ENE 101:
Introduction to Energy Engineering

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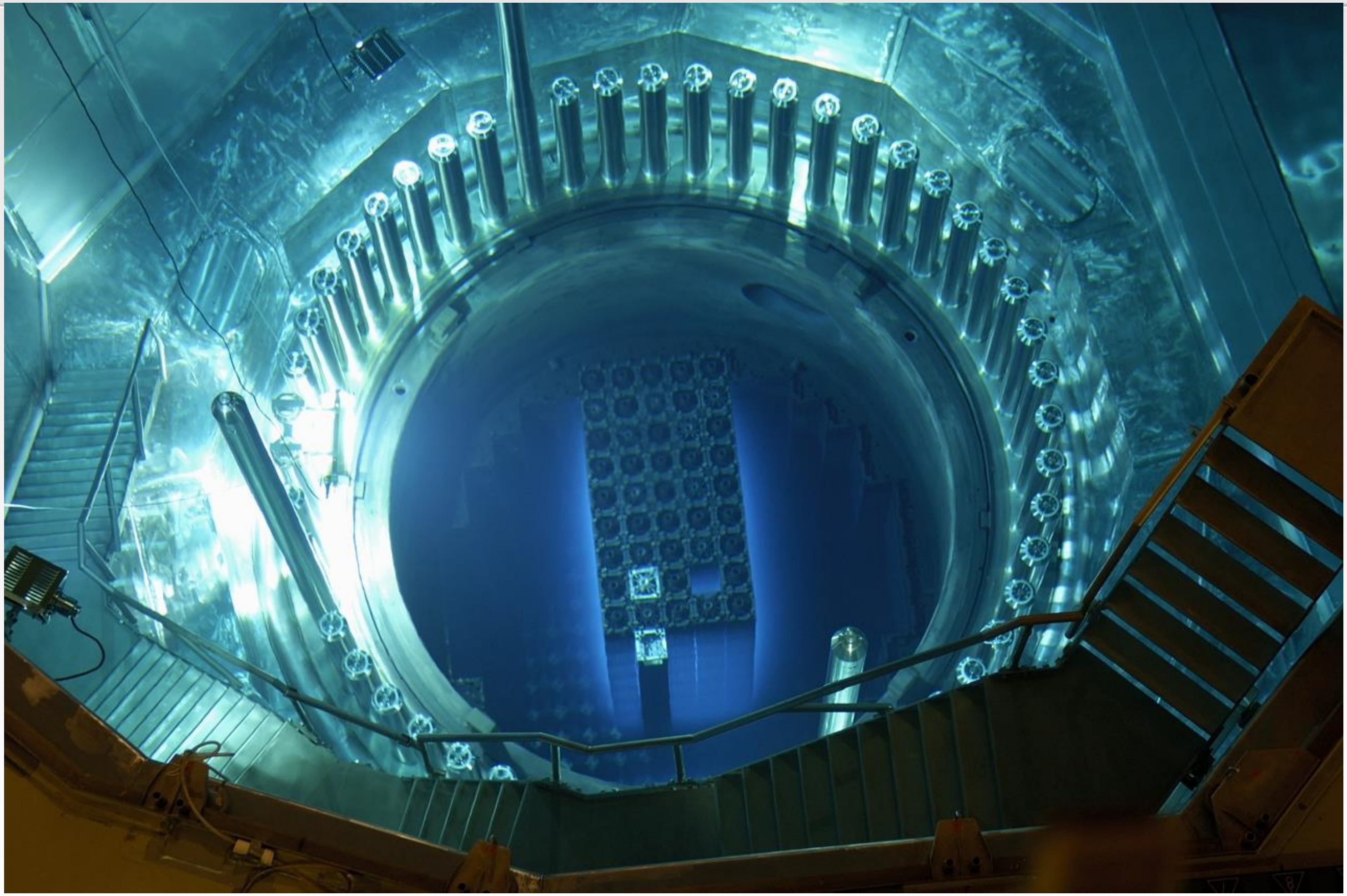
Week 10: Energy conversion cont.

Nuclear Energy Conversion

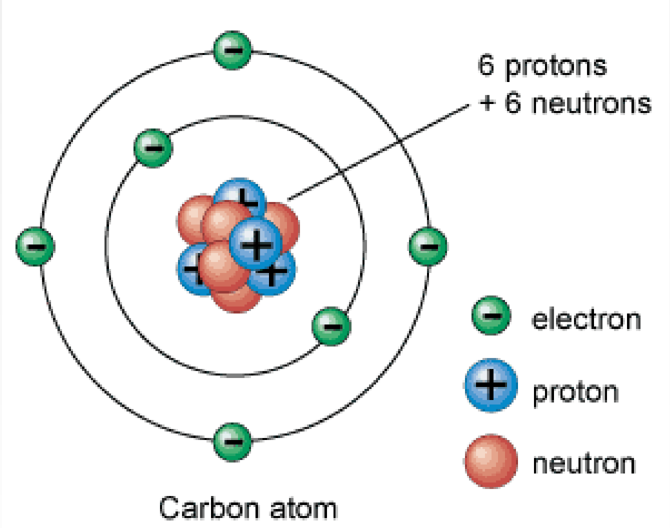


"Nuclear power is a hell of a way to boil water."
- Albert Einstein

Atomic Structure

Nuclear technology takes advantage of the power locked in structure of atoms, the basic particle of matter.

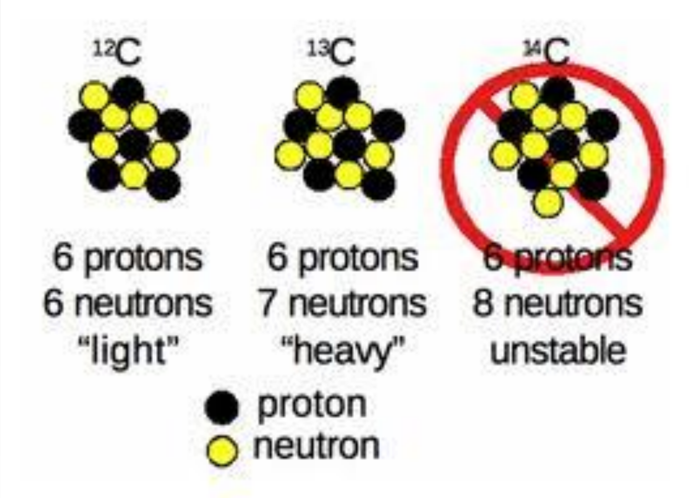
The nucleus of an atom contains all of its positively-charged protons and non-charged neutrons. Negatively-charged electrons orbit the nucleus.



Atoms always contain equal numbers of protons and electrons, making them electrically neutral.

Atomic Structure

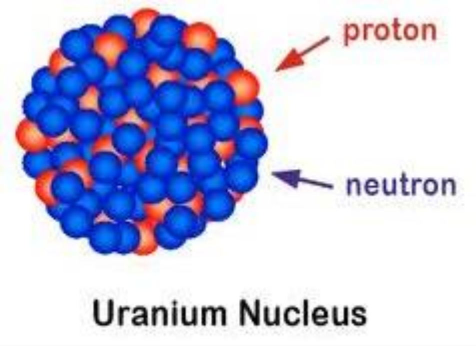
- Atoms can have different numbers of neutrons in their nuclei.
  - Nuclei from the same element with different numbers of neutrons are called isotopes.
- Most isotopes are stable, but some can spontaneously break apart, emitting energy and particles.
  - This is radiation.



Nuclear Fission

Nuclear weapons harness a specific type of decay called nuclear fission.

This is the splitting of the nucleus into two smaller fragments.



The fuel used by the first nuclear weapons was *Uranium-235*, a naturally occurring isotope.

Uranium-235 has an extremely large nucleus that can be split when it is hit with a high-speed neutron.

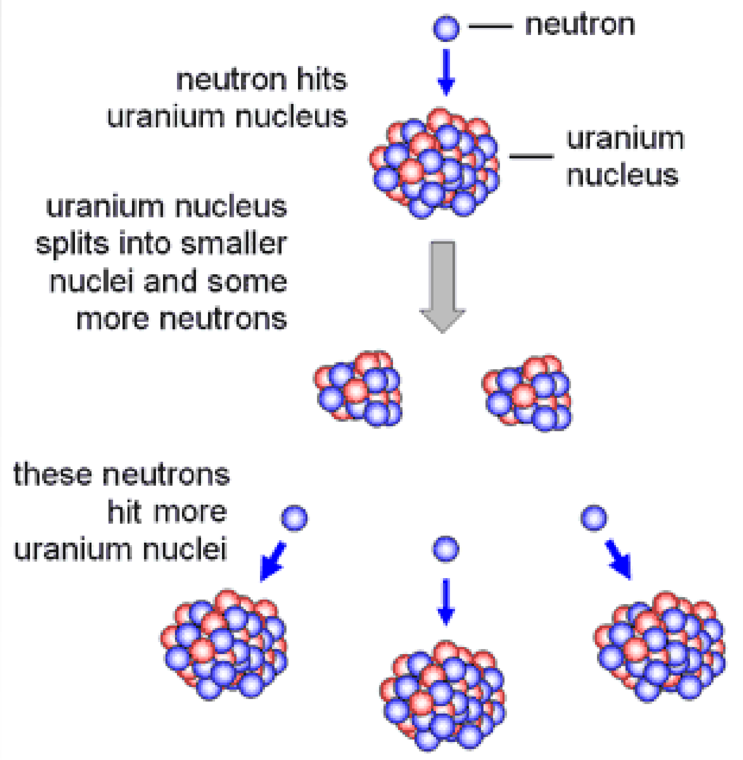
Nuclear Bomb

In a nuclear bomb, a large amount of uranium-235 is clustered together, so that when fission is initiated in one of the atoms, it splits and released more neutrons, which then cause fission in other atoms.

