Nuclear Energy and Power Plants

M. Kawaji

The Energy Institute
City University of New York
New York, USA

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Nuclear Energy in the US

- USA's 100 nuclear reactors produced 798 billion kWh in 2014, over 19% of total electrical output. There are now 99 units operable (98.7 GWe) and five under construction.
- Nuclear energy is the largest source of GHG emission-free electricity (~70%)
- Nuclear electricity is 10 times more than Solar, Wind and Geothermal combined.

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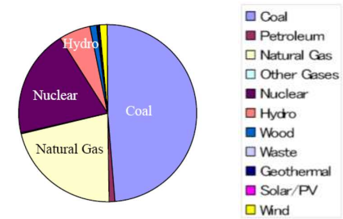
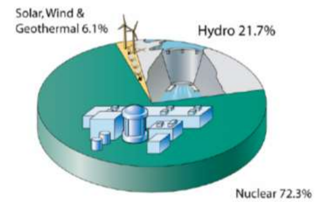


Power plant fuels used in US electricity generation in 2008



GHG emission-free electricity generation in 2008

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Fission and Energy Release

Einstein's Law of Special Relativity led to Mass-Energy Equivalence

$$E=mc^2$$

where E = energy, m = mass and c = speed of light

= 299,792,458 m/s

Mass-Energy Equivalence

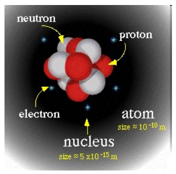
One gram (1/1000 of a kg) of mass is equivalent to:

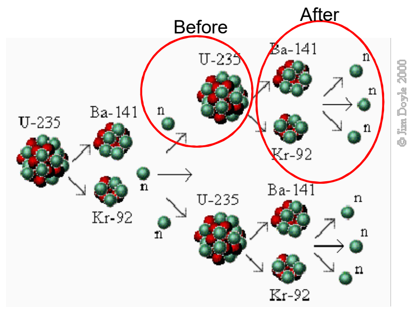
89.9 terajoules (89,900,000,000,000 Joules)
25.0 million kilowatt-hours (≈25 Gigawatt·hours)

or the energy released by
21.5 kilotons (21,500,000 kg) of TNT

combustion of 568,000 gallons of gasoline

Fission and Fission Products

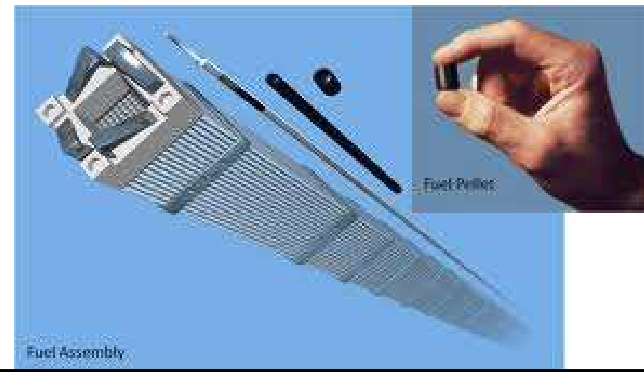




Difference in mass per fission = 0.1% of initial mass = 3.27 x 10^{-11} Joules= 9.08x10^{-18} kW-hr
1 gram of pure Uranium-235 is equivalent to 3500 kg of coal

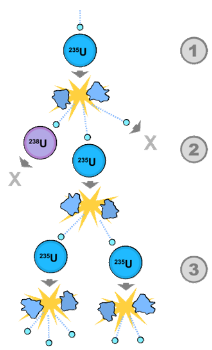
Nuclear Reactors

- Feed: Fresh uranium fuel (U-235 @ 3~5% + U238) assemblies
- Process: Nuclear chain reaction
- Product: Heat (and electricity)
- "Waste:" Irradiated fuel assemblies (spent fuel)
  - Uranium plus plutonium plus fission products



Fission Chain Reaction

- Nuclear reactors utilize chain fission reactions in a sustained and controlled manner.
- Each fission reaction produces ~200 MeV of energy.
- In contrast, most chemical reactions (such as burning coal or TNT) release at most a few eV per reaction.
- So, per unit mass, nuclear fuel contains at least 10,000,000 times more usable energy than does chemical fuel.
- In nuclear reactors, 1 gram of U-235 fuel can produce 7,583 kW-hours of electricity at 30% efficiency. Note an electric kettle uses ~1 kW-hr in 1 hr.



