NUCLEAR ENERGY BASICS, PART 1: FISSION, FUSION & THE BOMB

A presentation by

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QUESTIONS TO BE ADDRESSED:

I. What are the basics of nuclear fission?

II. What were the first nuclear bombs and how did they work?

III. How did single-stage fission bombs change after 1945?

IV. What are multiple-stage fusion weapons designs and how do they work?

BRIEF ANSWERS

I. Not so basic

II. Fission bombs that were sort of complicated

III. A lot

IV. Even more complicated

THE ATOM'S COMPONENTS AND ISOTOPES

BASIC COMPONENTS OF THE ATOM

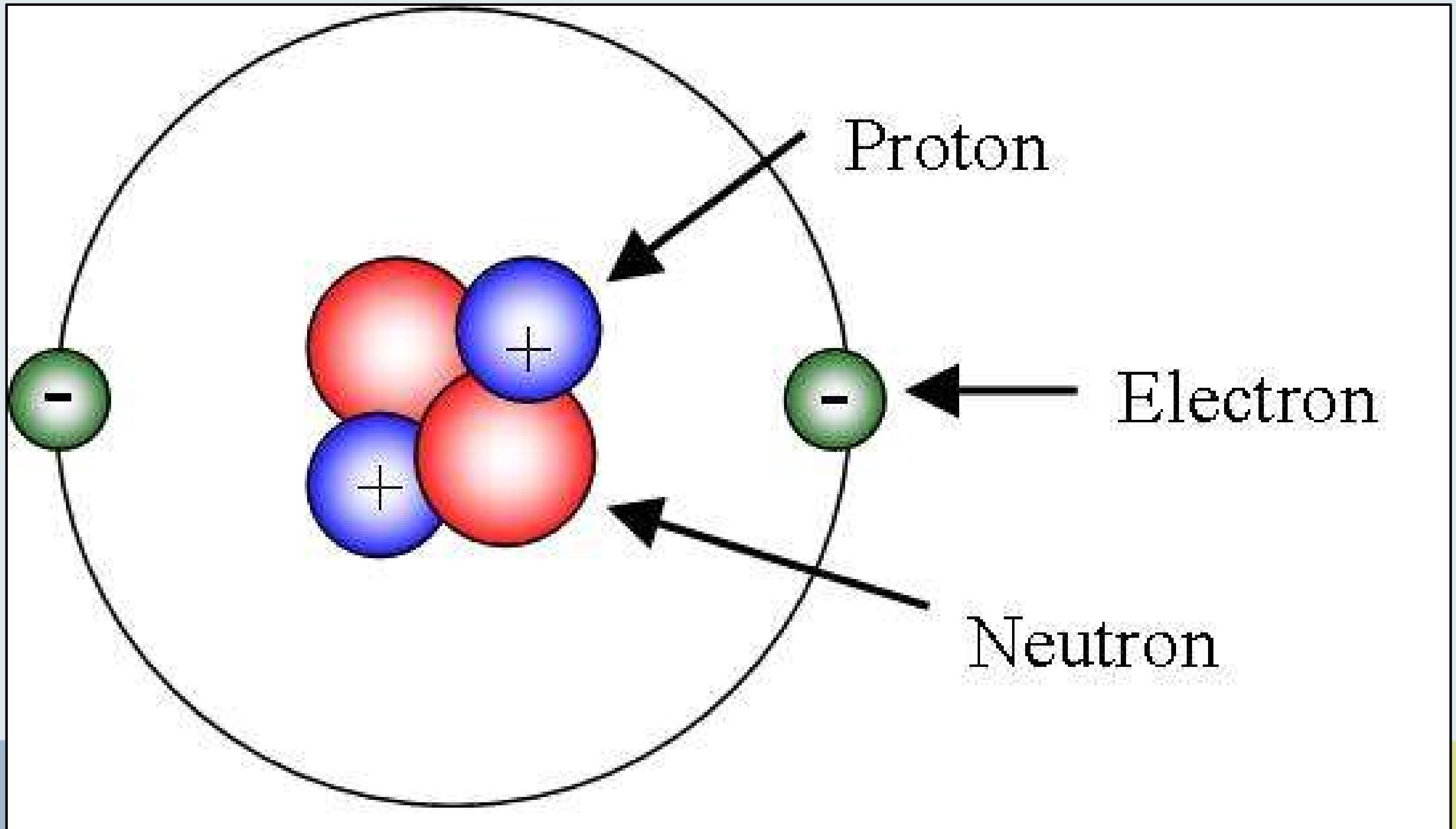
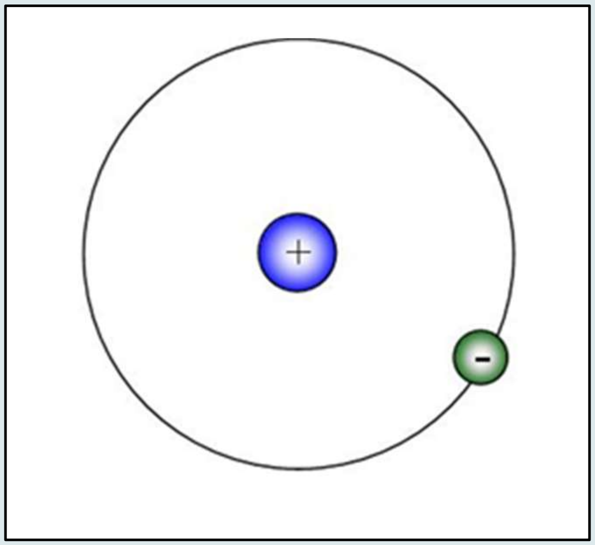


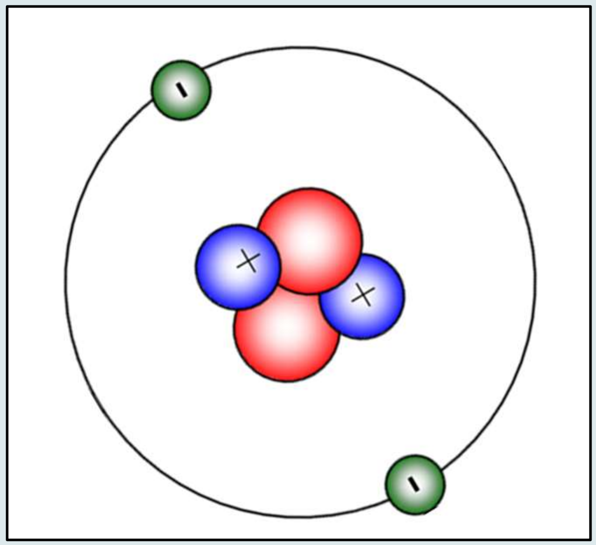
FIGURE 1A
The Atom

ATOMIC NUMBER: # OF PROTONS IN EACH ATOM OF A GIVEN ELEMENT

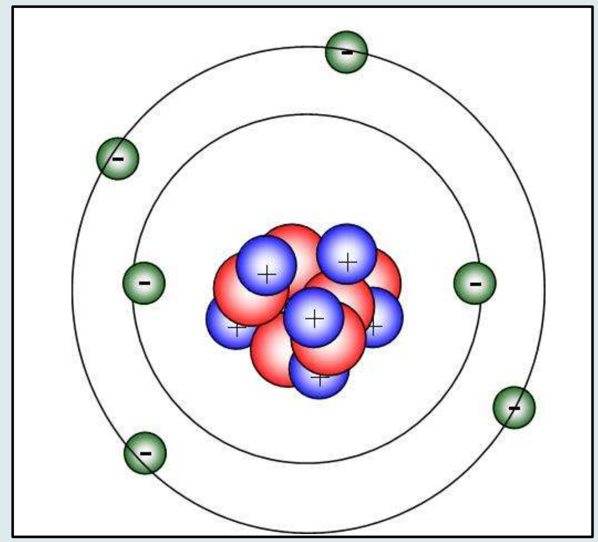
Hydrogen Atom (H)



Helium Atom (He)



Carbon Atom (C)



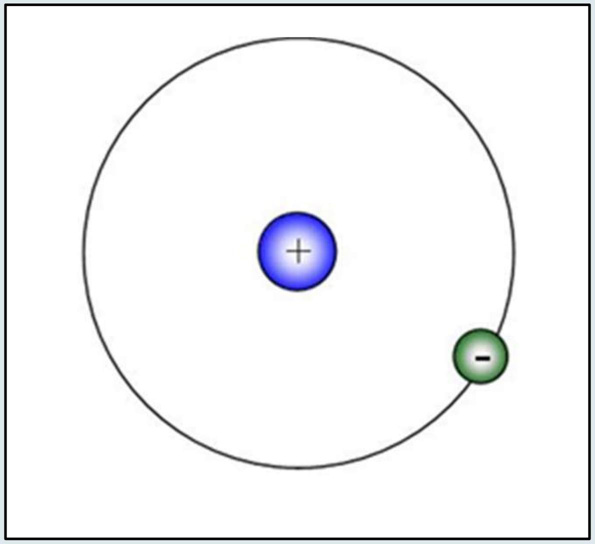
Atomic number 1

Atomic number 2

Atomic number 6

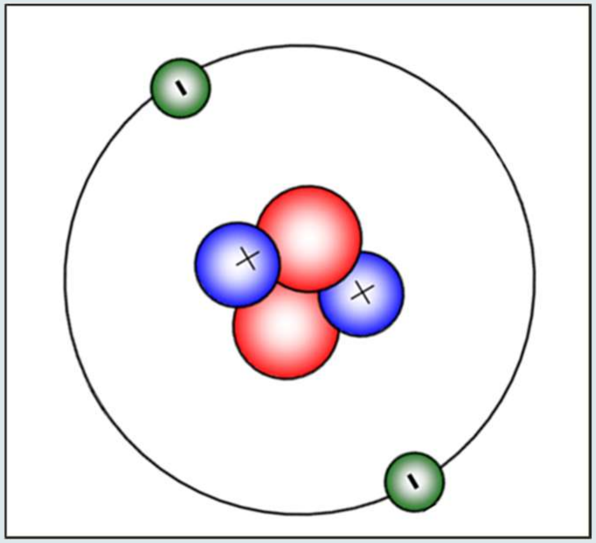
ATOMIC MASS: THE MASS OF ALL AN ATOM'S COMPONENT PARTS

Hydrogen Atom (H)



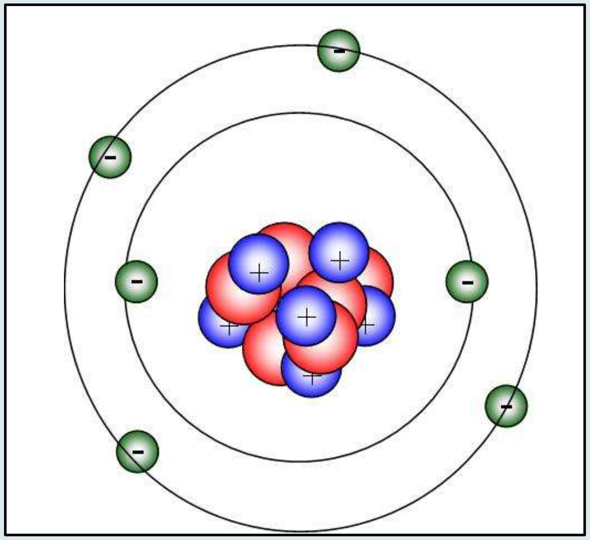
Atomic mass 1.008

Helium Atom (He)



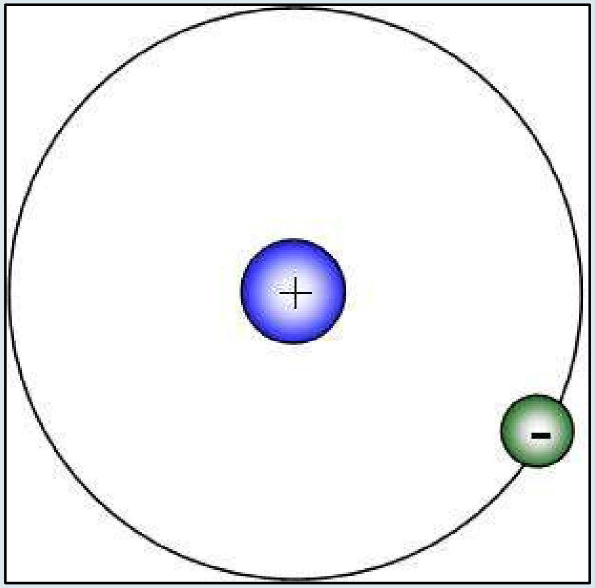
Atomic mass 4.003

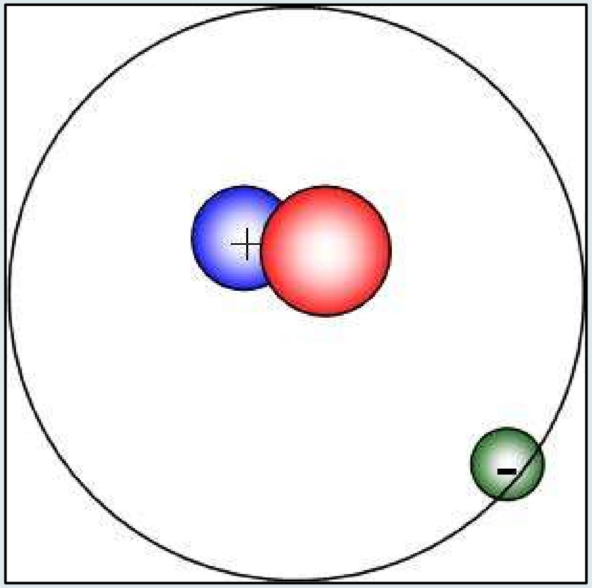
Carbon Atom (C)

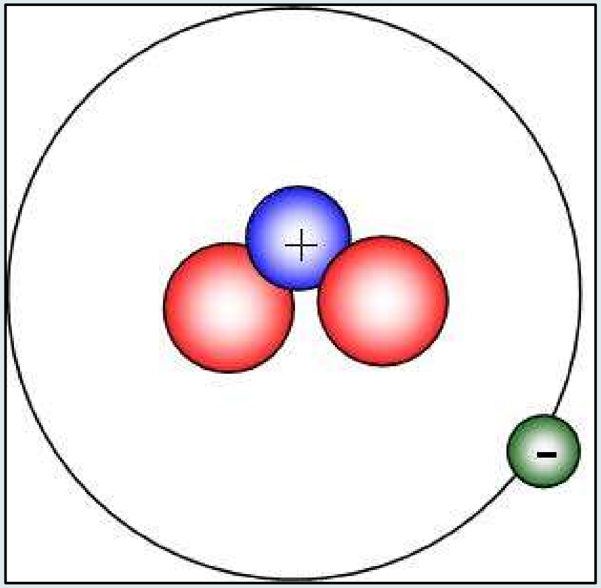


Atomic mass 12.011

ISOTOPES: EXAMPLE OF HYDROGEN





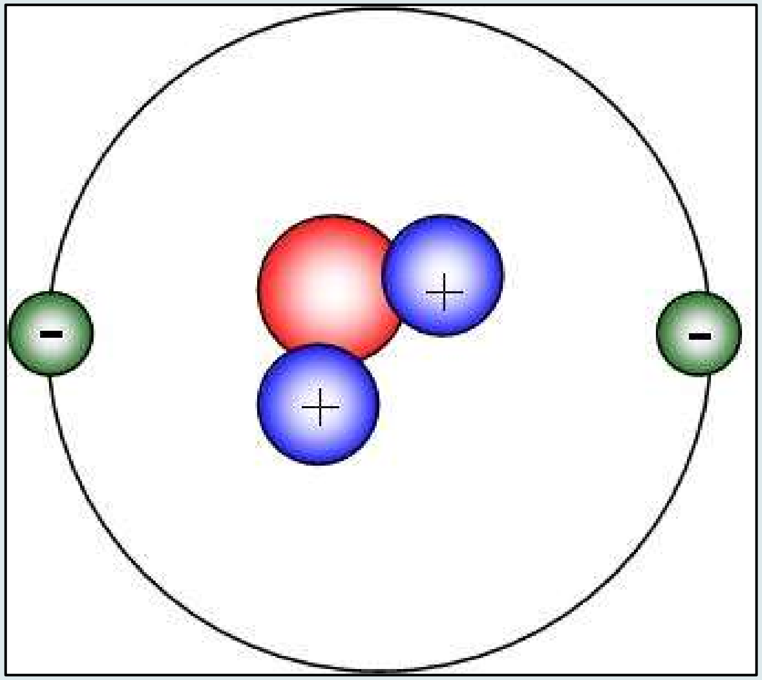


Hydrogen - 1

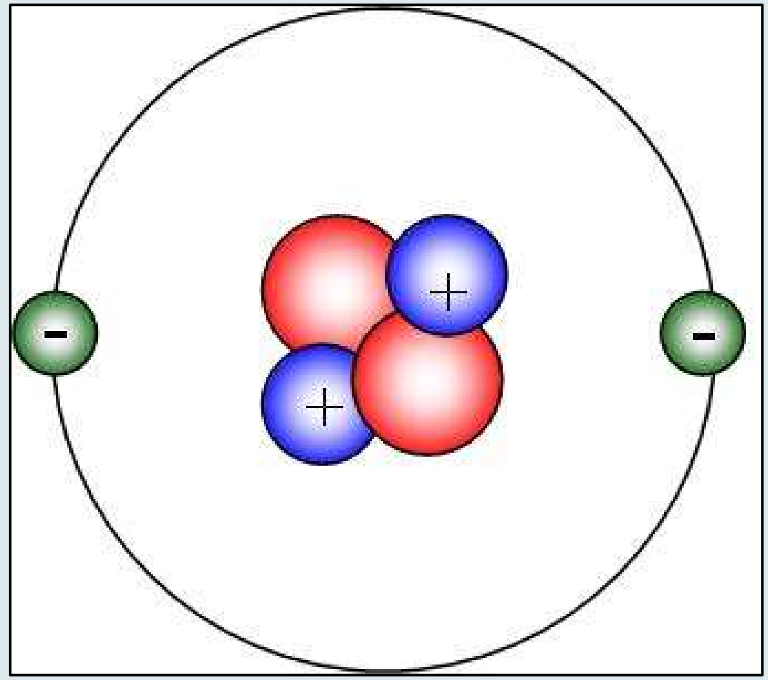
Hydrogen – 2 (Deuterium)

Hydrogen – 3 (Tritium)

