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United States Nuclear Regulatory Commission
Protecting People and the Environment

Principles of Nuclear Power and its Peaceful Applications

Union College
William Ostendorff
Nuclear Regulatory Commission

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Personal Background

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United States House of Representatives
House Armed Services Committee

U.S. Department of Energy
National Nuclear Security Administration
NNSA

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Overview

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- Nuclear Physics
- Health Physics
- Role of the Regulator

Nuclear Power Physics

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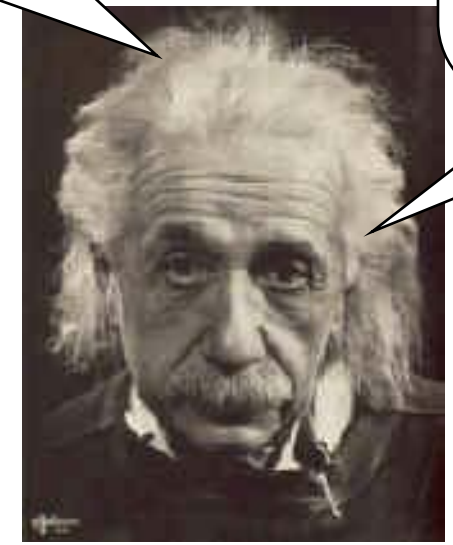
The total mass of a closed system will remain constant over time.



The total amount of energy in an isolated system is conserved over time.

What is Nuclear Fission?

Release of Energy and Neutrons

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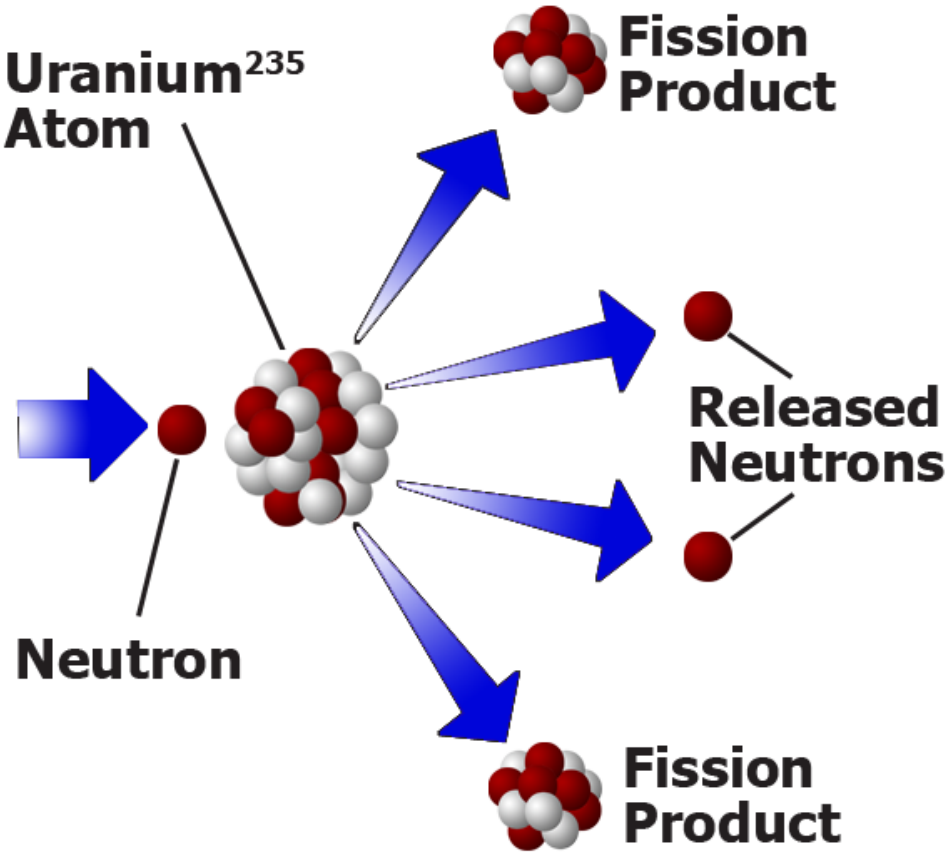

+ Energy

The energy holding the atom together is Binding Energy.

$E=mc^2$

What is Nuclear Fission?

Fission Chain Reaction

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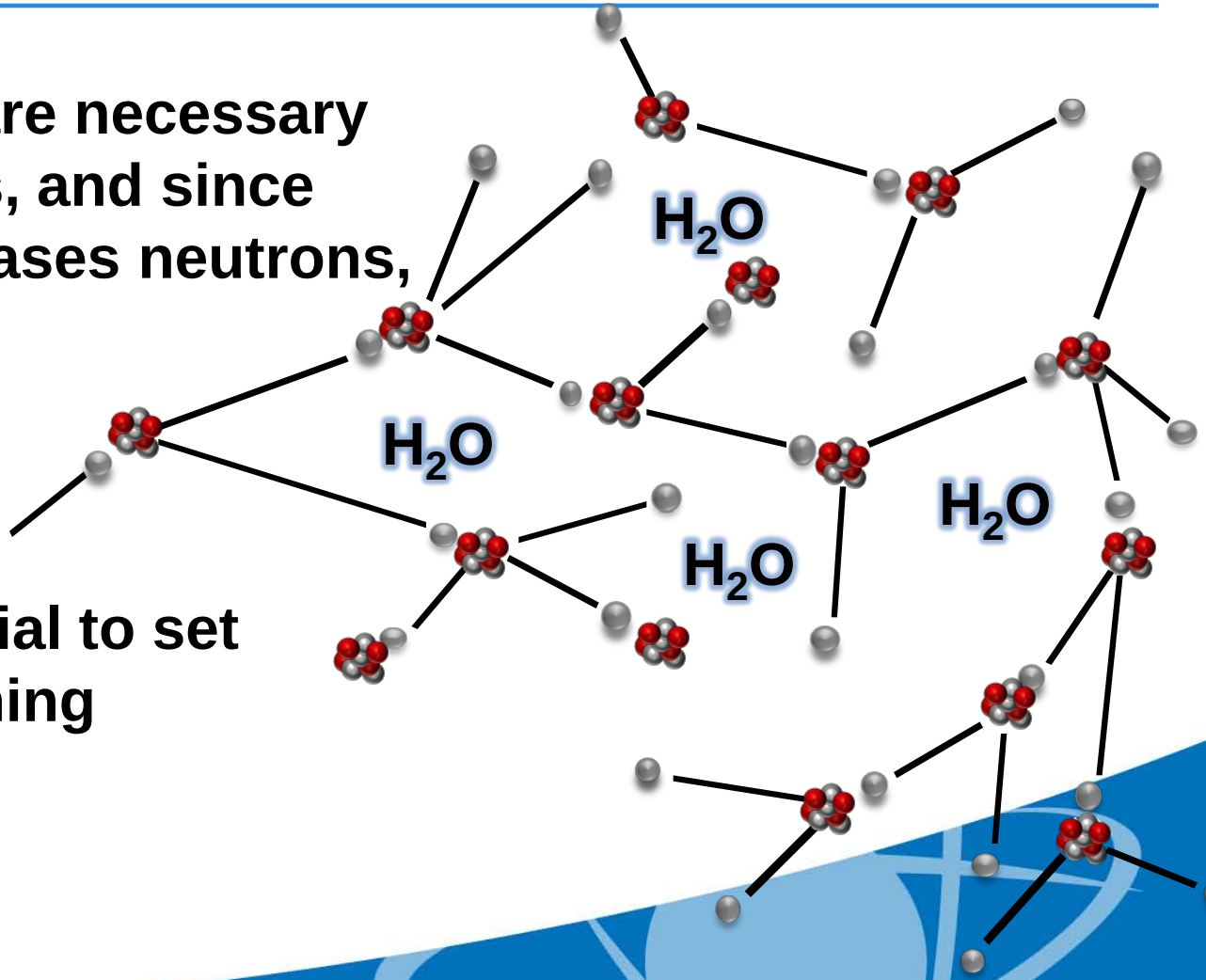
Since neutrons are necessary to cause fissions, and since each fission releases neutrons,



there is a potential to set up a self-sustaining chain reaction.

What is Nuclear Fuel?

