Nuclear Power - Overview

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ANS Teacher Workshop
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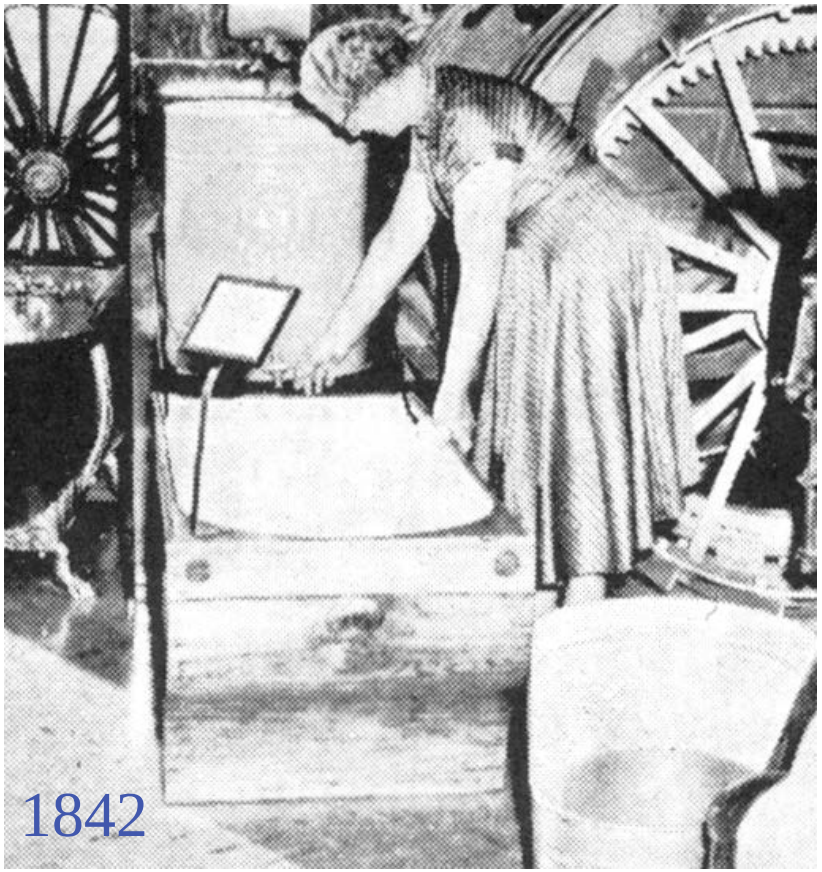
San Diego, CA

Human technology

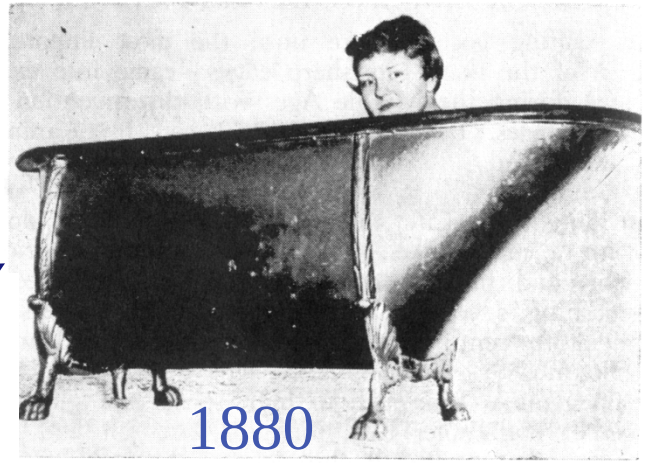
Proof that People Resist Technology Change

1st U.S. Bathtub 1842

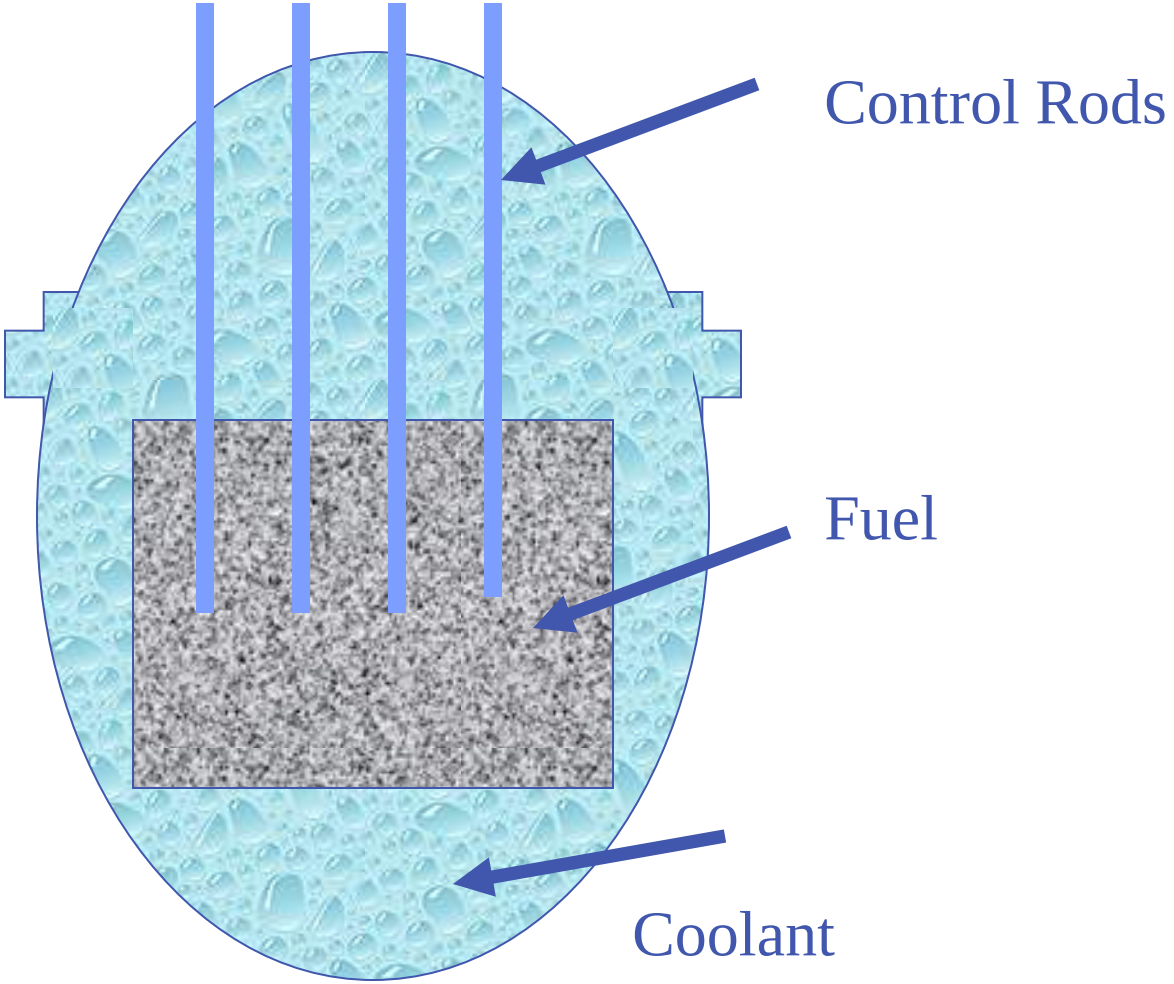


First bathtub was built in Cincinnati. It was a 1750 lb, seven foot mahogany box, lined with sheet metal. Local criticism followed although the Greeks and Romans had used tubs as far back as 1200 B.C. Cincinnati doctors were quick to condemn this outrageous contraption and local politicians slapped on a $30 luxury tax. A law was passed forbidding the use of a bathtub during the cold months as a health hazard. Quick acceptance of new inventions is never likely.

40 years later the copper bathtub



Components of a Reactor



Chemical Reactions

Basic chemical reactions

Fire

$CxHy + O2 \dashrightarrow CO2 + H2O$

Metallurgy

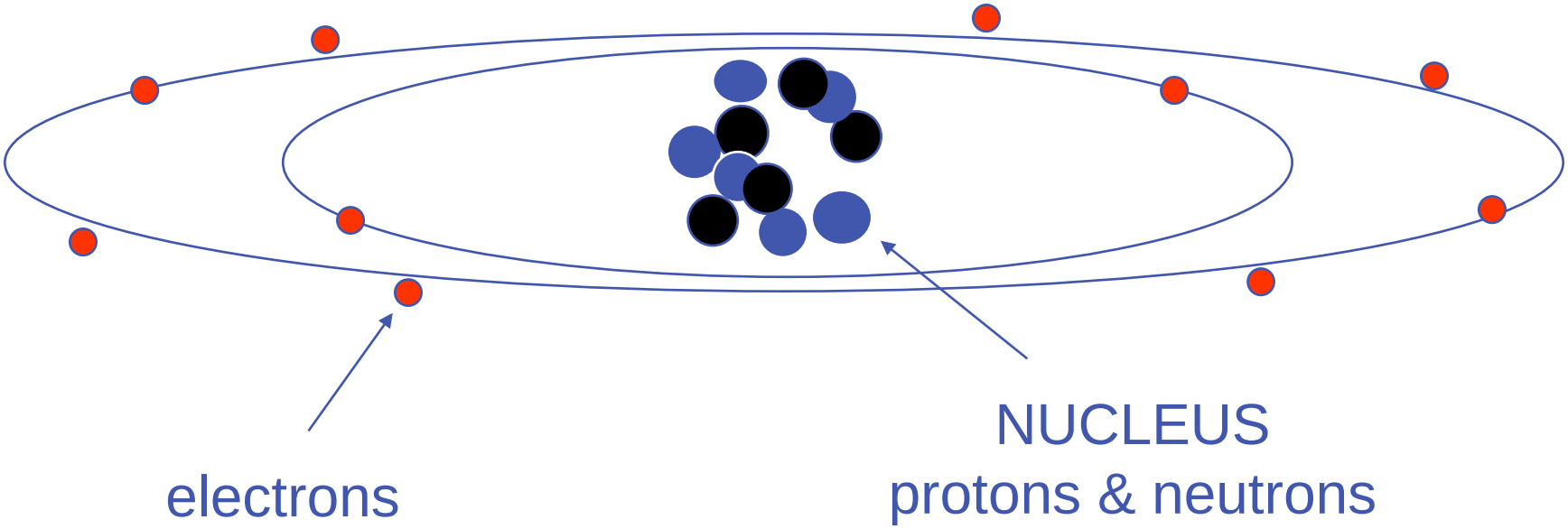
$3C0 + Fe203 + 2Fe + 3CO2$

Food

$C6H12O6 \rightarrow 2\ CH3CH2OH + 2\ CO2$

The Atom

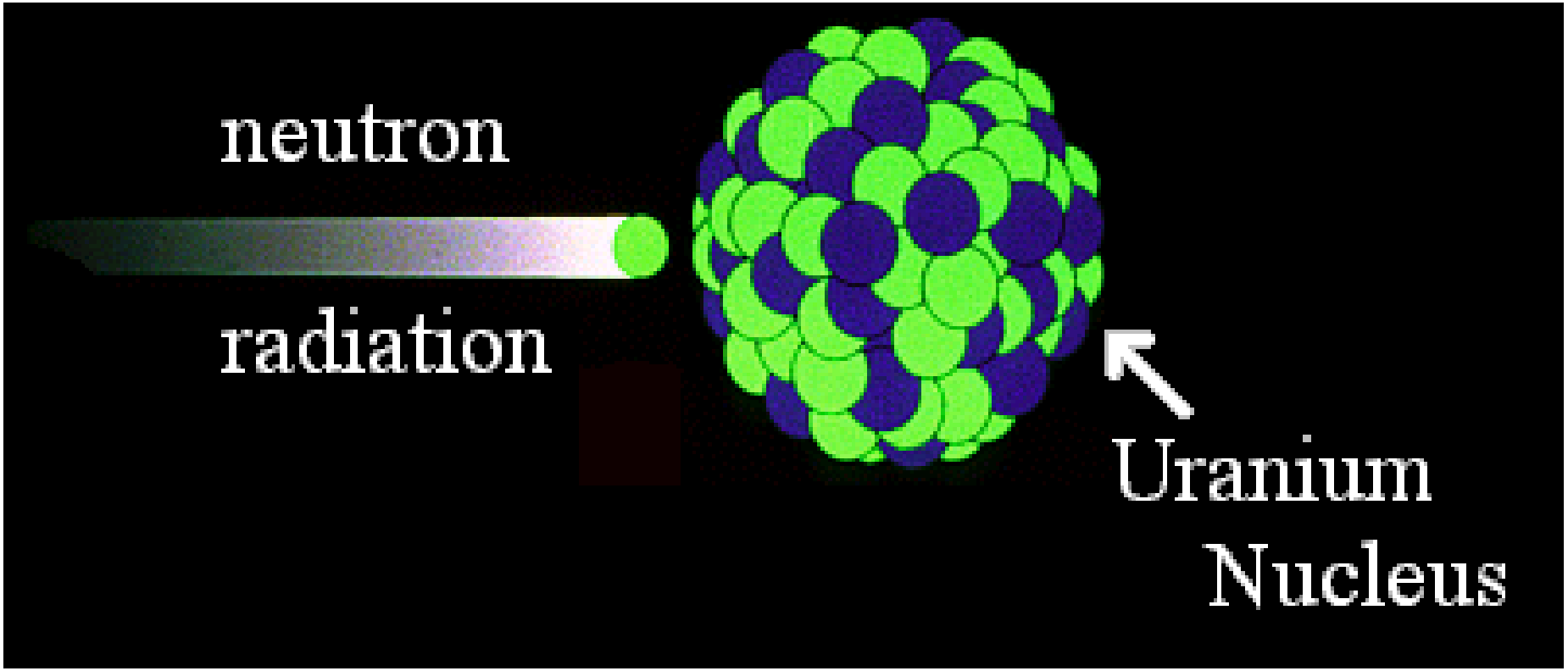
✓**A few electron volts!**



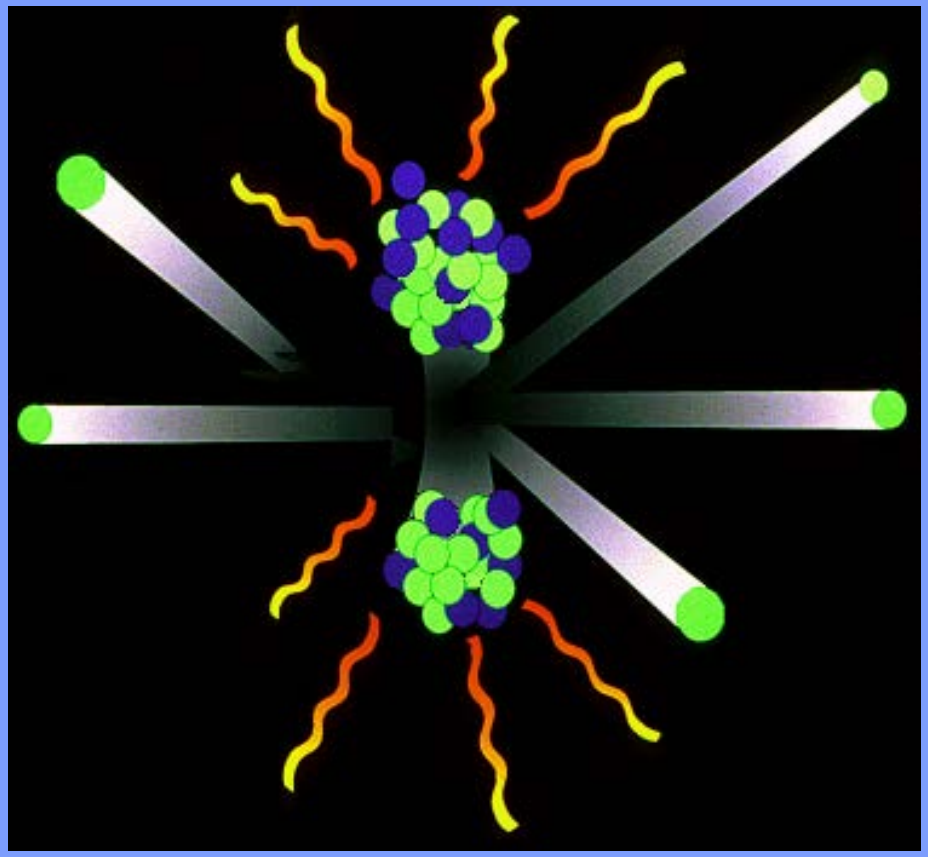
The nucleus of atom

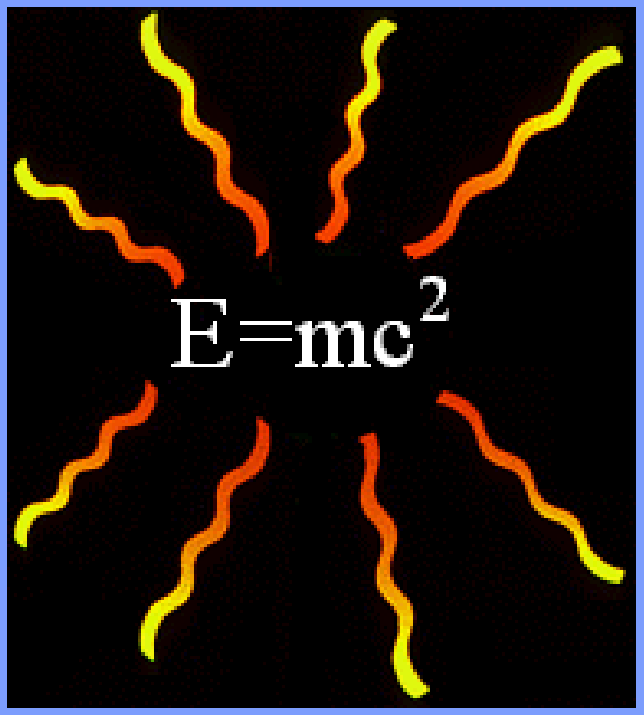
✓100s of millions of election volts!