EVOLUTION OF NUCLEAR REACTOR DESIGNS

- ***Generation I***
  - ***Early reactors (1960s) < 200 MWe, mostly shut down***
- ***Generation II currently operating***
  - ***Mostly light water reactors up to 1000 MWe***
- ***Generation III being built***
  - ***Different reactor designs awaiting commercialization***
- ***Generation IV under development***
  - ***Substantially different from earlier reactors***
  - ***Not ready for deployment till 2020 or later***
- ***Small Modular Reactors***
  - ***Power: 300 MWe or less***
  - ***e.g., NuScale, Terrapower, mPower***

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Generation-III Light Water Reactor (LWR) Designs

ABWR (GE-Hitachi)

- Design certified
- Operating plants in Japan
- **1370-1460 MWe**

AP1000 (Westinghouse-Toshiba)

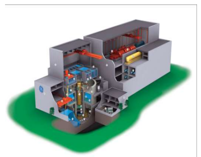
- Final design approved
- Engineering incomplete
- **1117 MWe**

US APWR Mitsubishi (not shown)

EPR (AREVA)

- Design certification not yet submitted
- Construction underway overseas
- Most costly of the designs
- **Large 1600 MWe**

ESBWR (GE-Hitachi)



- Design certification submitted in 2005
- Engineering incomplete
- **Large 1550 MWe**

Source : TVA 2007

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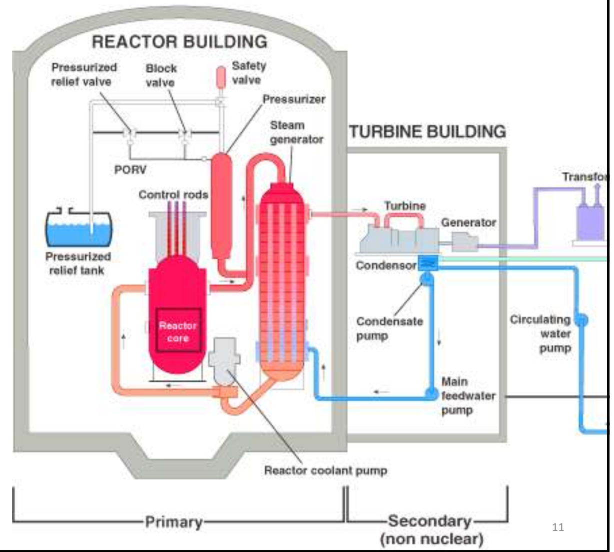

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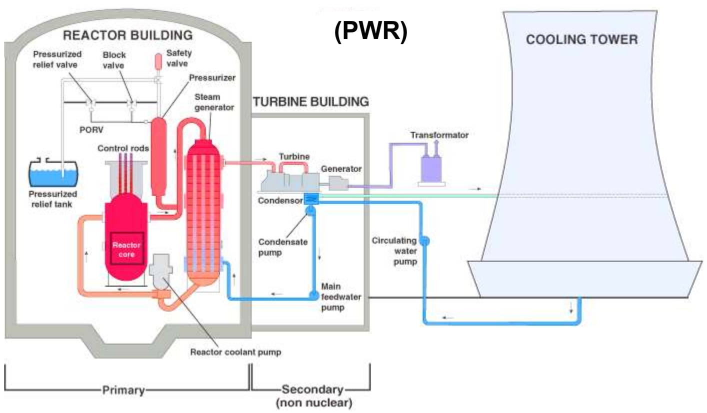
Pressurized Water Reactor (PWR)