U-235 *Fuel Manufacturing*

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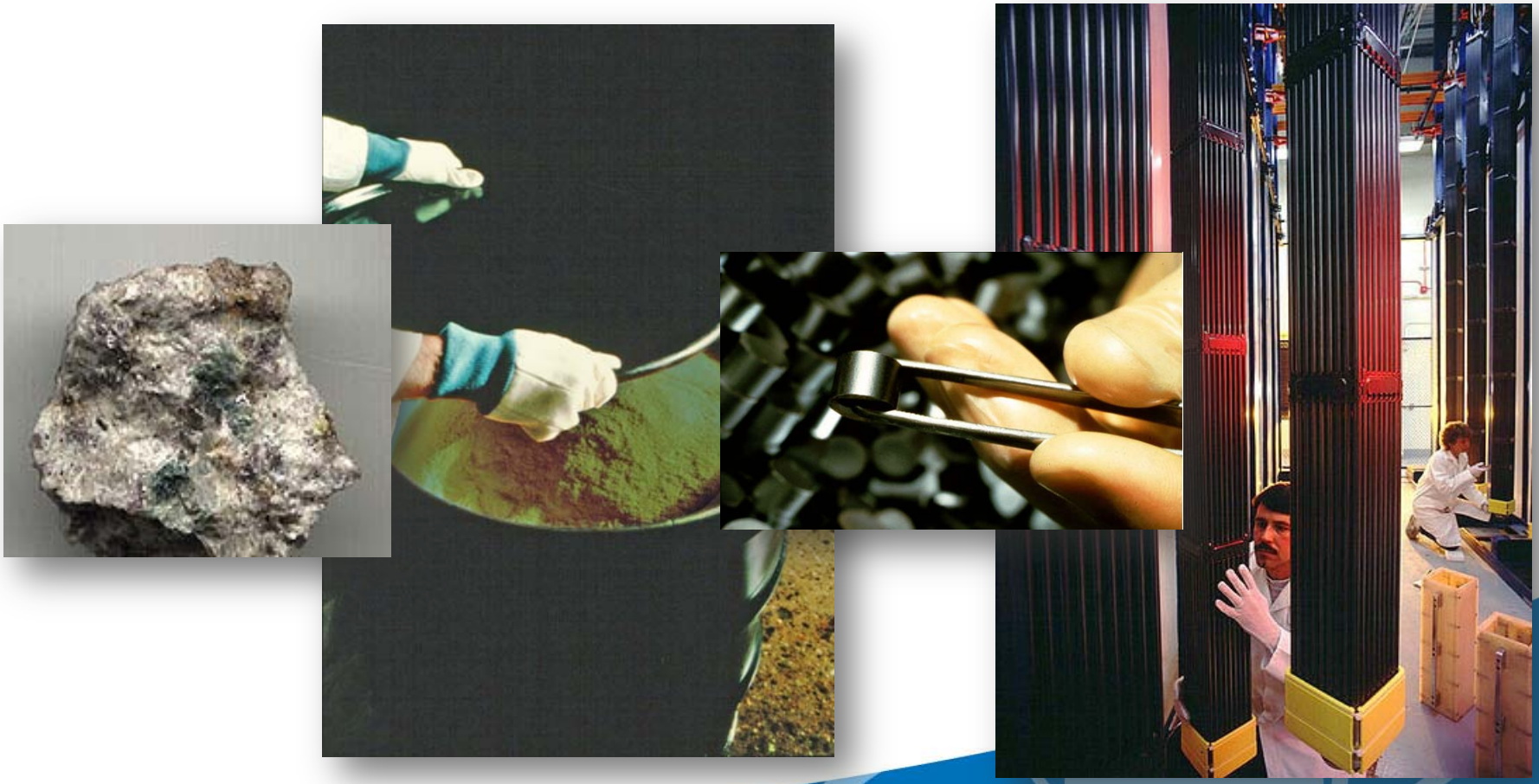

Benefit of Using Uranium
High Energy Density

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"If you got all your electricity for your lifetime from nuclear power, your total share of the waste would weigh two pounds and fit into one Coke can… [From coal], that person's mountain of solid waste would be 68.5 tons."
Cravens, Power to Save the World

Some aircraft carrier ships can be run for 10 years without refueling.

Pressurized Water Reactor

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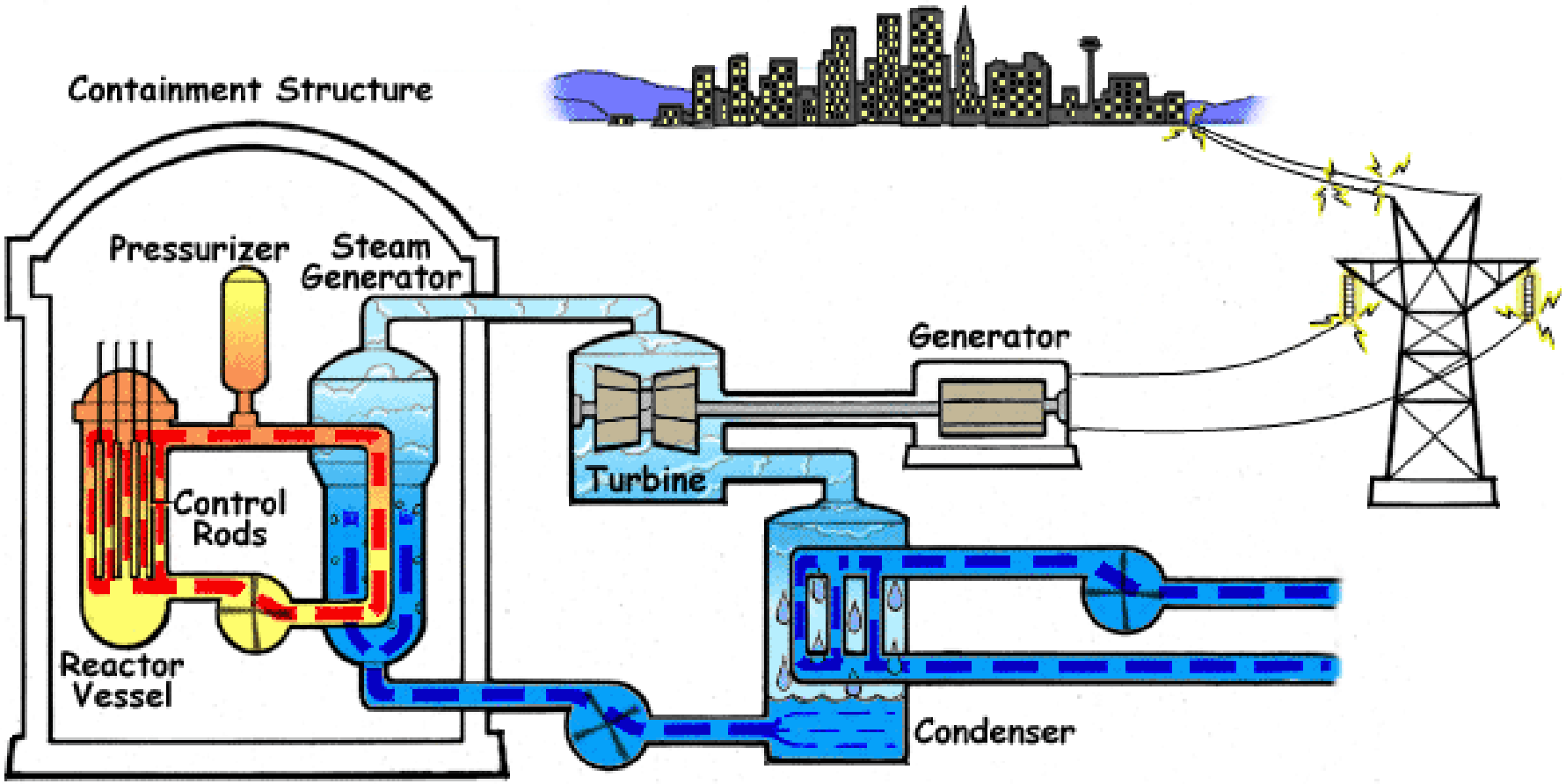