✓ $E = mC^2$



The nucleus **splits** in two halves and releases some **neutrons**, and radiation





During fission there is also a small **loss of mass,** that is transformed into ENERGY, which is released also.

First Reactor:

1) water cooled
2) U235 enrichment ~3%

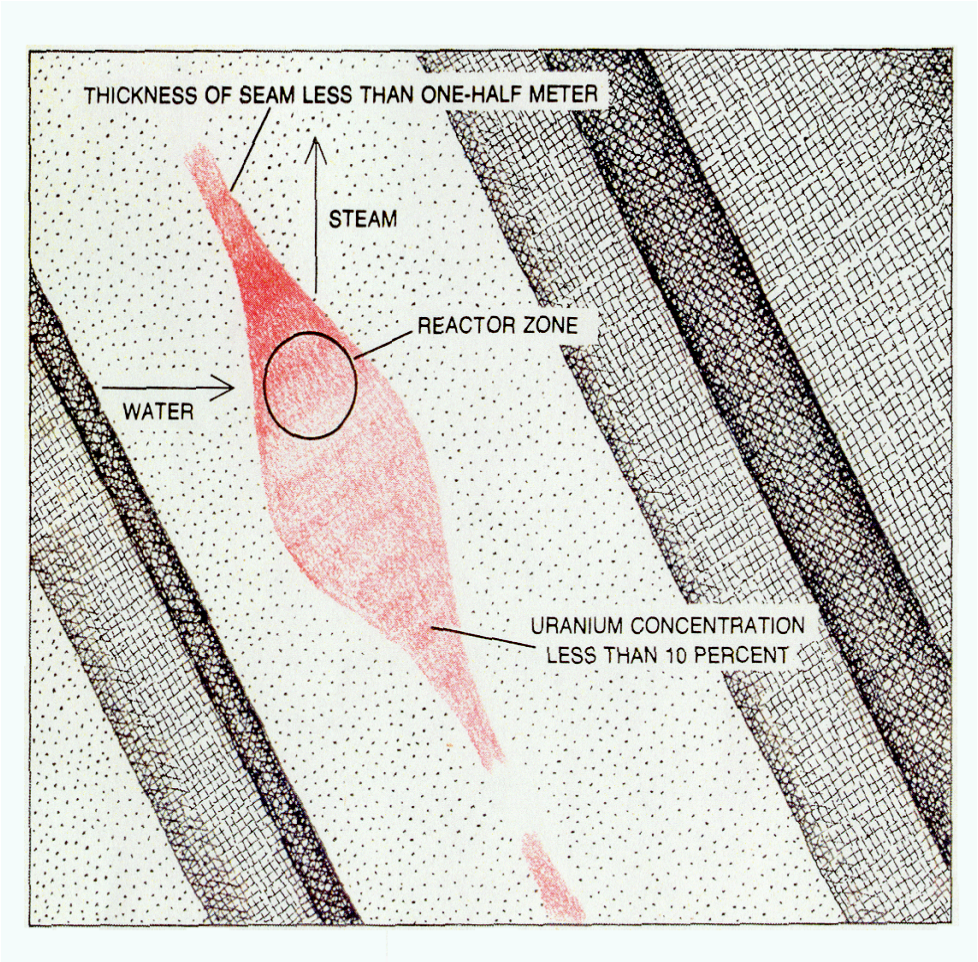
Africa

The Jungle of Gabon

The Oklo Mine had a fission reaction… 2 Billion Years Ago

Scientific American, July 1976

Mother Nature's Nuclear Reactor



15 natural reactors discovered

16,000 MW-years

Used 5 tons uranium

5 tonnes waste

1.5 tonnes of Pu

Human discovery of fission:

1) no coolant
2) U235 enrichment ~0.7%

James Chadwick 1932

Alpha Particle

$^{4}_{2}\alpha^{++}$ + $^{9}_{2}Be$ -> $^{12}_{6}C$ + neutron!

1920 Rutherford postulated neutral particle and approximate mass

Chadwick called it the **neutron** in his paper published in the Feb 1932, issue of *Nature*.

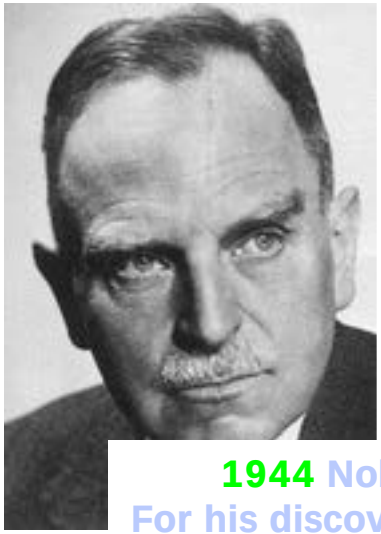
In 1935, Sir James Chadwick received the Nobel Prize in physics for this work.

Ida Noddack 1935

"Bombardment of heavy nuclei with neutrons, these nuclei breakup into several large fragments which are actually isotopes."

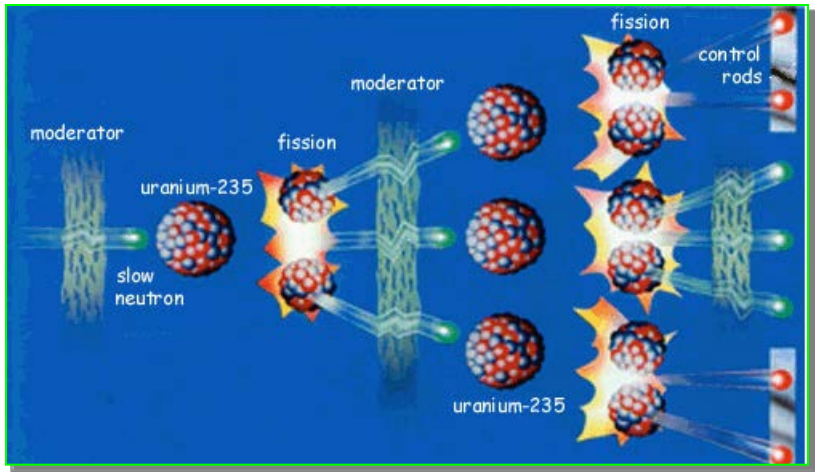
In 1939, Hahn, Maitner…

Otto Hahn and Fritz Strassman carried on experiments bombarding uranium with neutrons→ couldn't explain the results → Lise Maitner explained and gave the name FISSION.



1944 Nobel Prize
For his discovery of fission

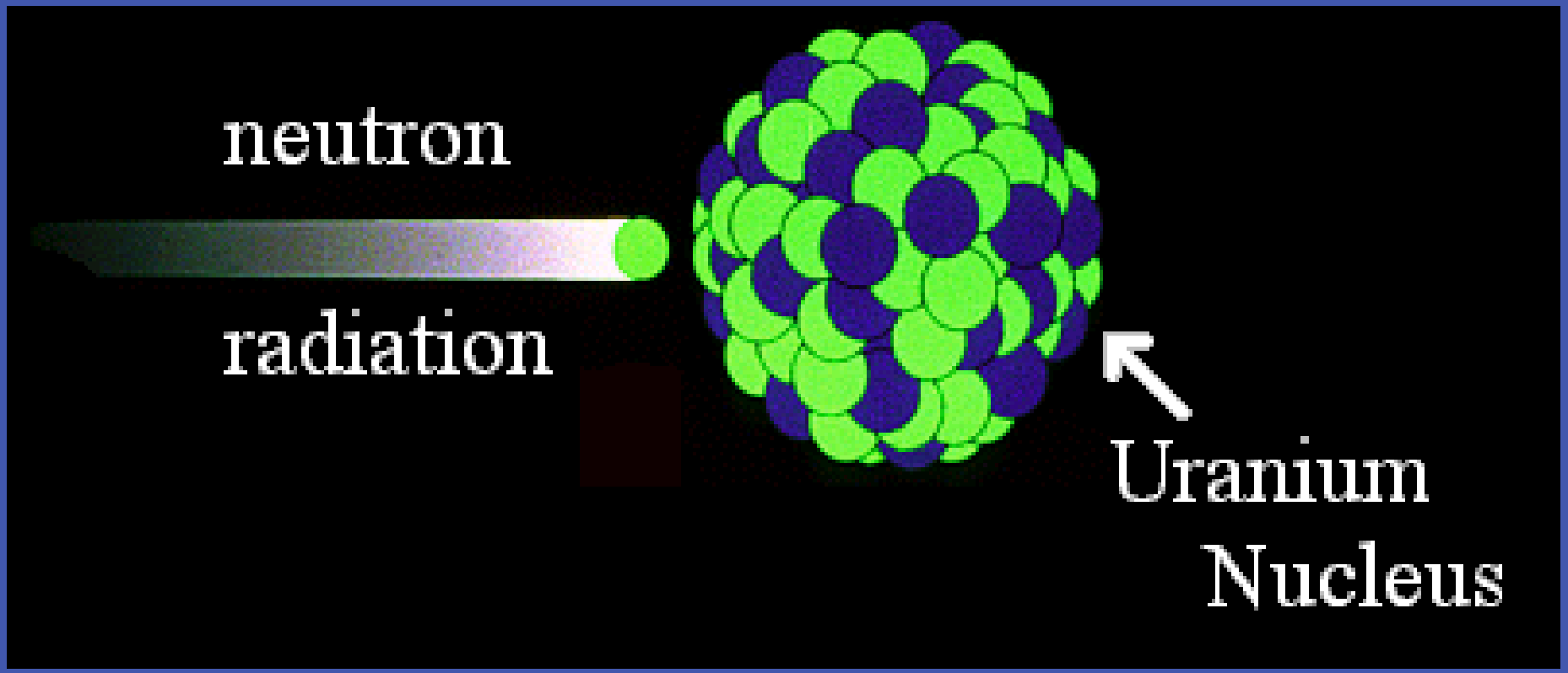
woman and a Jew fleeing Nazi persecution, did not have her name on Hahn's seminal paper



What is Nuclear Fission?

If the nucleus of a heavy atom (such as Uranium) absorbs a neutron, the nucleus can become **unstable** and split.

This is called **NUCLEAR FISSION.**



First fission chain reaction

1) no coolant
2) enrichment of U235 ~0.7%
3) moderator: carbon

Fermi 1942

The first artificial nuclear reactor created with uranium fuel at the University of Chicago.

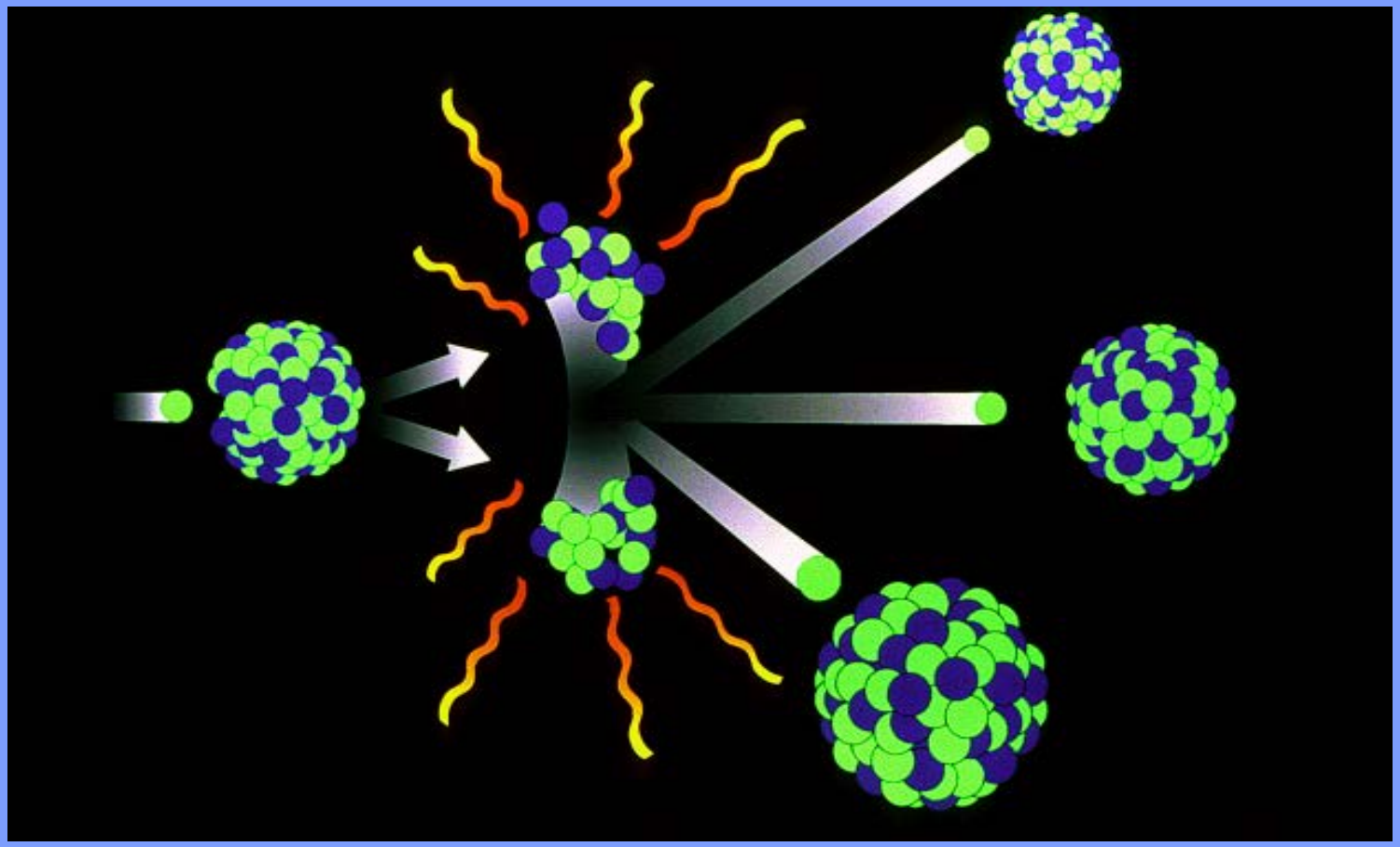
Controlled, this reaction potentially had untold benefits for Mankind. Uncontrolled, it could unleash awesome power.

- Szilard, who had worked with Fermi, 1942

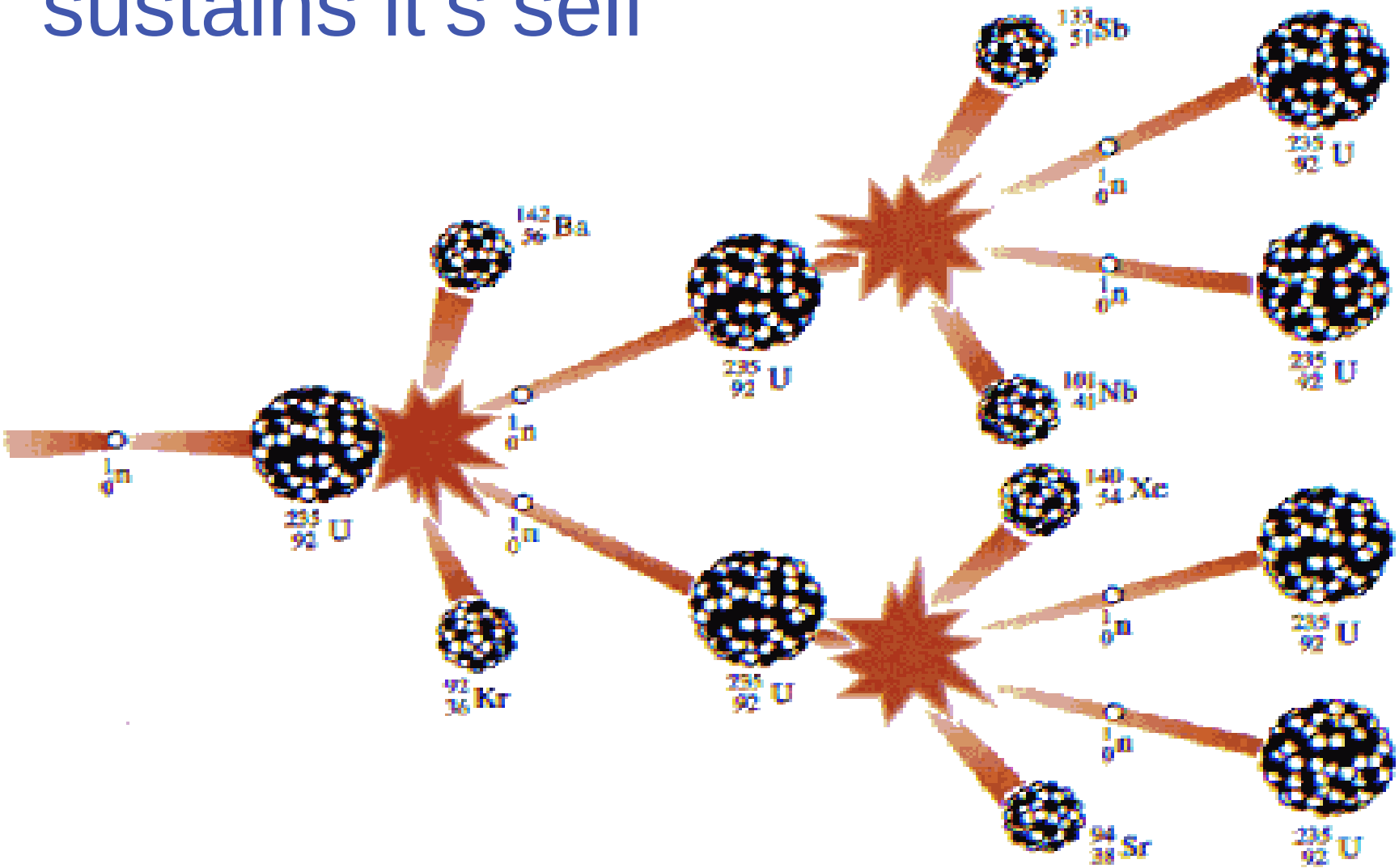
The Chain Reaction

•If the extra neutrons released during a fission event strike other nearby Uranium atoms, these atoms will split as well, releasing more neutrons and more energy.