This creates a fission chain reaction.

Each time a nucleus splits, a large amount of energy is released.

Multiplied across the entire chain reaction…



Nuclear Bomb

Two atomic bombs were dropped during World War II – Hiroshima and Nagasaki, Japan. Each had yields of 15-21 kilotons of TNT. These blasts ended World War II.

TNT='Trinitrotoluene

Following World War 2, additional nuclear weapons testing was moved to part of the Marshall Islands, called the Bikini Atoll (11°N, 165°E).

This testing was codenamed "Operation Crossroads."

Two nuclear devices were detonated at sea as part of Operation Crossroads.

The purpose was to study the effects of a nuclear blast on an armada of naval ships.

The first blast, called **Shot Able**, was dropped from a plane.

The second, **Shot Baker**, was detonated underwater, beneath the ships.

Different species of lab animals were placed on several ships, to test for radiation poisoning following the blast.

Operation Crossroads Fallout

Glenn Seaborg, chairman of the Atomic Energy Commission, called Baker “the world’s first nuclear disaster.”

The target ships of Shot Baker were all heavily contaminated with radioactive fallout.

> Some were so “hot” that they could not be safely decontaminated and had to be sunk.

Decontaminated: Zararli kimyasal maddeden arindirilmis

Operation Castle

In 1954, six large nuclear tests were conducted. The largest was code named **Castle Bravo.** This tested a new design, called a ***hydrogen bomb***.

Castle Bravo Fallout : Castle Bravo was a much more powerful blast than expected. Residents of nearby atolls were exposed to toxic levels of radioactive fallout. A Japanese tuna fishing boat called the Lucky Dragon 5 was also caught in the blast radius.

Nuclear fallout

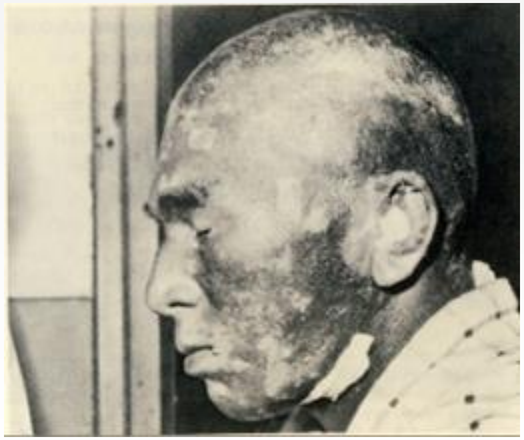
Nuclear fallout is dust and ash propelled into the atmosphere following a nuclear blast.

Radiation exposure from fallout is measured in rems.

- 100-200 rems causes mild symptoms, such as nausea and vomiting.
- 400-600 rems has about a 50% mortality rate.
- 600-1000 rems will usually cause death.
- Over 1000 rems will cause death in a few hours or less.

Interior exposure of fallout, from breathing or ingesting the dust and ash, would have even more severe effects.

An average person will be exposed to about 620 millirems of radiation per year from natural and man-made sources.



Radioactive coral dust fell on the Lucky Dragon 5.

- Fishermen touched the dust with their bare skin, inhaled it, and in some cases, tasted it.

One crewmember died from exposure.

Nuclear Disasters

In 1986, a full meltdown occurred at the **<u>Chernobyl nuclear plant</u>** located in Ukraine (formerly Soviet Union). A 30km radius around the plant, called the exclusion zone, has been designated as uninhabitable to people.

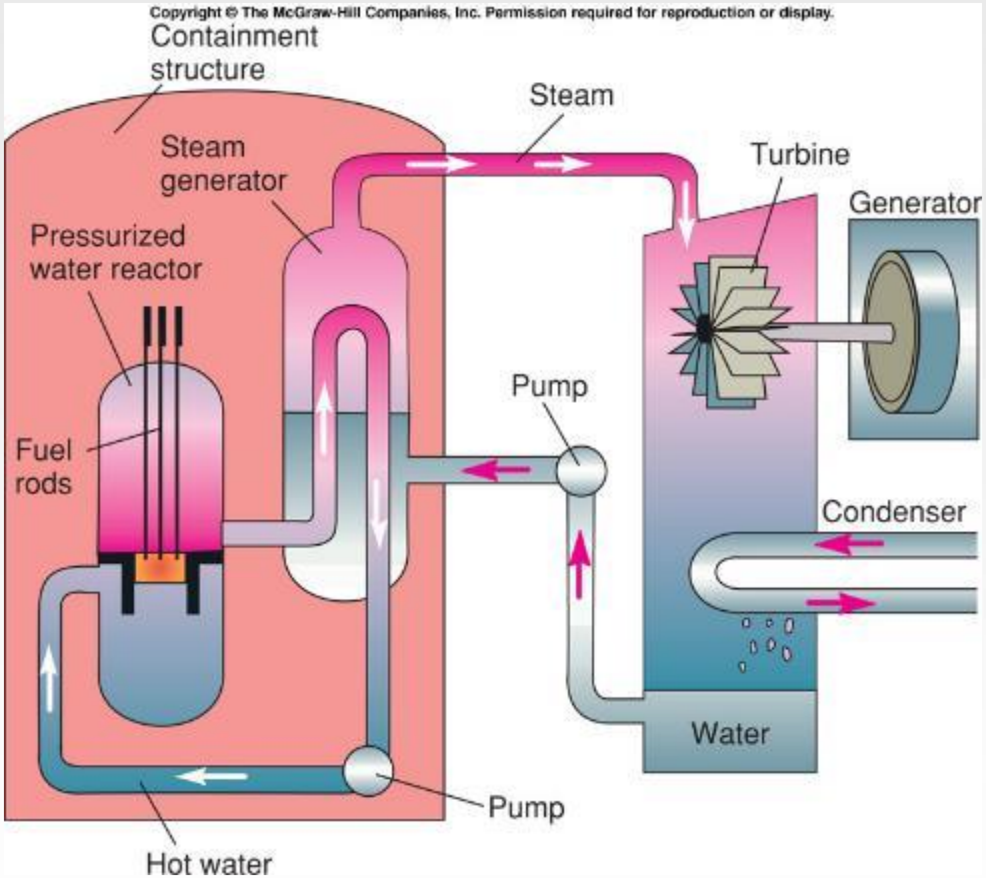
<u>Fukushima:</u> The most recent meltdown occurred following a massive earthquake and tidal wave off the coast of Japan.
The generators powering the water pumps of some of the Fukushima Daiichi reactors were flooded.
Without cooling water, the core overheated and experienced a meltdown.
Contaminated water from the plant leaked into the Pacific.
Top predators, like Bluefin tuna, caught in the Pacific have positively tested for small amounts of radioactive fallout.

Nuclear Reactors

The process of converting nuclear energy into electricity is similar to that of using fossil fuels.

Water is boiled,

the steam is passed through a turbine, which spins a generator.