ISOTOPES: EXAMPLE OF HELIUM



Helium-3



Helium-4

SHARING ELECTRONS: EXAMPLE OF HYDROGEN

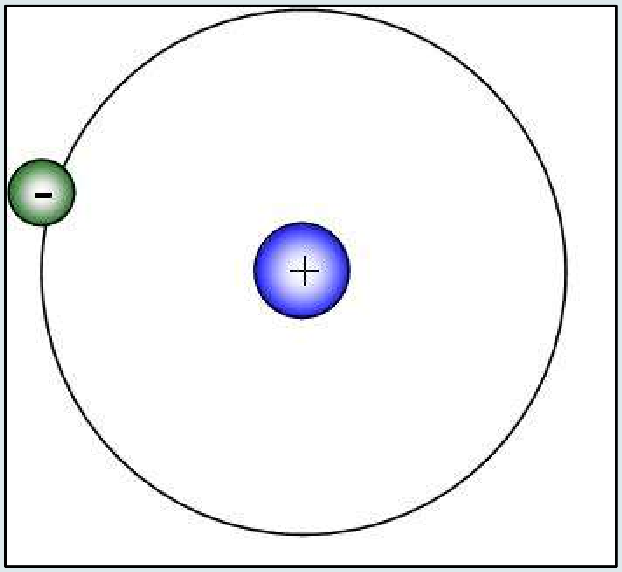


FIGURE 4
Hydrogen Atom

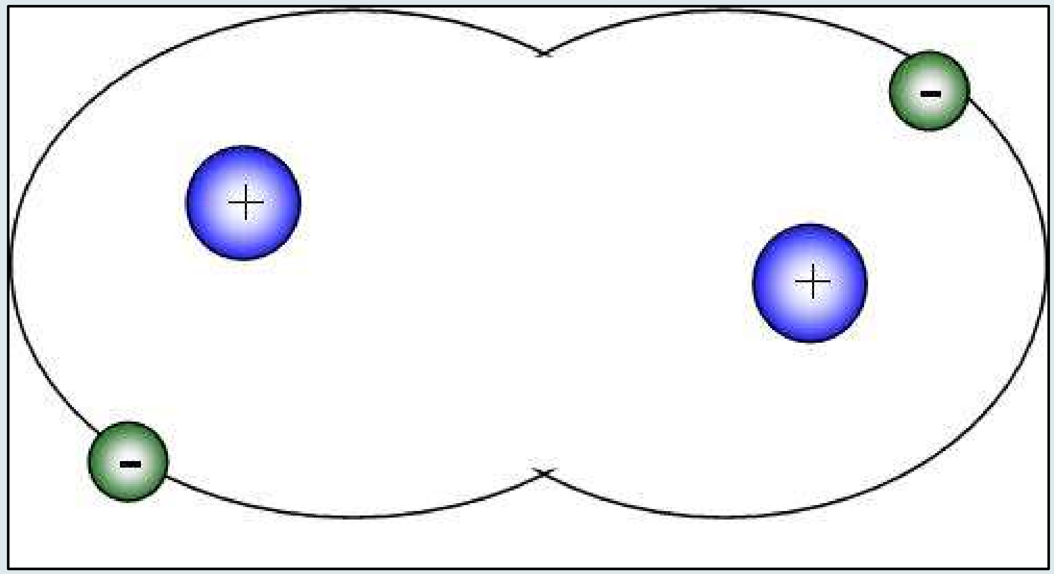


FIGURE 5
Two Hydrogen Atoms Sharing Electrons

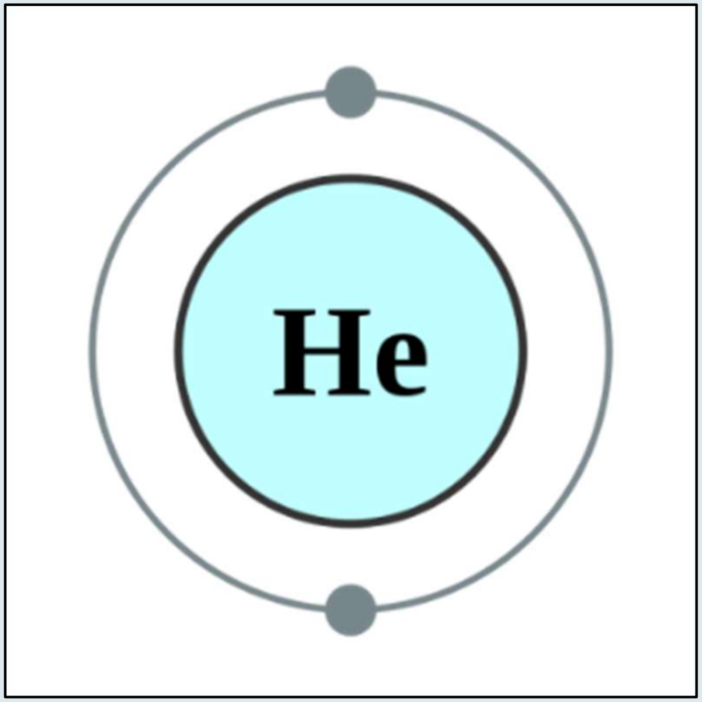
CHEMICAL BONDS AND CONVENTIONAL EXPLOSIVES

ENERGY RELEASE EXAMPLE, LIKE A HOUSE OF CARDS

Less Stable State → **More Stable State**

Net release of energy

CHEMICAL STABILITY COMES WHEN ELECTRON SHELLS ARE FILLED



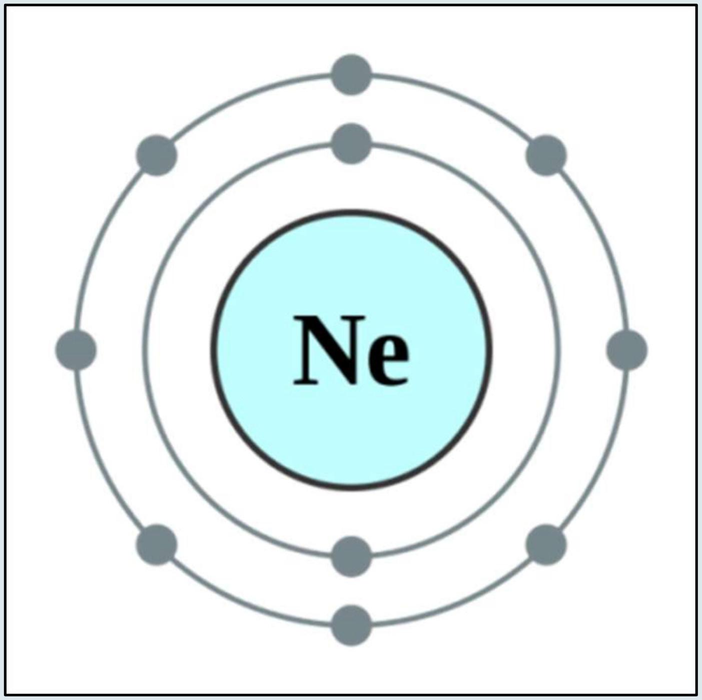


FIGURE 6
Helium Atom

FIGURE 7
Neon Atom

CHEMICAL REACTIONS CAN RELEASE ENERGY

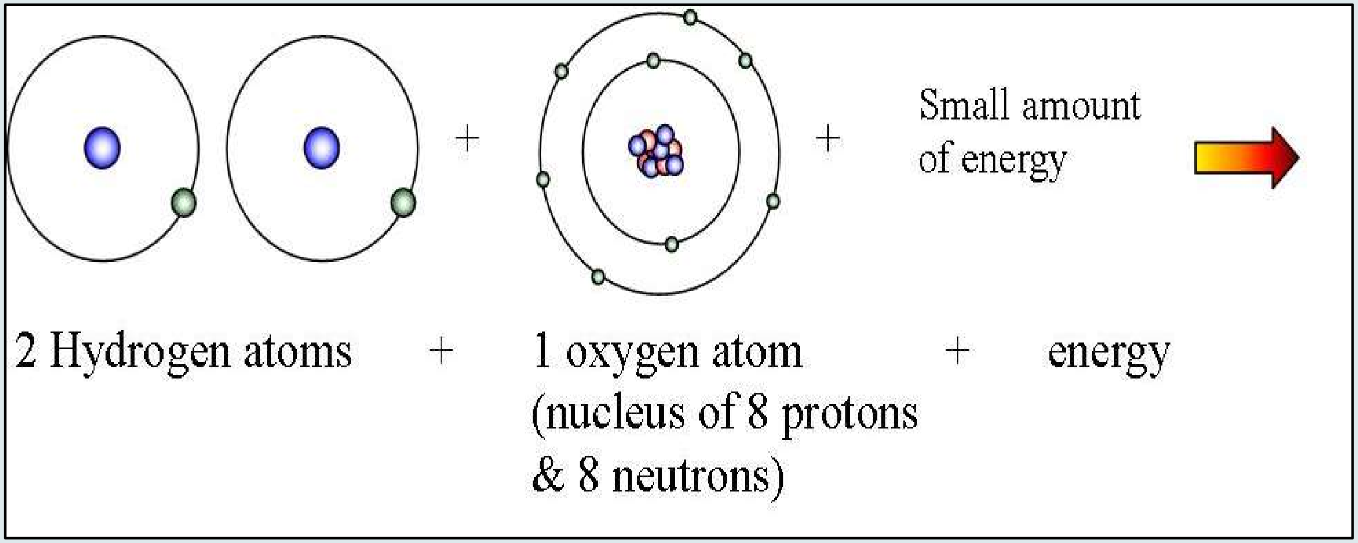


FIGURE 8

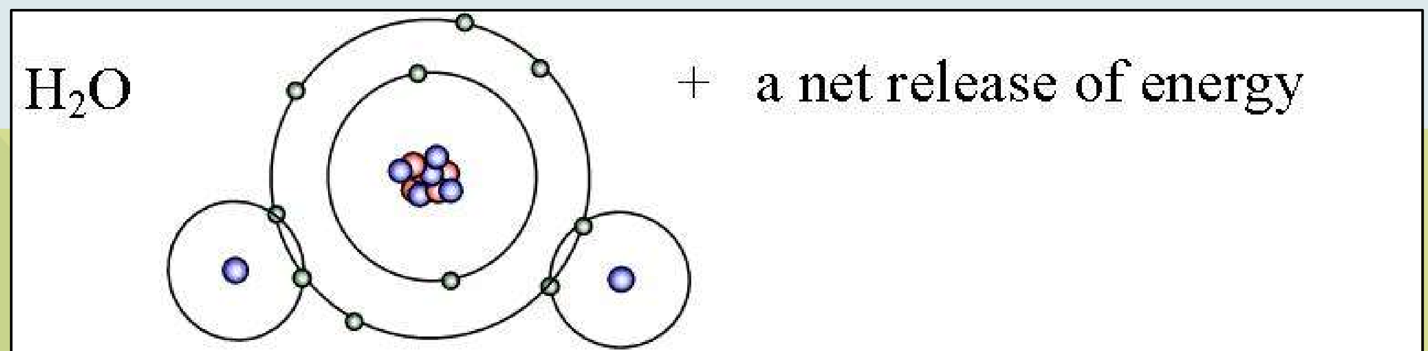


FIGURE 9

CHEMICAL REACTIONS CONTINUED

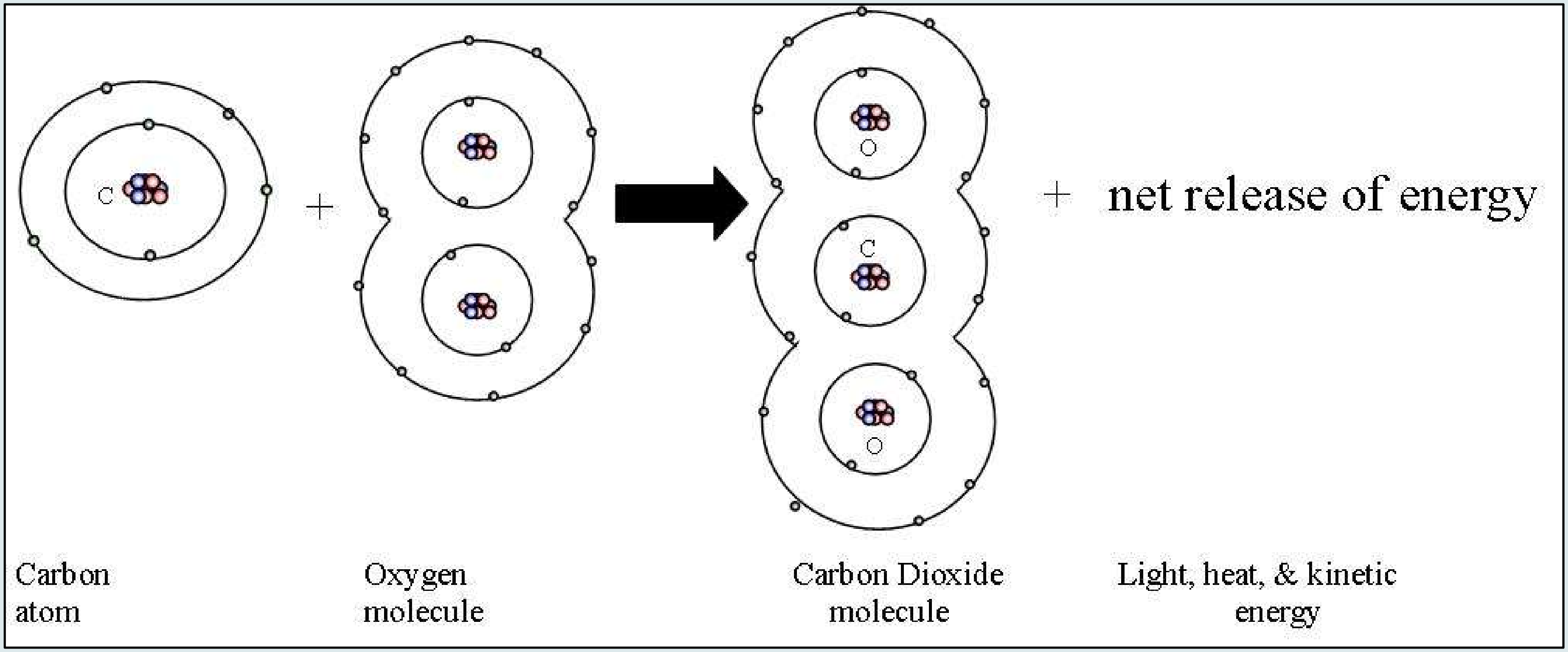
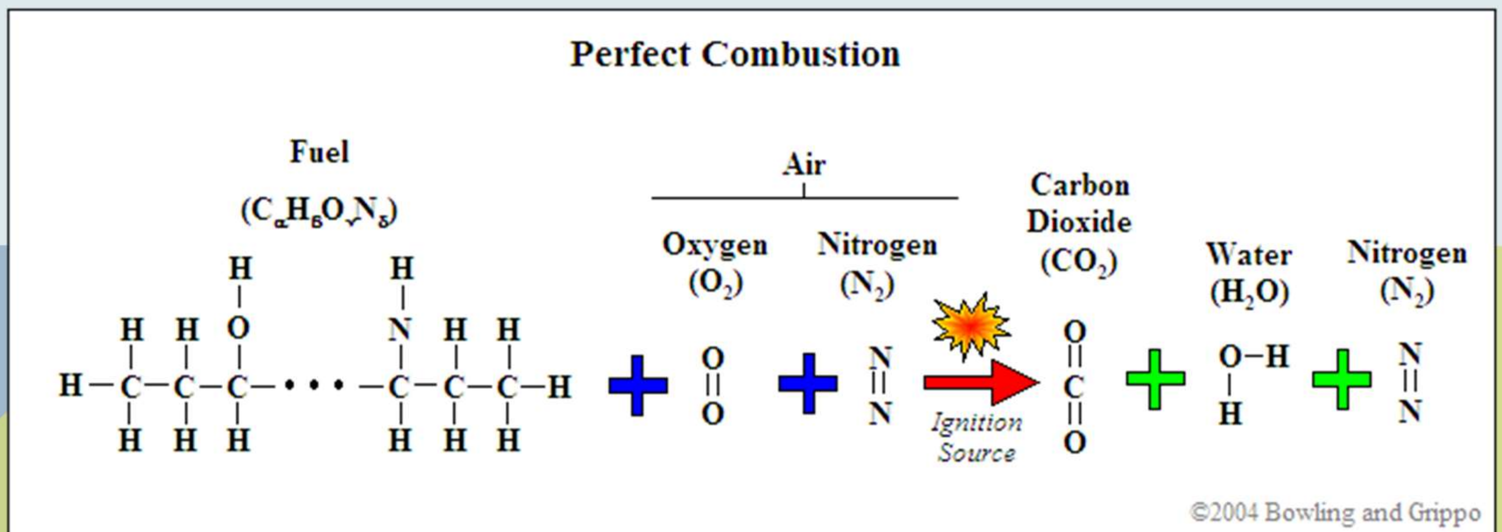