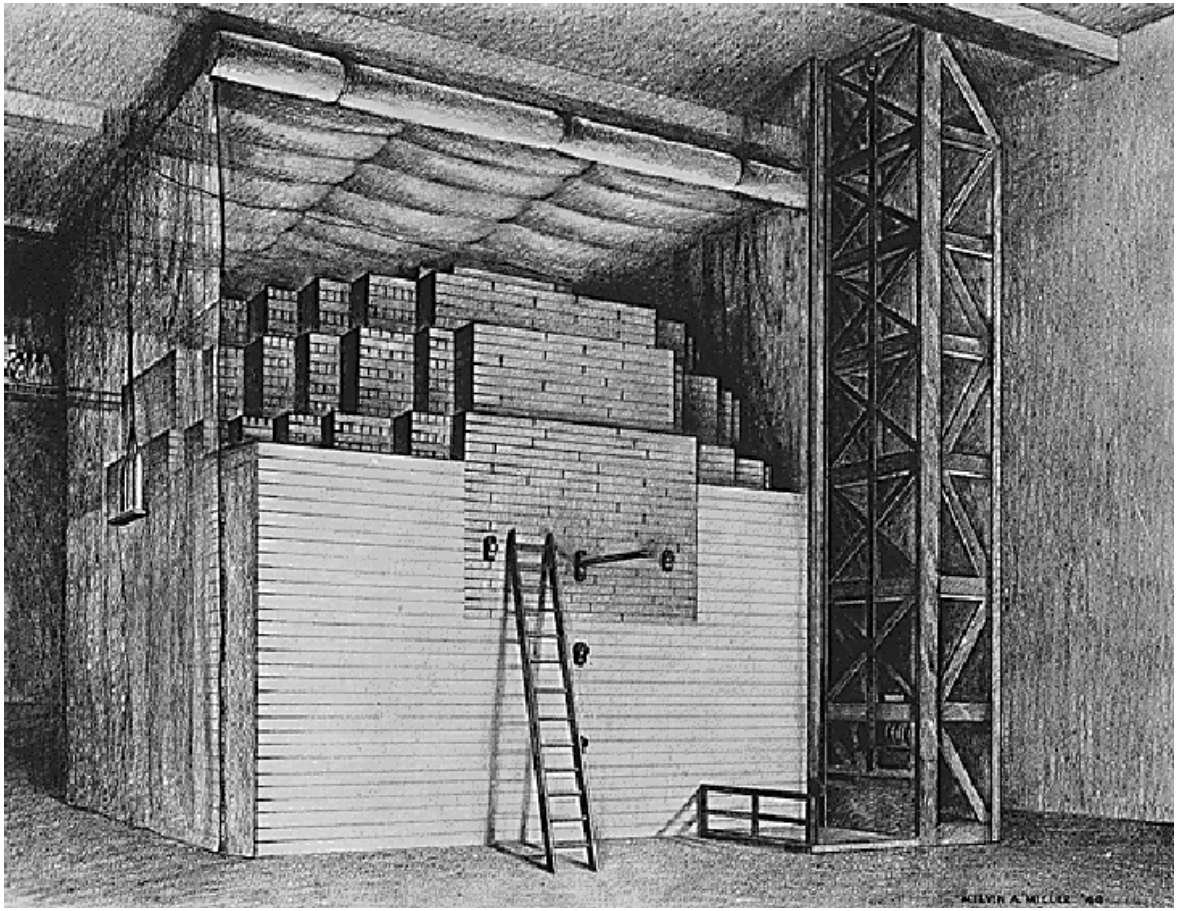
•The CHAIN REACTION can be stopped just by blocking the neutrons from hitting new atoms.



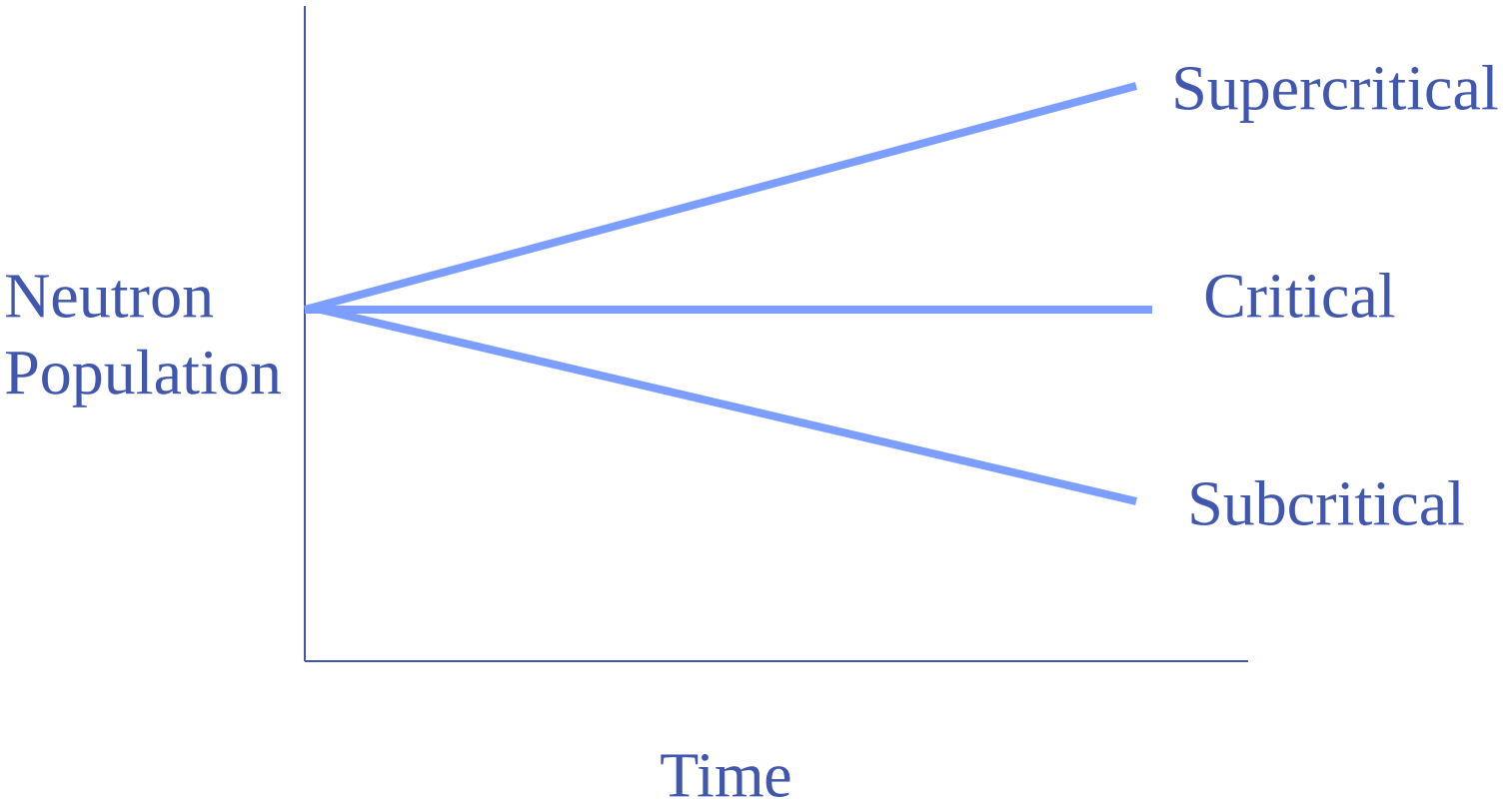
How the chain reactions starts and sustains it’s self



SCRAM
Chicago Pile - 1

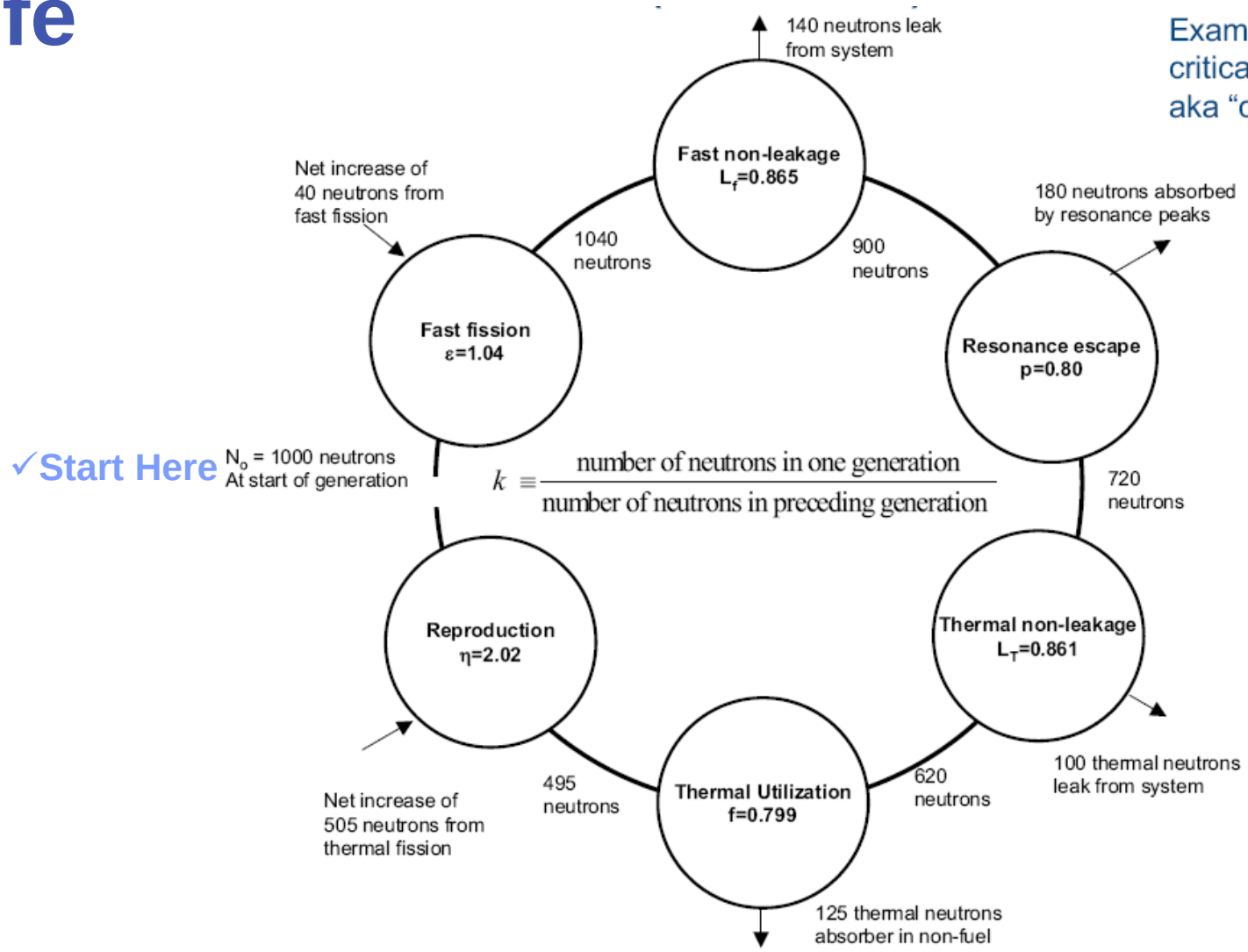


Criticality



✓Circle of (neutron) Life

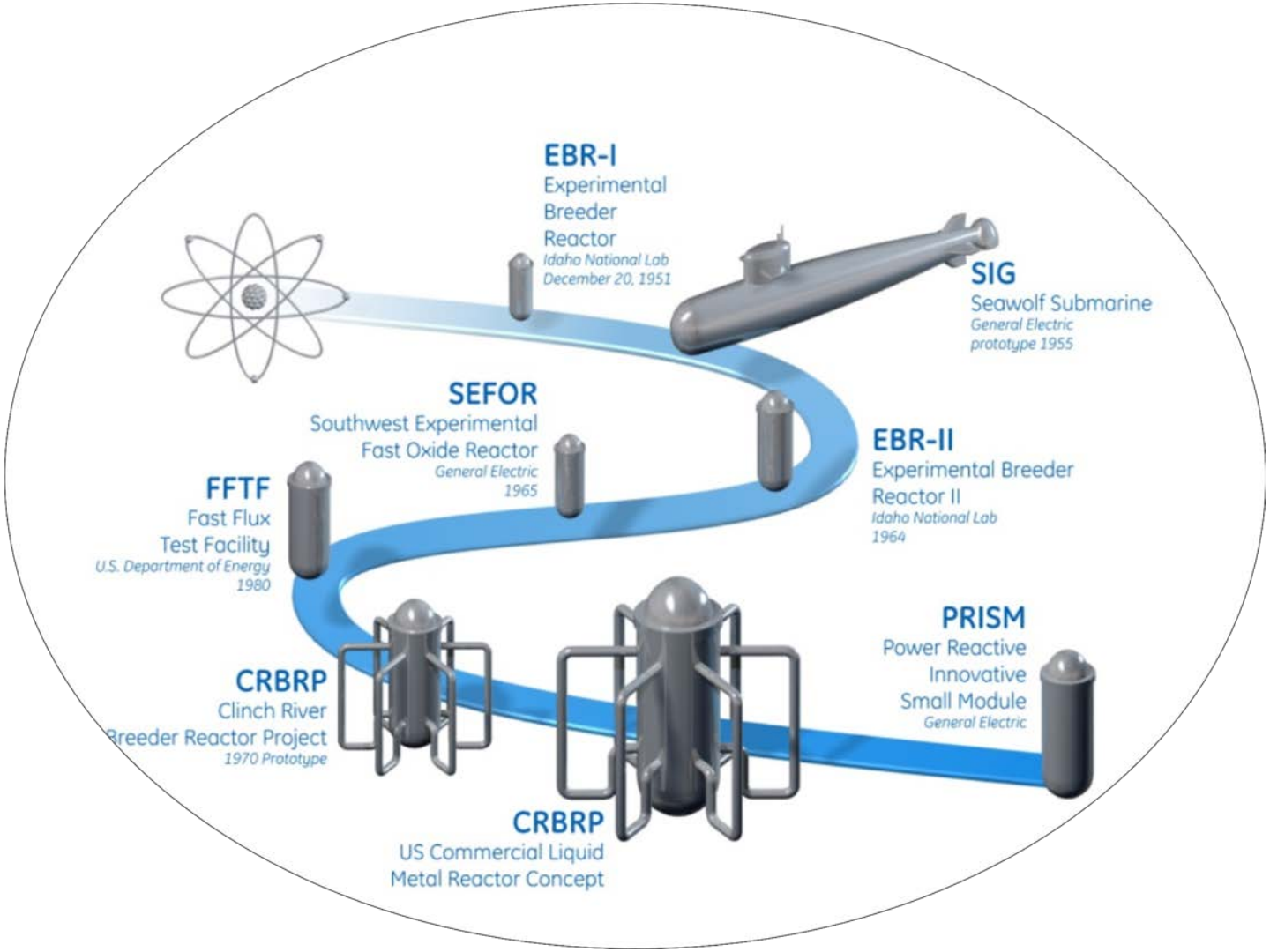
Example of k=1, critical condition, aka "chain reaction"



First fission reactor to produce electricity

1) sodium/potassium (NaK) coolant
2) enrichment of U235 ~20%
3) moderator: none

Sodium reactor development



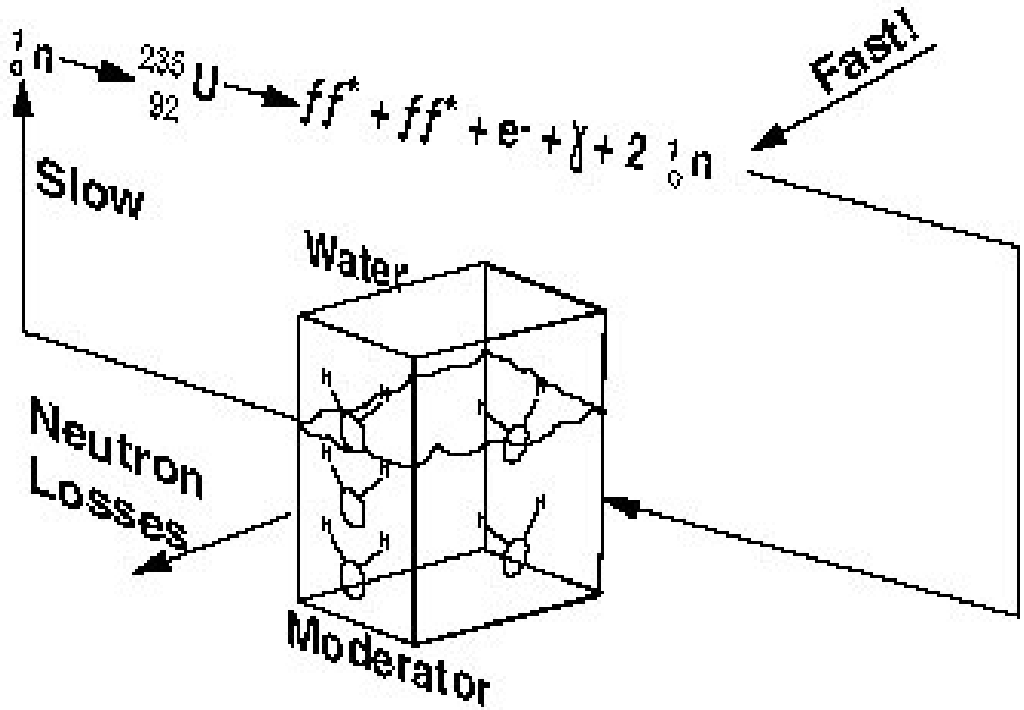
First water cooled reactor to produce electricity