Nuclear Power Plants

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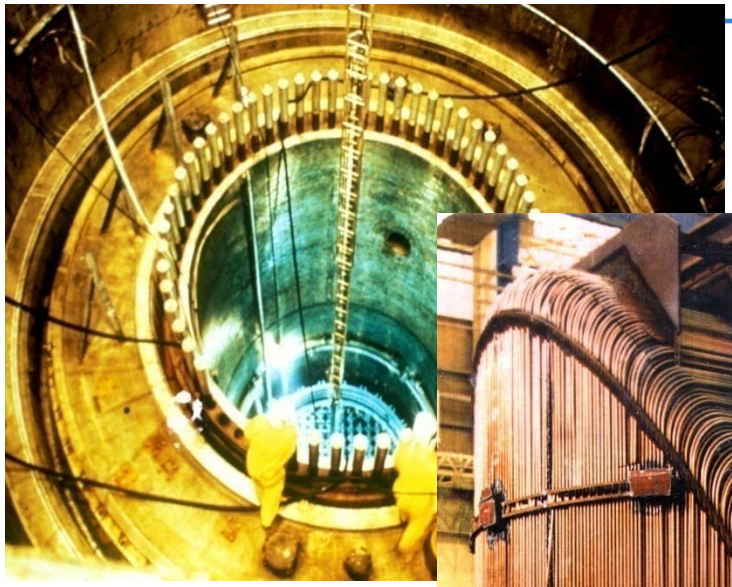
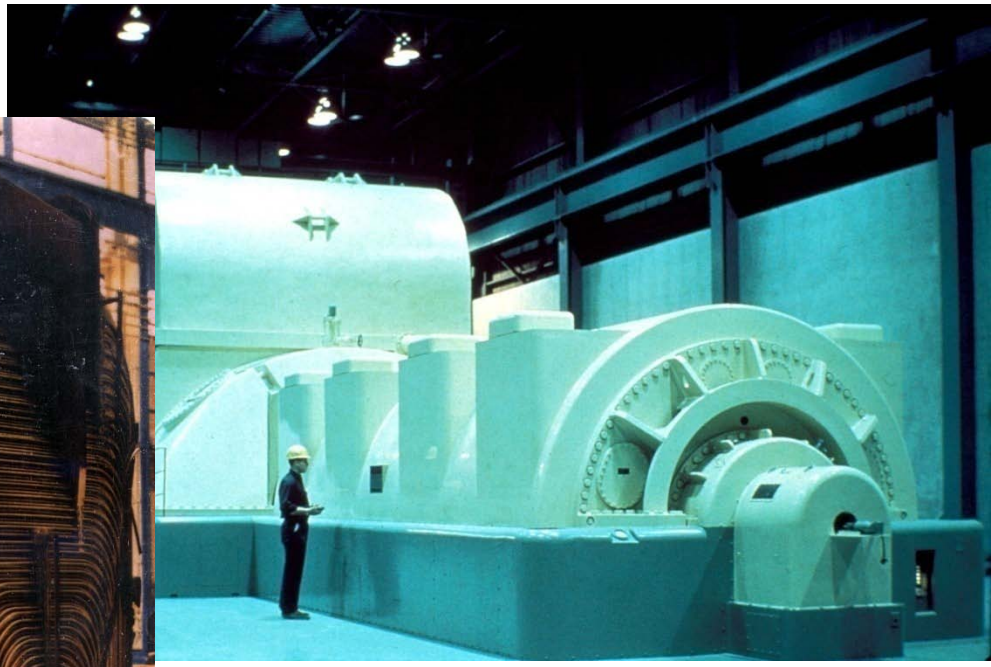


Reactor Vessel with Head and Fuel Removed

Steam Generator Internals Showing Pressure Tubes



Turbine Generator

Criticality

Steady Power Rate Generation

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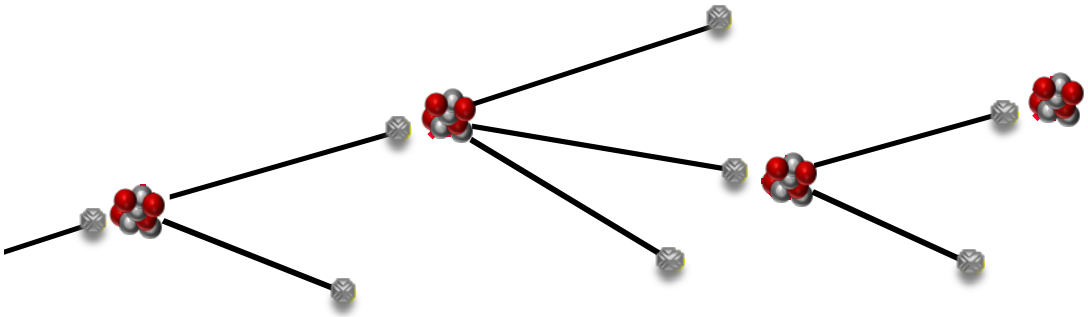

If the proper conditions in the core exist, the chain reaction will be self-sustaining which means that for every fission event that occurs, a second event occurs

This condition is called criticality, and means that the reactor is in a steady state of power and heat production

The number of neutrons produced by fission is equal to the number of neutrons that will cause more fissions plus the number of neutrons that do not cause fission

What happens to the neutrons?
The Six Factor Formula

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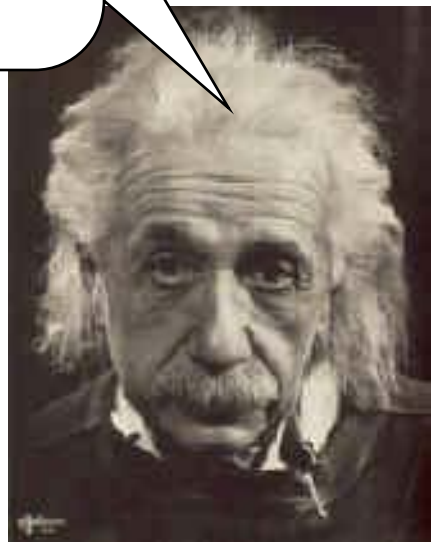
Reactor theory consists mostly of considering the "life cycle" of a neutron.



- Fission
- Absorption (Capture)
- Leakage

How do we control the reaction?

Control Rods and Other "Poisons"

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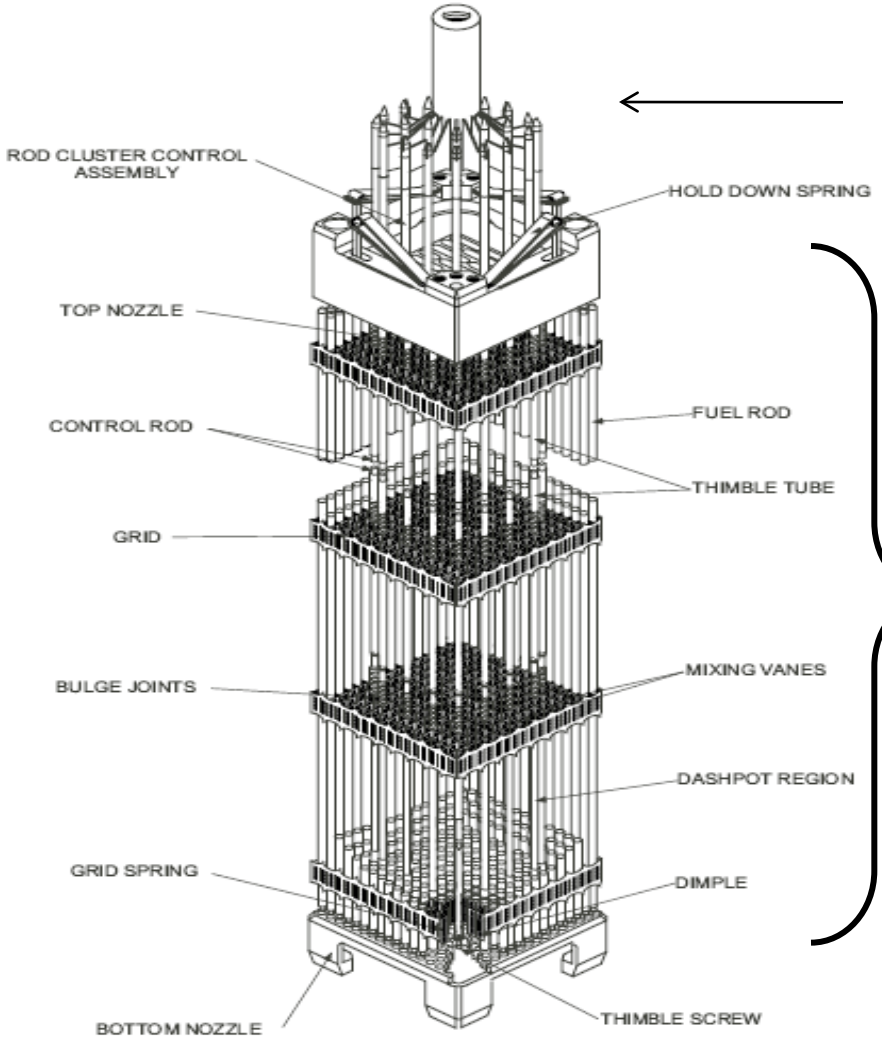
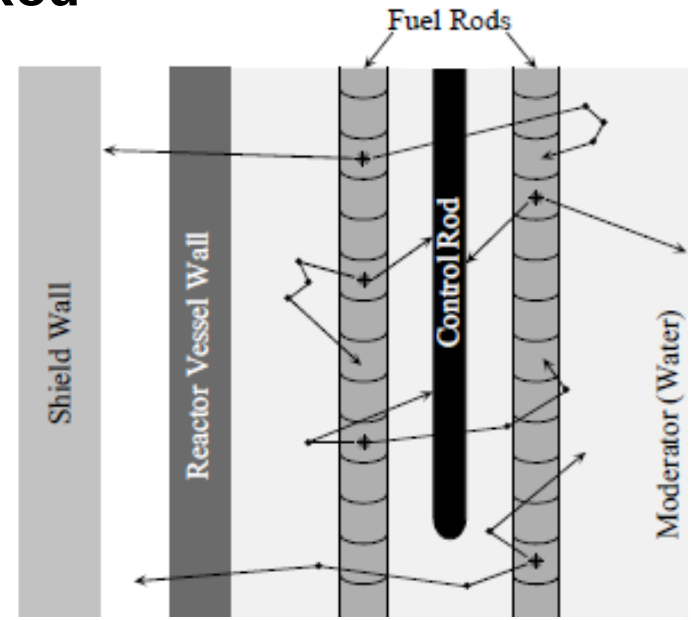


