# CHEM 108

## The Nucleus

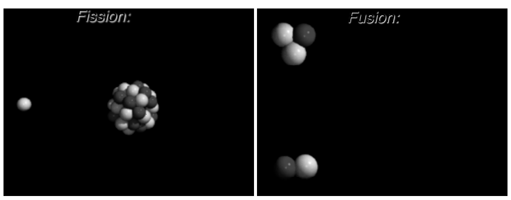
## Nuclear Reactions



## Nuclear Reactions

- *The mass of the visible universe is 73% $H_2$ and 25% He. The remaining 2%, "heavy" elements, have atomic masses > 4.*
- *The "heavy" elements are formed at very high temperatures (T >10 $^6$ $^o$C) by FUSION, i.e. nuclei combining to form new elements.*
- *There is an upper limit to the "natural" production of heavy nuclei at Atomic Number = 92, Uranium.*
- *Heavier nuclei split to lighter ones by FISSION*

## Nuclear Reactions:




- *Fission and Fusion reactions are highly exothermic; they give off a tremendous amount of energy.*
- *The energy produced in "nuclear" reactions is one million (10 $^6$) times larger than "chemical" reactions per atom.*

## Nuclear Reactions / Fission

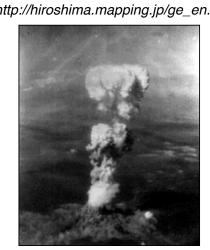
$$^{235}_{92}U+^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{141}_{56}Ba+^{92}_{36}Kr+3^{1}_{0}n$$

- *The Fission Chain Reaction proceeds geometrically: 1 neutron → 3 → 9 → 27 → 81 neutrons etc.*
- *1 Mole of U-235 (235 grams, about 1/2 lb) produces 2 x $10^{10}$ kJ which is equivalent to the combustion of 800 tons of coal, which is more than 1.75 million pounds of coal!*
- *Commercial nuclear reactors use fission to produce electricity....Fission bombs were used in the destruction of Hiroshima and Nagasaki, Japan, in August 1945.*

## Nuclear Reactions / Fission

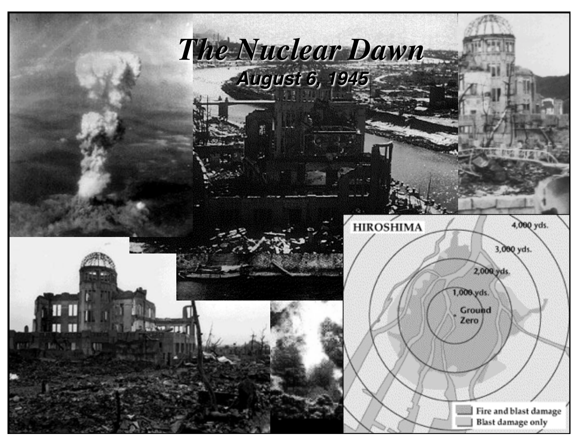
*President Truman / Hiroshima*

*http://hiroshima.mapping.jp/ge_en.html*

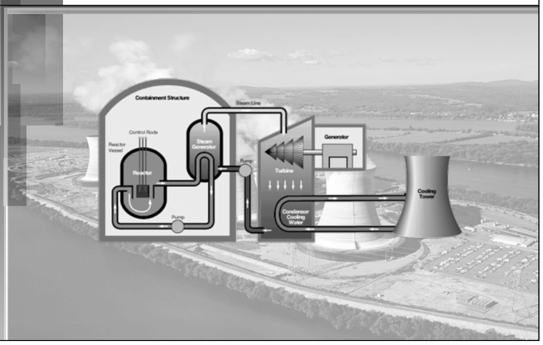


***August 6, 1945***

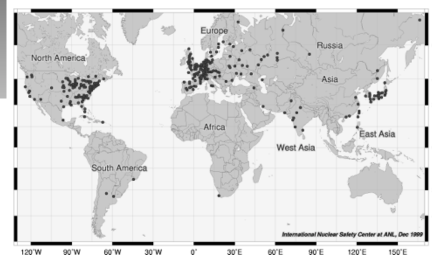
*http://hiroshima.mapping.jp/ge_en.html*



## Nuclear Power Plant




## Worldwide Nuclear Power Plants



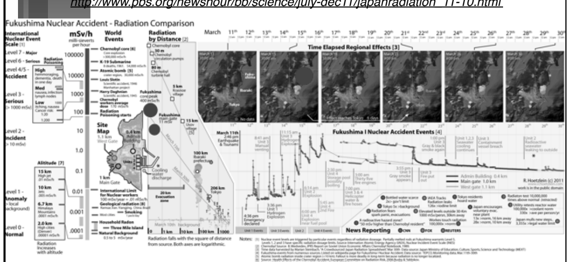

## Chernobyl, Ukraine

April,1986; April, 2001; August, 2016

## Nuclear Plant Disaster March 2011 Fukushima, Japan

## Fukushima Radiation

http://www.pbs.org/newshour/bb/science/july-dec11/japanradiation_11-10.html




1 millisievert (mSv) = 100 mrem
0.01 Sievert (Sv) = 1 rem

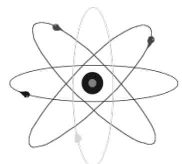
## QUESTION

Which of the following is/are true of fission reactors that produce electricity?