1) water coolant
2) enrichment of U235 ~3%
3) moderator: water

Fission Energy: Fast and Slow Neutrons

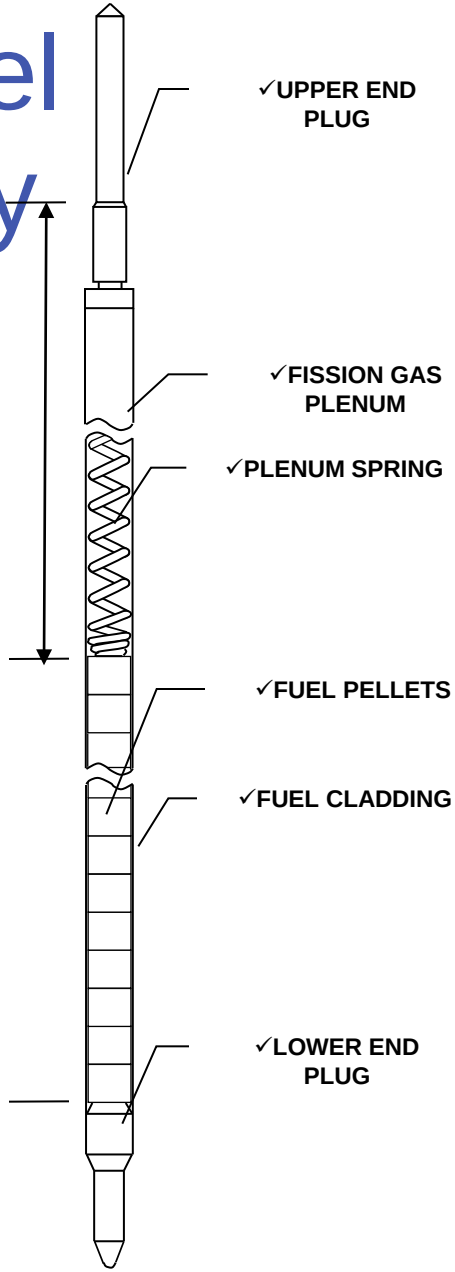
Energy Breakdown

ff^*	=	166 mev
Promt γ	=	6mev
Delayed γ	=	6 mev
Neutrons	=	5 mev
Neutrino	=	10 mev
Total Energy	$\cong$	200 mev

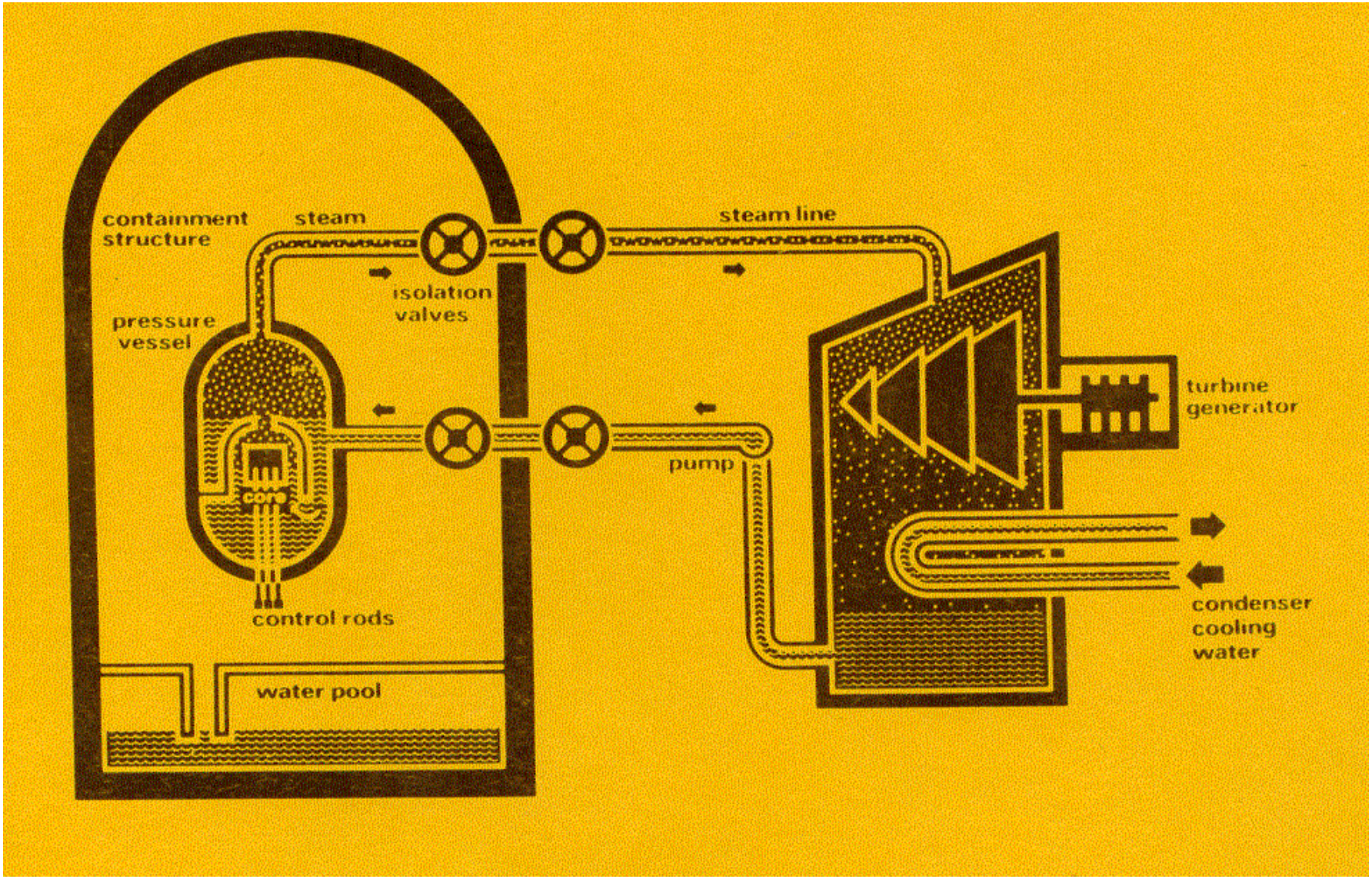


Uranium Fuel Pellets (one pellet equals 2,000 lbs of coal)

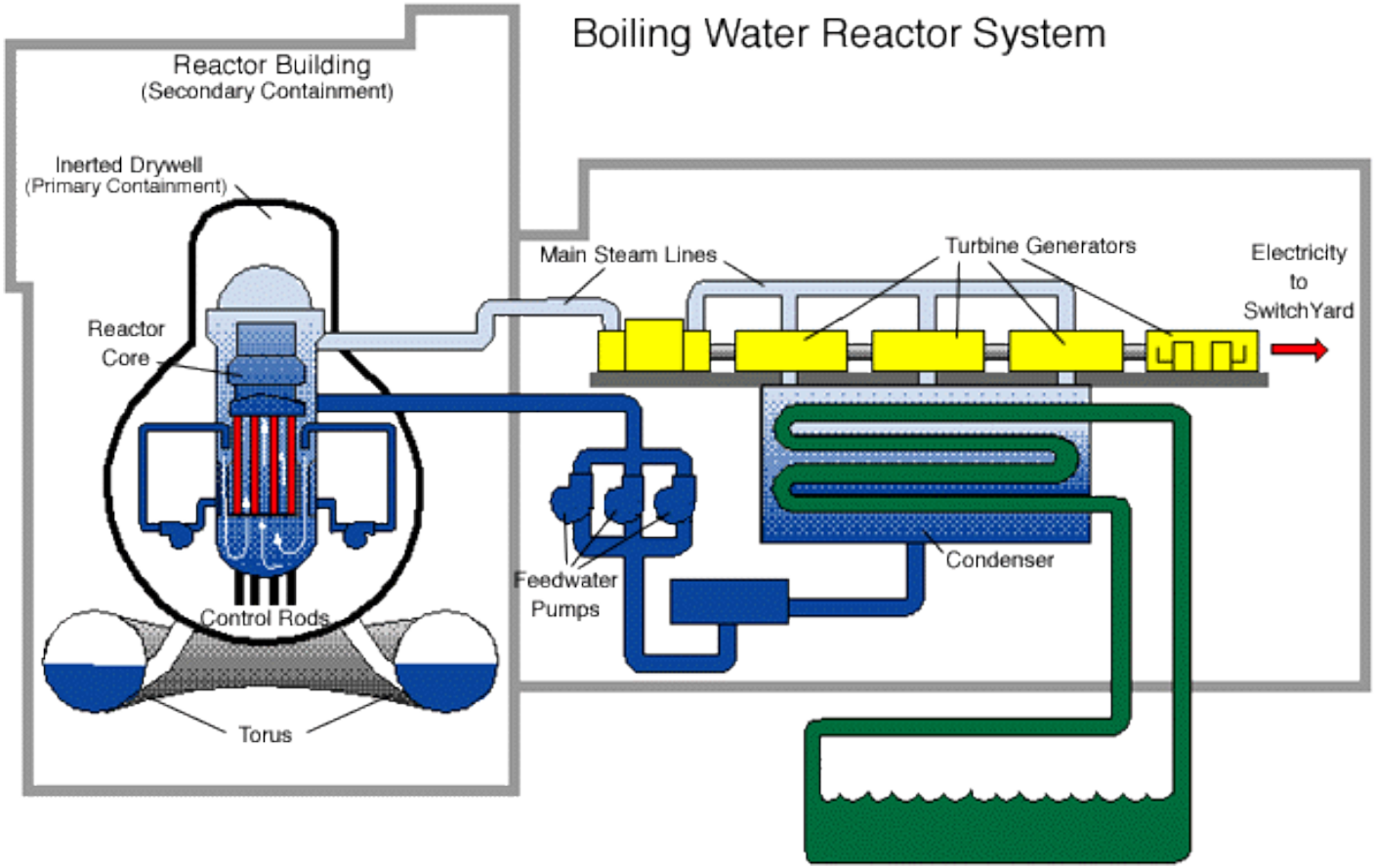
BWR Fuel Assembly



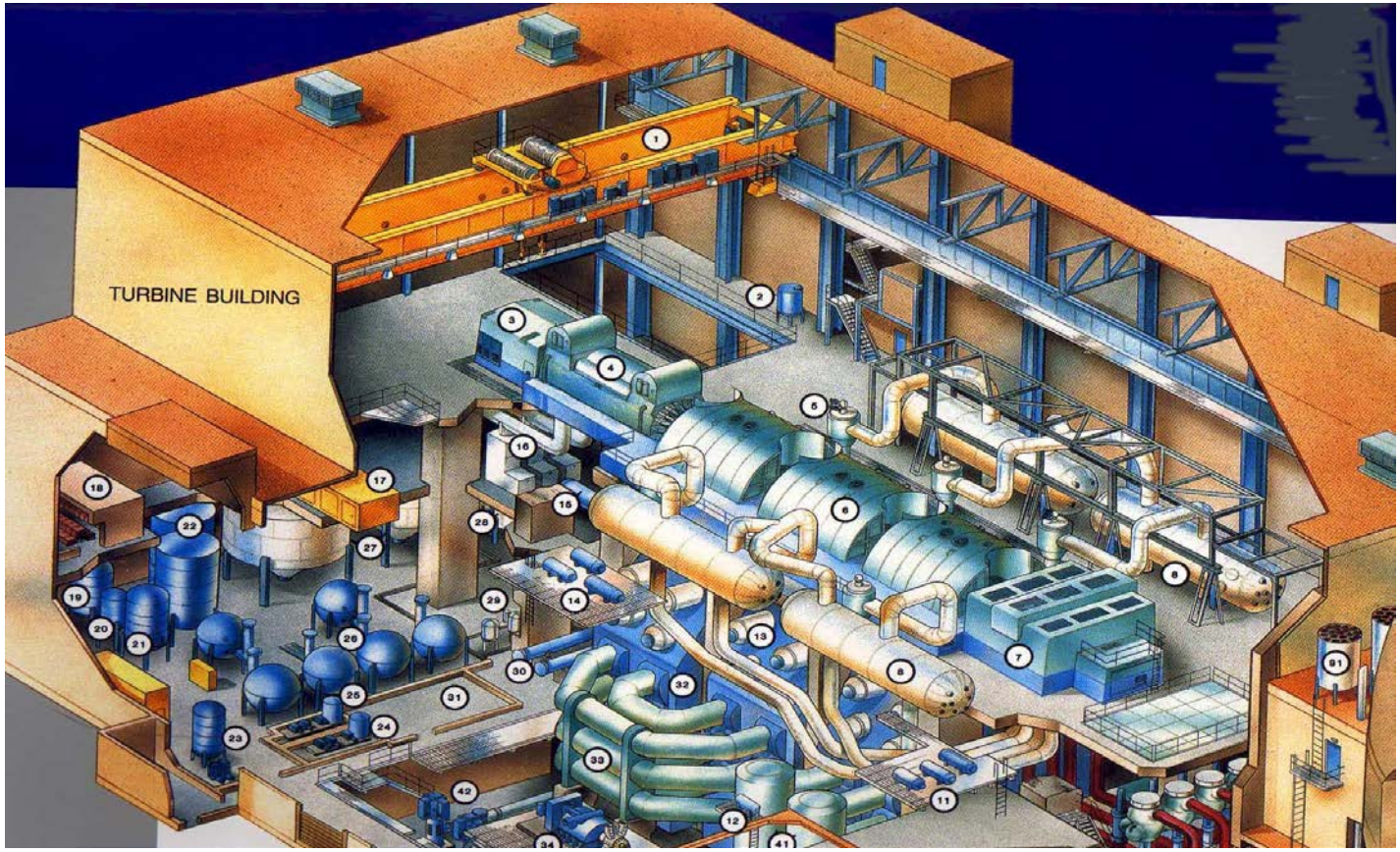
Boiling Water Reactor (BWR)