Figure 1-11 Typical PWR Fuel Assembly with Control Rod

Control Rod

Fuel Assembly



Reactor Trip (SCRAM)

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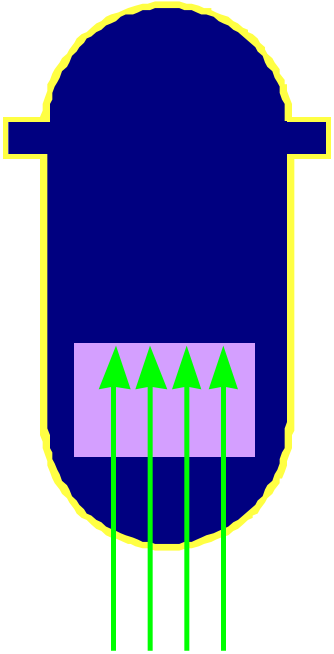
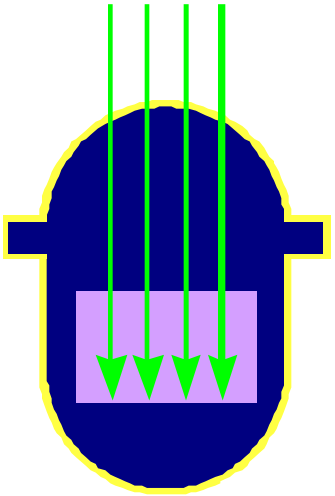
Rapid insertion of control rods



BWR



PWR

Shuts down fission chain reaction

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Basics of Health Physics

Radioactive Decay

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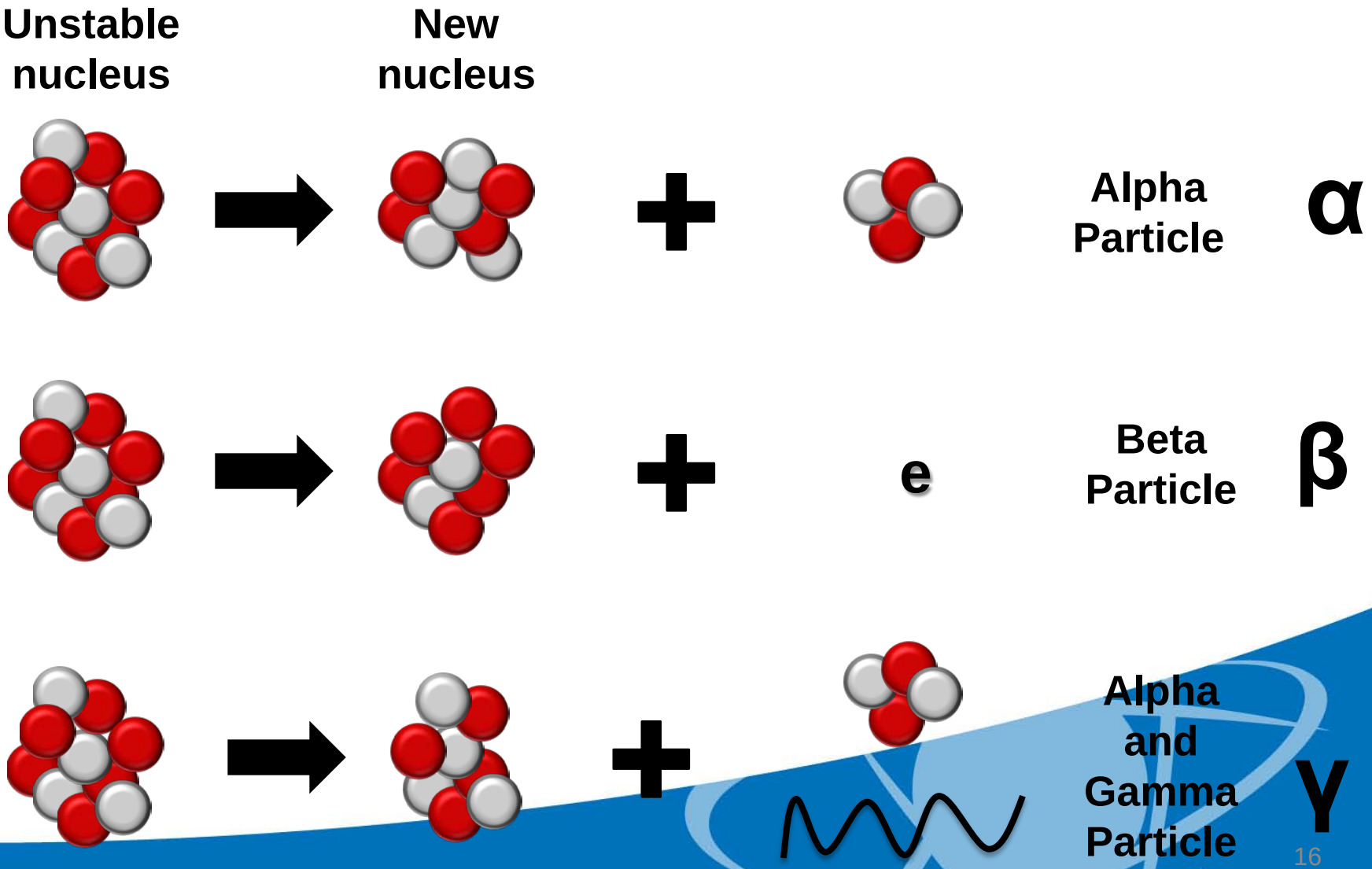
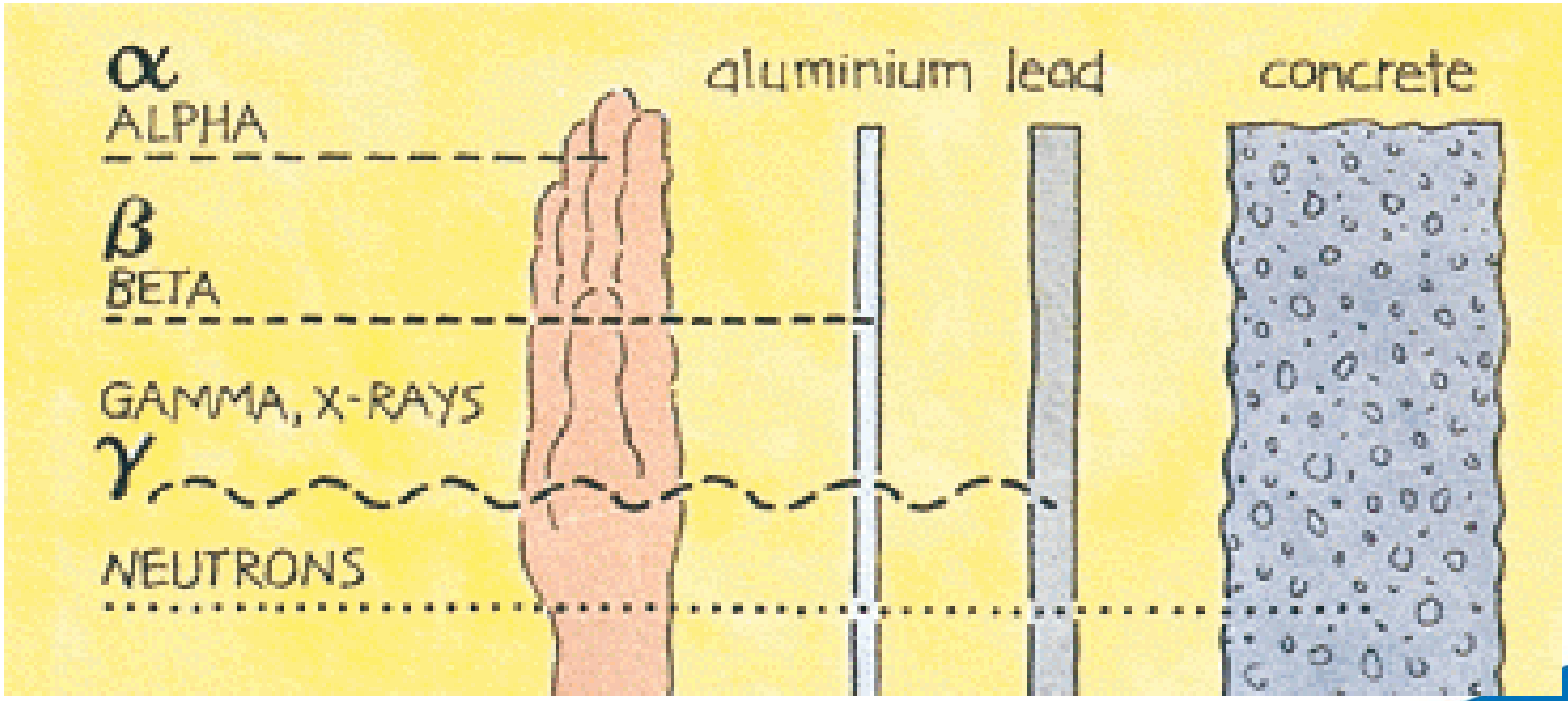
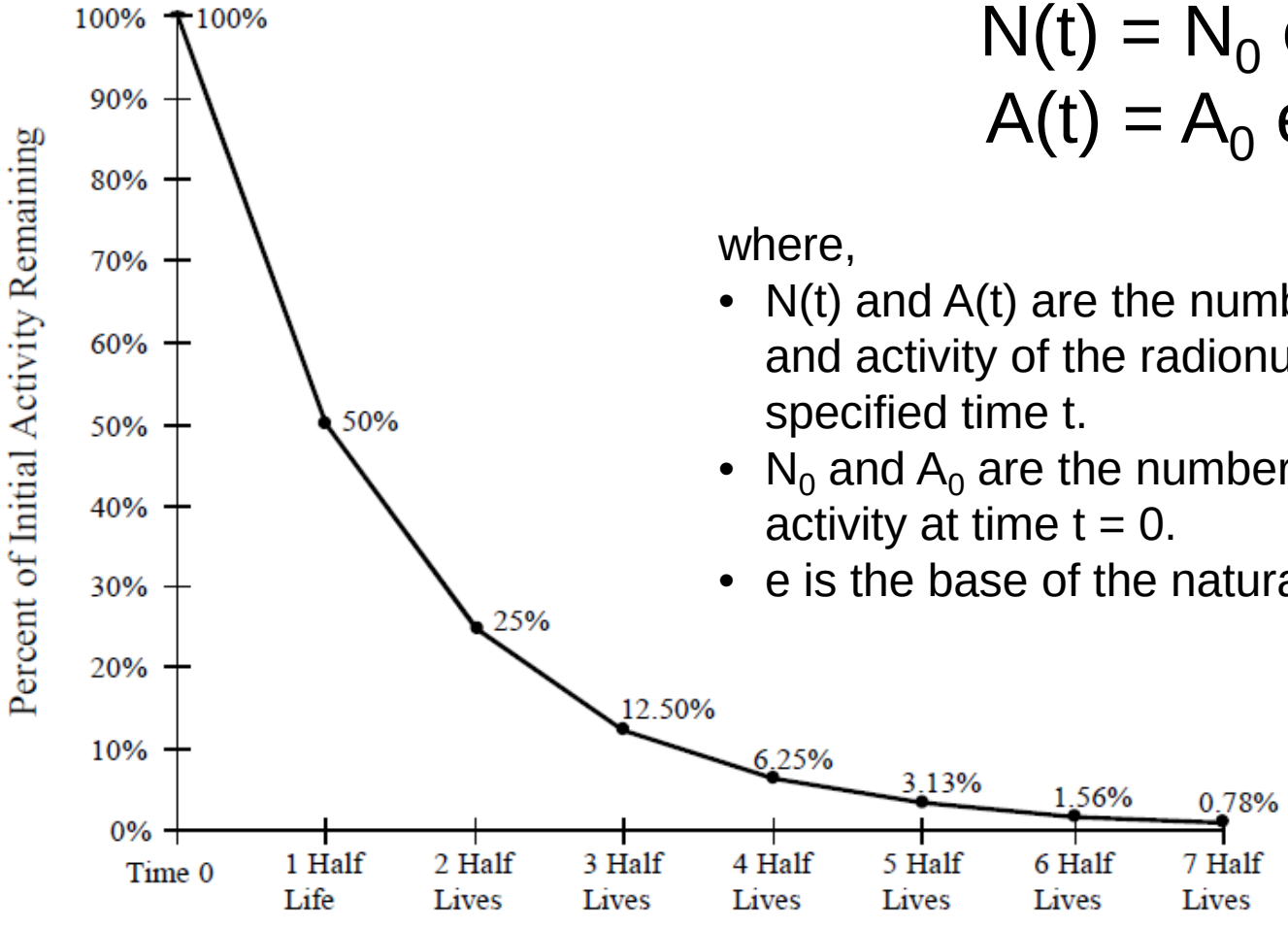