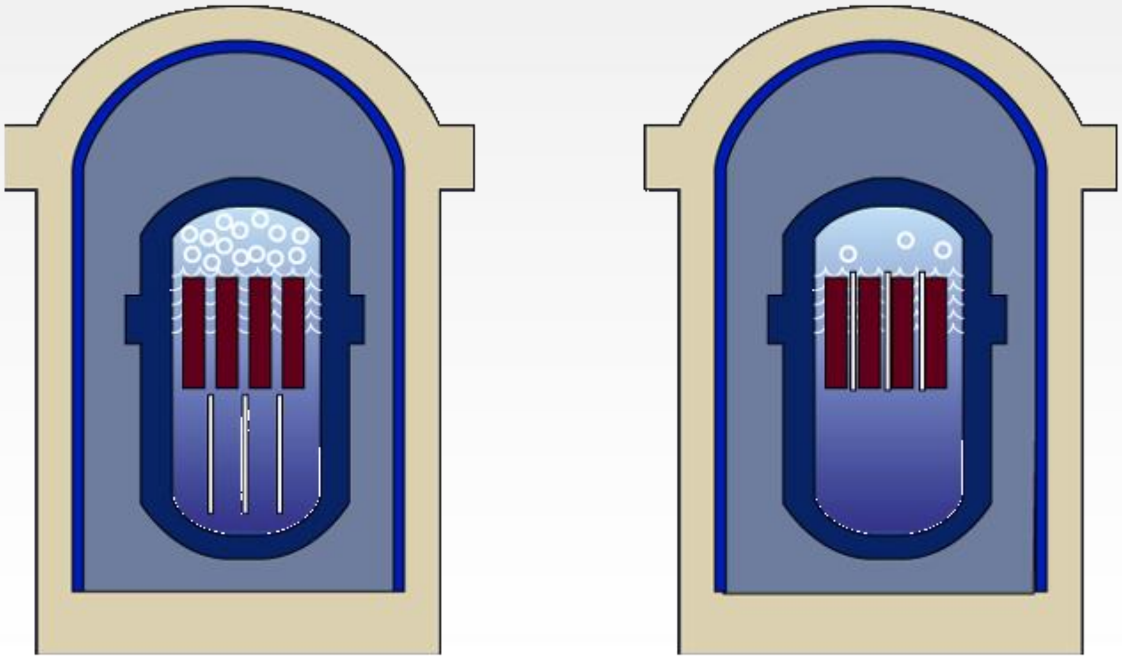


Both reactor vessel and steam generator are housed in a special containment building preventing radiation from escaping, and providing extra security in case of accidents.

Under normal operating conditions, a reactor releases very little radioactivity

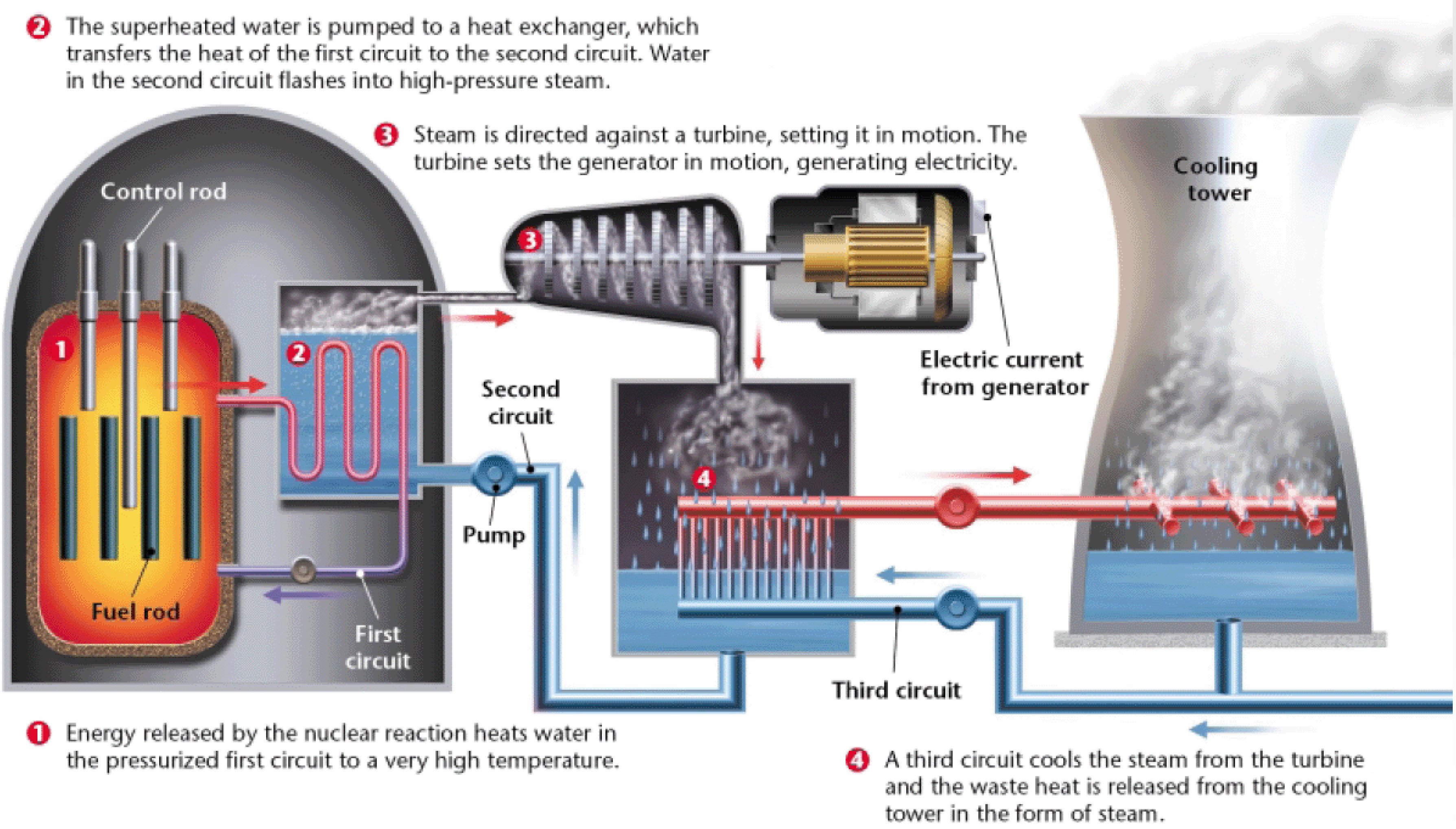
As with nuclear bombs, the primary fuel is uranium-235.

- Uranium ore is enriched and formed into fuel pellets.
- The fuel pellets are stacked into long, cylindrical fuel rods.
- Control rods, made of a neutron-absorbing material, are placed amongst the fuel rods.
  - Can be removed and inserted to adjust the rate of the chain reaction.



Withdraw control rods, reaction increases

Summary: How Nuclear Energy Works



One big advantage to nuclear power is that, under normal conditions, it does not release any air pollution, only steam.

Cooling Tower in Byron, Illinois

Types of Nuclear Reactors

- ❑ **Boiling Water (BWR) Nuclear Reactors**
- ❑ **Pressurized Water (PWR) Nuclear Reactors**
- ❑ **Canada Deuterium Uranium (CANDU)**
- ❑ **Advanced Nuclear Reactors**