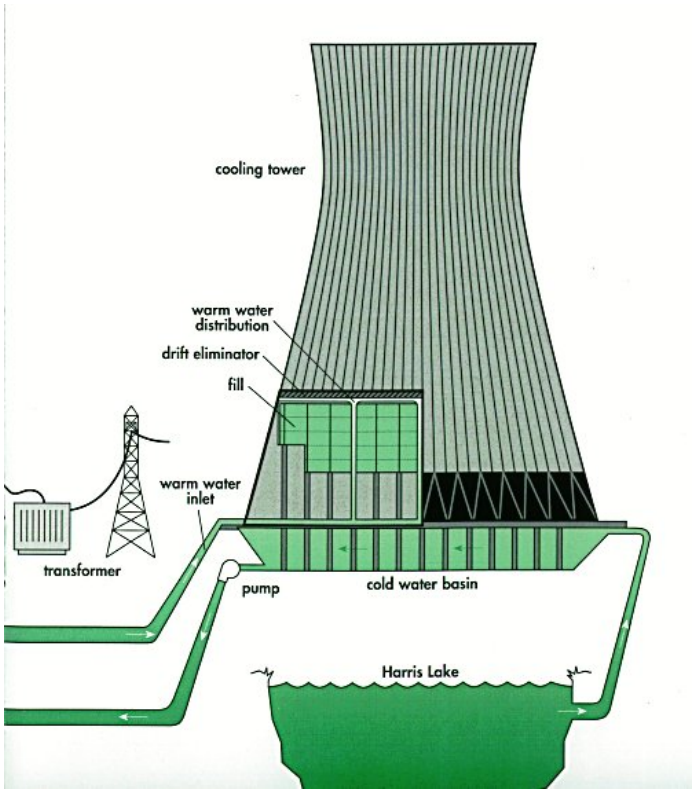
Boiling Water Reactor



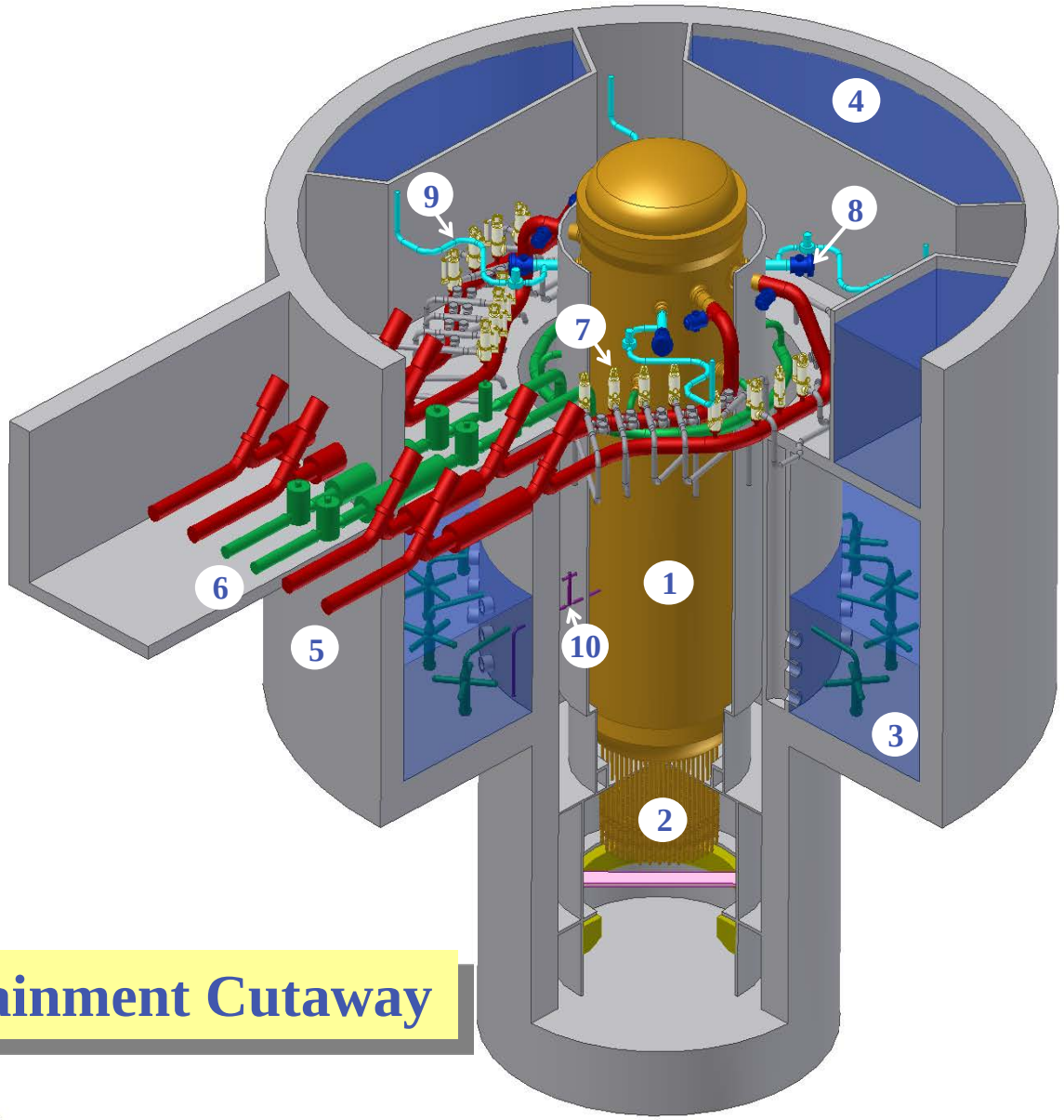
Turbine Building



Cooling Towers



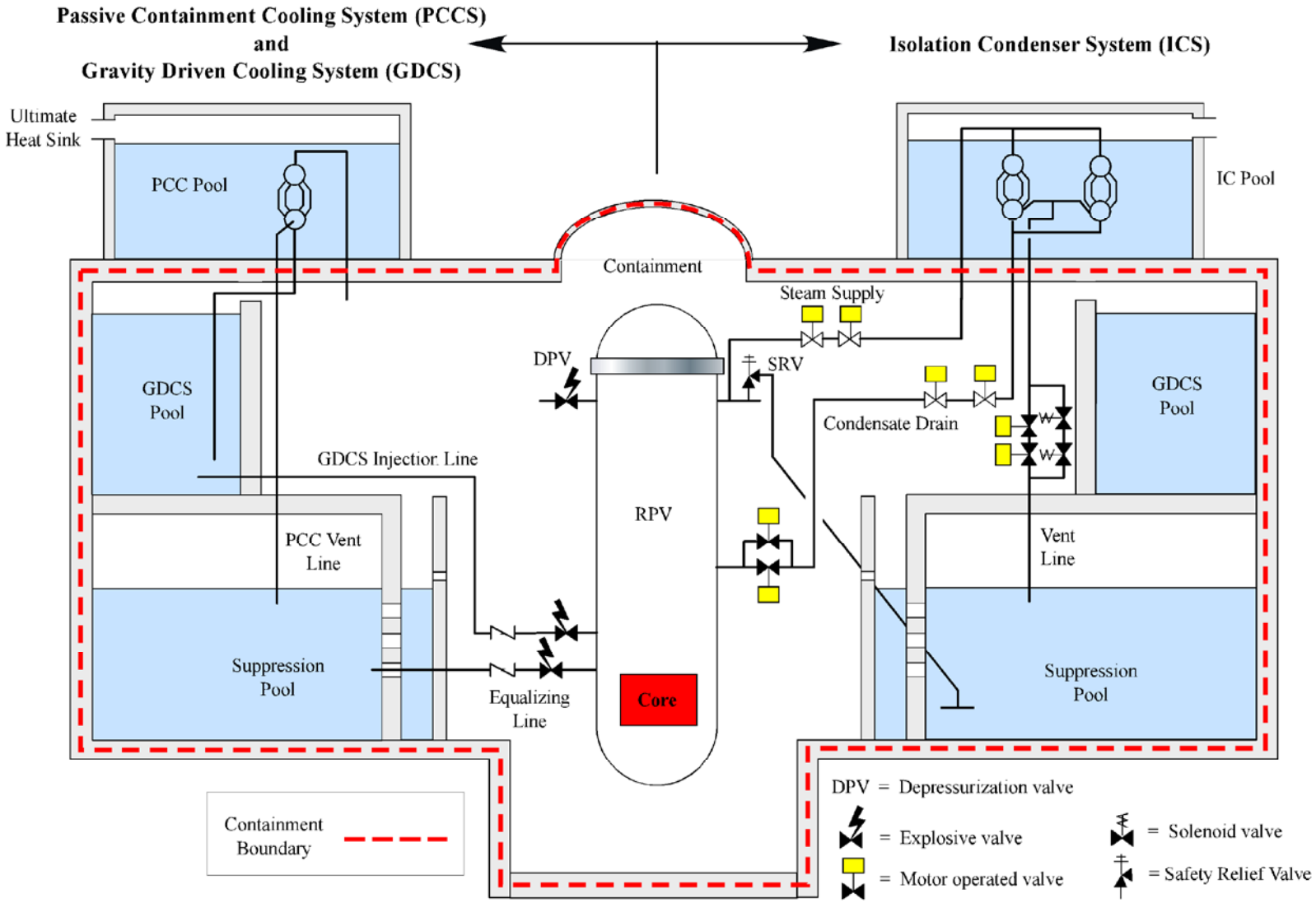
GEH ESBWR



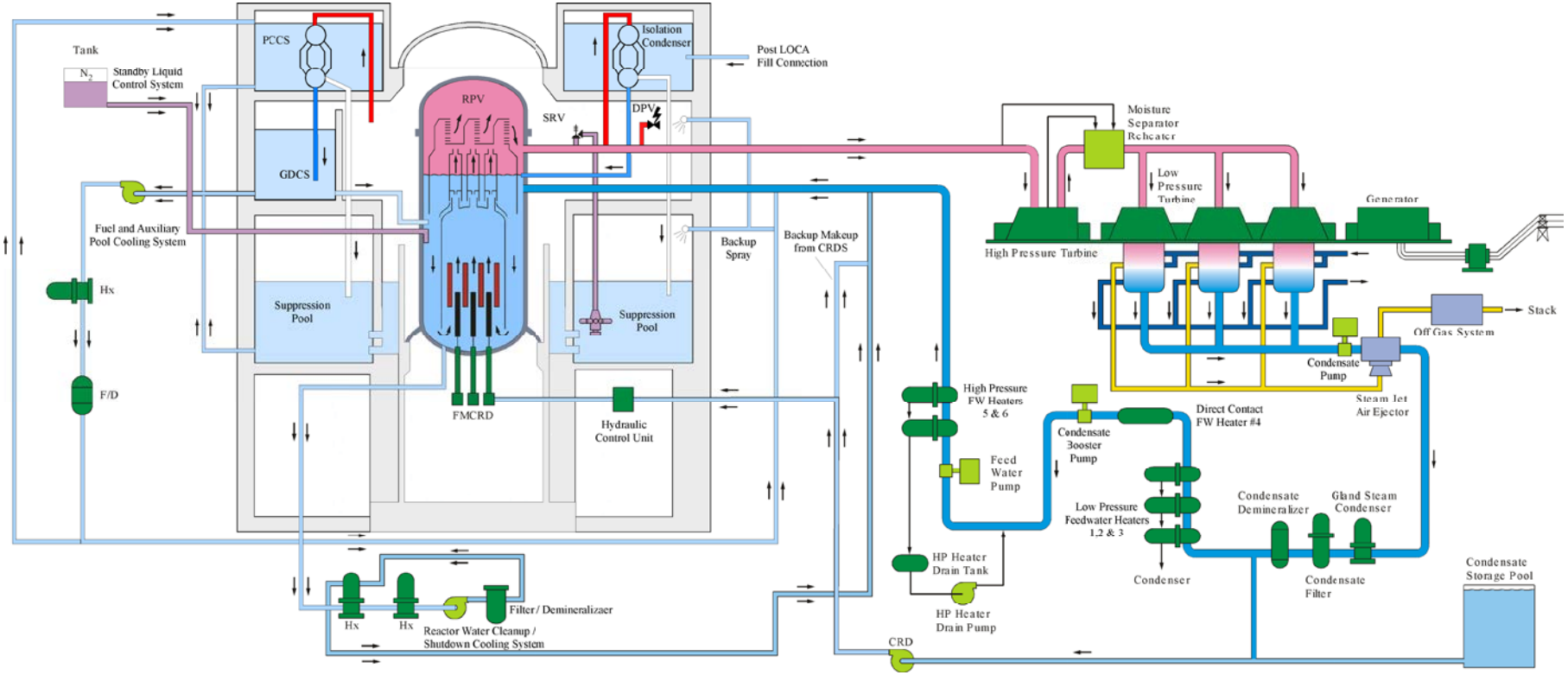
Containment Cutaway

1. Reactor pressure vessel
2. Control rod drives
3. Raised suppression pool
4. Gravity Driven Cooling System (GDCS) pools
5. Main steam lines
6. Feedwater lines
7. Safety relief valves
8. Depressurization valves
9. Isolation condenser steam lines
10. Equalizing line

Passive Safety …



Simplification …

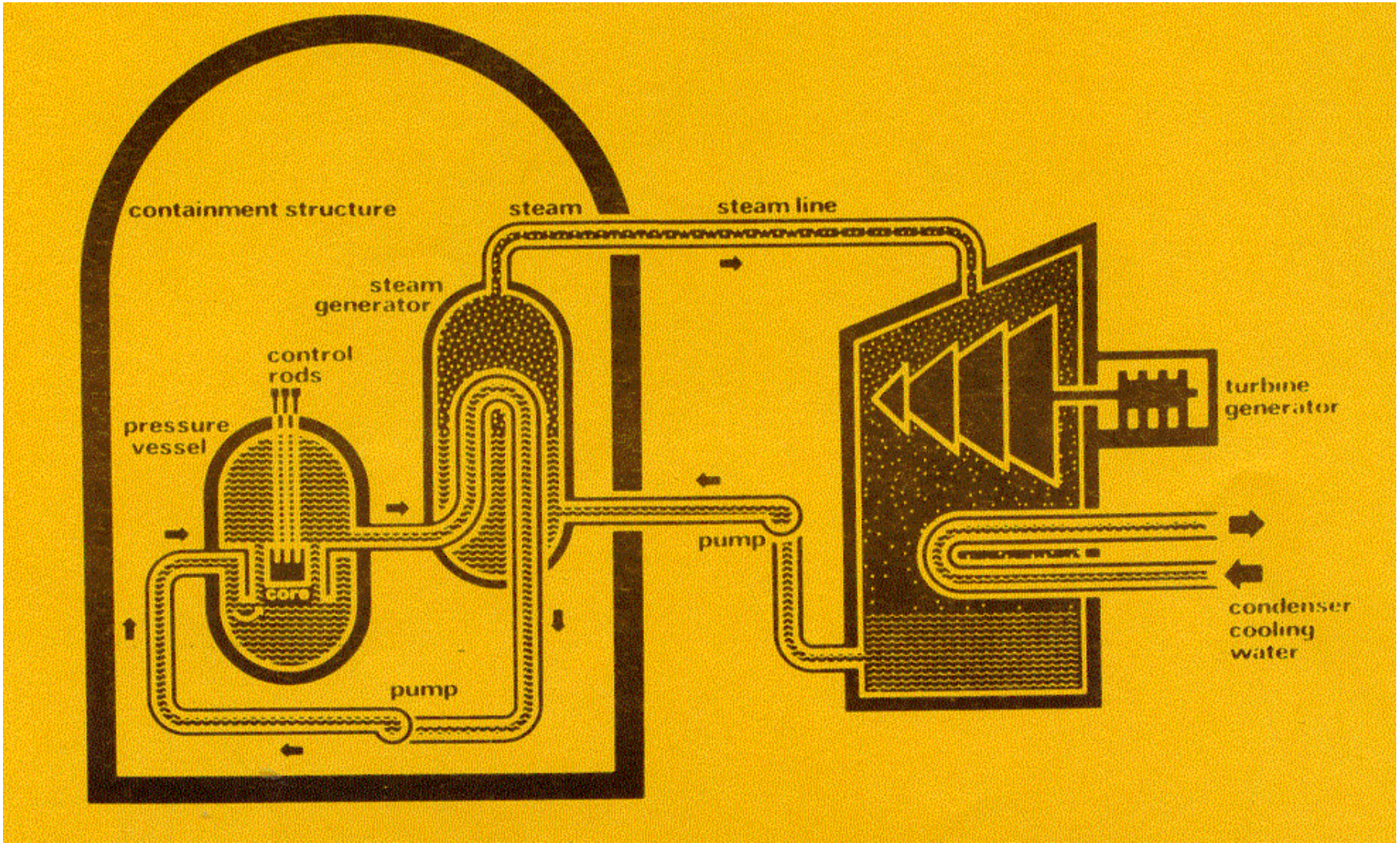


Plant Design Reduces Operator Challenges – Direct Cycle With Major Simplifications

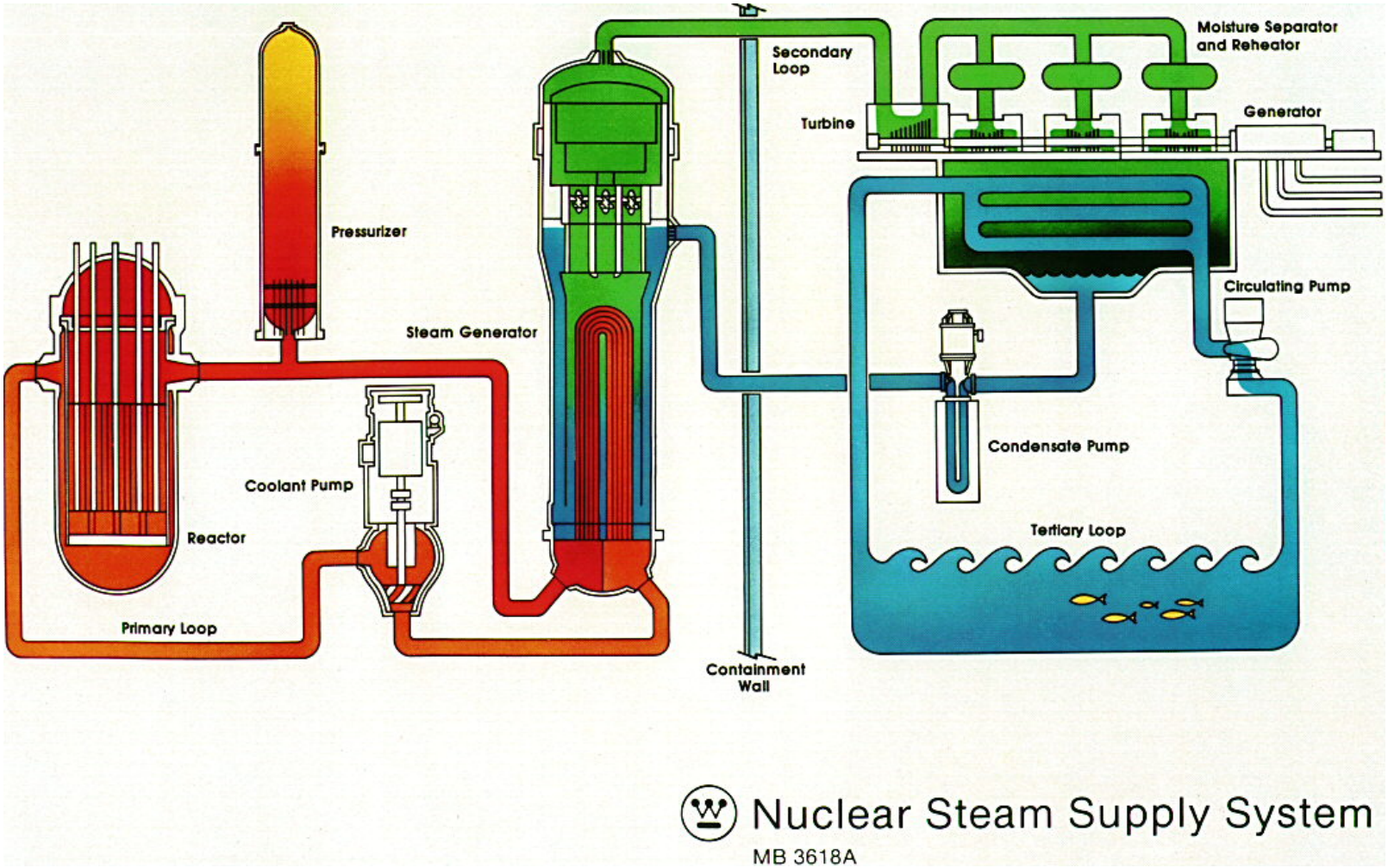
Pressurized Water Reactor

1) water coolant
2) enrichment of U235 ~3%
3) moderator: water

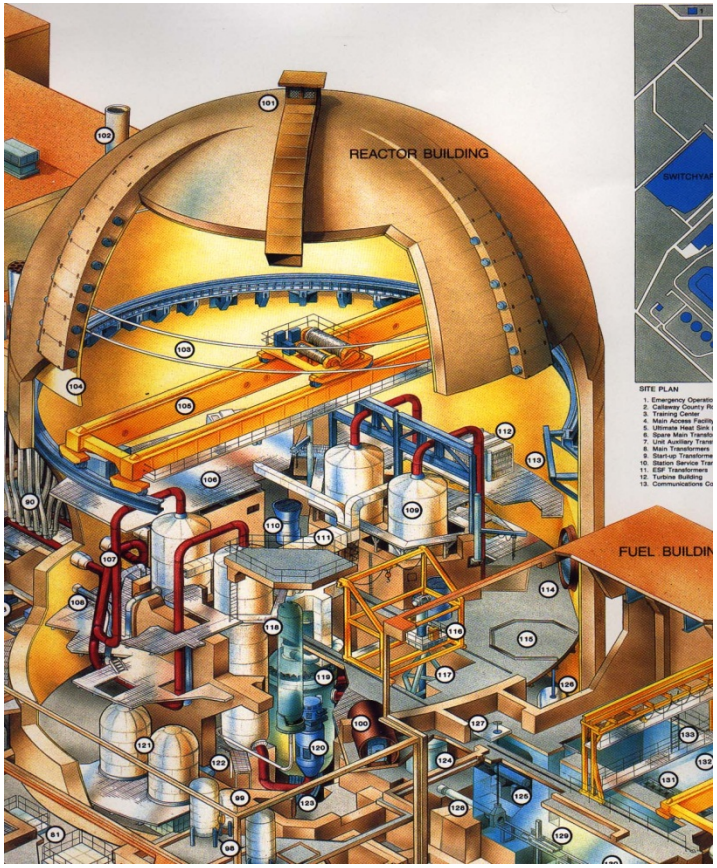
Pressurized Water Reactor (PWR)