FIGURE 10

GASOLINE COMBUSTION: SMALL EXPLOSIONS GET US TO WORK

$C_4H_6N_6O_6 \rightarrow 3\ CO + 3\ H_2O + 3\ N_2$



http://www.useasydocs.com/theory/chemistry.gif

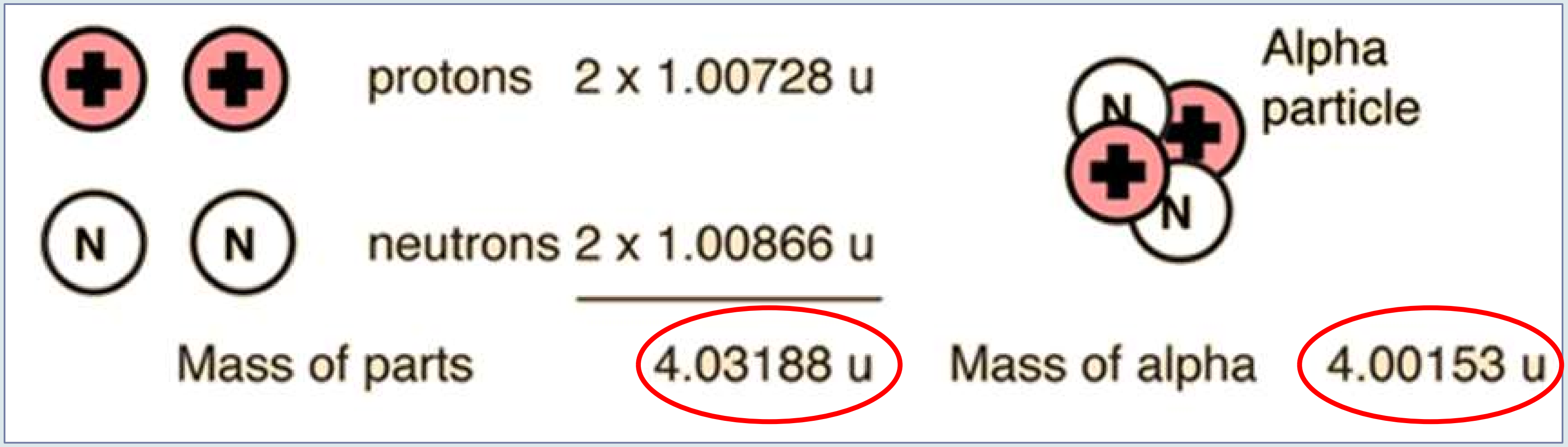
TNT CHEMICAL REACTION: LARGE EXPLOSIONS

$2\ C_7H_5N_3O_6 \rightarrow 3\ N_2 + 5\ H_20 + 7\ CO + 7\ C$

$2\ C_7H_5N_3O_6 \rightarrow 3\ N_2 + 5\ H_2 + 12\ CO + 2\ C$

BINDING ENERGY AND ATOMIC TRANSMUTATIONS

BINDING ENERGY COMES WITH THE LOSS OF A SMALL AMOUNT OF MASS

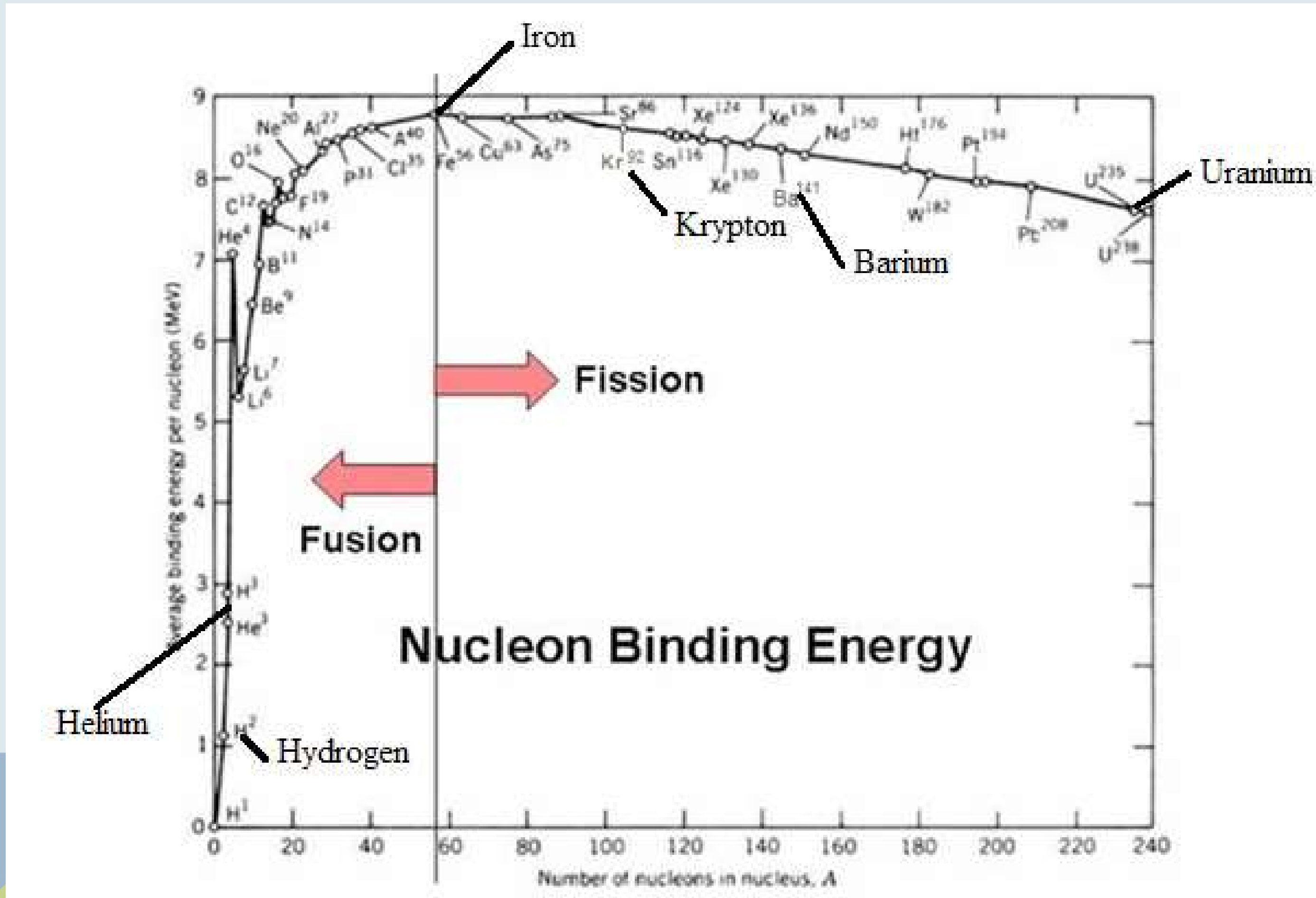


Separate components of an atom weigh more than they do when combined

U = Atomic Mass Unit
U = 1.660539040(20) X 10^{-27} kg

http://hyperphysics.phy-astr.gsu.edu/hbase/NucEne/nucbin.html

IRON SITS ON TOP OF THE CURVE OF BINDING ENERGY, IT HAS THE MOST



CYCLOTRONS 1^{ST} PROPELLED ALPHA PARTICLES TO ACHIEVE NUCLEAR TRANSMUTATIONS

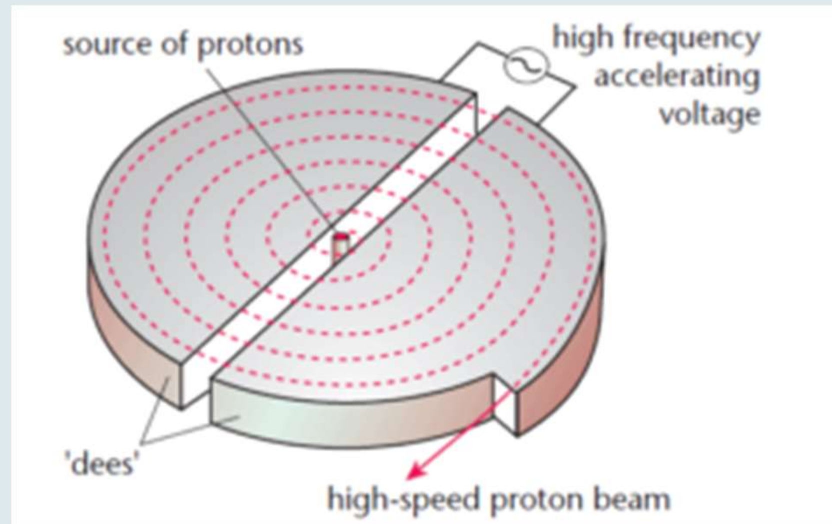
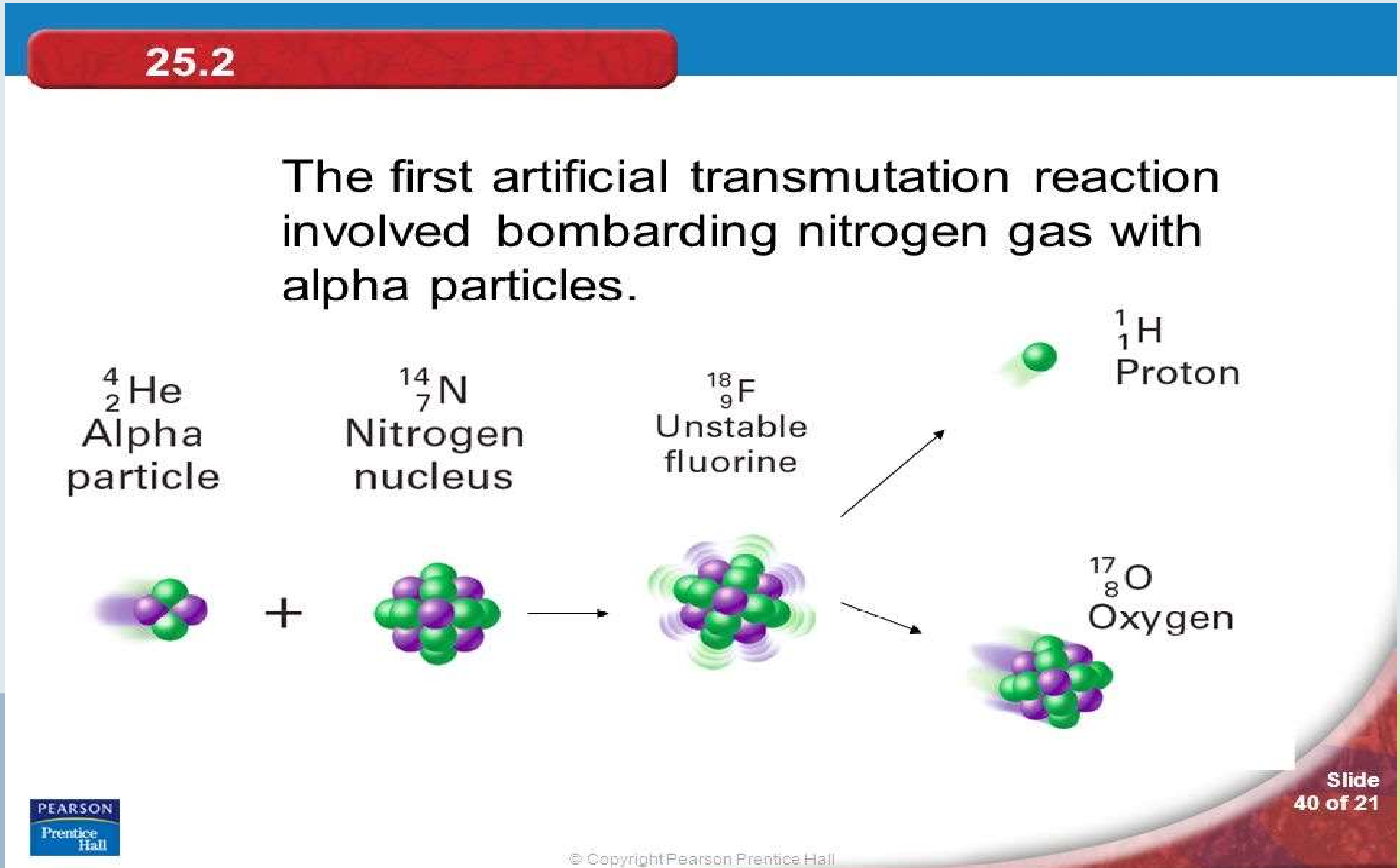
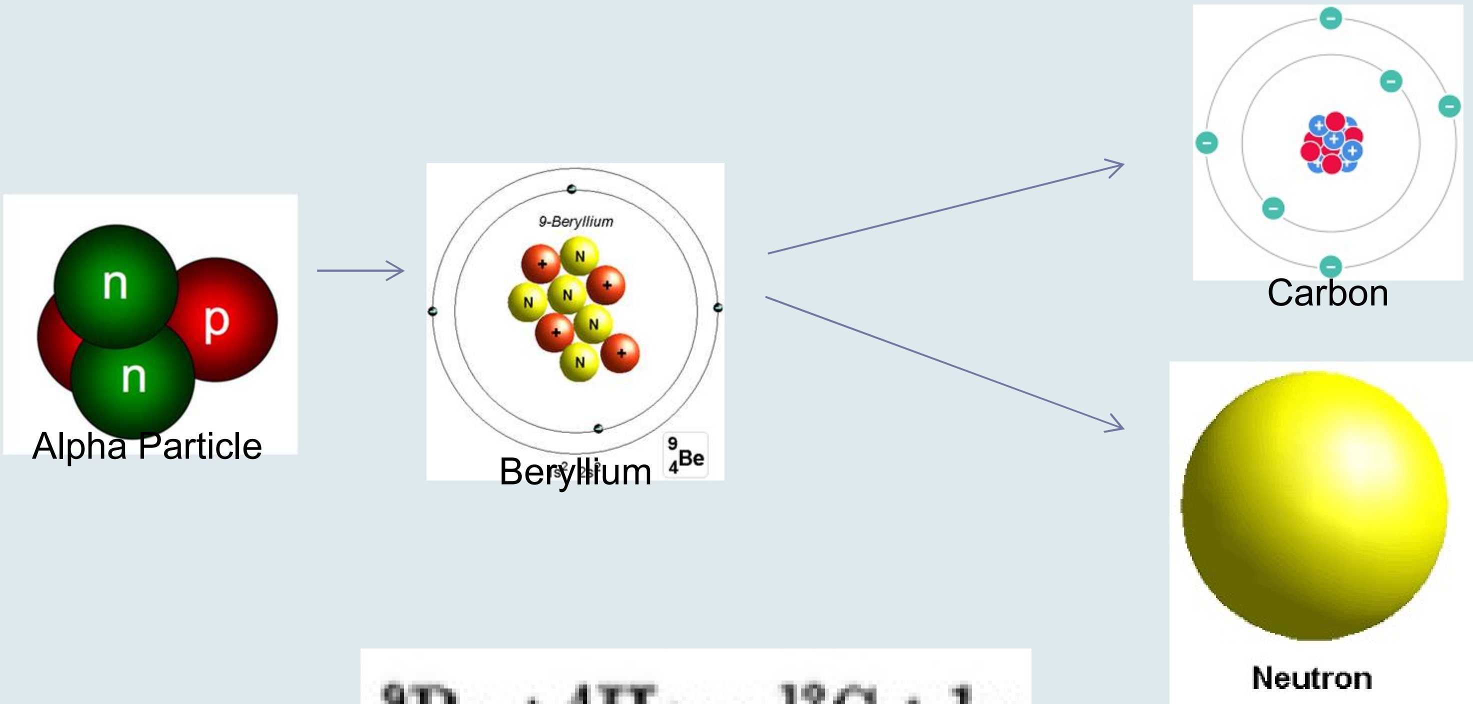


FIGURE 12
An early cyclotron from the 1930s

ALPHA PARTICLES TRANSMUTATION OF NITROGEN



NEUTRONS – THE ULTIMATE AGENTS OF TRANSMUTATION – CAME WITH THE ALPHA BOMBARDMENT OF BERYLLIUM

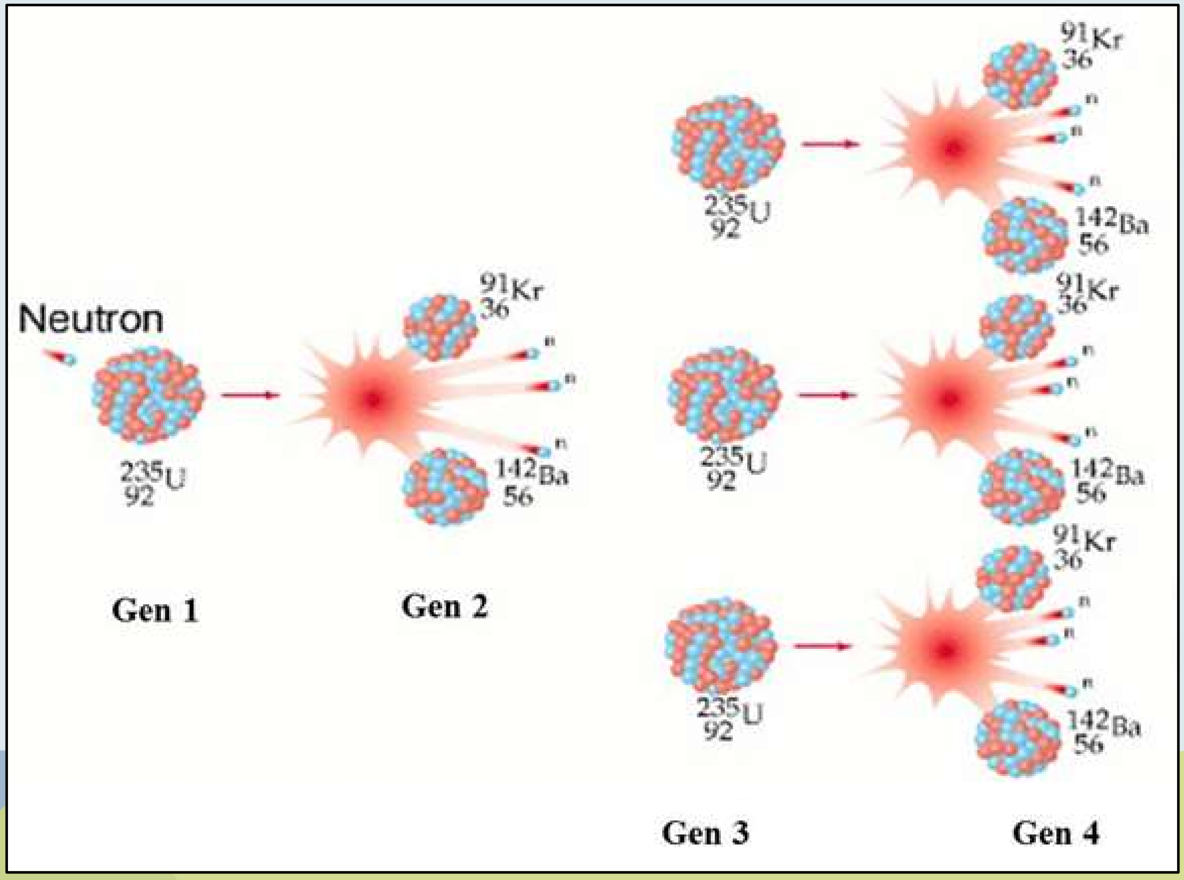


$$ {}^{9}_{4}\mathrm{Be} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{1}_{0}n. $$

http://rspa.royalsocietypublishing.org/content/164/917/243

FISSION

NUCLEAR FISSION CHAIN REACTIONS: DRIVEN BY NEUTRON PENETRATIONS OF URANIUM ATOMS



Nuclear Fission Chain Reaction with Uranium-235 Atoms

$E=MC^2$: CALCULATING ENERGY RELEASED BY FISSION

The amount of atomic energy released from the fissioning of an element, such as uranium, depends on how much mass is lost in the course of the fissioning of the material– i.e., the difference in mass between the original uranium atom and that of the fission products produced after it fissions.

