fueled For 20 To 30 Years!
- Safe, Sealed, Pollution-free, Reliable & EMP/Terrorist Protected.
- Advanced Reactors Produce Power 24/7/365, Pure Water & Hydrogen For Fuel Cells
- Creech AFB, NV: Could be considered as a Military Pilot Test Site





Thank you!