Coolant: Light Water (H_2O)

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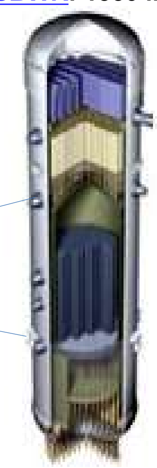
Advanced Boiling Water Reactors

ABWR: 1500 MWe **ESBWR: 1550 MWe**



Steam Dryer

Steam Separator

Chimney

Core with nuclear fuel assemblies

Recirculation pumps

Control Rods

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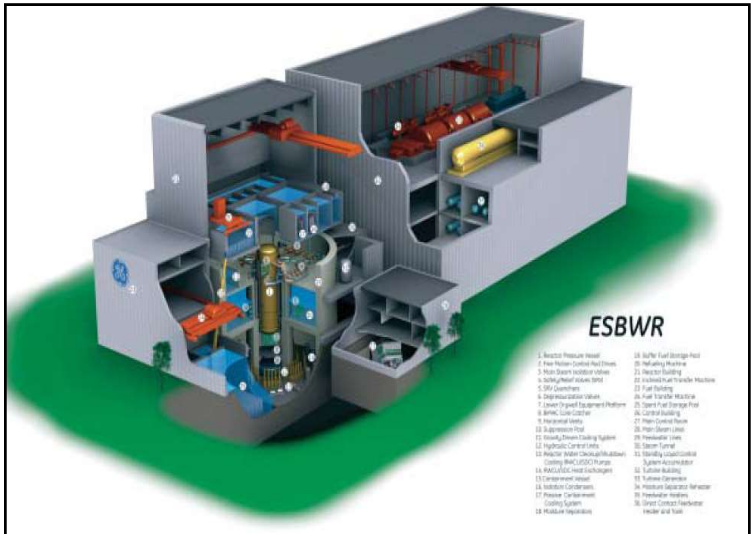
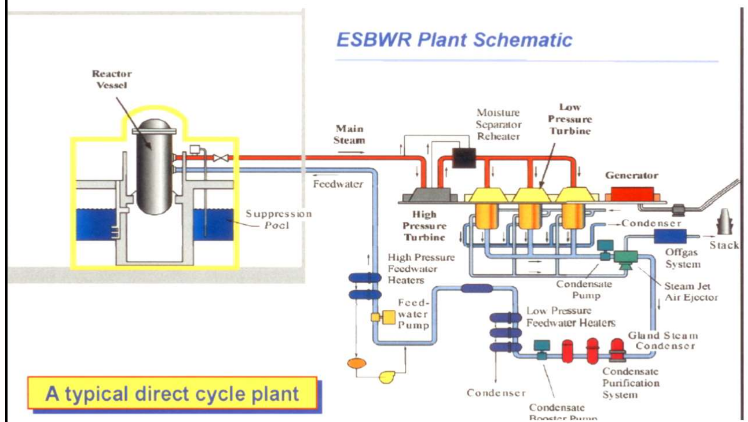


Fig. 1. Cutaway view of the ESBWR reactor and fuel, control, and turbine buildings



Corradini: Adv anced Nuclear Energy Systems;
Heat Transfer Issues and Trends, MIT, May 166h 2003