Energy (E) equals mass (m) times the speed of light squared (c^2).

Speed of light (c) equals 300,000 kilometers per second (km/sec) or 3×10^{10} centimeters per second (cm/sec)

Thus:

$$E = mc^2 \text{ cm/sec}$$

$$E = m\,(3 \times 10^{10})^2 \text{ cm/sec}$$

$$E = m\,(3 \times 10^{10})(3 \times 10^{10}) \text{ cm/sec}$$

$$E = m\,(9 \times 10^{20}) \text{ cm/sec}$$

EXAMPLE: ENERGY RELEASED BY FISSION OF 1 KG OF URANIUM

To compute the amount of atomic energy released from fission, need to know only m, the quantity of mass in grams lost in the fissioning of the uranium. This quantity is the difference between the mass of uranium before it is fissioned and the sum of the masses of its immediate fission fragments.

In the case of U^{235} we know that when 1 kilogram undergoes fission, slightly less than 1 gram of mass is lost.

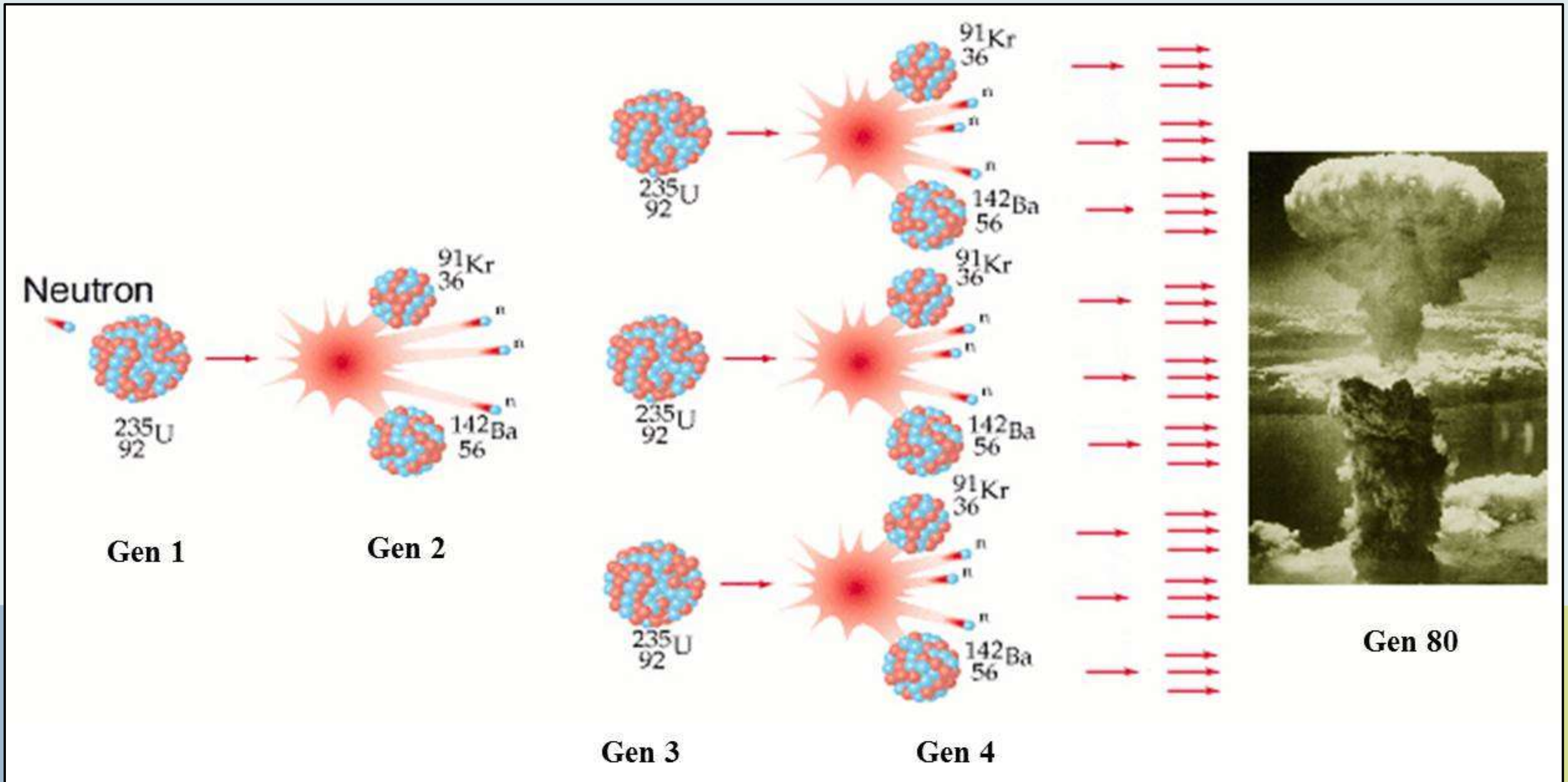
Thus, in the case of U^{235}, the amount of energy released equals (1 gram)(9 x 10^{20} cm/sec). To get E, or energy expressed in terms of calories (a measure of heat), we simply divide our figure by the constant, 4.2 x 10^7:

$$E = \frac{9 \times 10^{20}}{4.2 \times 10^{7}} \text{ calories}$$

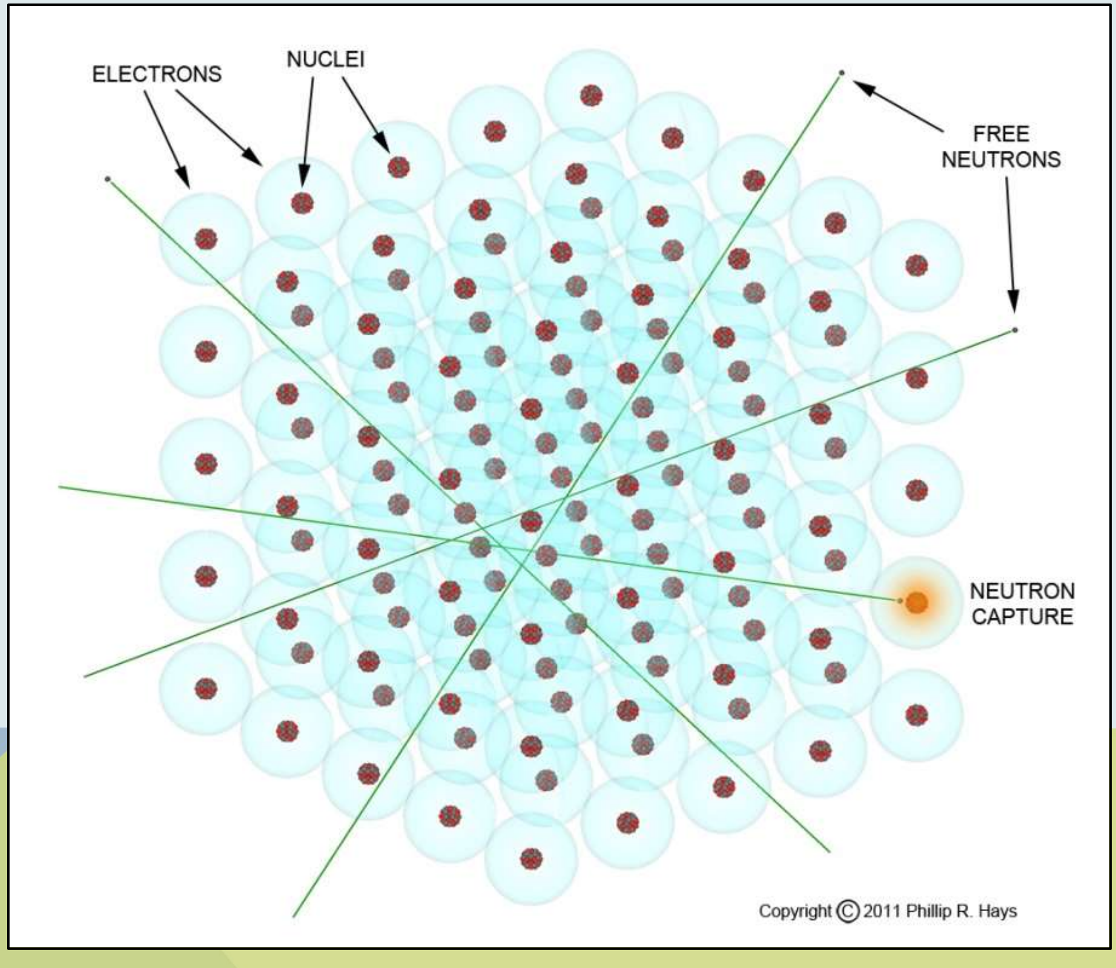
$$E = 2.1 \times 10^{13} \text{ calories}$$

ATOMIC WEAPONS DESIGN BASICS

THE RELEASE OF 10-20 KILOTONS OF NUCLEAR ENERGY REQUIRES 80 GENERATIONS OF U235 FISSIONING

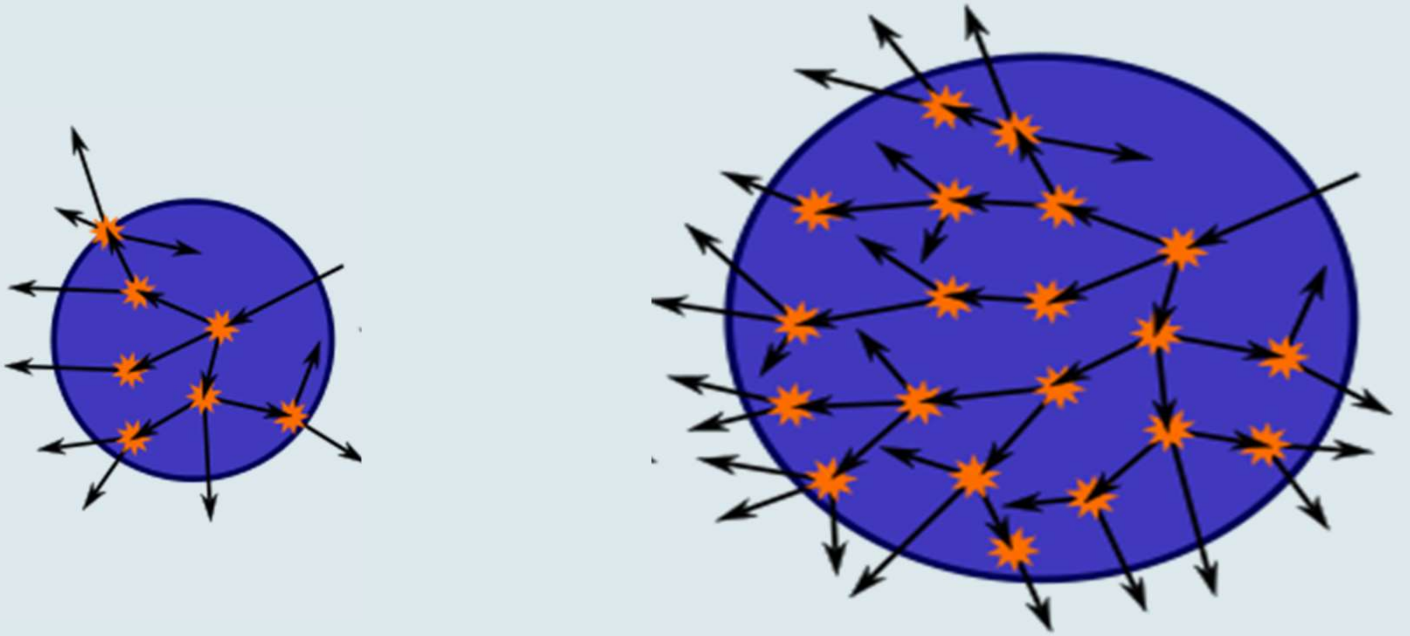


A MINIMUM AMOUNT OF BOMB MATERIAL IS NEEDED TO ENSURE ENOUGH NEUTRONS ARE CAPTURED AND FISSIONED



Neutron Capture by U^{235} Atoms

DECREASING RATIO OF SURFACE AREA TO VOLUME INCREASES LIKELIHOOD OF FISSION



Neutron Escape

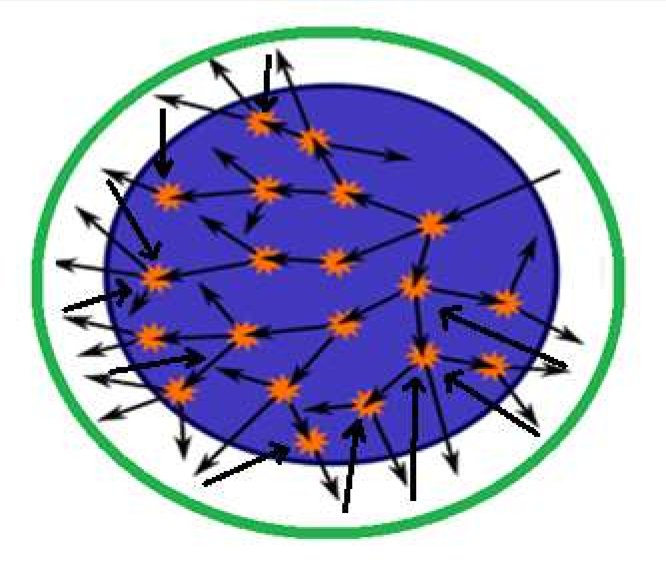
Diagrammatic representation of effect of size of fissionable material on relative loss of neutrons by escape.

METHODS OF REDUCING THE CRITICAL MASS OF A WEAPON

REFLECT NEUTRONS BACK TO WEAPONS CORE

Neutron reflector may be made from:

- **Graphite**
- **Beryllium**
- **Steel**
- **Tungsten carbide**
- **Uranium^{238}**



A neutron reflector can reduce the critical mass by a factor of 2 to 3.

INCREASE DENSITY OF WEAPONS MATERIAL AT THE TIME OF DETONATION

Atoms are closer together and, thus, more likely to be hit by generated neutrons.

Doubling the density at the time of detonation increases yield four-fold, or allows one quarter of the amount of material to be used to produce a given yield.

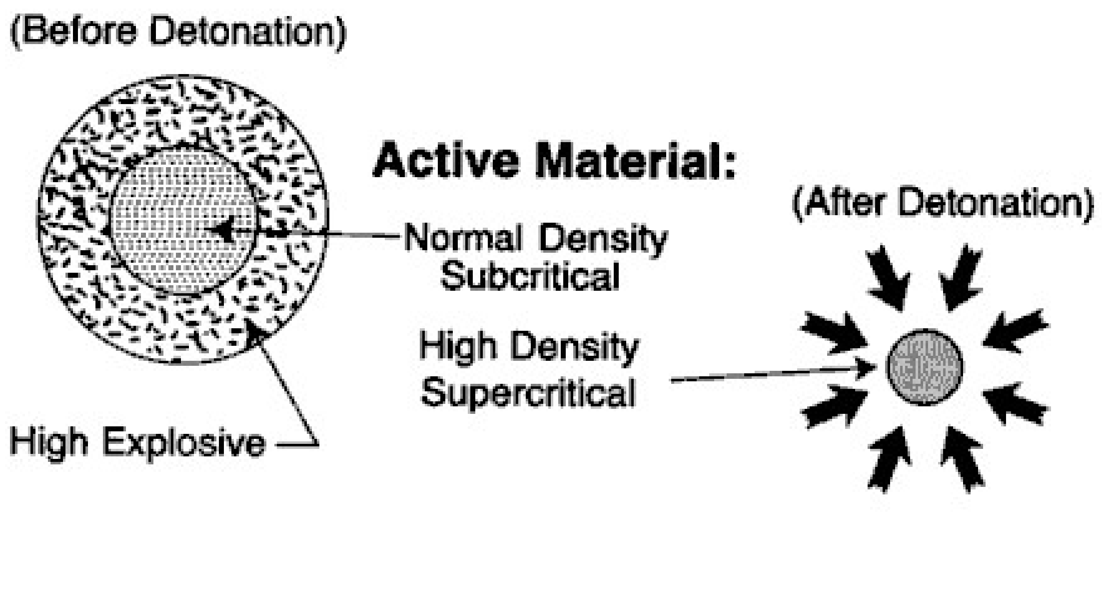
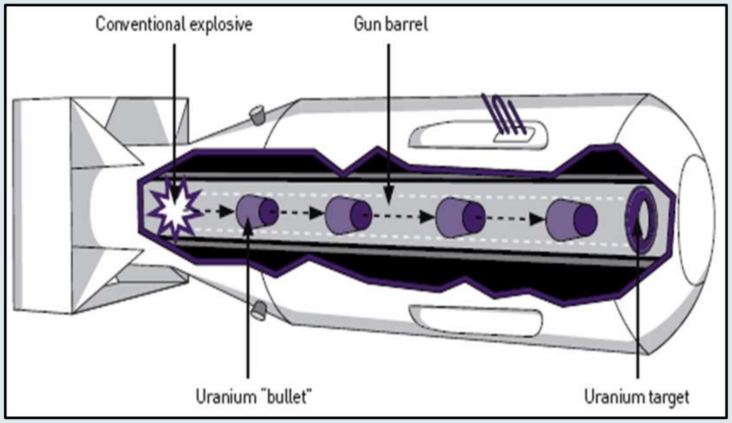


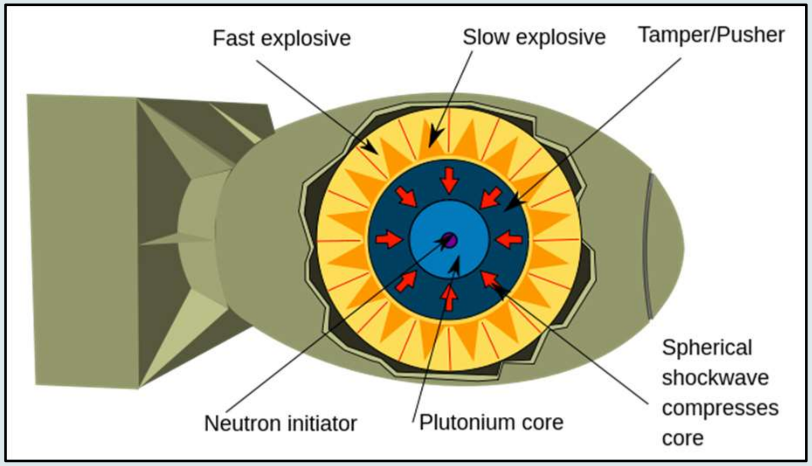
Figure 2-VIII. Implosion Assembly Principle

FACILITATE SPEEDY ASSEMBLY: TWO WEAPONS DESIGNS

Increase the speed at which subcritical masses are brought together to prevent premature fission of material because of predetonation through excessive neutron emission.