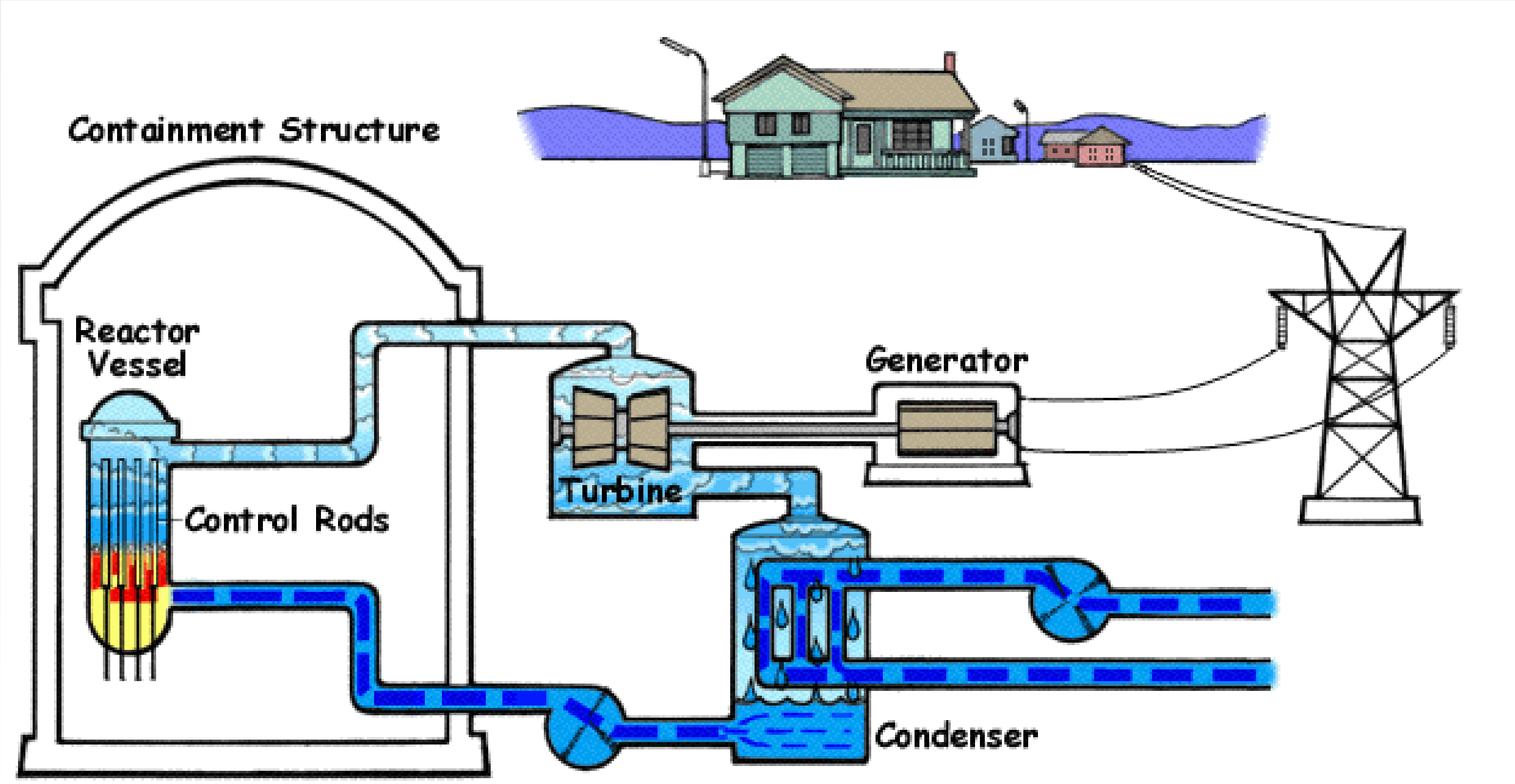
- Components of a Nuclear Power Plant

To characterize the unique capability of nuclear fuel simultaneously to produce and consume fissile material, a figure of merit known as the **conversion ratio** (CR) is informative. It is defined by the relation:

$$CR = \frac{\text{number of fissile nuclei produced from fertile nuclei}}{\text{number of fissile nuclei consumed}}$$

Boiling Water (BWR) Nuclear Reactors

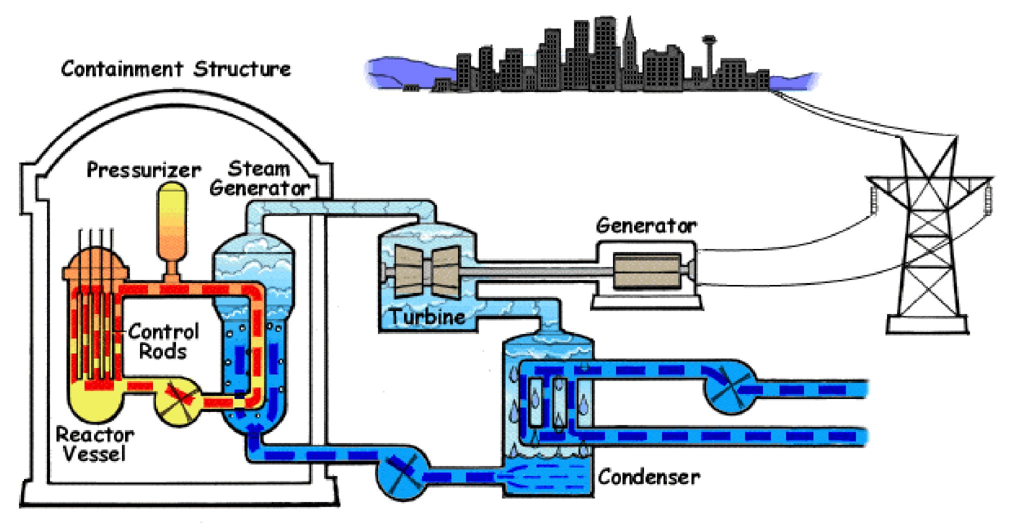
In a BWR the water is boiled by the core, turned to steam and that steam is used to drive the turbines which generates the electricity. The spent steam is cooled back to liquid and recycled through the core.



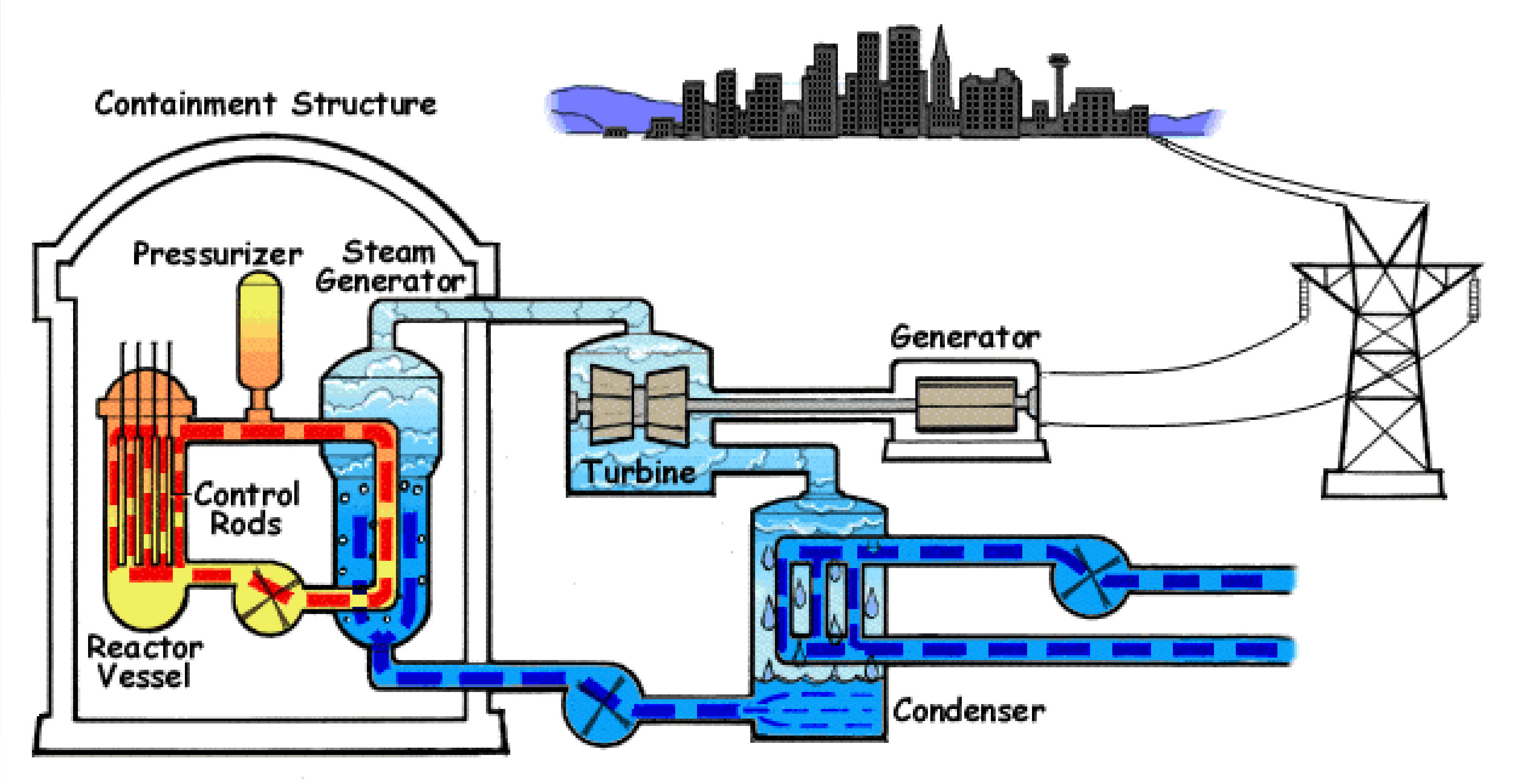
Pressurized Water (PWR) Nuclear Reactors

In a PWR, water is heated in the core and converted to superheated steam. This is a closed system and is called the primary loop. This contaminated water/steam does not exit the containment. The heat from the steam in the primary loop is transferred to a separate water supply (the secondary loop) causing it to boil and turn to steam. **This is done by using “steam generators” which have many small tubes inside.** The steam from the primary loop travels through the tubes giving up heat to the water surrounding the tubes.

The steam in this 2ndry loop is used to run the turbines to generate the electricity. In this way, the contaminated water supply is always maintained inside the containment unless of course the steam generator tubes leak causing cross contamination in the secondary loop. After passing through the turbines, the spent steam in the secondary loop is cooled back to water and run through the steam generators again.