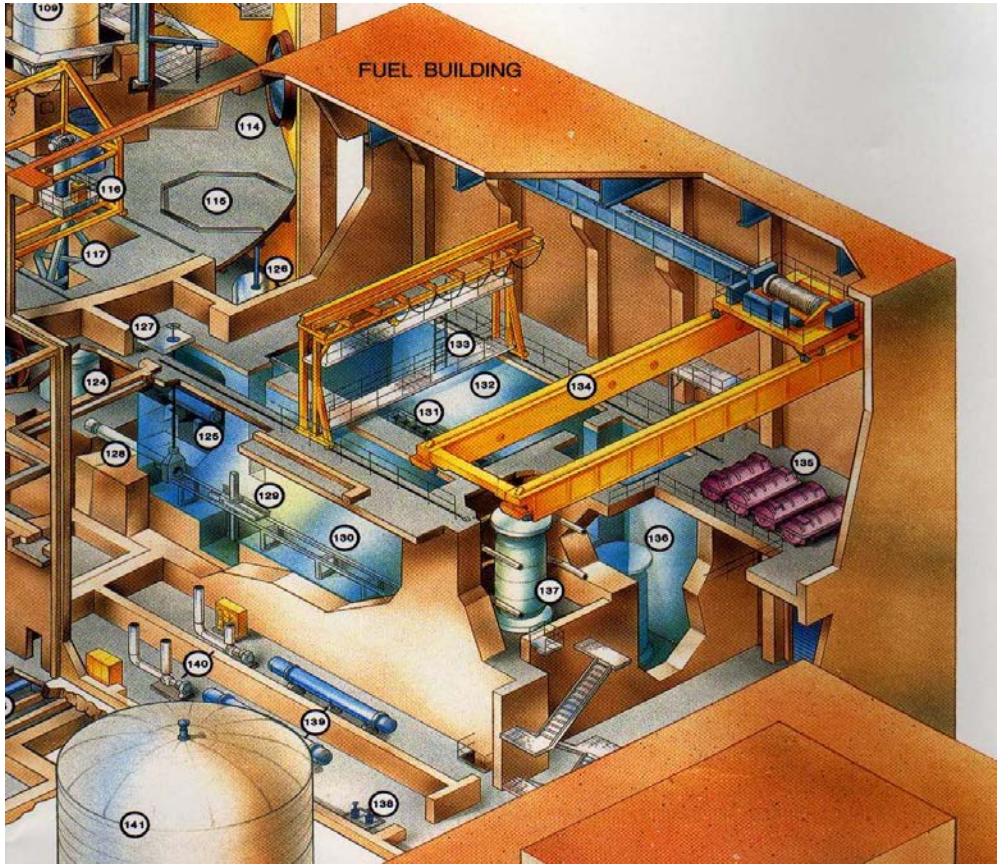
Pressurized Water Reactor



Containment Building



Fuel Building



We have the same sunsets, however, we all see different horizons

The Evolution Nuclear Power.....

Generation I

- Early prototype/ demo reactors
- Shippingport
- Dresden, Fermi I
- Magnox

- First demo of nuclear power on commercial scale
- Close relationship with DOD
- LWR dominates

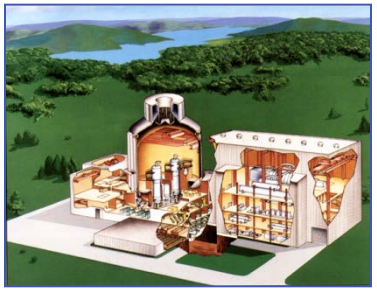
Generation II

- LWR-PWR, BWR
- CANDU
- HTGR/AGR
- VVER/RBMK

- Multiple vendors
- Custom designs
- Size, costs, licensing times driven up

Generation III

- ABWR, System 80+, AP600, EPR



- Passive safety features
- Standardized designs
- Combined license

Generation IV

- Highly economical
- Proliferation resistant
- Enhanced safety
- Minimize waste

Atoms for Peace

TMI-2

Chernobyl

1950 | 1960 | 1970 | 1980 | 1990 | 2000

Fast Reactors

Fast-Spectrum Reactors

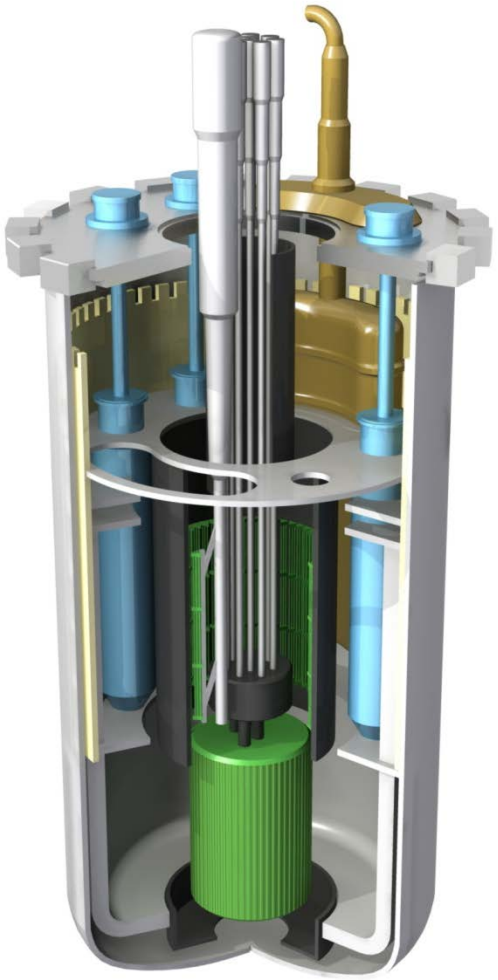
The Integral Fast Reactor Program pulled together the basic elements

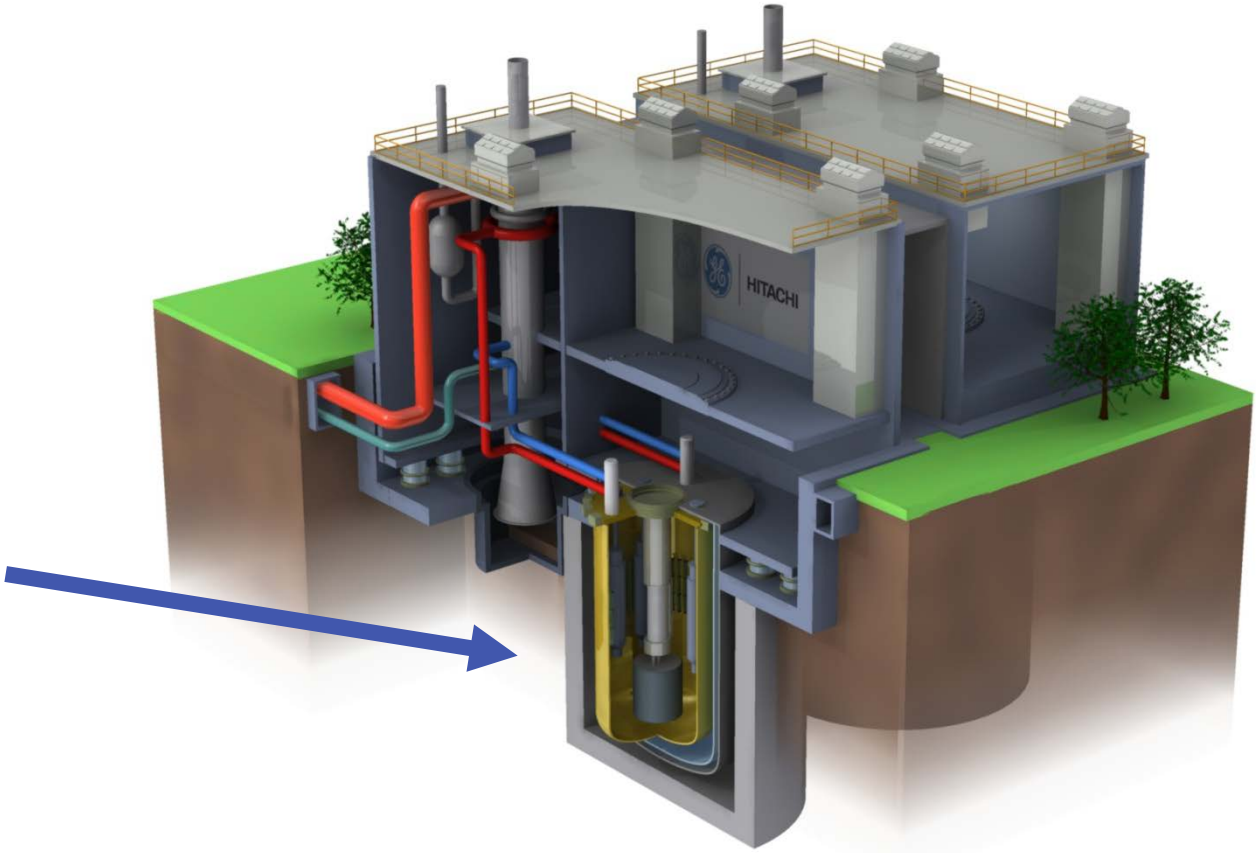
- Safety
- Closed fuel cycle

Target was breeding to sustain significant growth: not an issue today

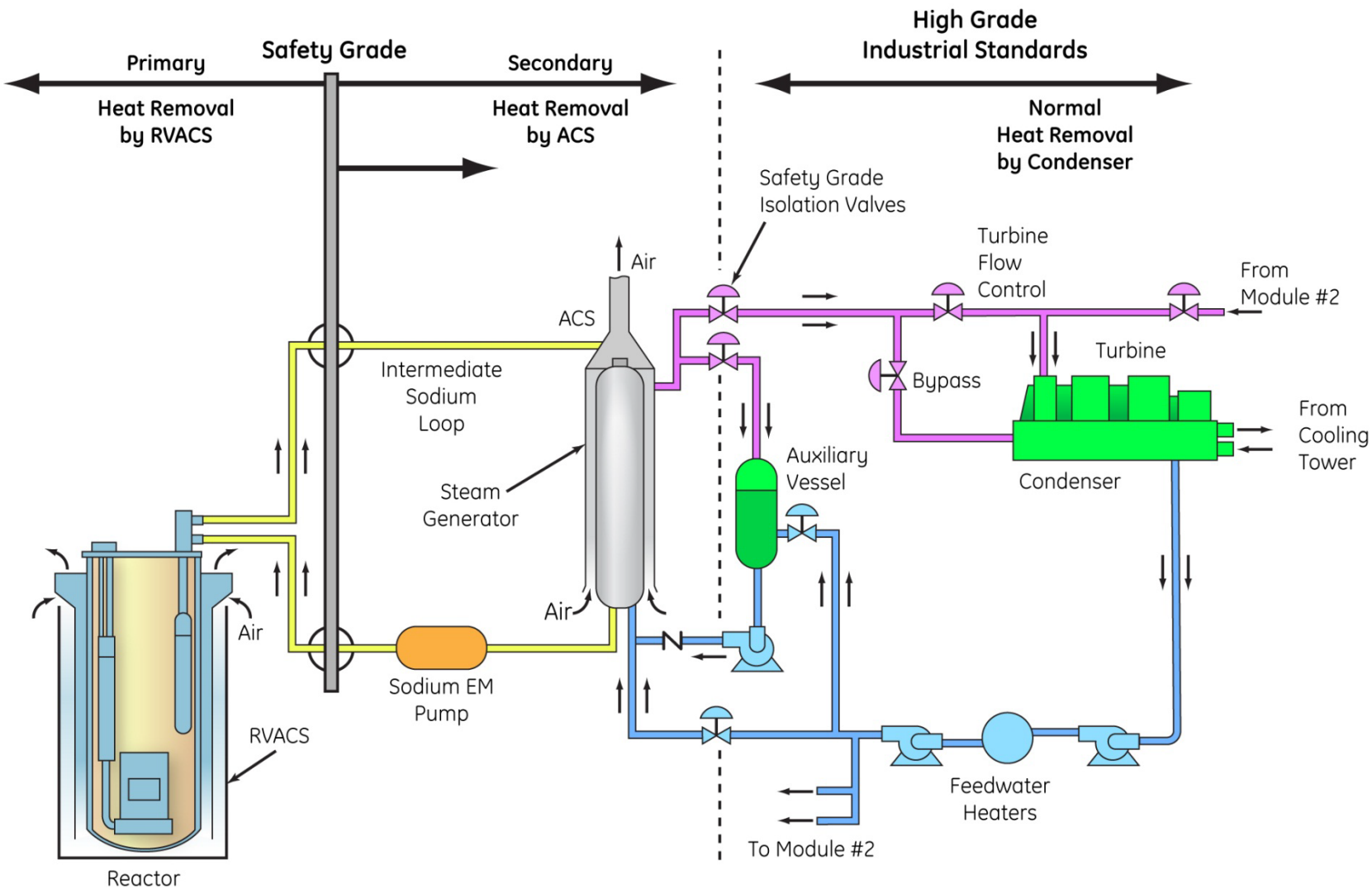
- Uranium resources not limiting

PRISM – with Advanced Multi-Cavity Rectangular Containment

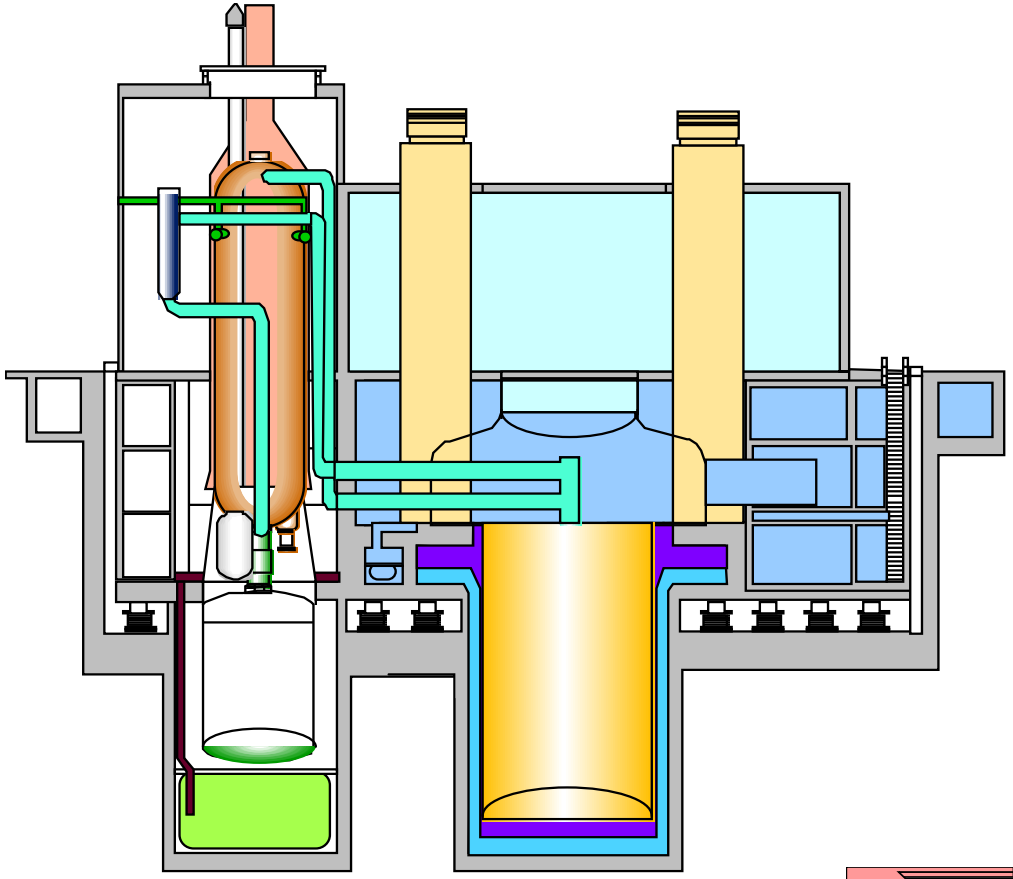




Power Train

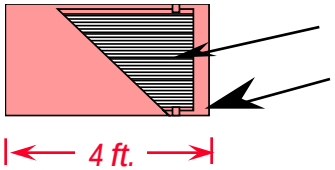

Safety Grade
Primary
Secondary
Heat Removal by RVACS
Heat Removal by ACS
High Grade Industrial Standards
Normal Heat Removal by Condenser
Safety Grade Isolation Valves
Turbine Flow Control
From Module #2
Air
ACS
Intermediate Sodium Loop
Turbine
Bypass
From Cooling Tower
Steam Generator
Auxiliary Vessel
Condenser
Air
Air
Sodium EM Pump
RVACS
Feedwater Heaters
To Module #2
Reactor