Gun barrel



Implosion

REINFORCE THE WEAPON CASING OR TAMPER

Decrease the bomb's tendency to blow apart by encasing it with a heavy metal casing or a tamper to ensure a sufficient amount of material fissions.

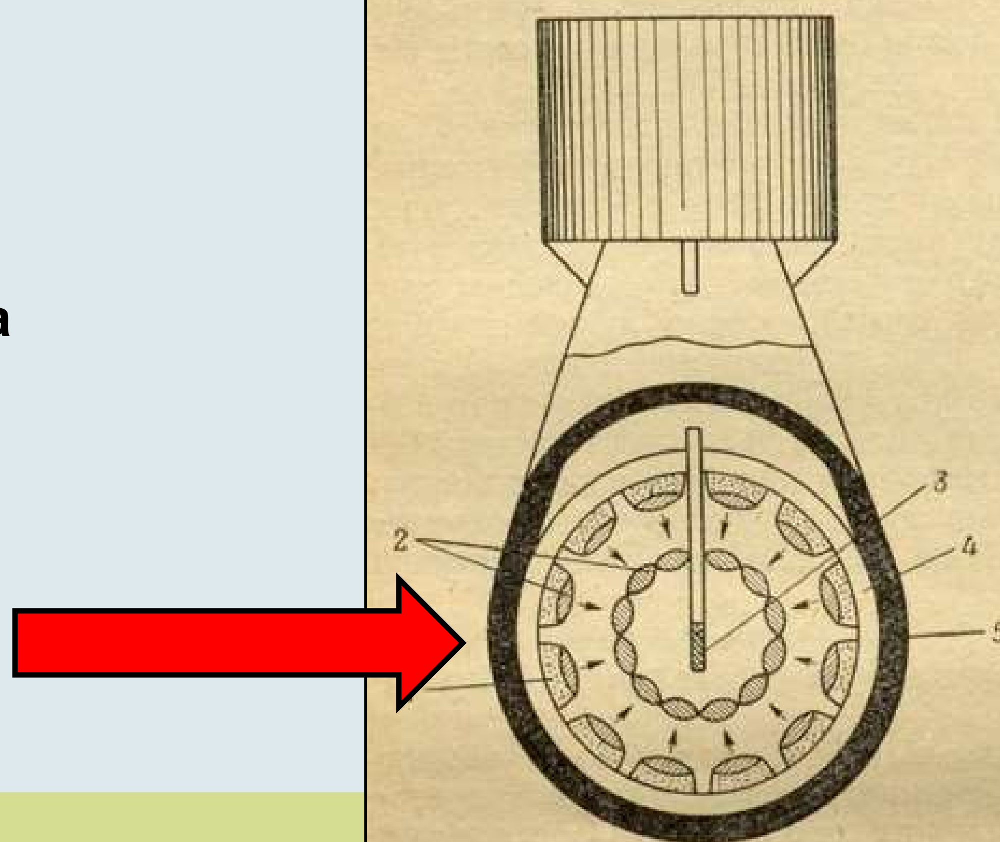
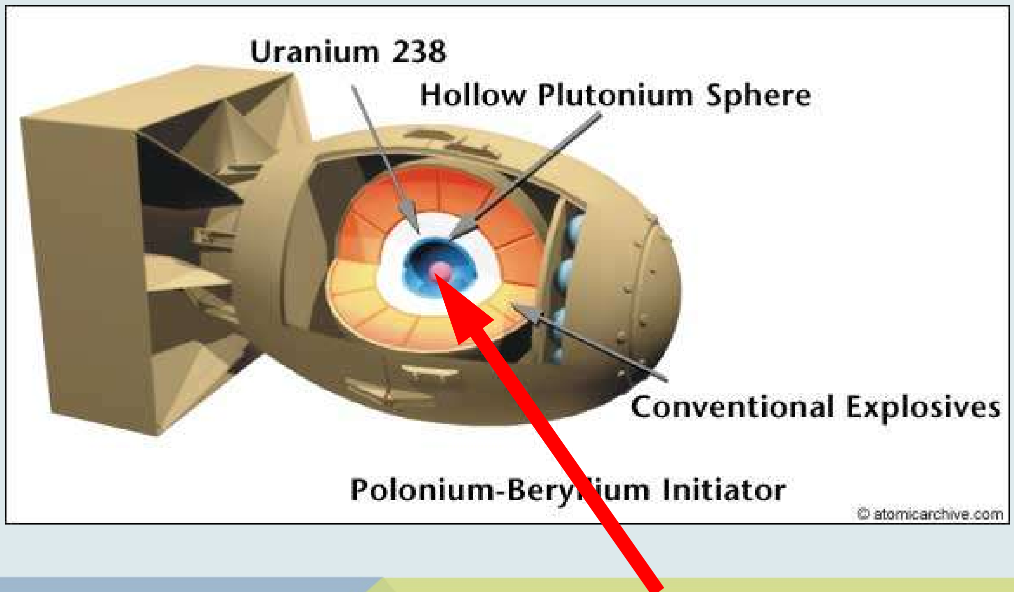


Рис. 9. Принципиальная схема атомной бомбы (заряд разделен на несколько частей):

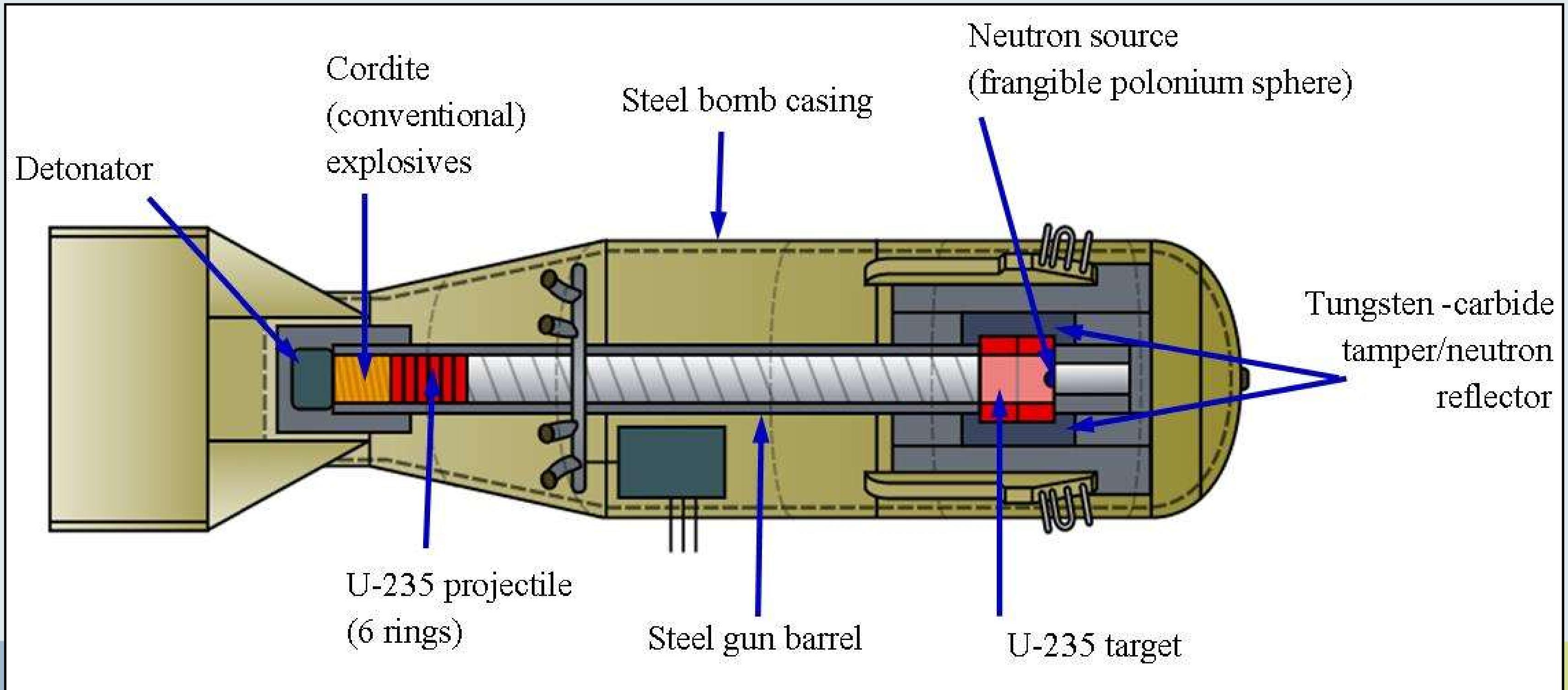
1 — взрывчатое вещество; *2* — плутоний; *3* — нейтронный источник; *4* — отражатель нейтронов; *5* — оболочка

INCREASE THE NUMBER OF NEUTRONS THAT START THE REACTION WITH A NEUTRON INITIATOR

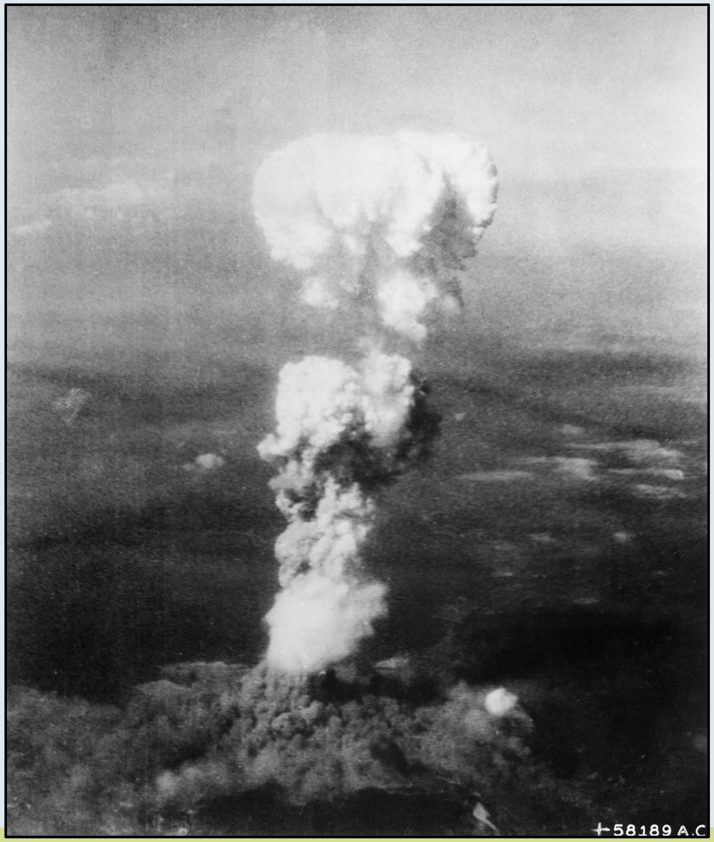


THE FIRST NUCLEAR BOMB: LITTLE BOY

GUN-BARREL MARK-1 URANIUM DESIGN, "LITTLE BOY" WAS NEVER TESTED



"LITTLE BOY" WAS DETONATED AT 1,870 FT. FOR MAXIMUM BLAST EFFECT



"Little Boy"

It was 10 feet long, had a diameter of 28 inches, and weighed 4,400 kg.
It contained 64 kilograms (kg) of HEU and had a yield of approximately 15 kilotons (kt).

THE SECOND NUCLEAR BOMB: FAT MAN

PLUTONIUM IS PRODUCED BY THE TRANSMUTATION OF U^{238} INTO PU^{239}

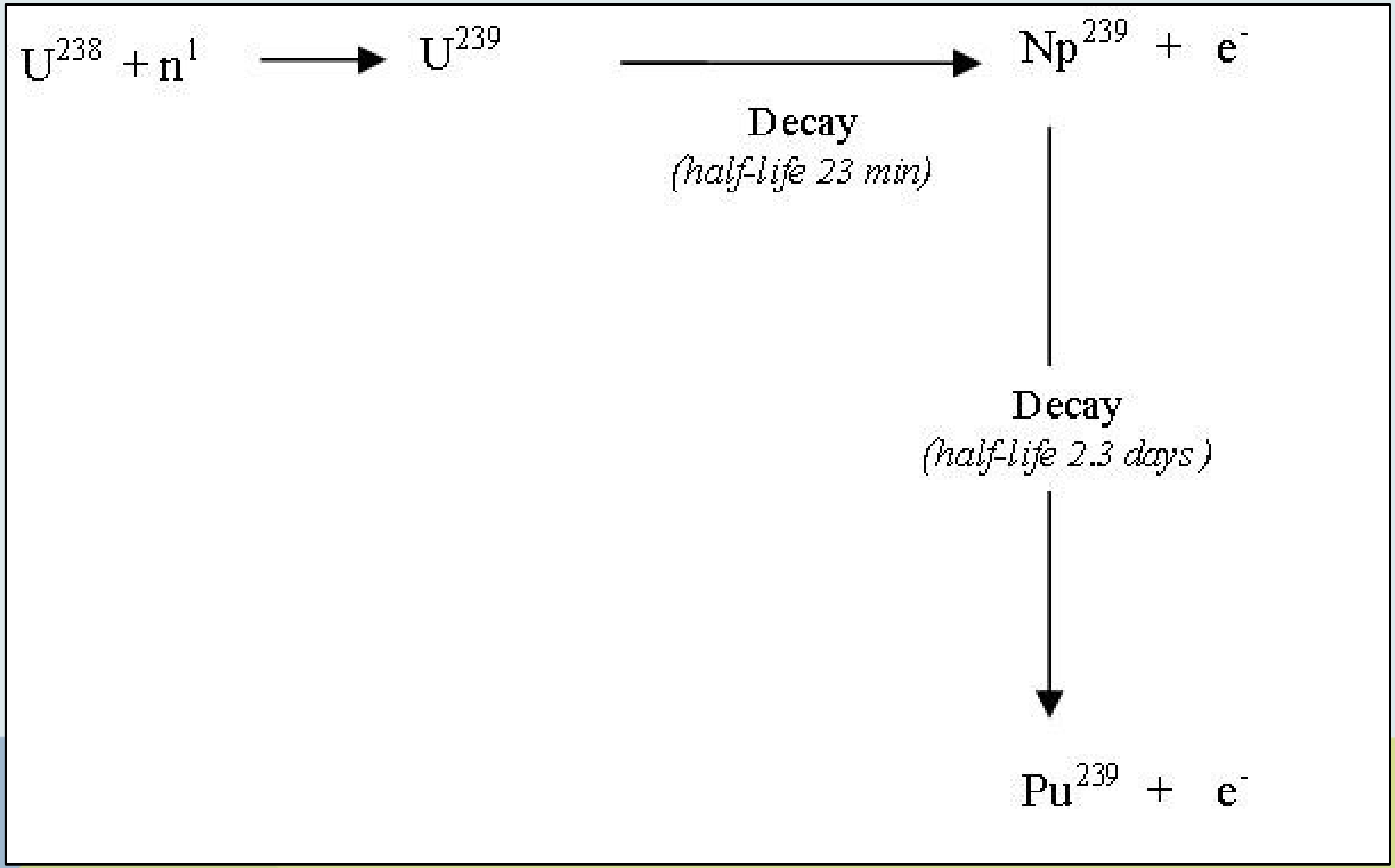


FIGURE 17

PU^{239} DECAYS INTO THE MORE SPONTANEOUS FISSION-PRONE ISOTOPE PU^{240}

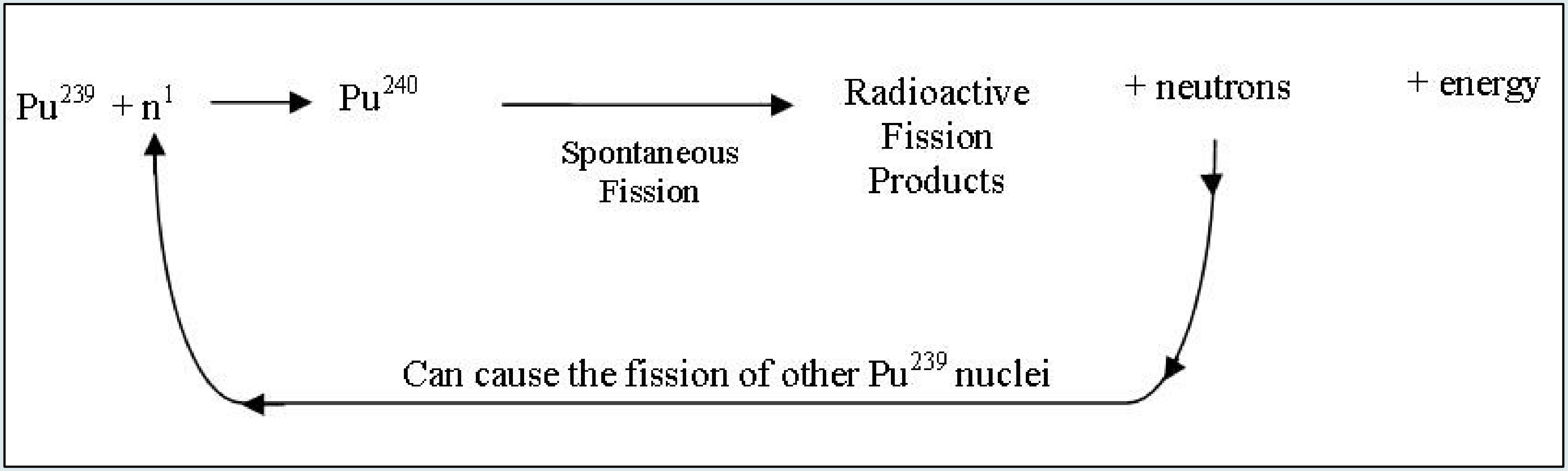
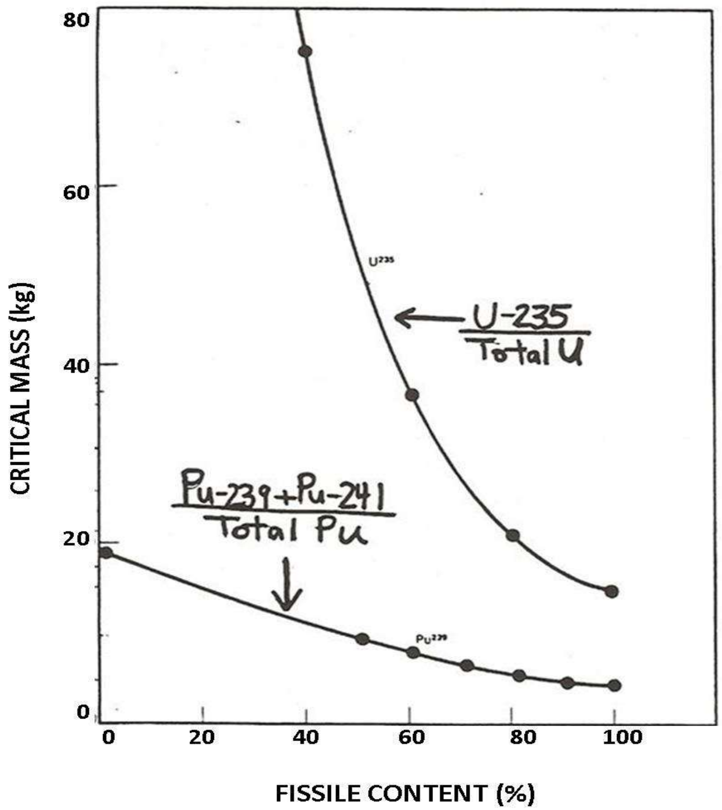


FIGURE 18

REACTOR-GRADE (RG) URANIUM CAN'T MAKE BOMBS, RG PLUTONIUM CAN



Critical Mass (CM)

CM (U)
Infinite for U235 / U < ~10%

CM (Pu)
Finite for all isotopic mixes

CRITICAL MASS OF URANIUM & PLUTONIUM AS A FUNCTION OF ISOTOPIC MIX
FIGURE 20

Bare spheres have critical masses three to four times larger than the device assumed here, in which the bomb material is surrounded by a thick neutron reflecting uranium shell.