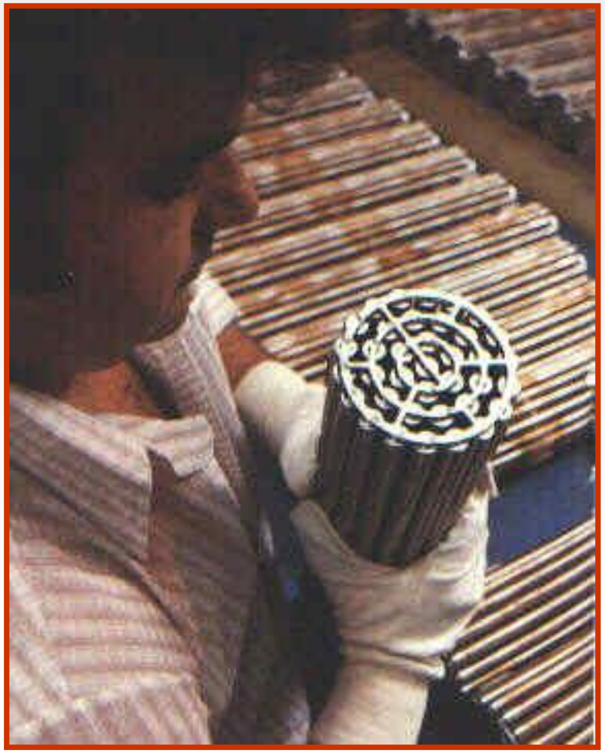
Pressurized Water (PWR) Nuclear Reactors



Canada Deuterium Uranium (CANDU) Reactors

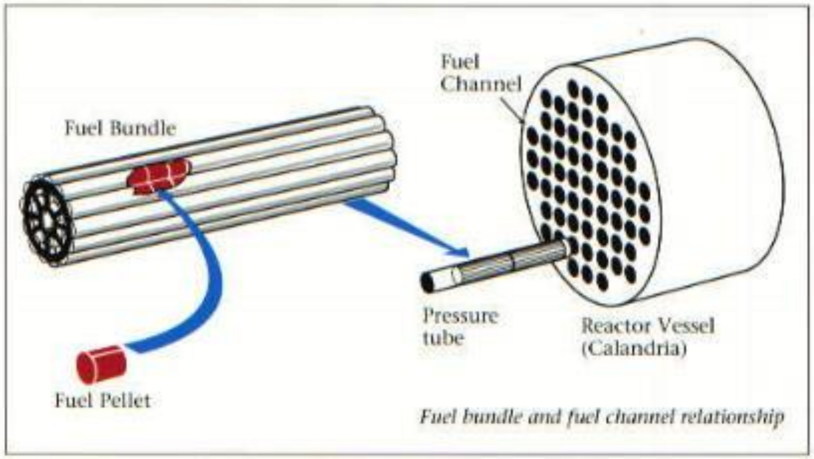
- **It is a pressurized-heavy-water, natural-uranium power reactor designed first in the late 1950s by a consortium of Canadian government and private industry**
- **All power reactors in Canada are CANDU type**

The CANDU reactor uses natural uranium fuel and heavy water (D_2O) as both moderator and coolant (the moderator and coolant are separate systems). It is refueled at full-power, a capability provided by the subdivision of the core into hundreds of separate pressure tubes.



CANDU Reactors

Each pressure tube holds a single string of natural uranium fuel bundles (each bundle half a meter long and weighing about 20 kg) immersed in heavy-water coolant, and can be thought of as one of many separate "mini-pressure-vessel reactors" - highly subcritical of course. Surrounding each pressure tube a low-pressure, low-temperature moderator, also heavy water, fills the space between neighboring pressure



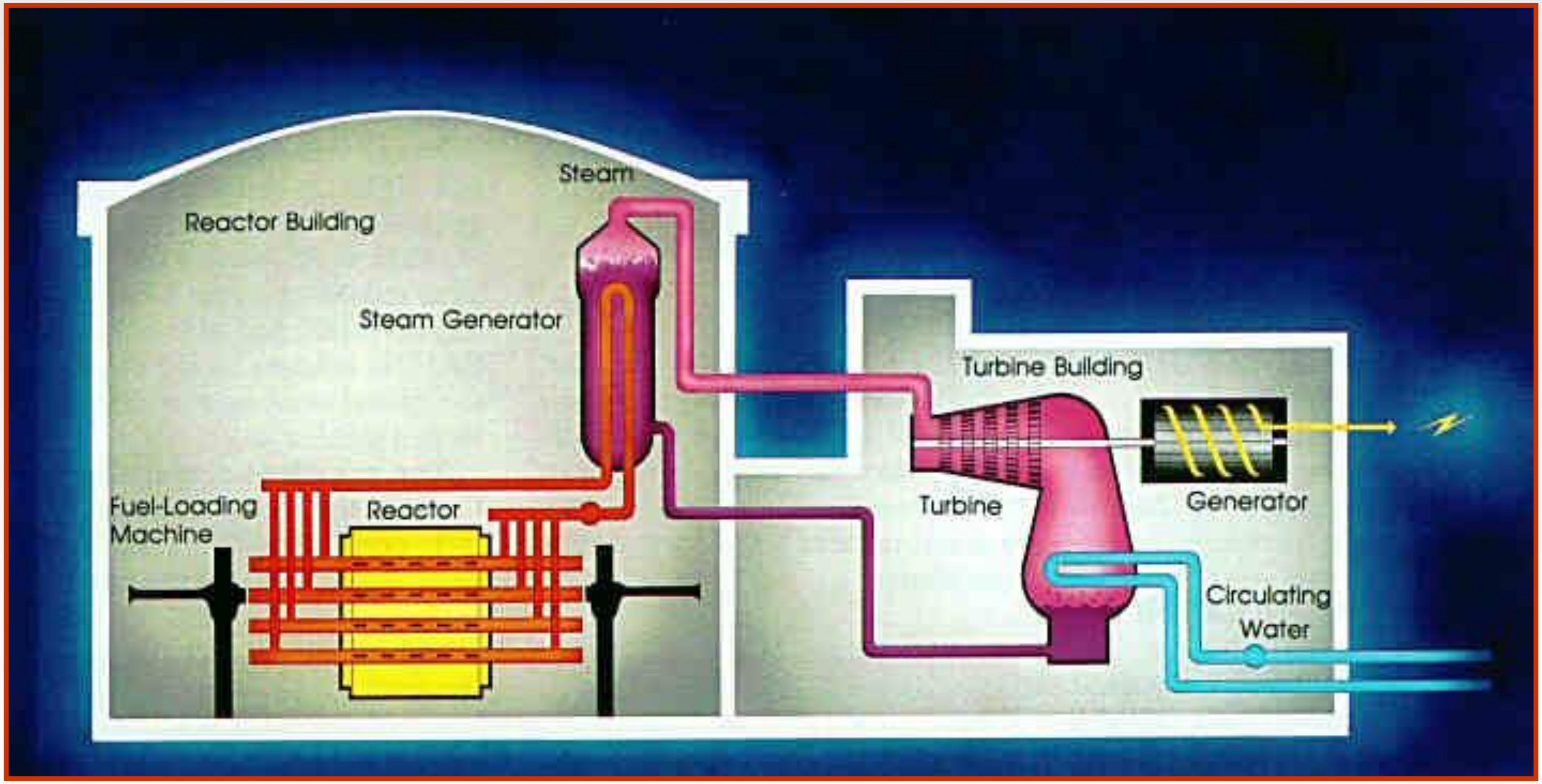
Fuel bundle and fuel channel relationship

The cylindrical tank containing the pressure tubes and moderator, called the "calandria", sits on its side. Thus, the CANDU core is horizontal.

CANDU Reactors

In the CANDU design, as with the PWR design, the heat of fission is transferred, via a primary water coolant, to a secondary water system. The two water systems "meet" in a bank of steam generators, where the heat from the first system causes the second system (at lower pressure) to boil. This steam is then dried (liquid droplets removed, since they can damage turbine blades) and passed to a series of high-pressure and low-pressure steam turbines. The turbines are connected in series to an electrical generator. The primary water system, which becomes radioactive over time, does not leave the reactor's containment building. It is a highly complex system from start to finish, involving a series of energy transformations with associated efficiencies. The potential energy of nuclear structure is converted first to heat via the fission process, then steam pressure, kinetic energy (of the turbine and generator), and ultimately to electrical energy. Fueling is accomplished by a fuelling machine which visits each end of the core, one fuelling and the other de-fuelling, allowing operators to insert fresh fuel at alternate ends for neighbouring fuel channels. From six to ten bundles are "shuffled" each day. Flux-shaping is provided by fuel management. Long-term reactivity control is also achieved through fuel management. Short-term reactivity control is provided by controllable light-water compartments, as well as absorber rods.

CANDU Reactors



Advanced Reactors

Today's nuclear reactor technology is distinctly better than that represented by most of the world's operating plants, and the first advanced reactors are now in service in Japan.

- The first advanced reactors now operating in Japan
- Nine new nuclear reactor designs either approved or at advanced stages of planning
- Incorporate safety improvements and are simpler to operate, inspect, maintain and repair

Advanced Reactors

The new generation of reactors:

- have a standardized design for each type to expedite licensing, reduce capital cost and reduce construction time,
- are simpler and more rugged in design, easier to operate and less vulnerable to operational upsets,
- have higher availability and longer operating life,
- will be economically competitive in a range of sizes,
- further reduce the possibility of core melt accidents,
- have higher burn-up to reduce fuel use and the amount of waste.