S-PRISM NSSS and Seismic Design



Characteristics of Seismic Isolation System

- Safe Shutdown Earthquake
  - Licensing Basis 0.3g (ZPA)
  - Design Requirement 0.5g
- Lateral Displacement
  - at 0.3g 7.5 inch.
  - Space Allowance
    - Reactor Cavity 20 inch.
    - Reactor Bldg. 28 inch.
- Natural Frequency
  - Horizontal 0.70 Hz
  - Vertical 21 Hz
- Lateral Load Reduction > 3

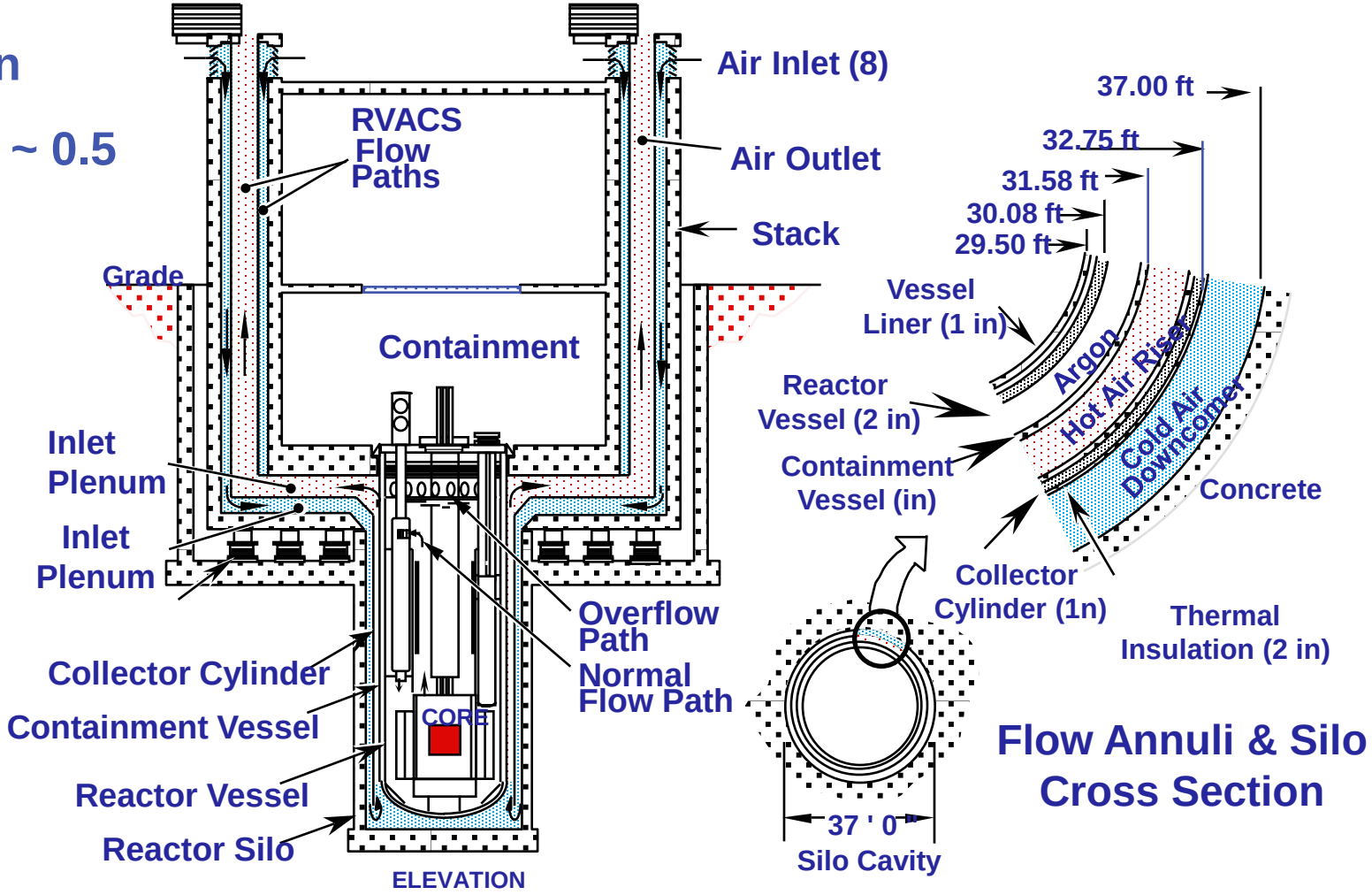


Seismic Isolators (66)

Reactor Vessel Auxiliary Cooling System (RVACS)

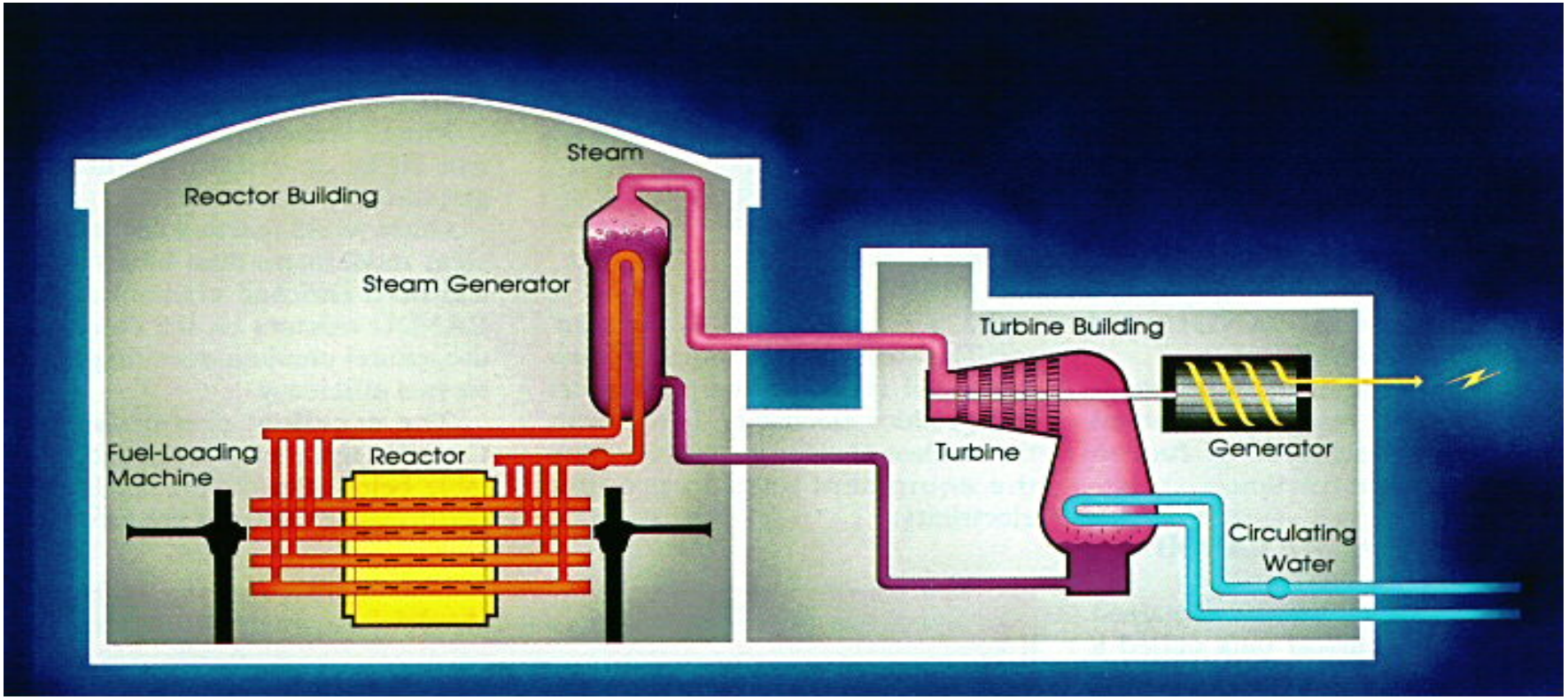
Always on

Removes ~ 0.5 MWt



Flow Annuli & Silo Cross Section

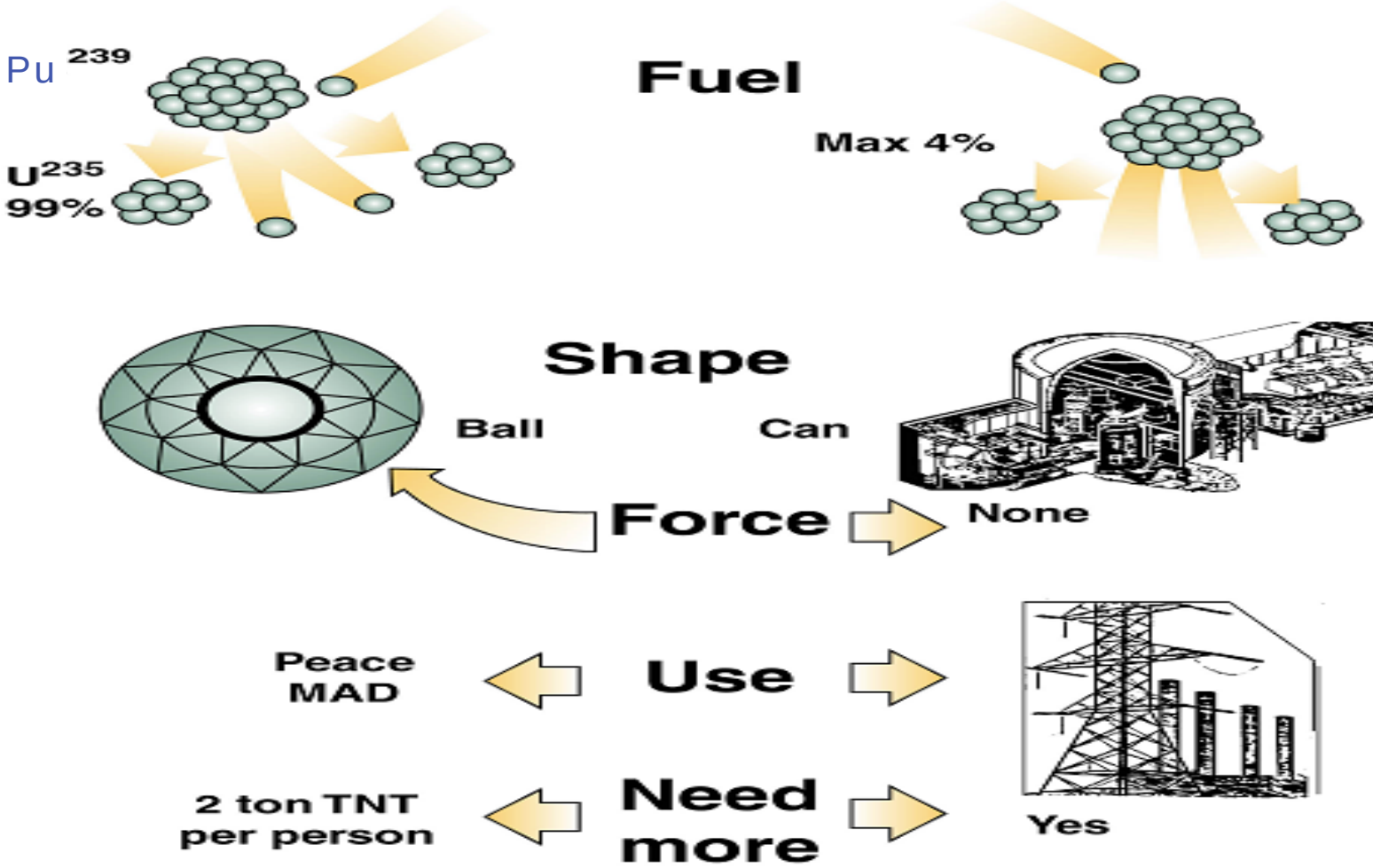
Canadian Deuterium-Uranium



Summary

Nuclear Energy

Weapons —— Versus —— Power



Backups

BORAX-III 1955

Experimental boiling-water reactor was the first reactor in the world to provide all of the electricity to an entire town, Arco, with a population of 1,000.

THE ARCO ADVERTISER

Serving America's Newest Atomic Center — Voice of the Last River Country Since 1909 — 10 Cents Per Copy

Vol. XLVI—Number 24 — Arco, Butte County, Idaho — Friday, August 12, 1955

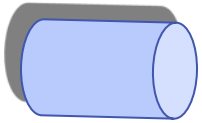
Arco First City In United States Lighted By Atomic Power

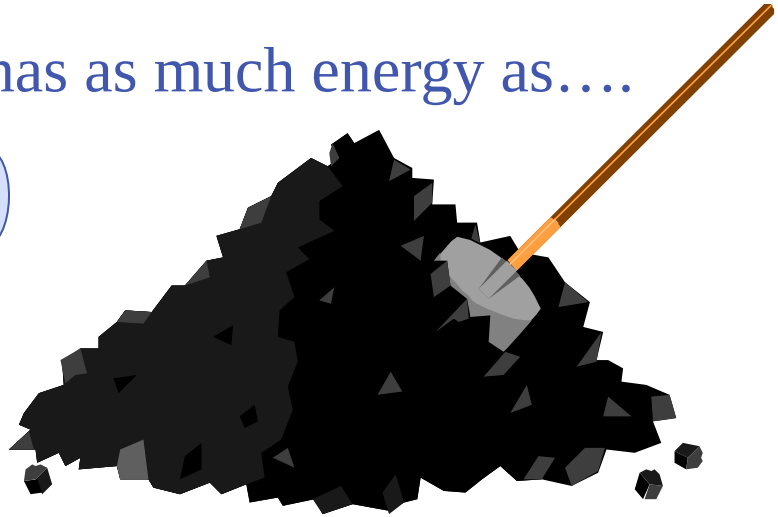
Energy Equivalents

One uranium Fuel Pellet has as much energy as….

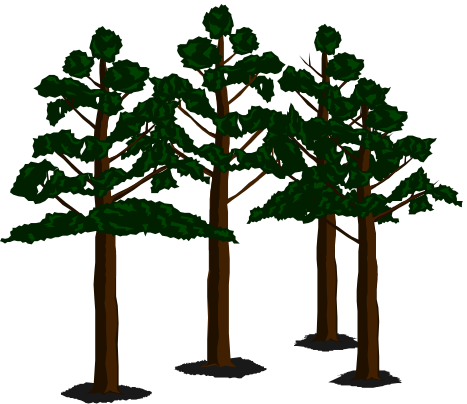
3 Barrels of Oil

(42 gallons each)