Radiation Shielding



Radioactive Half-Life



$$N(t) = N_0 e^{-t}$$
$$A(t) = A_0 e^{-t}$$

where,

- N(t) and A(t) are the number of atoms and activity of the radionuclide at the specified time t.
- N_0 and A_0 are the number of atoms and activity at time t = 0.
- e is the base of the natural log system

Biological Effects

What is the radiation risk?

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Dose	Effects on individuals	Consequences for an exposed population
Very low dose: about 1 rem or less	No acute effects; extremely small additional cancer risk	No observable increase in the incidence of cancer, even in a large exposed group
Low dose: towards 10 rem	No acute effects; additional cancer risk < 1%	Possible observable increase in the incidence of cancer, if the exposed group is very large (e.g., >100,000 people)
Moderate dose: towards 100 rem (acute whole body dose)	Nausea, mild bone marrow depression; additional cancer risk of about 10%	Probable observable increase in the incidence of cancer, if the exposed group is more than a few hundred people
High dose: above 100 rem (acute whole body dose)	Certain nausea, likely bone marrow syndrome; high risk of death from about 400 rem (without medical treatment). Significant additional cancer risk.	Observable increase in the incidence of cancer

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How Safe is Safe Enough?

The role of the regulator in ensuring adequate protection and communicating risk.

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Radiation is constantly present and is emitted from a variety of natural and man-made sources

What do you think is the #1 source?

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The amount of radiation released from a nuclear power plant daily,

= 0.01 mrem

is less than the radiation from eating a banana.

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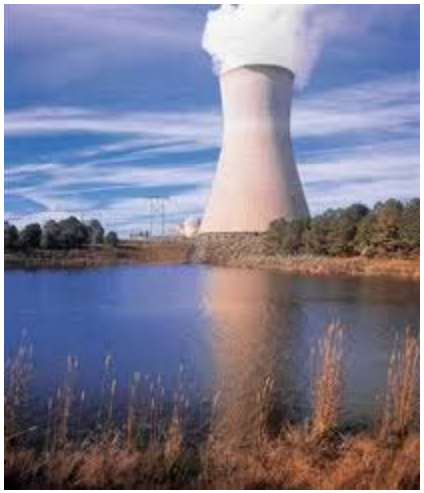
To receive the amount of energy in a single X-ray,



you would need to live next to a power plant for 2000 days.