IMPLOSION: NEEDED TO DETONATE PLUTONIUM, CAN ALSO DETONATE URANIUM

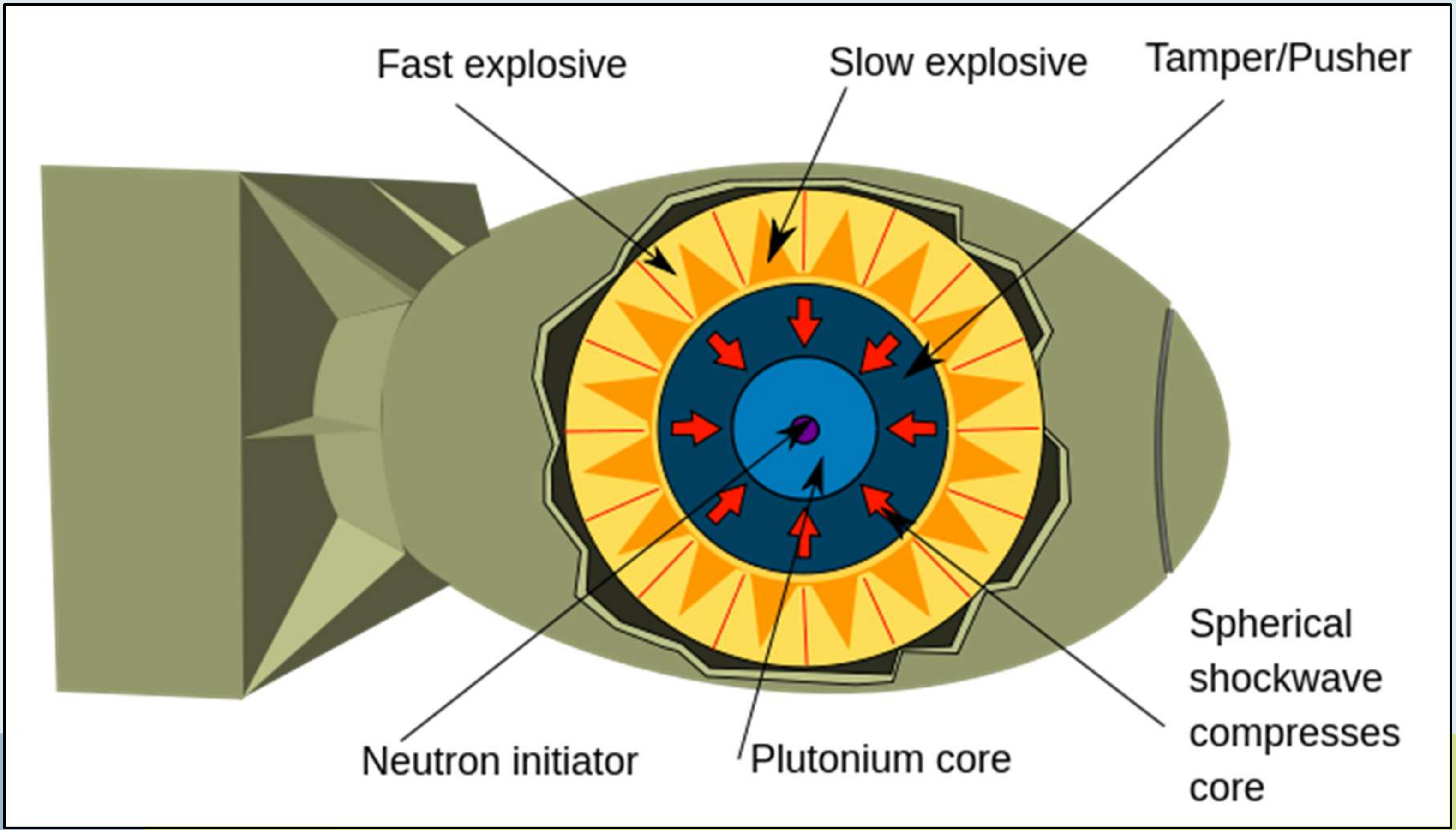


FIGURE 23

Mark-3 "Fat Man" Implosion Bomb

Core was a solid sphere of plutonium

SHAPED IMPLOSION "LENSES" PRODUCE A SPHERICAL SHOCK WAVE

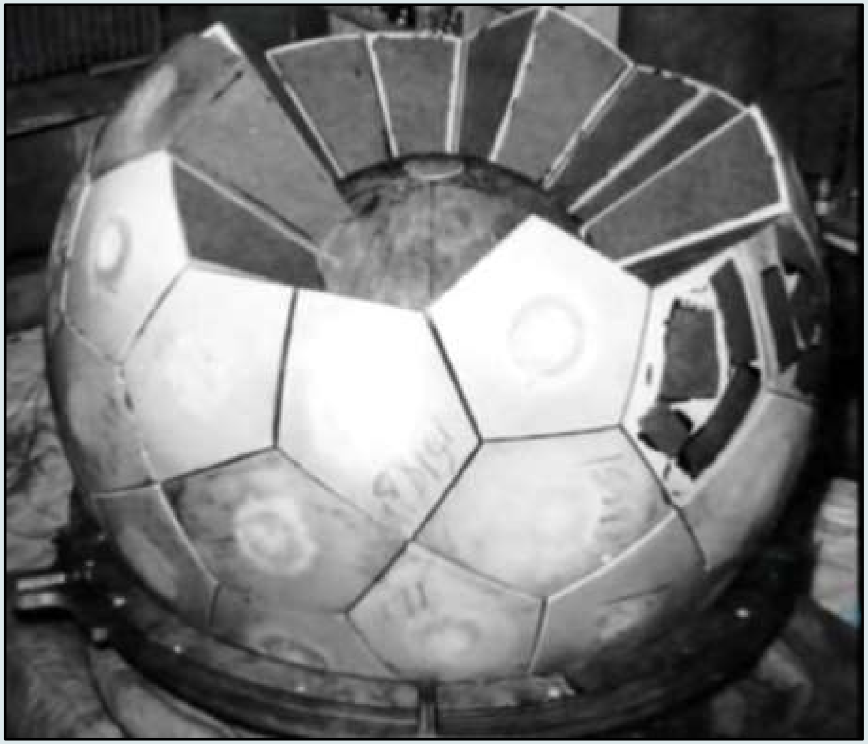


FIGURE 24
High explosive lenses
Arranged in the typical "soccer ball" pattern

USE COMBINATION OF HIGH AND LOW VELOCITY EXPLOSIVES FOR A SPHERICAL IMPLOSION

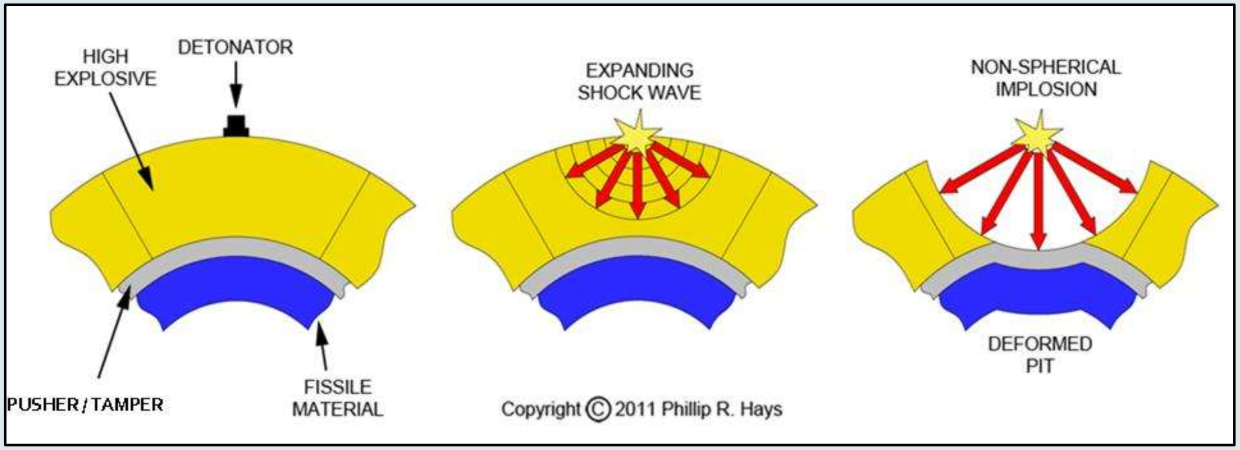


FIGURE 25
High Velocity Explosives Only

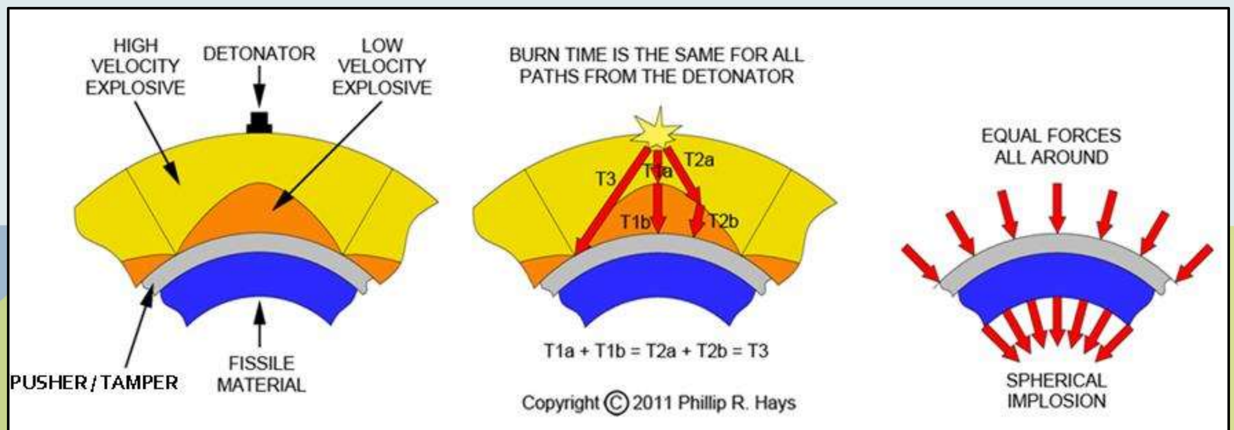


FIGURE 26
Combination of High and Low Velocity Explosives

NUCLEAR PHYSICS PACKAGE IS SOMETIMES CALLED A "GADGET"

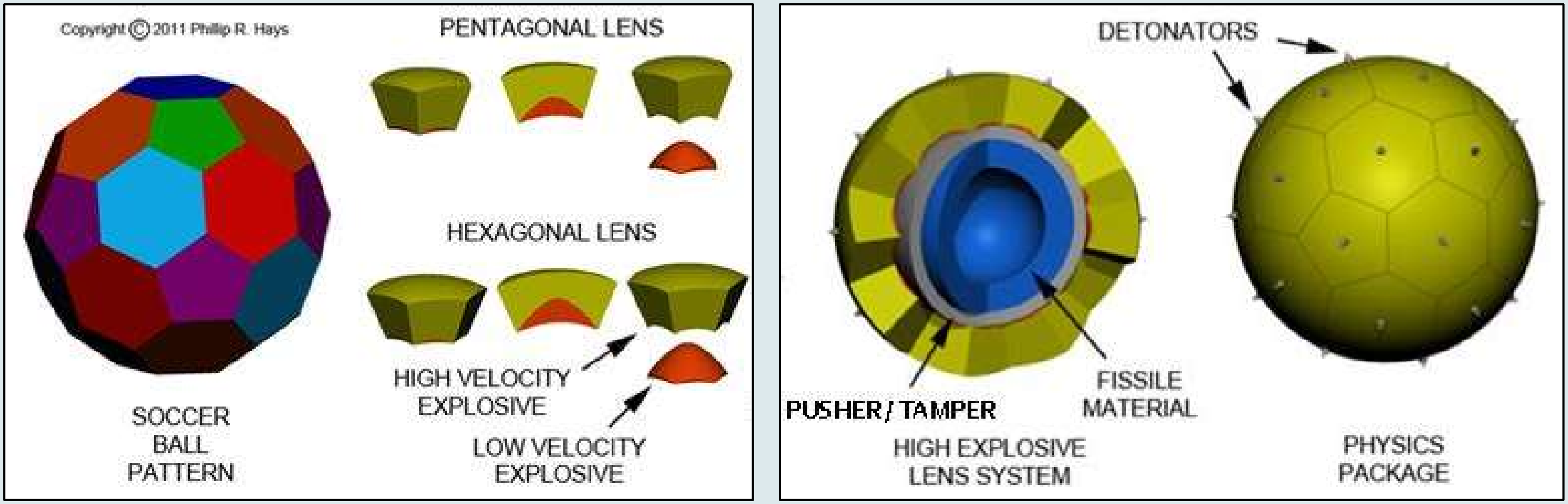
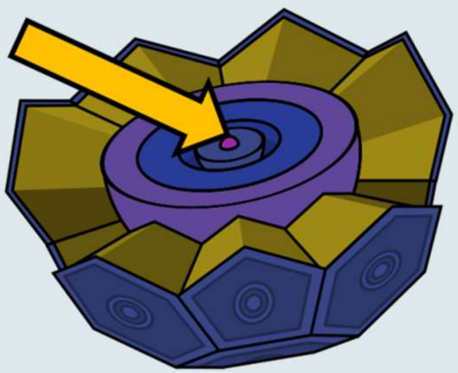
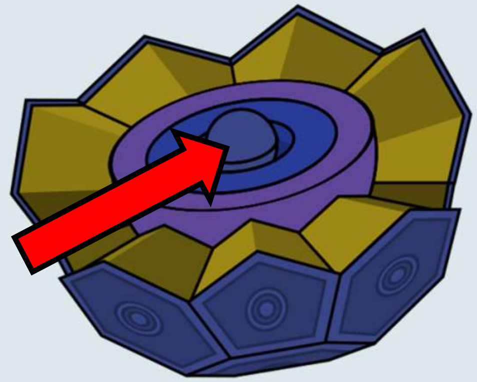


FIGURE 27

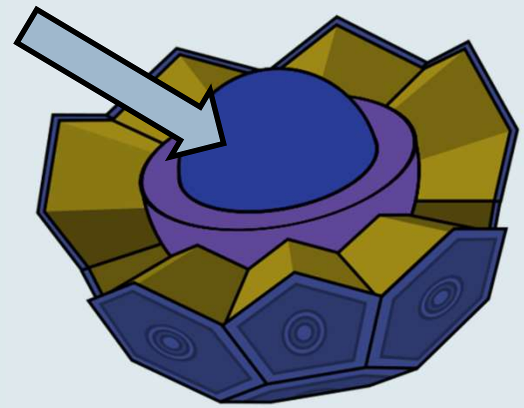
ANOTHER VIEW OF THE MARK-3 GADGET



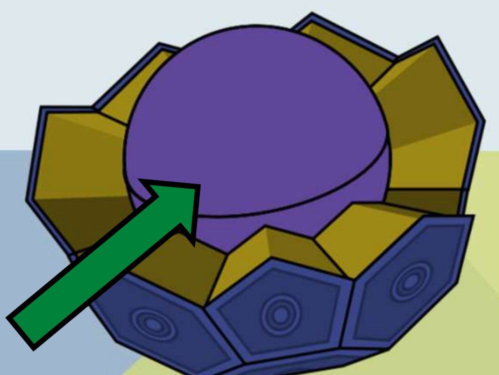
A: Neutron Initiator



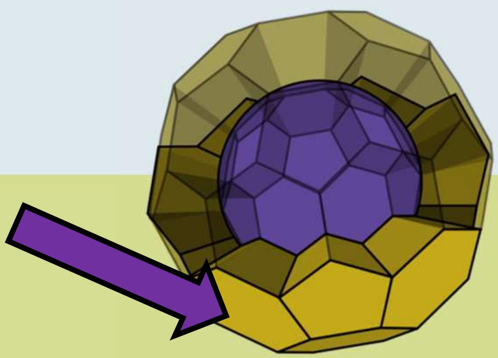
B: Plutonium Core



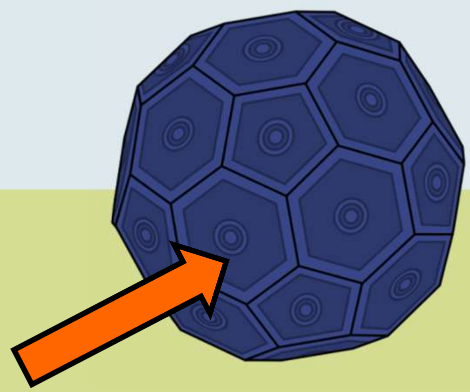
C: Tamper



D: Pusher



E: Explosive Lenses



F: Outside Plates and Detonators

1ST NUCLEAR DEVICE EVER TESTED, "THE GADGET", WAS HUGE – 6 KGS OF PLUTONIUM 10,300 LBS. 60" DIAMETER

FIGURE 29

Many of the wires seen in the photo are connected with detonators/initiators that are triggered by krytrons