Components of a Nuclear Plant

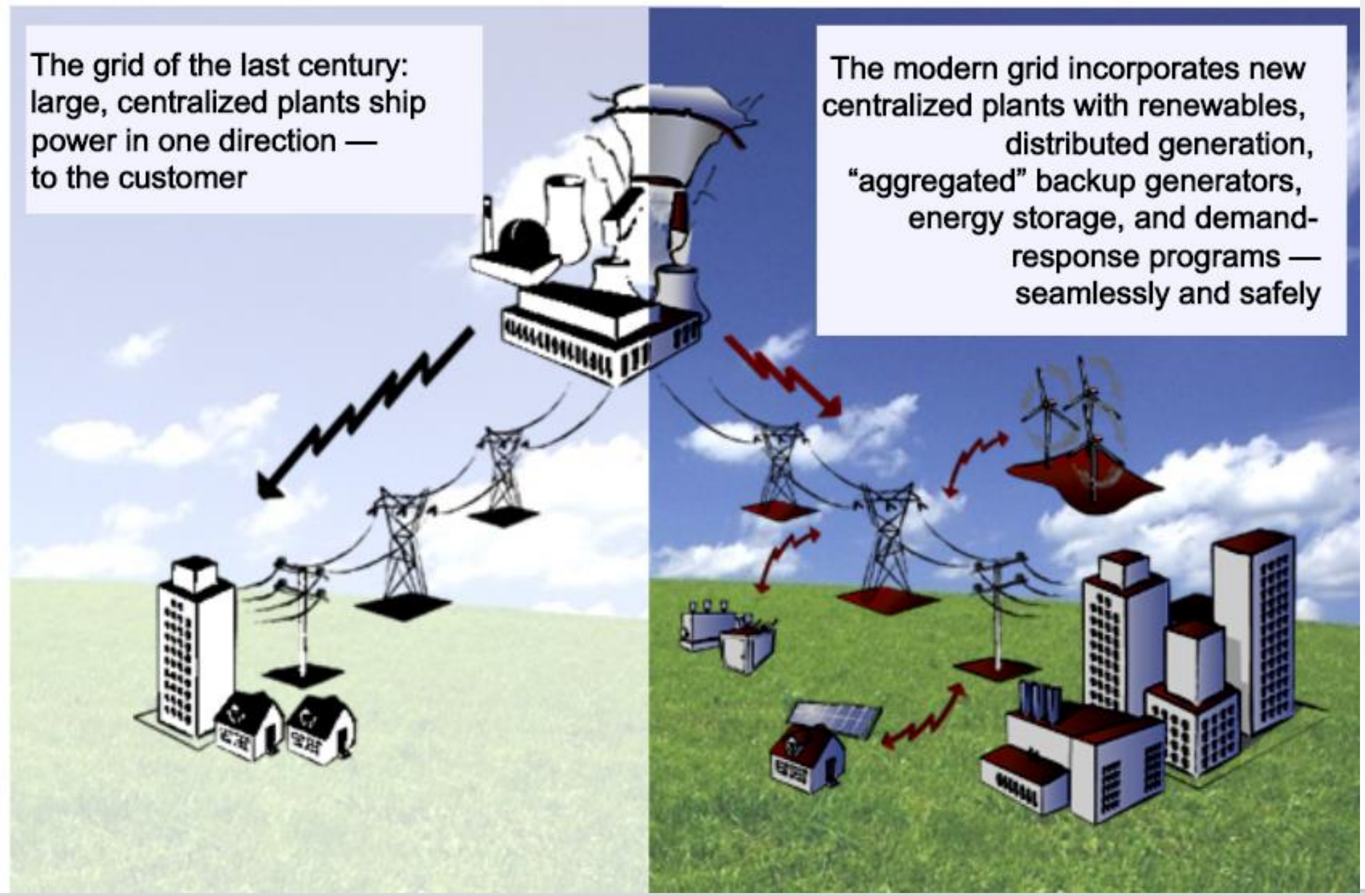
- Control Building: From this location, the operator controls the reactor.
- Containment Building: This is the location of the core and primary components including the steam generators if it is a PWR.
- Turbine Building: This is where the steam is converted to electricity. In a PWR it is “clean” whereas in a BWR, the steam is contaminated since it is produced from water which has been in contact with the core. Thus the turbine floor in a BWR has elevated radiation levels.
- Fuel Building: This is where the spent fuel is stored onsite in a pool.
- Diesel Generator Building and Auxiliary Buildings: This is the location of the generators which supply emergency power and the other components which support the water/steam system.

Nuclear Reactors

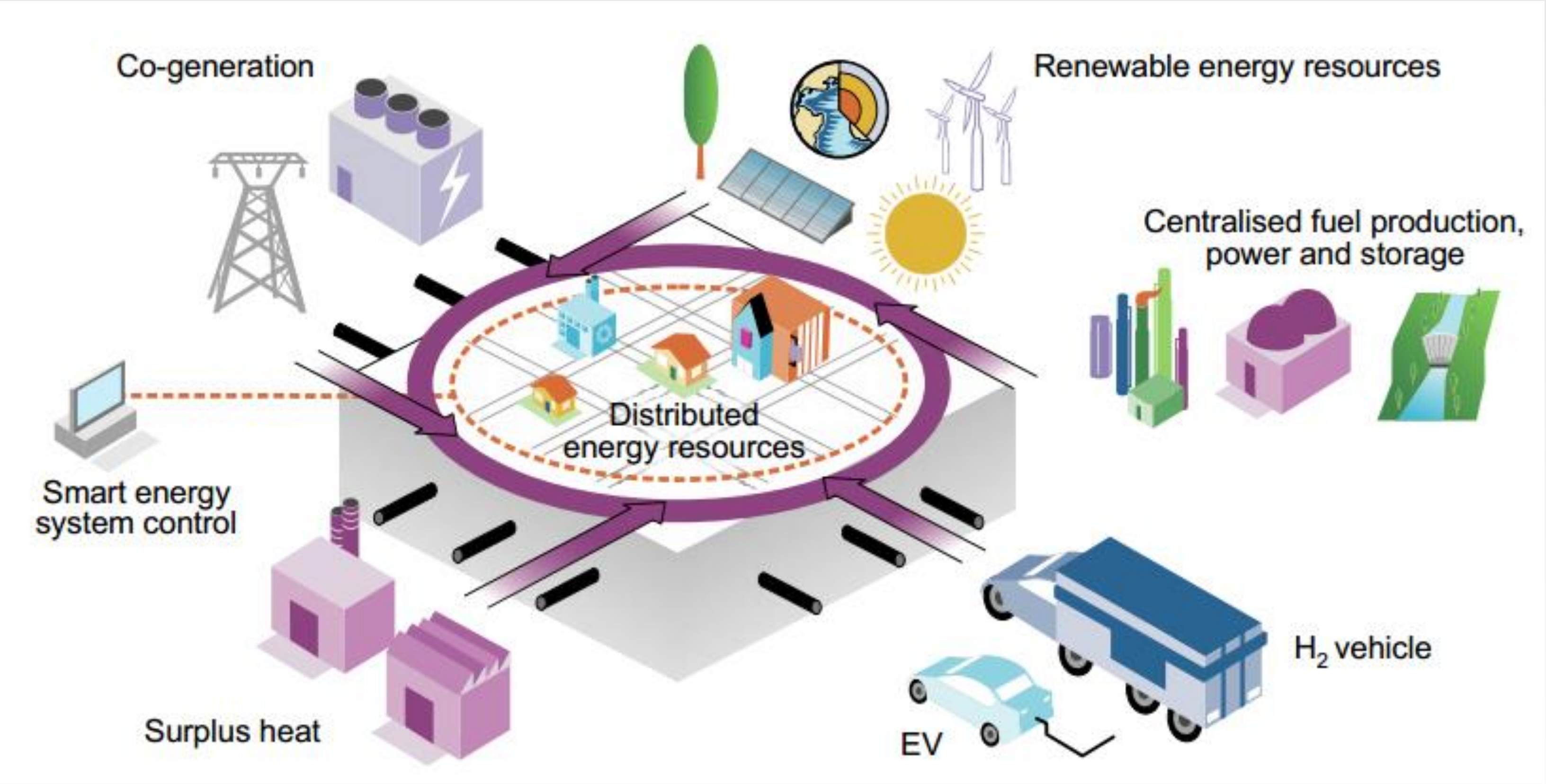
Reactor building don't always look the same. Many people believe the cooling towers are the reactors. They are not. They provide cooling for the lake or river water which is used to condense the spent steam back to water in the closed system. They typically exhaust condensation from the cooling process. This condensation cloud is sometimes mistaken for leakage from the reactor.

Smart Grid Supports 21 st-Century Demand

is able to provide more energy options and choices for consumers, to help them save energy and better reflect the costs of supply, not only making the grid more reliable, but also increasing the efficiency and safety of the energy supply chain.



Enery distribution/transmission – electricity & smart technologies:



Electricity is generated at power plants and moves through a complex system, sometimes called the ***grid,*** of electricity substations, transformers, and power lines that connect electricity producers and consumers. Most local grids are interconnected for reliability and commercial purposes, forming larger, more dependable networks that enhance the coordination and planning of electricity supply.