A. The reactors boil water.
B. Relatively small amounts of fuel are needed.
C. Fission based reactors produce much more energy than coal-burning power plants with the same amount of fuel.
D. Fission reactors produce toxic waste that have very long half-lifes and Nuclear accidents are possible.
E. All of the above

# NUCLEAR ENERGY

- *EINSTEIN'S EQUATION FOR THE CONVERSION OF MASS INTO ENERGY*

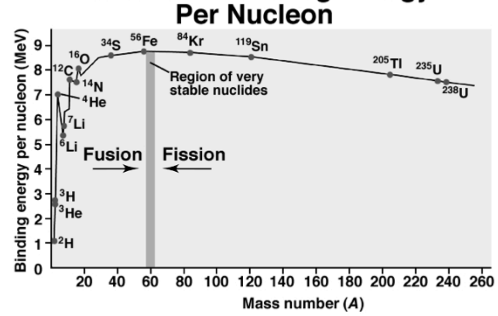


- $E = mc^2$

- m = *mass (kg)*
- c = *Speed of light*

c = *2.998 x $10^8$ m/s*

## Variation in Binding Energy Per Nucleon




*A nucleon is either a proton or a neutron; its mass = 1 amu*
*1 amu = 1.66054 x $10^{-27}$ kg*

## QUESTION

*When a $^{235}$U nucleus absorbs a high energy neutron and undergoes nuclear fission, it undergoes a chain reaction that produces $^{141}$Ba, plus $^{92}$Kr, and 3 neutrons.*

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$$

*When a $^{235}$U nucleus absorbs a slow moving, low energy neutron, it produces 2 neutrons, plus $^{94}$Sr. What is the other nuclide produced?*

A. $^{141}$Ba
B. $^{140}$Ba
C. $^{91}$Kr
D. $^{140}$Xe
E. $^{141}$Xe

*http://physics.bu.edu/~duffy/sc546_notes11/fission.html*

## *Mass ⇔ Energy*

**Electron volt (ev)**
The energy an electron acquires when it moves through a potential difference of one volt:

**1 ev = 1.602 x $10^{-19}$J**

Nuclear Binding energies are commonly expressed in units of *megaelectron volts* (Mev)

**1 Mev = $10^6$ ev = 1.602 x $10^{-13}$J**

A particularly useful factor converts a given mass defect in atomic mass units to its energy equivalent :

**1 amu** = 931.5 x $10^6$ ev = 931.5 Mev = **3.829 x $10^{-17}$ kcal**

## *Binding Energy per Nucleon of Deuterium*

GIVEN: Deuterium has a mass of 2.01410178 amu.

Hydrogen atom mass = 1 x 1.007825 amu = 1.007825 amu
Neutron mass = 1 x 1.008665 amu = 1.008665 amu
2.016490 amu

Mass difference = theoretical mass - actual mass
= 2.016490 amu - 2.01410178 amu = **0.002388 amu**

Binding energy per nucleon:

$$\frac{\text{Binding energy}}{\text{Nucleon}} = \frac{-0.002388 \text{ amu} \times 931.5 \text{ Mev/amu}}{2 \text{ nucleons}}$$

= **-1.1123 Mev**

2.01410178 grams (0.002 kg/ 0.0044 lbs) = -2.26 x $10^7$ kcal
Enough energy to boil 488 liters of water *(*over 125 gallons)

## Nuclear Reactions / Fusion

- *Fusion has been described as the chemistry of the sun and stars.*
- *It too has been used in weapons and has not yet found a peaceful commercial applicationç*

- *Fusion has great promise in producing relatively "clean" abundant energy through the combination of Hydrogen isotopes particularly from $^{2}$H, deuterium and $^{3}$H, tritium: (NIF/National Ignition Facility, LLNL & ITER, France)*

$$^{2}H + ^{3}H \rightarrow ^{4}He + ^{1}_{0}n + 18.38 MeV$$

## *QUESTION*

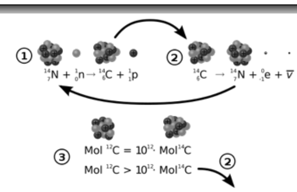
*Which of the following is/are true of fusion designed reactors that will be used to produce electricity?*

A. *The reactors will boil water.*
B. *Relatively small amounts of fuel will be needed, and there will be less radioactive waste.*
C. *Fusion reactors will produce much more energy than fission based reactors with the same amount of fuel.*
D. *Nuclear accidents are possible.*
E. *All of the above*

## *Another Type of Nuclear Reaction*

*Genesis of $^{14}C$ in living organisms*

*https://www.youtube.com/watch?v=phZeE7Att_s*




*#1: Formation of Carbon-14 in the upper atmosphere*
*#2: Beta decay of Carbon-14*
*#3: $^{14}C/^{12}C$ in living organisms; [Photosynthesis produces a steady state ratio of $^{14}C/^{12}C$ while living.]*
*In dead organisms C-14 decays (#2); the ratio and concentration of C-14 decreases; the ratio is used to date artefacts up to > 40,000 yrs*