ESBWR Plant Schematic

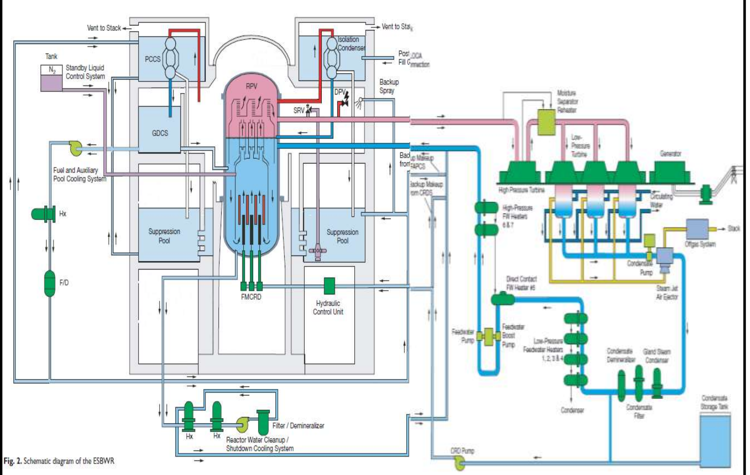
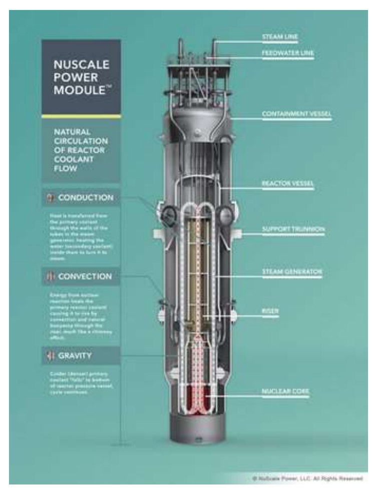


Fig. 2. Schematic diagram of the ESBWR

NuScale's Small Modular Reactor



NuScale Power Module
Coolant: Pressurized Light Water
Thermal capacity – 160 MWt
Electrical capacity – 50 MWe (gross)

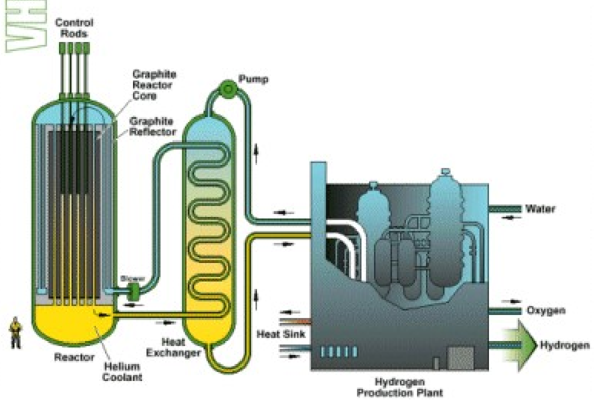
Up to 12 modules are operated from a single control room

- ***Reactor core with nuclear fuel assemblies and a Steam Generator housed in the same Reactor Vessel***
- ***Natural circulation of the coolant***

Very-High-Temperature Reactor

VHTR

Coolant: High Pressure/High Temperature Helium



http://en.wikipedia.org/wiki/Generation_IV_reactor

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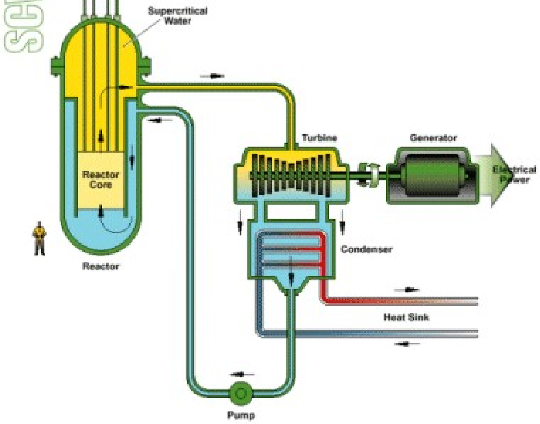
Supercritical-Water-Cooled Reactor