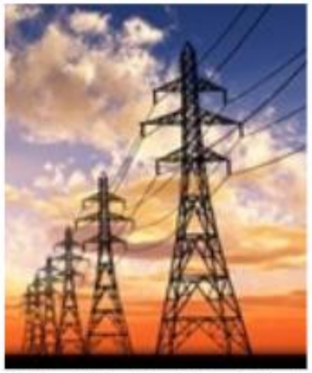
Electric Power System

Markets, System Operators and Communications

Generation

- Coal
- Gas
- Nuclear
- Hydropower
- Wind
- Solar
- Geothermal
- Utility-ScaleStorage

Transmission



- SynchroPhasor Tech
- Dynamic Line Rating

Substations

- Solid State Transformers
- Substation Monitor
- Dissolved Gas Analysis
- Fault Current Limiters
- Smart Relays

Distribution

- Distribution Capacitors
- SCADA Systems
- Smart Switches/Reclosers
- Automated Regulators
- Distributed Generation
- Energy Storage

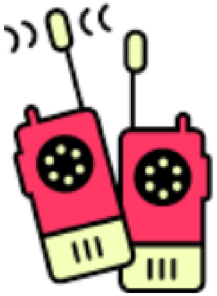
Consumers

- Electric Vehicles
- Home Area Network
- In Home Device
- Direct Load Control
- Distributed Generation -(Wind, Solar, Combined Heat Power)
- Smart Meters
- Smart Appliances
- Energy Storage

Distributed Energy Resources

- Microturbine
- Fuel Cell
- Photovoltaic (PV): “Solar Panel”
- Wind Turbine
- Energy Storage
  - Batteries (NaS, vanadium redox, ultracapacitor)
  - Compressed air
  - Flywheels
  - Pumped hydro

What's Different with The Smart Grid

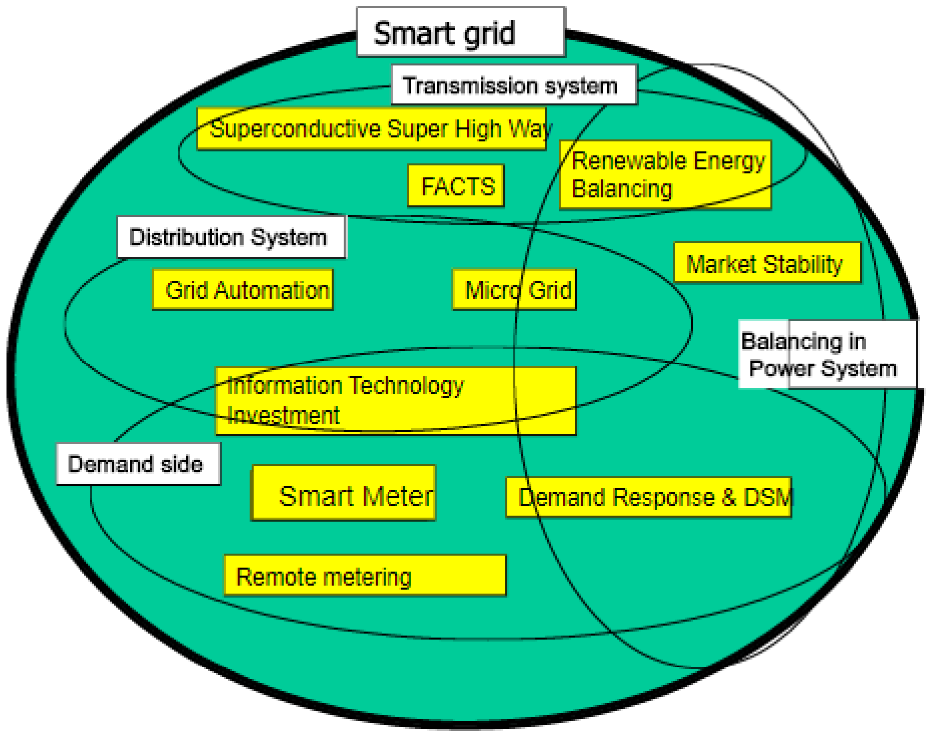


- Consumer engagement with resources to solve power issues locally
- Two-way power flow in Distribution
- Two-way communications
- More and smaller and distributed sources of electric power
- Imperative to transform from passive to active control in Distribution
- Dynamic pricing
- New ways for Distribution to become a Transmission resource
- Potential to transform transportation sector

- Smart Grid is an automated, widely distributed energy delivery network characterized by a ***two-way flow*** of electricity and information, capable of monitoring and responding to changes in everything from power plants to customer preferences to individual appliances.

- In other words, a smart grid is the ***electricity delivery system*** (from point of generation to point of consumption) ***integrated*** with information and communications technology

- There is ***NO single definition*** for smart grid - It is an evolving paradigm

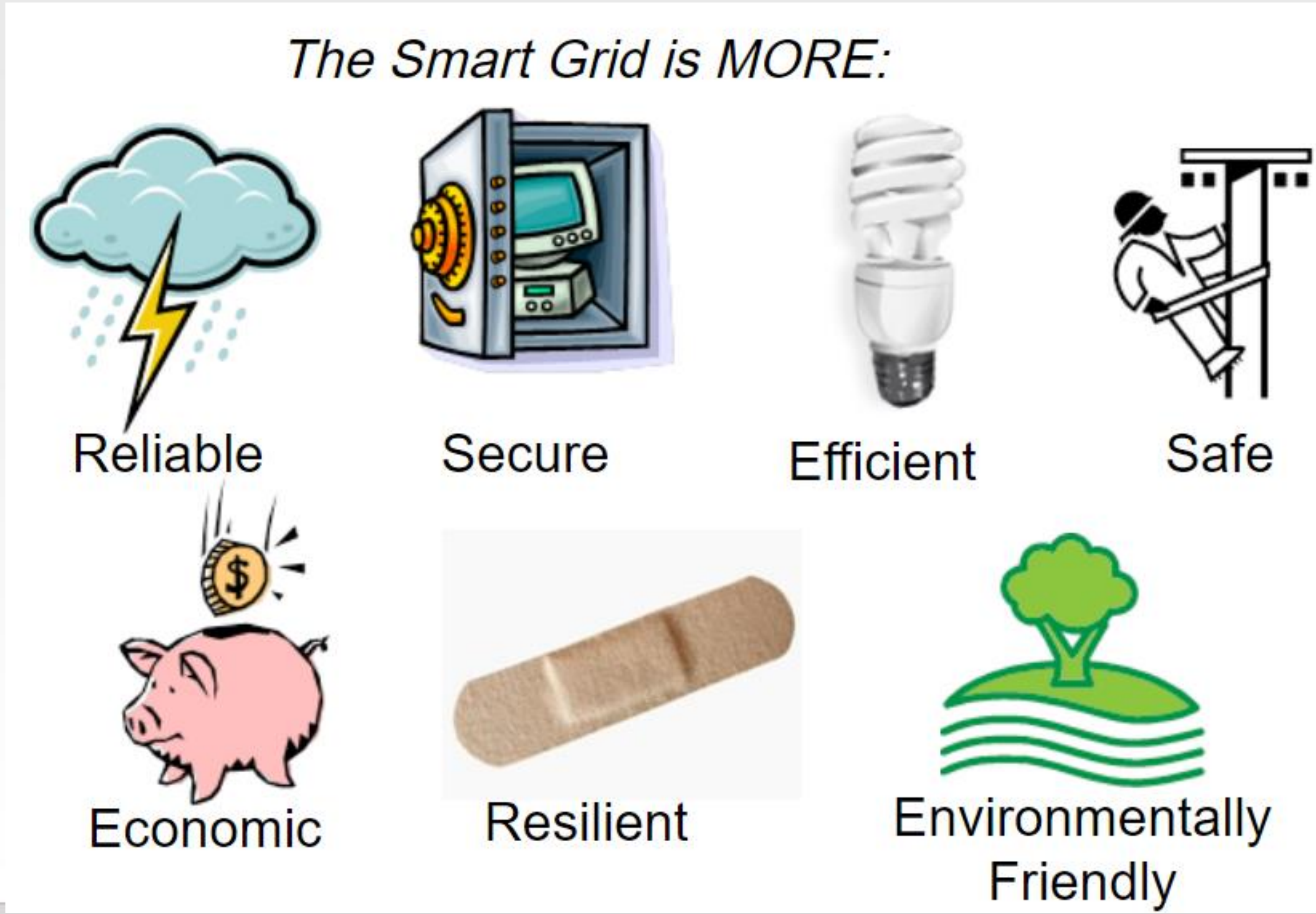


Smart Grid Principle Characteristics

The Smart Grid will:

- Enable active participation by consumers
- Accommodate all generation and storage options
- Enable new products, services and markets
- Provide power quality for the digital economy
- Optimize asset utilization and operate efficiently
- Anticipate & respond to system disturbances
- Operate resiliently to attack and natural disaster

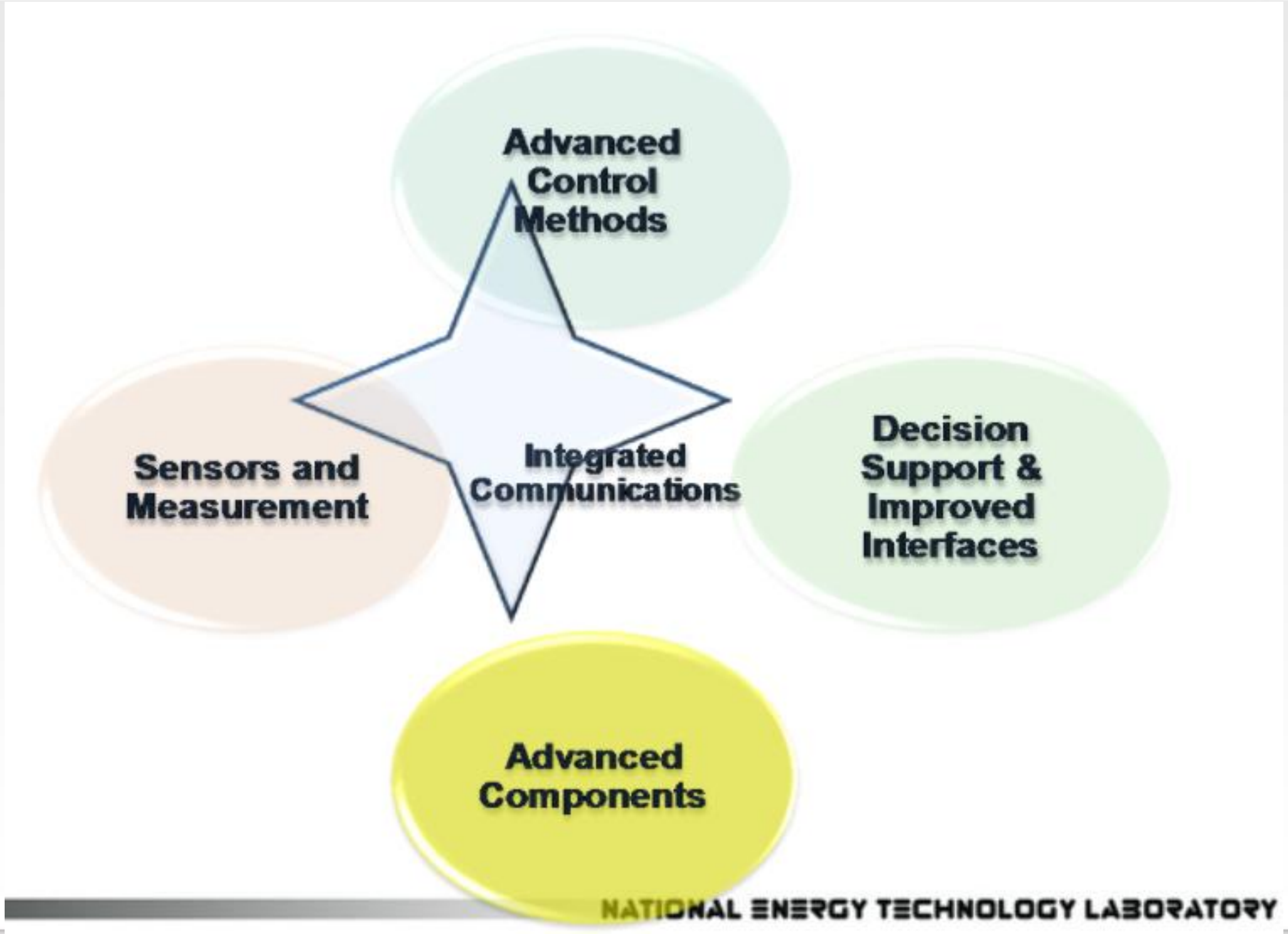
Smart Grid Key Success Factors

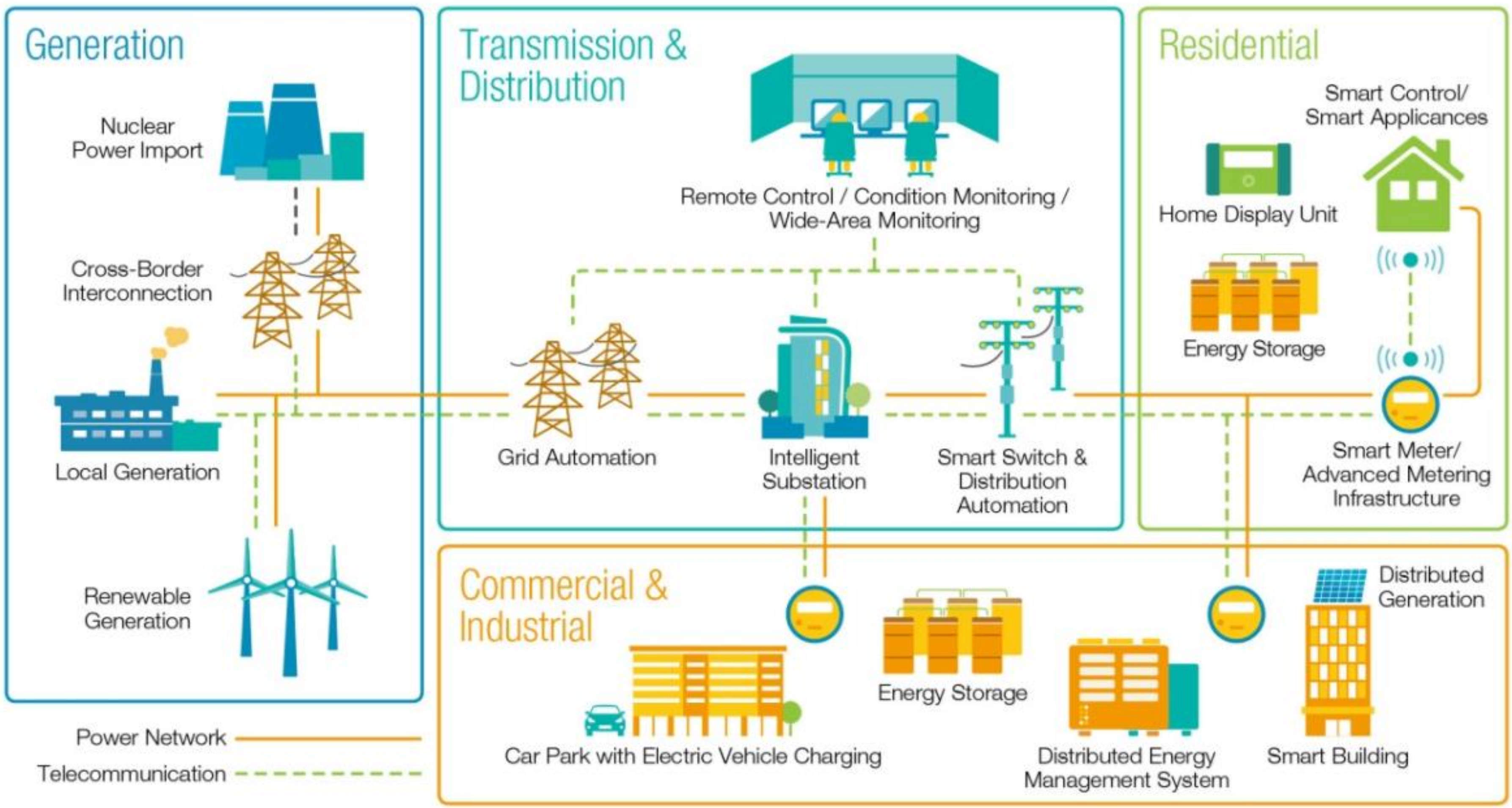


Context of Smart Grid

Smart Grid	Enhanced by Smart Grid
Two-way communications Sensors Controls Decision support tools Components Transformers Power electronics Conductors	Renewable energy resources Electric vehicles Energy storage Distributed generation Grid friendly appliances/devices
Sensing, control, power transformation, and communications	*Generation, storage, and load*

Smart Grid Technologies




Generation
Nuclear Power Import
Cross-Border Interconnection
Local Generation
Renewable Generation
Transmission & Distribution
Remote Control / Condition Monitoring / Wide-Area Monitoring
Grid Automation
Intelligent Substation
Smart Switch & Distribution Automation
Residential
Smart Control/ Smart Applicances
Home Display Unit
Energy Storage
Smart Meter/ Advanced Metering Infrastructure
Commercial & Industrial
Energy Storage
Distributed Generation
Car Park with Electric Vehicle Charging
Distributed Energy Management System
Smart Building
Power Network
Telecommunication

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