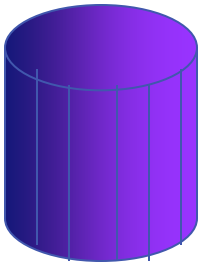




1 Ton of Coal

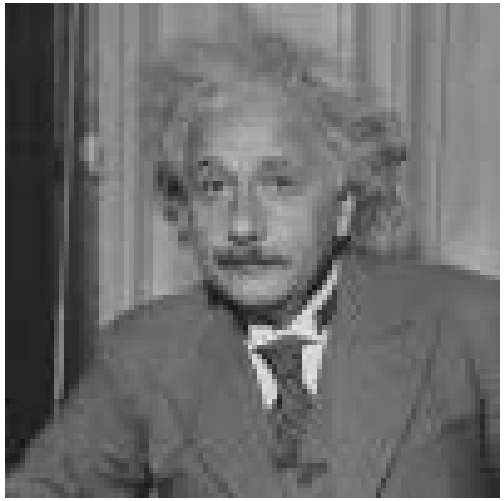


2.5 Tons of Wood



17,000 Cubic Feet of Natural Gas

$E = mc^2$



Einstein's Famous Equation

- E = Energy
- m = Mass
- c = Speed of light

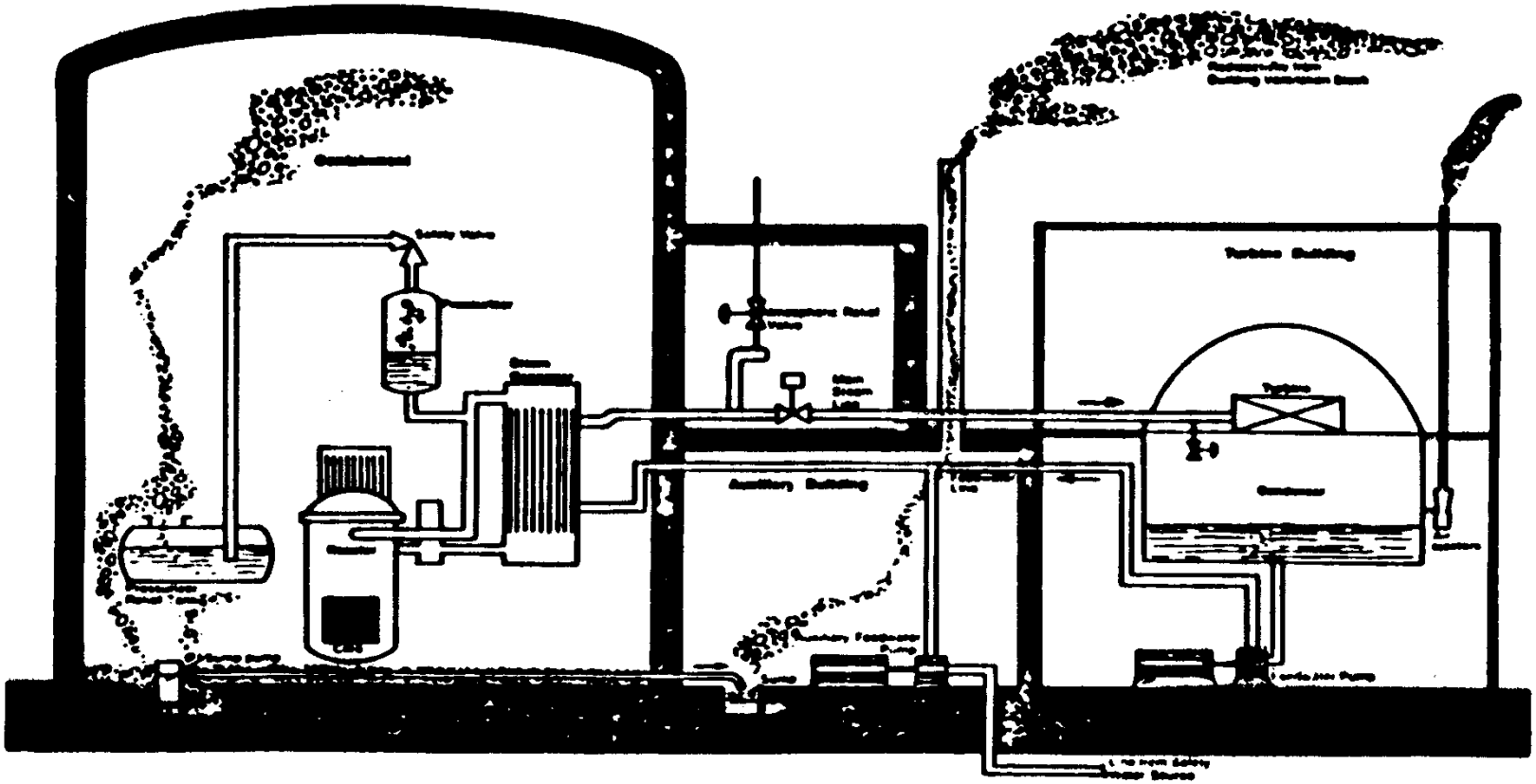
  3×10^8 m/s

A very small change in mass will create a large change in energy

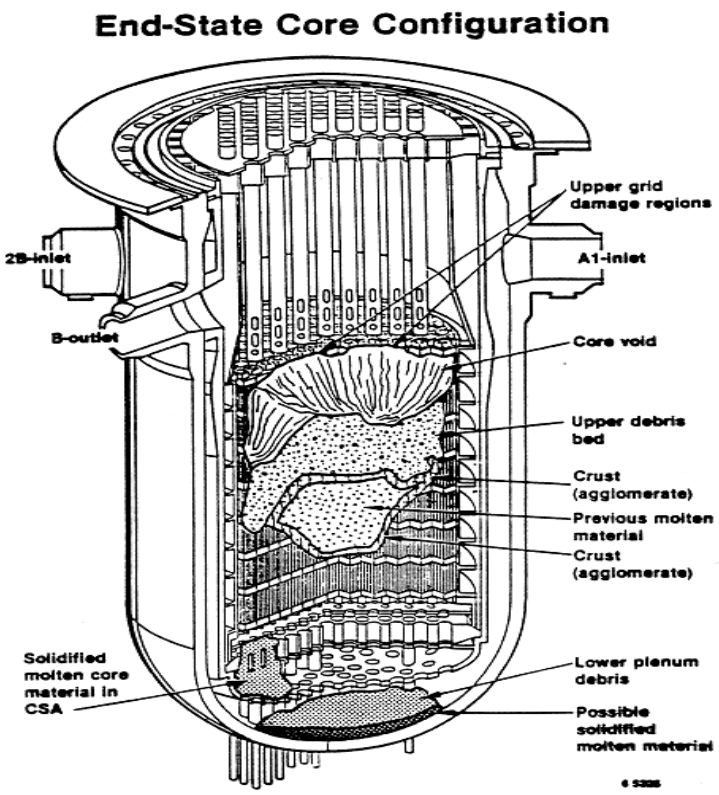
Pressurized Water Reactor: TMI

1) water coolant
2) enrichment of U235 ~3%
3) moderator: water

Simplified PWR Showing Three Mile Island Release Paths



TMI Lessons Learned

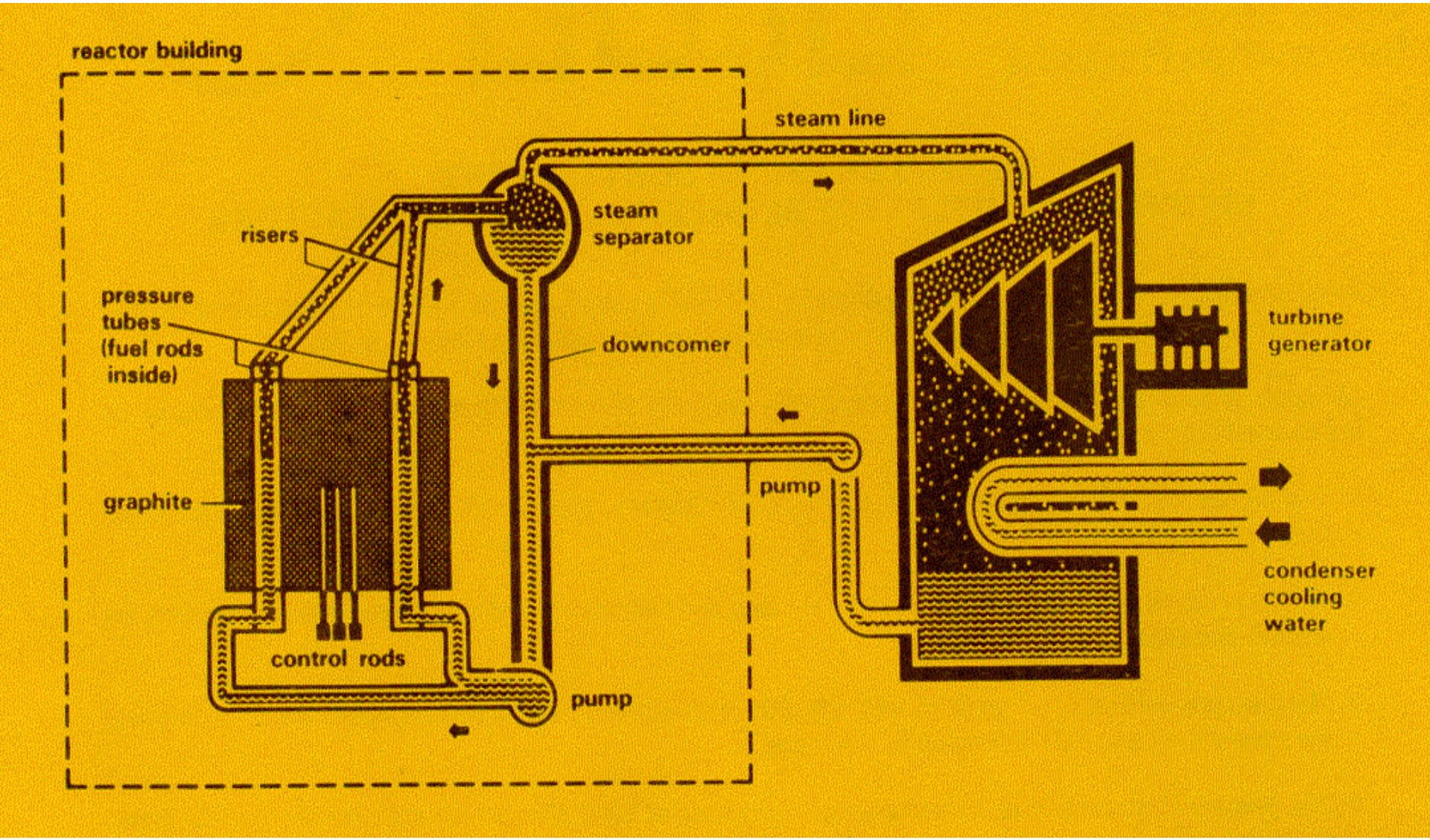


- Industry is only as strong as the weakest plant.
- Institute of Nuclear Power Operation (INPO) started.
- Plant simulator use increased.
- Conduct of plant operations formalized.
- Safety systems worked; no one was harmed.
- Degreed person required in control room.

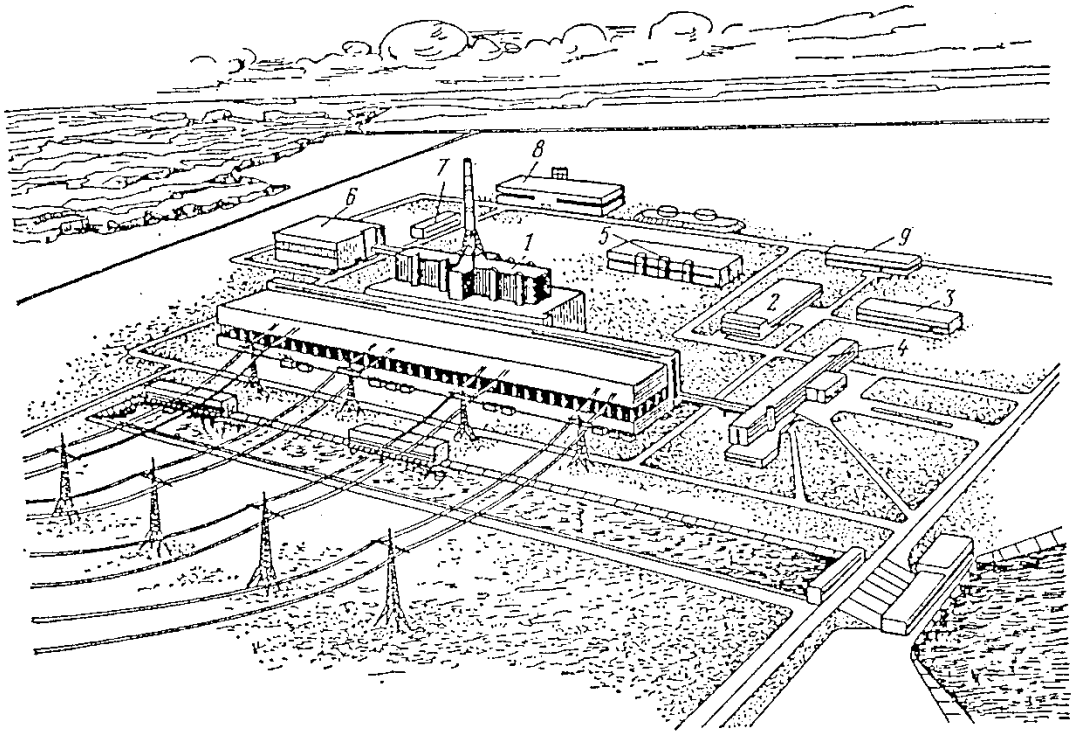
Chernobyl Nuclear Power Plants

1) water coolant
2) enrichment of U235 ~<1%
3) moderator: carbon

USSR RBMK - 1000



Chernobyl Nuclear Power Plants

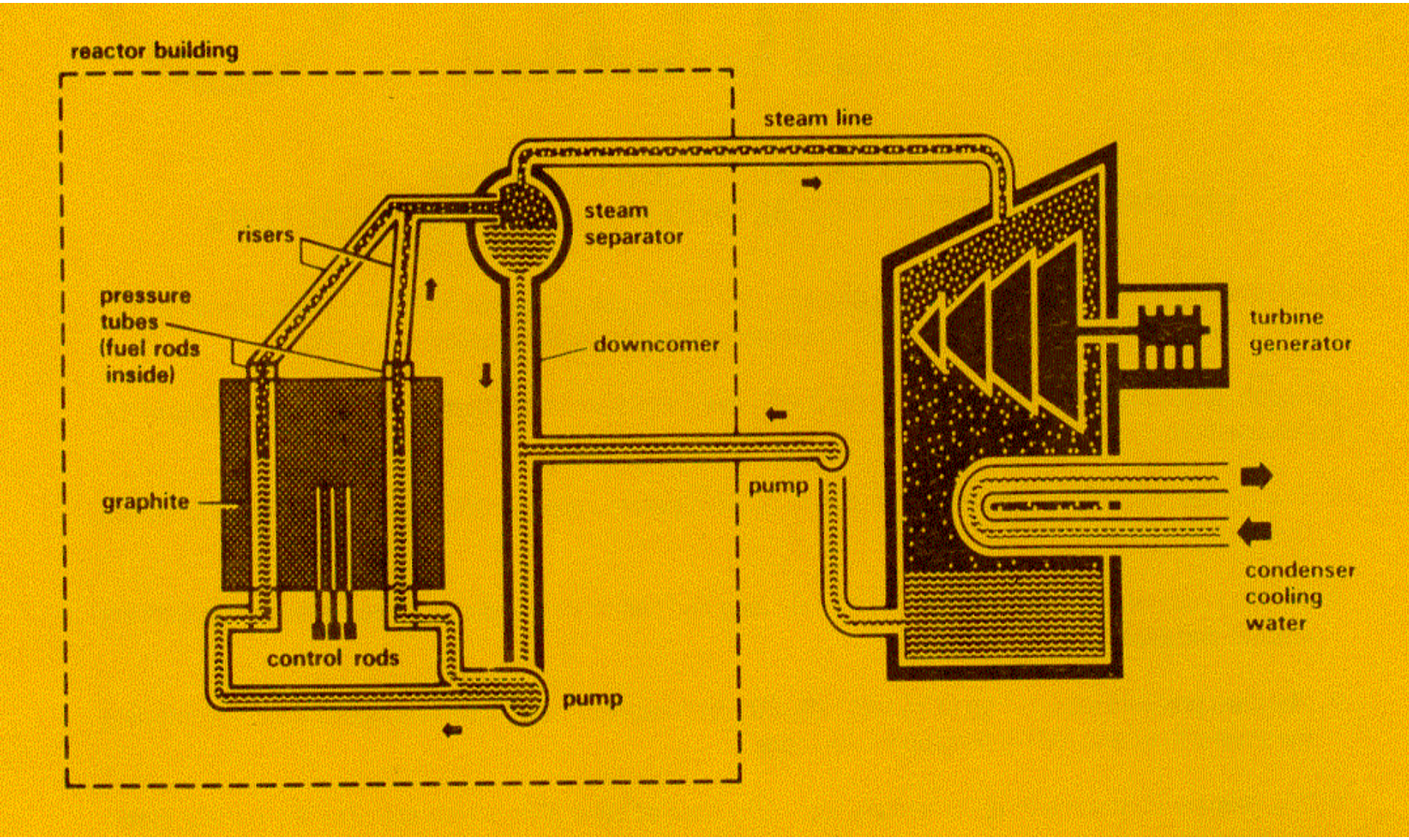


- *Located on the Pripyat river, 10 miles northwest of Chernobyl.*
- *Chernobyl is 60 miles north of Kiev.*
- *Population of Kiev: 2.5 million*
- *Population of Chernobyl: 49,000*

Chernobyl Plant Characteristics

- Each unit is rated at about 3200 MWth (Four Units).
- Direct-cycle, boiling-water, pressure-tube reactors. Steam is produced within the assembly.
- The reactor fuel rods (~1700) are each contained in individual zircaloy pressure tubes embedded in a matrix of graphite blocks.
- Each pressure tube contains 18 zircaloy-clad UO_2 fuel pins, enriched to 1.8% U-235.
- The reactor is 40 ft in diameter and 26 ft high.
- The graphite matrix is enclosed within an inerted atmosphere and a stainless steel vessel, housed in a reactor vault.
- Six operating pumps circulate water to the inlet of each pressure tube through individual lines for each assembly.
- On-line refueling at a rate of about one assembly/day.

USSR RBMK - 1000



Final Scenario

Test is begun:

1:23:02	Test begins at reactor power of 200 MWth.
1:23:04	Power in the reactor increases (500 MWth) due to void buildup and pressure increases; the 8 circ pumps still feed the core.
1:23:31	Operator manually initiates reactor scram, but it is too late, since 15-20 s required for control rod insertion.
1:23:40	Reactor is now on a high power ramp,and reactor power reaches 110% normal (estimate).
1:23:43	Doppler feedback curtails first burst.
1:23:44	Second rector excursion to 4 times normal power.
1:23:45	Pressure falls and circ-pump flow returns to core; two audible/visible explosions observed.

Scenario (continued)

Speculative Observations:

Reactor shield block destroyed, and all 1700 pressure tubes severed.

The audible explosions caused by a succession of events in sequence:

> Transient overpower reactor excursion

> Loss of flow

> Fuel-coolant interaction

> Hydrogen production

> Hydrogen combustion

Fuel hydrodynamic dispersal was caused, and eventual melting and slumping of remainder of fuel took hours.

Question?

What are the three components of a reactor?

Explain what was found at the Oklo Mine.

What did Madam Curie discover.

Explain alpha particle decay.

How did Chadwick use Curie's alpha particle?

How was the neutron discovered?

What did Ida Noddack theory in 1935 regarding the bombardment of heavy nuclei?

What experiment did Otto Hahn and Fritz Strassman carry out?

Explain what nuclear fission is.

How did Fermi extend the fission process?

What is a fast and a slow neutron?

How much energy is released from the fission of one atom?

What does in mean when a reactor is supercritical, critical, and subcritical?

The energy content of uranium is equivalent to how many tons of coal?

Explain Einstein's famous equation.

Explain how a boiling water reactor works.

What reactor supplied what town nuclear electricity for the first time?

What is the function of the turbine building?

Draw and explain the cooling towers used at both coal and nuclear power plants.

Draw and explain the containment building.

What is the spent fuel pool? What happens when it gets full?

What happened at the nuclear power plant at three mile island?

What happened at the Chernobyl nuclear power plants to produce the steam explosion?

What is a fast reactor?

How does a fast reactor burn up old nuclear waste?

How does a CANDU reactor work?