Radiation Risks

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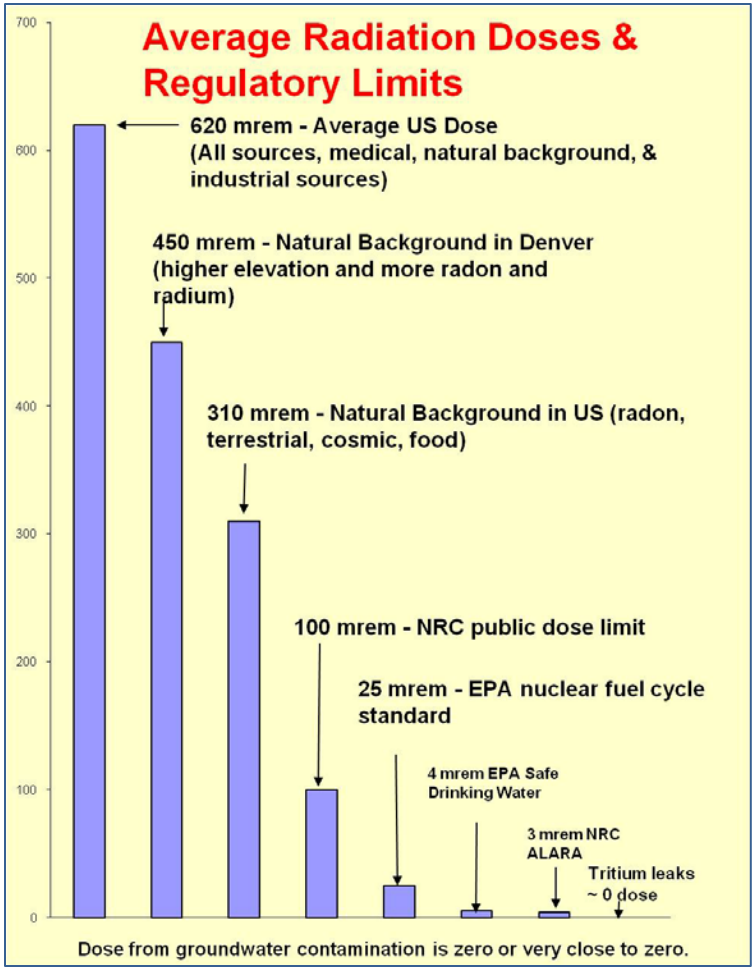

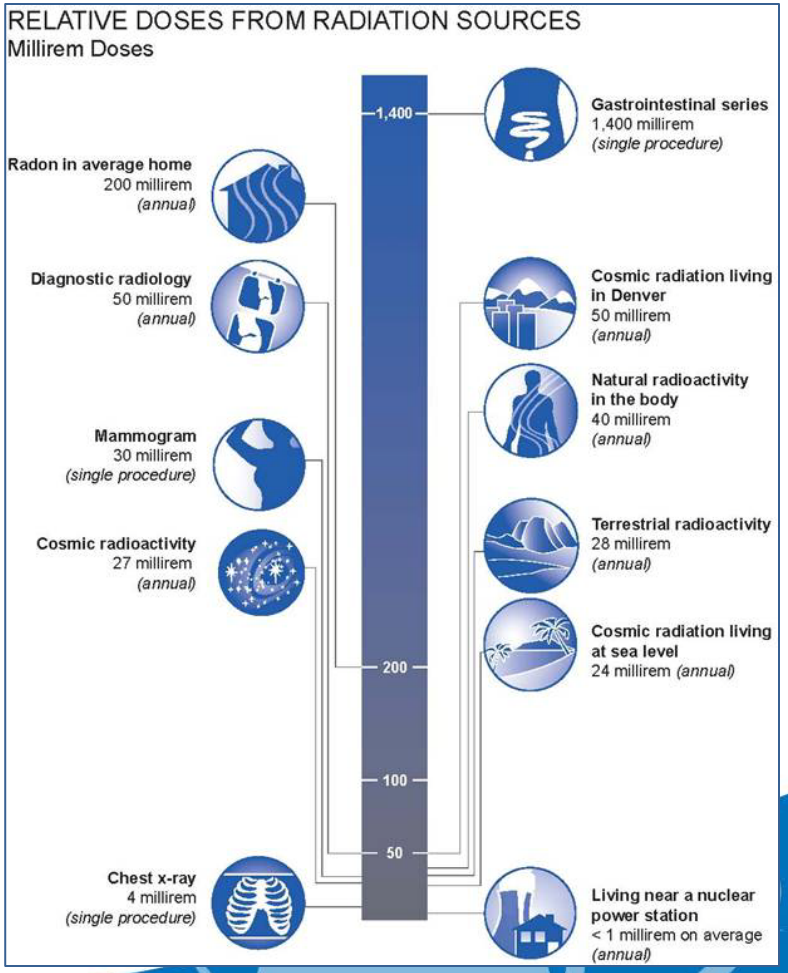

Nuclear Regulatory Commission
What We Regulate

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- **Nuclear Reactors -** commercial power reactors, research and test reactors, new reactor designs
- **Nuclear Materials -** nuclear reactor fuel, radioactive materials for medical, industrial and academic use
- **Nuclear Waste** – transportation, storage and disposal of nuclear material and waste, decommissioning of nuclear facilities

Nuclear Power Reactors

104 Units in Operation in US

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Courtesy: Nuclear Management Co.

Prairie Island Nuclear Power Plant, near Minneapolis, MN.

Courtesy: Entergy Nuclear

Indian Point Energy Center, located near New York City, NY.

Courtesy: Entergy Nuclear

Vermont Yankee Nuclear Power Plant, located near Brattleboro, VT.

Sources: NRC , NEI

Nuclear Power Reactors

104 Units in Operation in US

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QUESTIONS ?

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What is Nuclear Fission?
Binding Energy of an Atom

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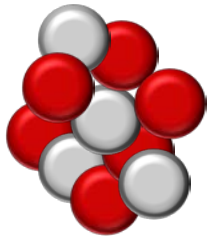
Proton
1.67×10^{-24} g

Neutron
1.675×10^{-24} g

e Electron
9.11×10^{-28} g

Aluminum



13 + 14 + 13 **e** =
4.52×10^{-23}g ≠ 4.48×10^{-23}g

The difference in mass is Binding Energy!
$E=mc^2$

Nuclear Power and Energy Mix in the New Millennium

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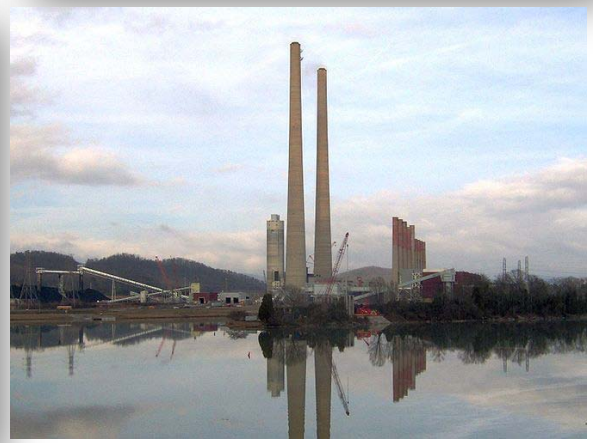