"FAT MAN" DETONATED OVER NAGASAKI AT 1,500 FT. TO MAXIMIZE BLAST AND FIRE EFFECTS AGAINST HOMES

ADVANCED NUCLEAR WEAPONS: POST-1945 DESIGNS

SINGLE STAGE FISSION IMPLOSION DESIGNS

LEVITATED PIT WITH A SOLID-CORE MARK-4 DESIGN FIRST TESTED IN 1948

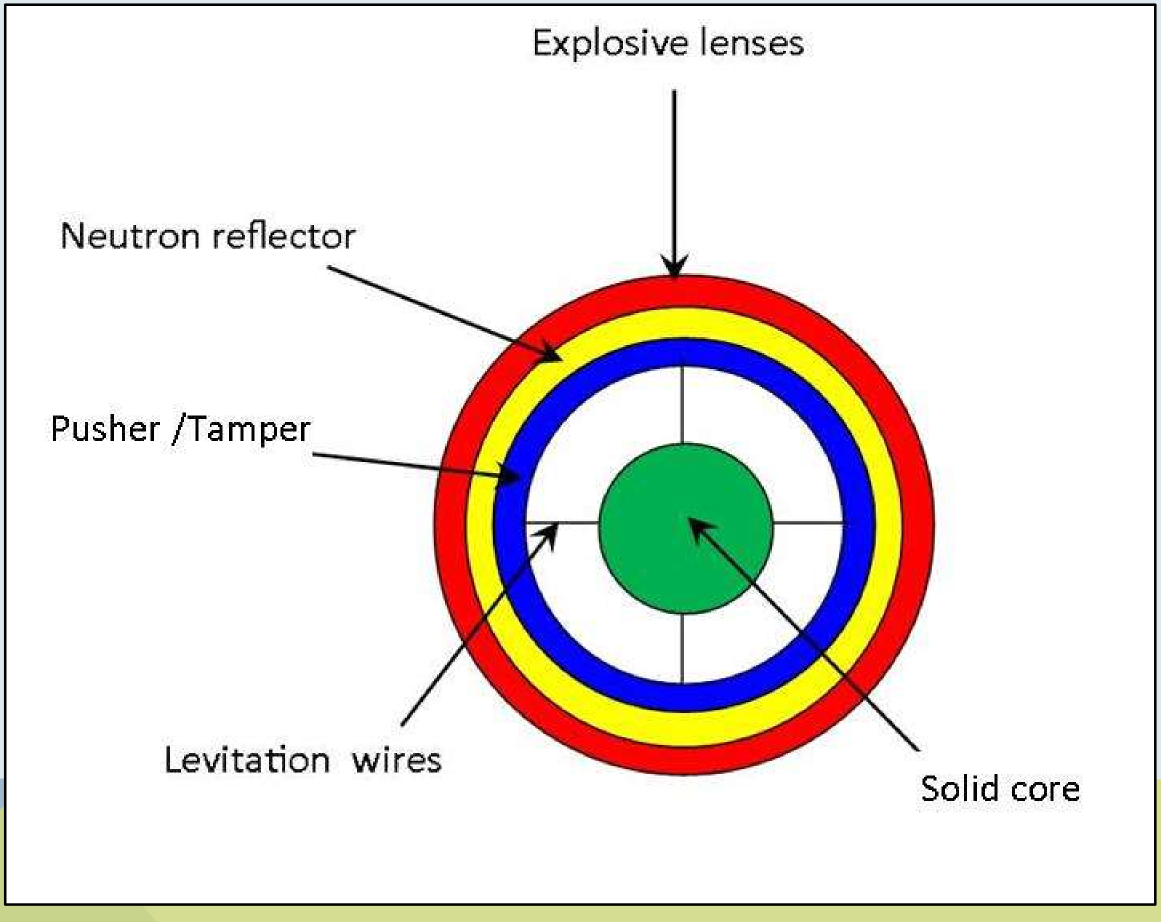


FIGURE 31

LEVITATED PIT WITH A HOLLOW CORE DESIGN TESTED IN 1951

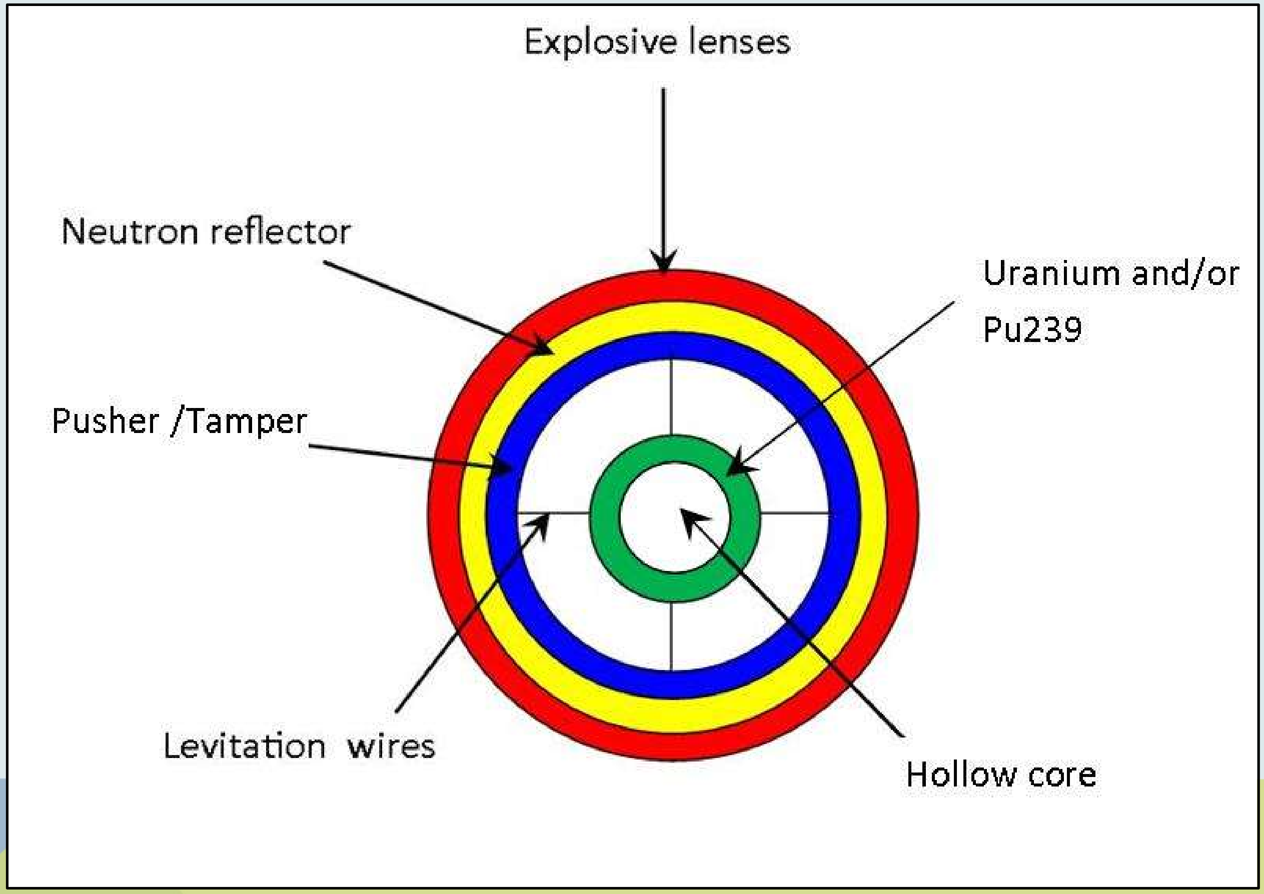
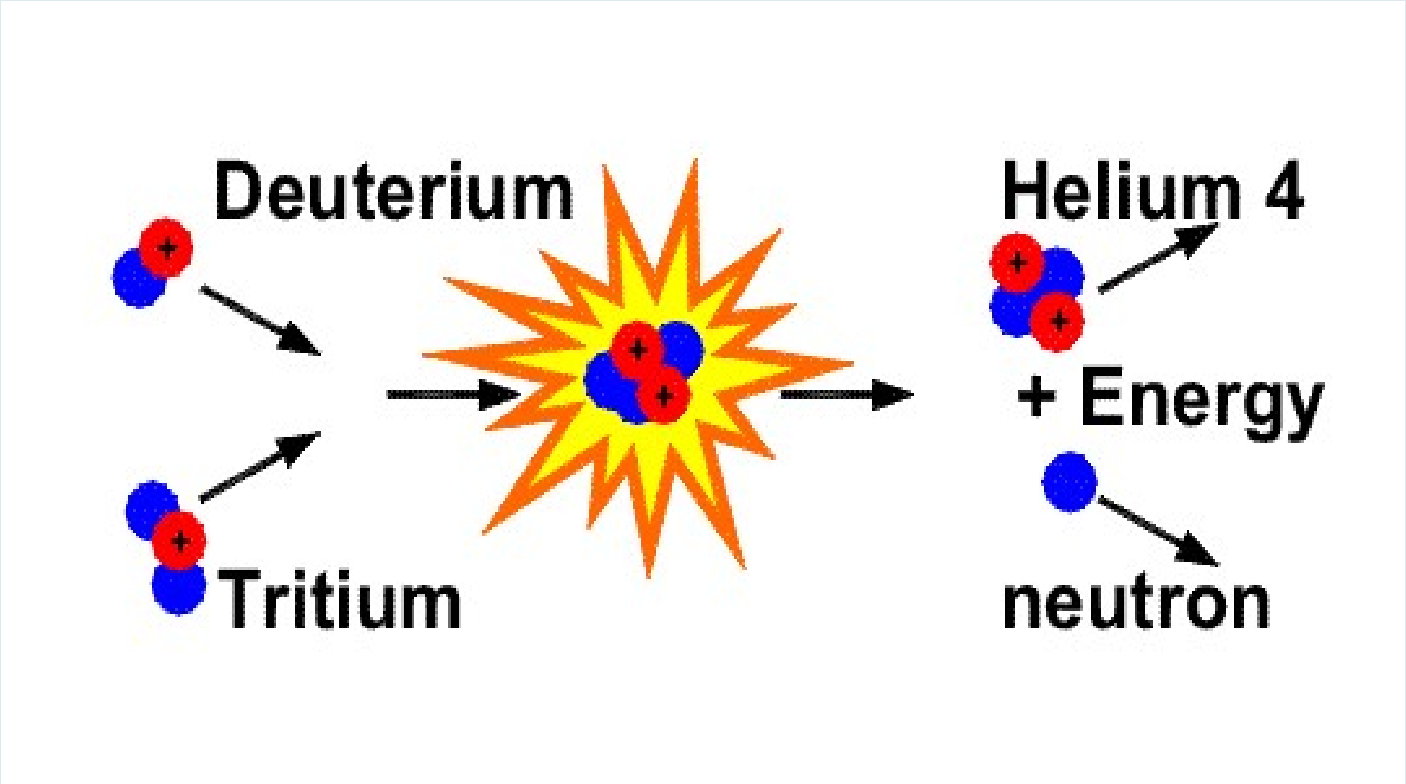


FIGURE 32

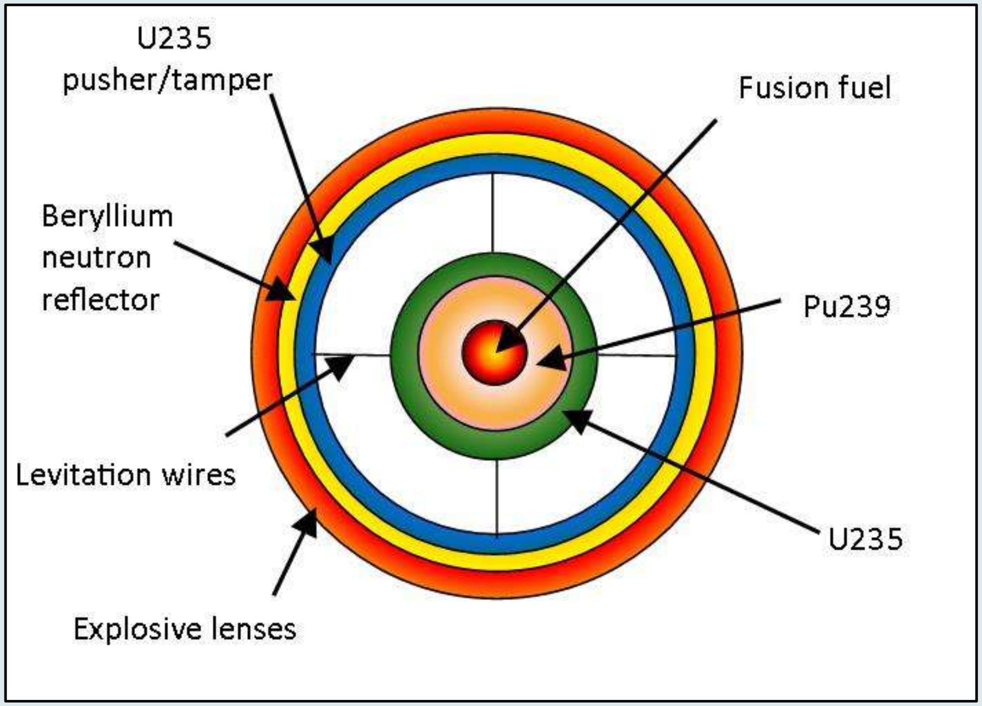
HIGH YIELD PURE FISSION WEAPON, 500 KT YIELD, USED HOLLOW CORE DESIGN

FIGURE 33

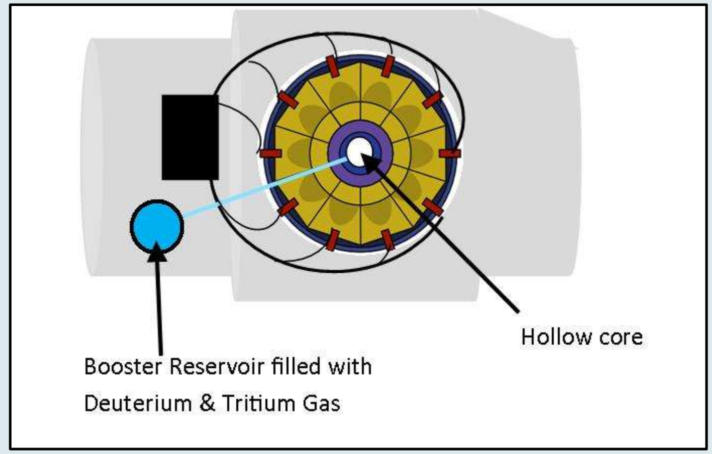
BOOSTING PRODUCES ADDITIONAL NEUTRONS FOR FISSION WEAPONS



BOOSTED FISSION WEAPONS FIRST TESTED IN 1951

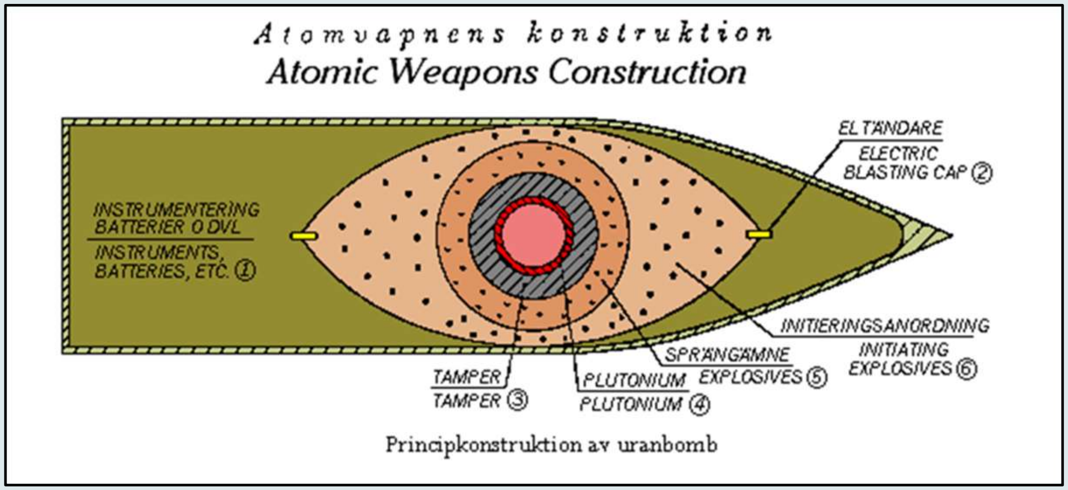


Boosted Fission Design



Greenhouse Item Boosting Device

TWO-POINT (ELLIPSOID) DESIGN, MID 1950S



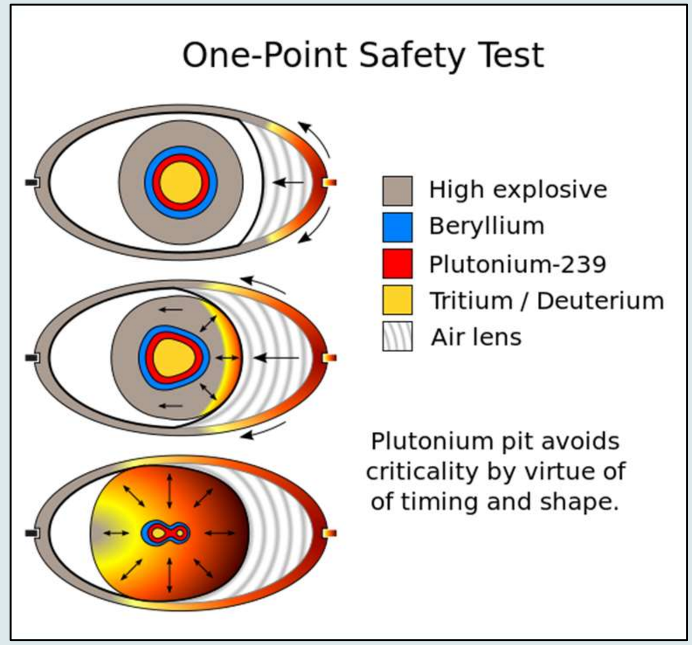
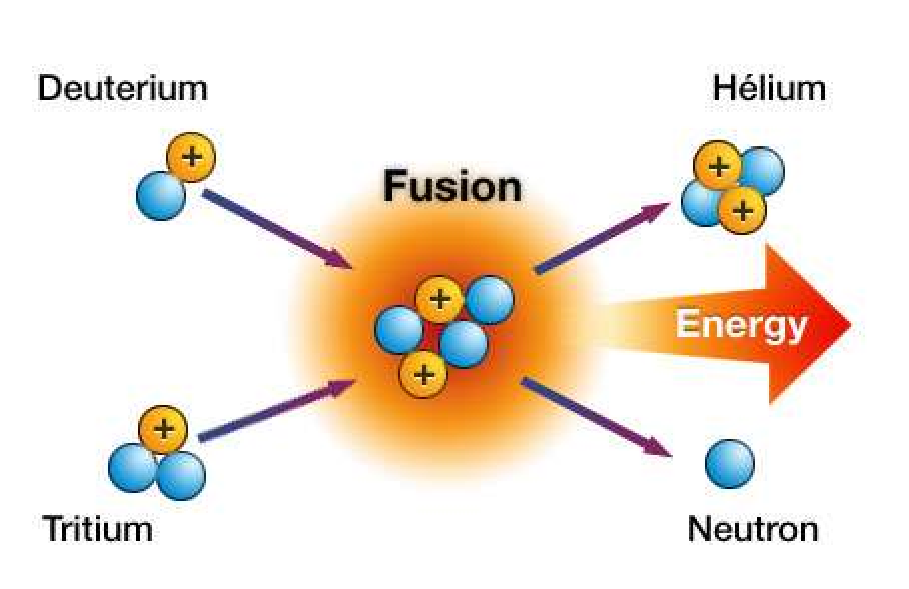