SCWR

Coolant: Supercritical Water



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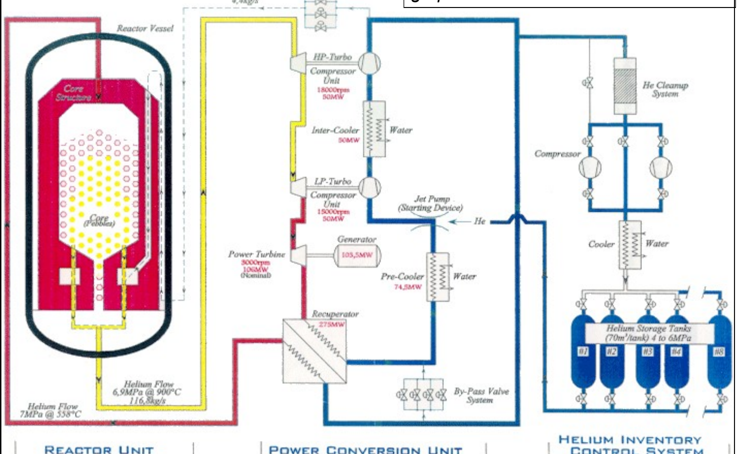
PBMR Helium Flow Path Schematic (Brayton Cycle)

Pebble Bed reactor

The reactor is a helium-cooled, graphite-moderated unit



http://www.eskom.co.za/nuclear_energy/pebble_bed/pebble_bed.html

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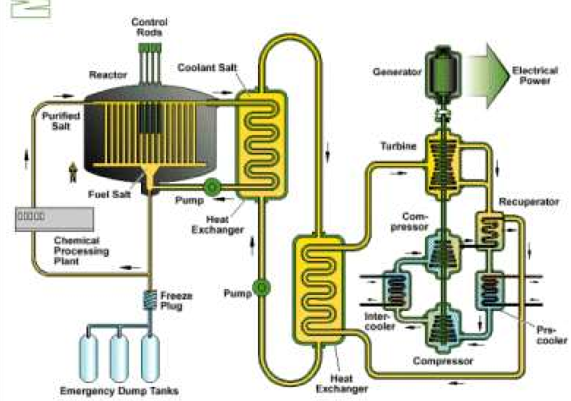
Molten Salt Reactor

MSR

Coolant: Molten Salt (e.g., 2LiF–BeF_2)



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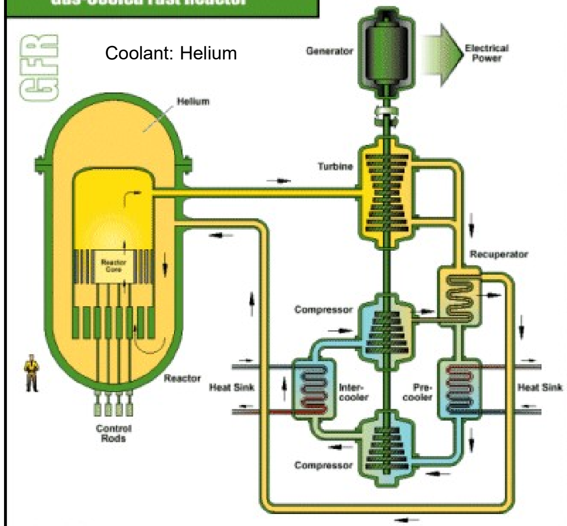
Gas-Cooled Fast Reactor

GFR

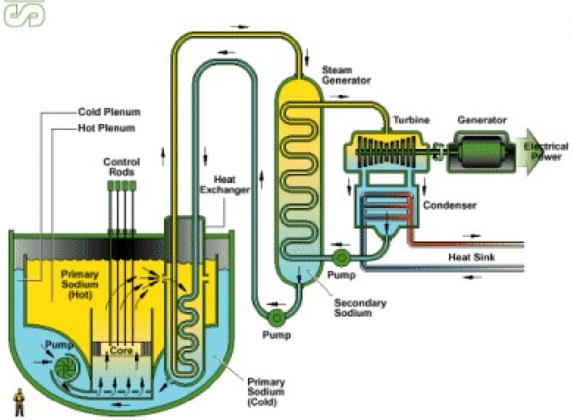
Coolant: Helium



Sodium-Cooled-Fast Reactor

SFR

Coolant: Molten Sodium (Na)



Lead-Cooled Fast Reactor

LFR

Coolant: Molten Lead (Pb)