Operating Power Reactors

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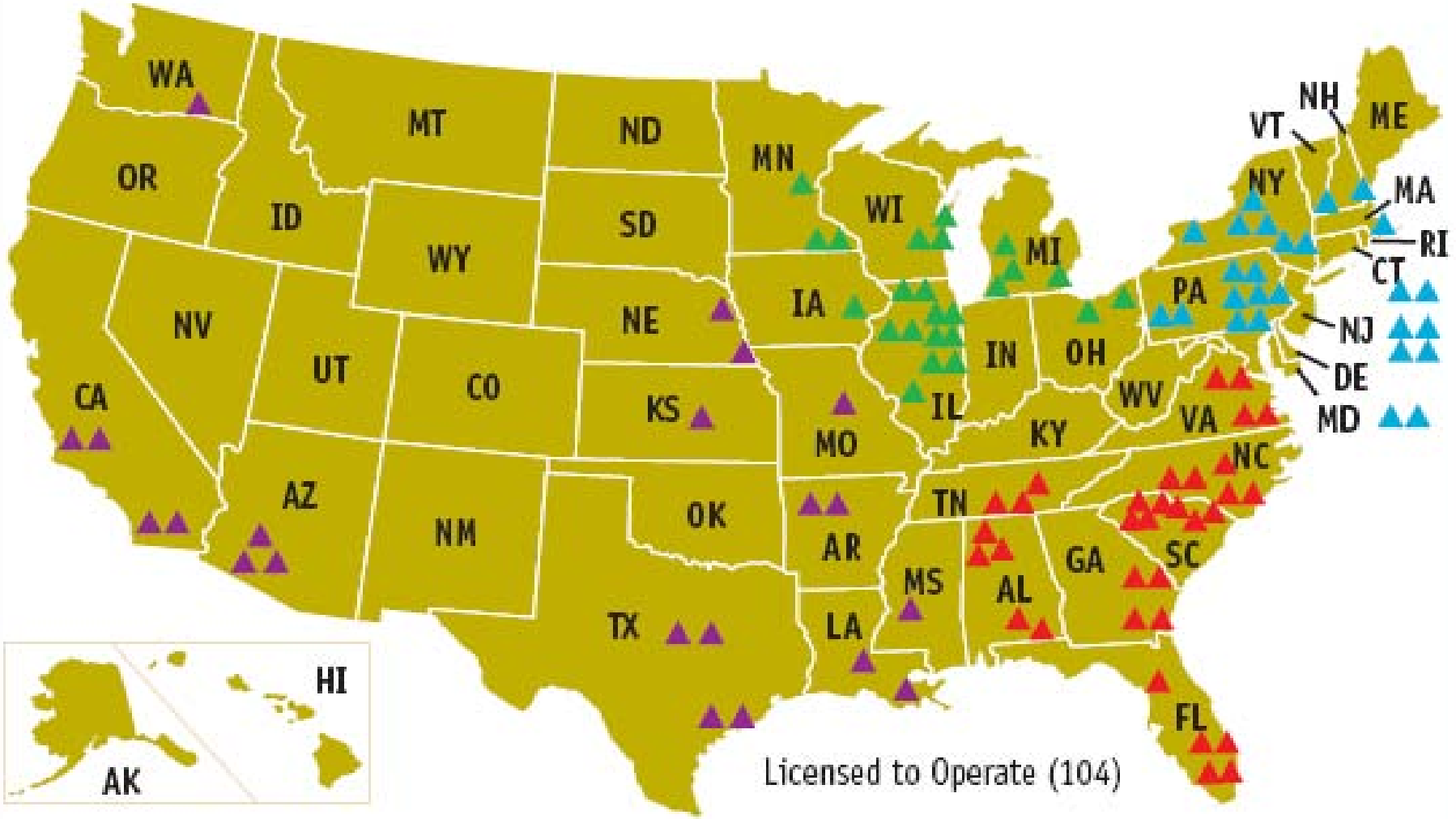

What are the sources of energy in the US?

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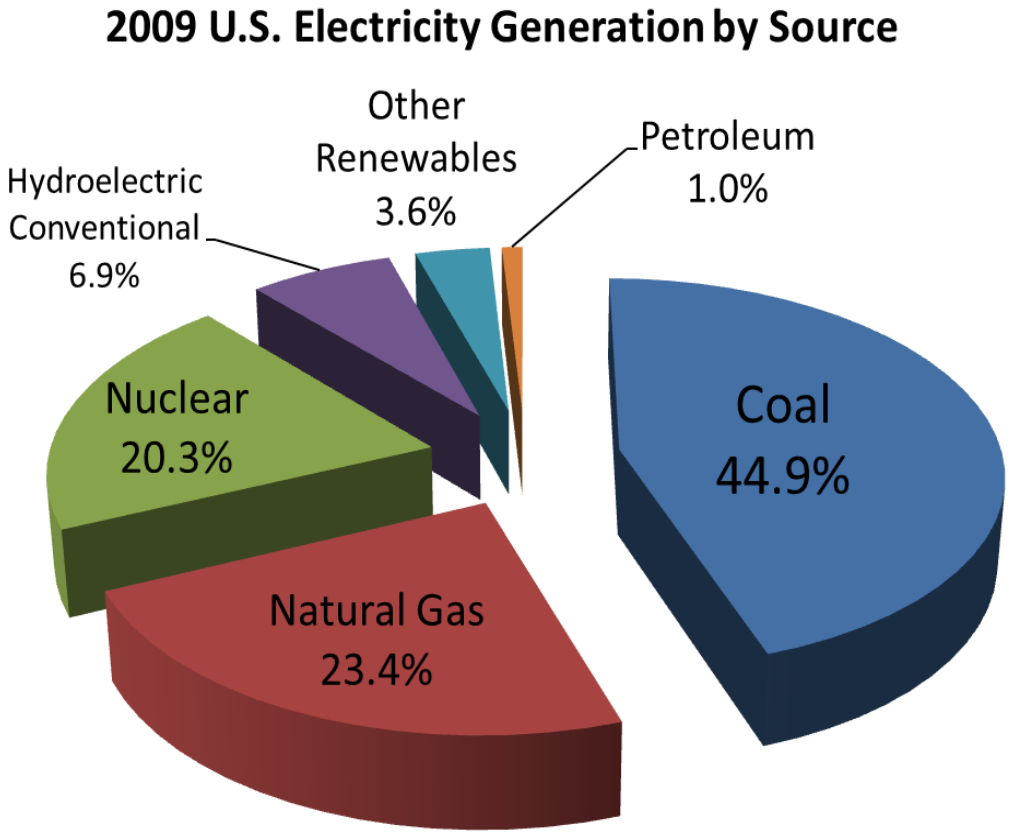

How does the U.S. compare?

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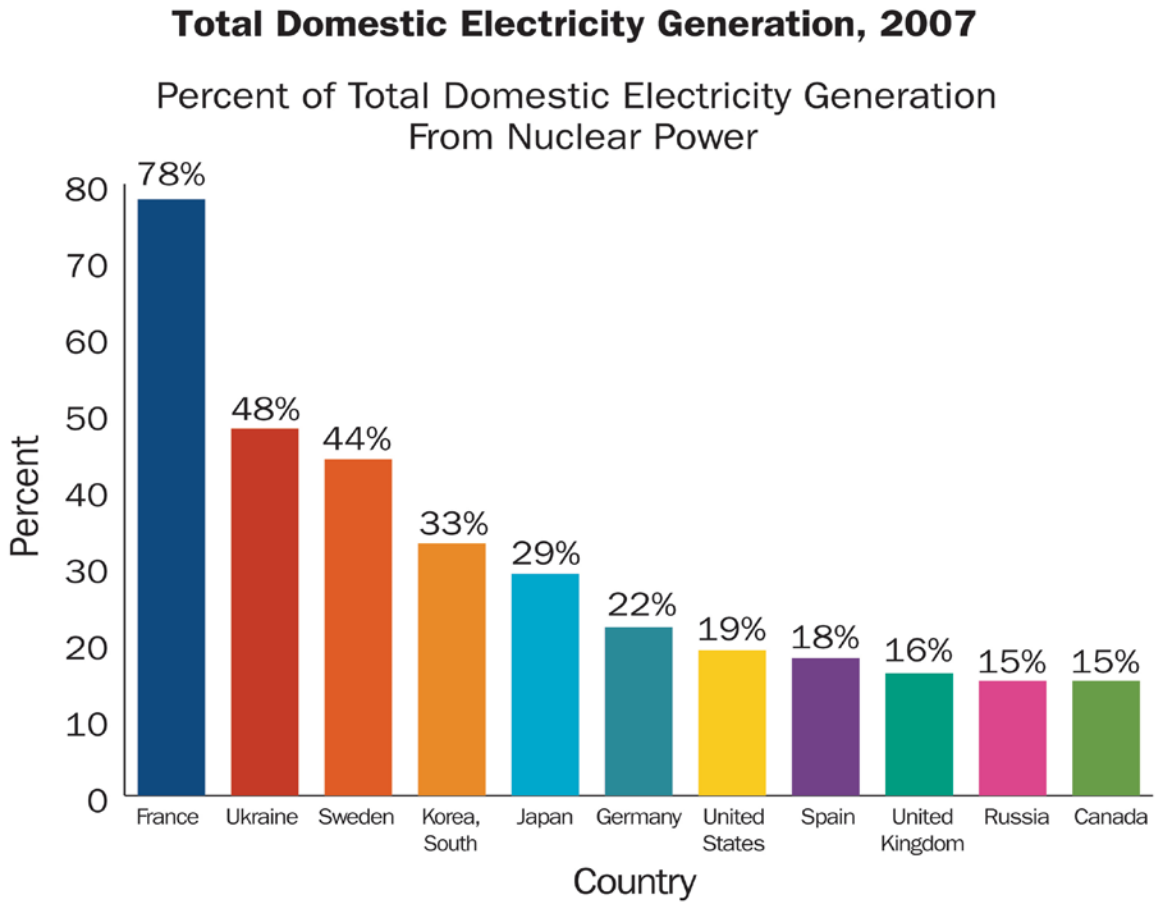

Note: Country's short-form name used.

Source: Energy Information Administration, Office of Energy Markets and End Use, International Energy Statistics Team

What happens to the neutrons?

The Six Factor Formula

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- **$K_{effective}$** is a measure of the change in fission neutron population from one neutron generation to the next,

or

$$K_{effective} = \frac{\#\ of\ \ fission\ neutrons\ in\ this\ \ generation}{\#\ of\ \ neutrons\ in\ the\ \ previous\ \ generation}$$

$$K_{eff} = \frac{N}{N_0}$$

What happens to the neutrons?

The Six Factor Formula

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$$K_{eff} = \varepsilon L_f \, p L_{th} \, f \eta$$

Where:

ε = *fast fission factor*

L_f = *fast non – leakage probability*

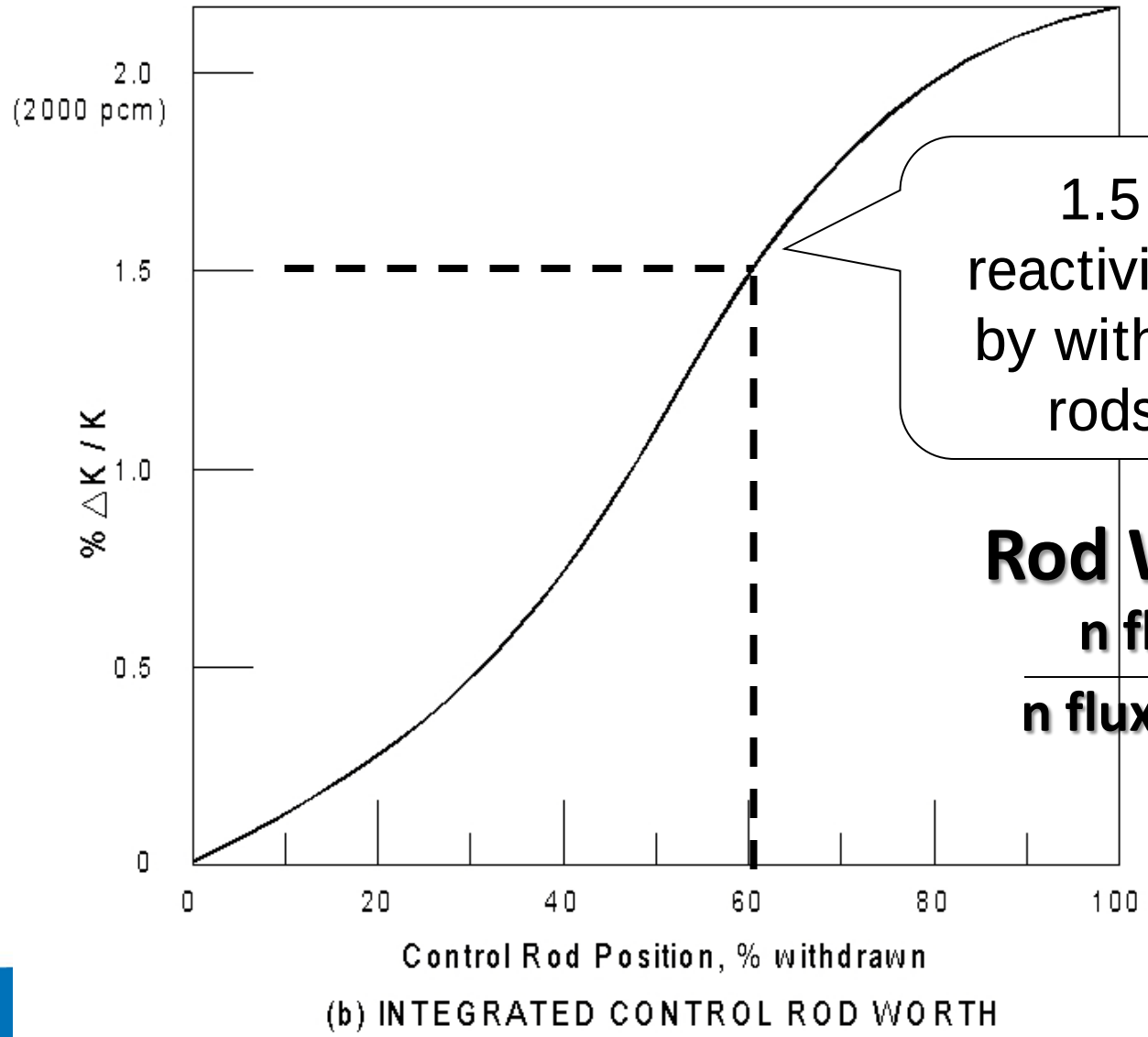
p = *resonance escape probability*

L_{th} = *thermal non – leakage probability*

f = *thermal utilization factor*

η = *reproduction factor*

Integrated Control Rod Worth

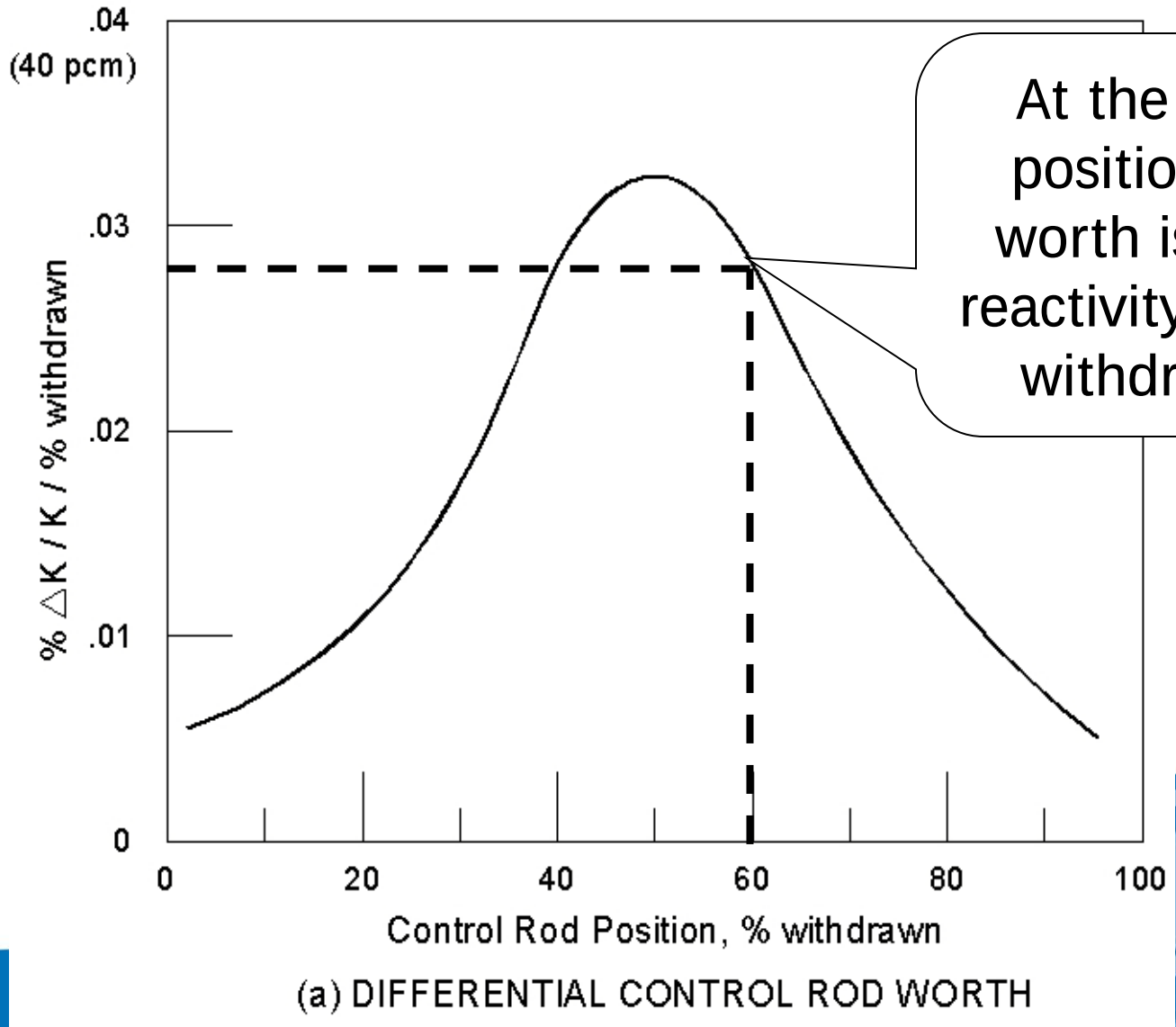


1.5 units reactivity added by withdrawing rods 60%

Rod Worth α

$$\frac{\text{n flux}^2 \text{ Tip}}{\text{n flux}^2 \text{ average}}$$

Differential Control Rod Worth



At the 60% position rod worth is .028 reactivity per % withdrawn.