FIGURE 39
Two-point (Ellipsoid Design)
1956 Sketch from the Swedish Nuclear Weapons Program

FIGURE 40
One-Point Safety Test

MULTIPLE STAGE WEAPONS DESIGNS

FUSING DEUTERIUM AND TRITIUM RELEASES ENERGY



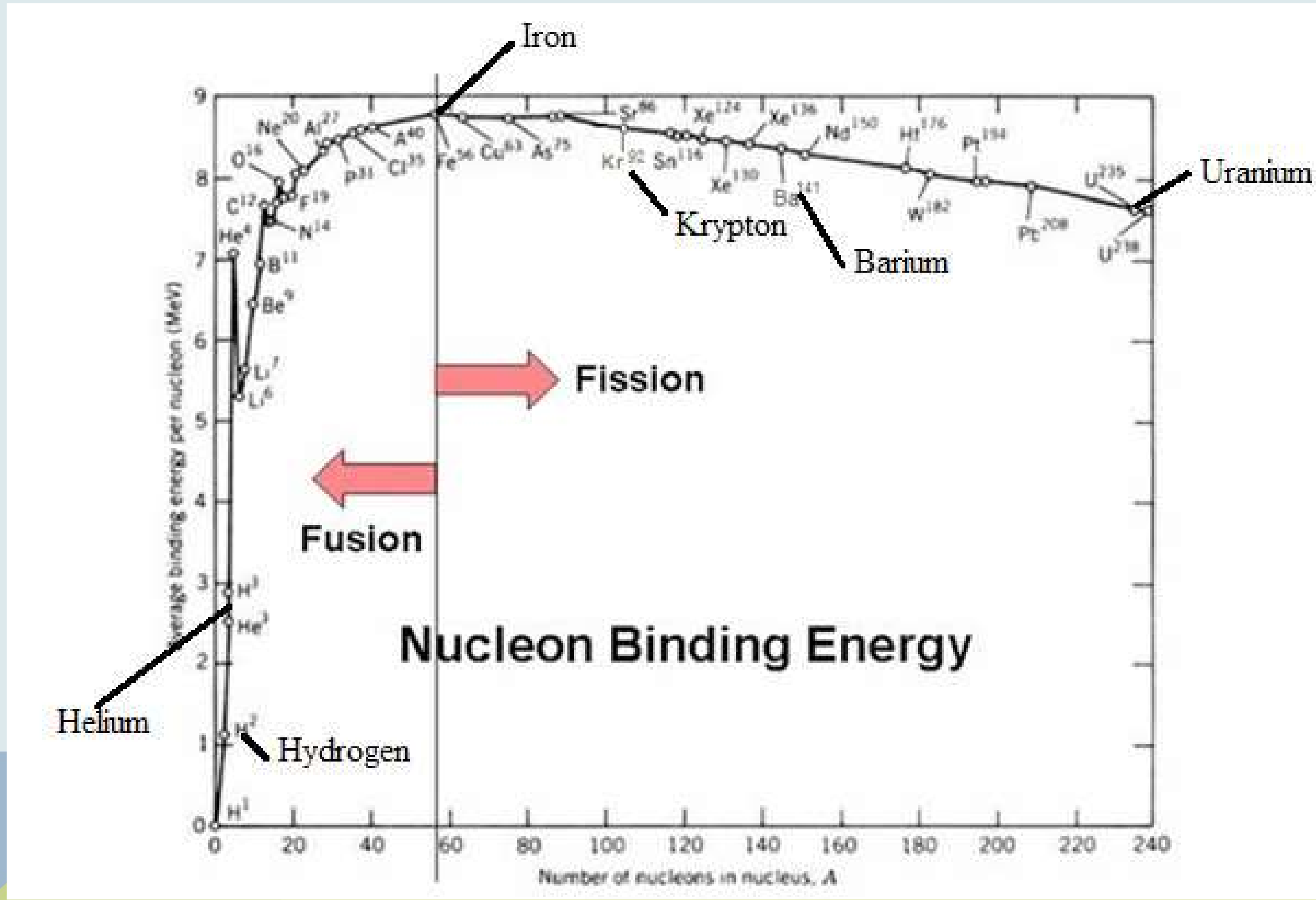
Deuterium:	2.01410178 u	Helium:	4.002602 u
Tritium:	3.0160492 u	Neutron:	1.008664 u
Total:	**5.03015098 u**	Total:	**5.011266 u**

Difference in Mass = 0.01888498 u

U = Atomic Mass Unit

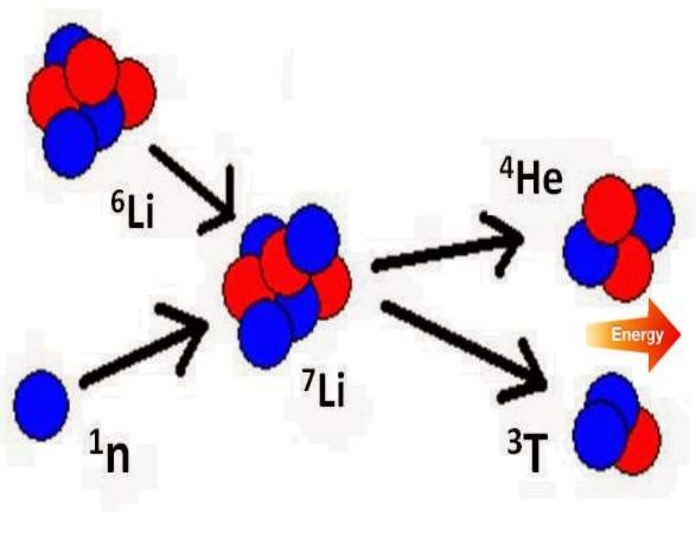
U = 1.660539040(20) X 10^{-27} kg

THE CURVE OF BINDING ENERGY

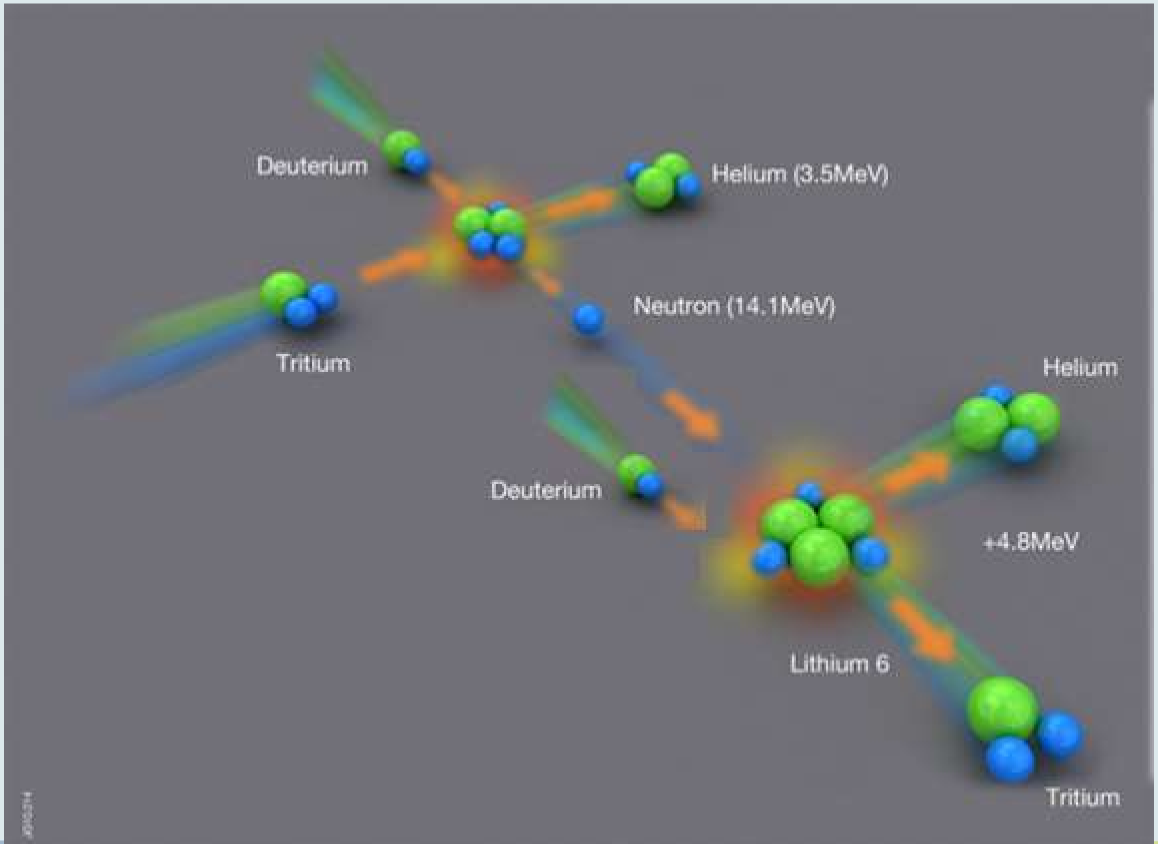


GRIST FOR FUSION: TRITIUM, DEUTERIUM, AND LITHIUM-6 DEUTERIDE

- **Thermonuclear weapons entail the fusion of deuterium and tritium**
- **To produce deuterium and tritium for this reaction, weapons designers use lithium-6 deuteride (6LiD)**
  - **6LiD consists of lithium-6 chemically bound to deuterium**
- **When 6LiD absorbs a neutron, it transmutes to helium and tritium**
  - **Deuterium detaches from 6LiD molecule**
  - **Tritium produced by transmutation is available for fusion with deuterium**



DEUTERIUM, TRITIUM, AND LITHIUM CHAIN REACTIONS



^{6}Li + Neutron = ^{3}H + ^{4}He + Energy

$^{2}H + {}^{3}H = {}^{4}He + n + 17.6$ MeV

--- or ---

$D + T = {}^{4}He + n + 17.6$ MeV

https://www.nap.edu/openbook/13371/xhtml/images/15.jpg

TWO-STAGE FUSION WEAPONS DESIGNS

TELLER-ULAM DESIGN

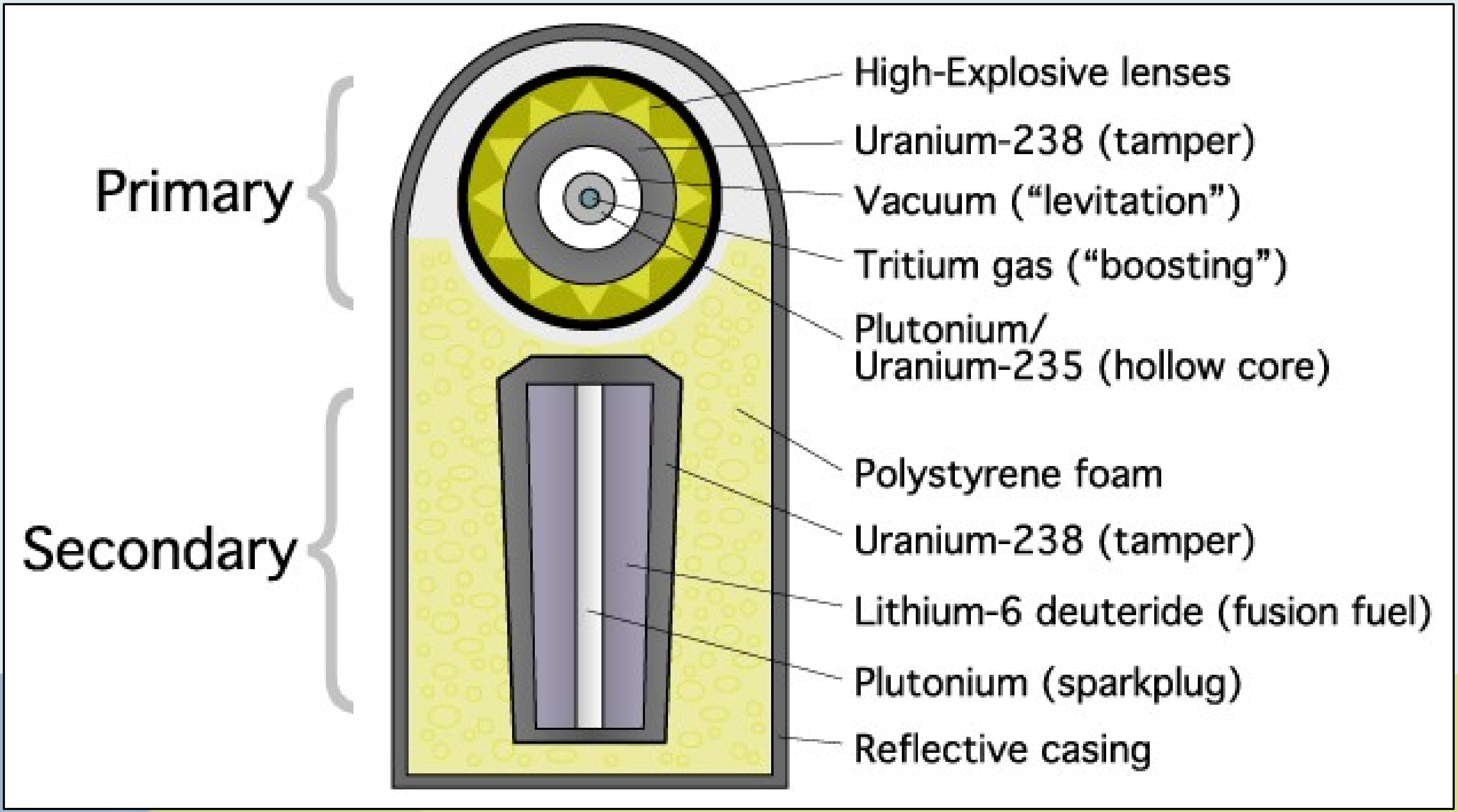


FIGURE 42
Two-Stage fusion weapon

DETONATION OF A TWO-STAGE FUSION WEAPON

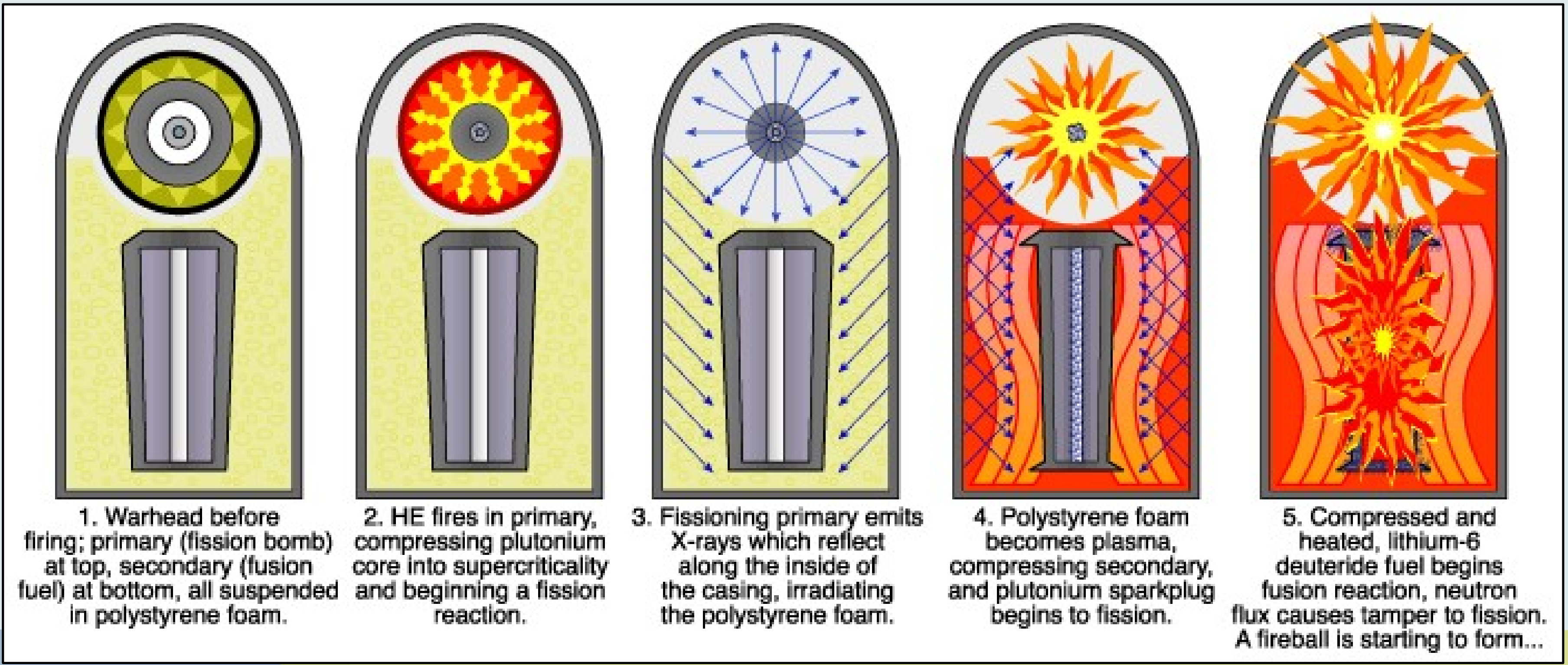


FIGURE 43

MARK-17: 1ST MASS-PRODUCED FUSION WEAPON DEPLOYED BY THE U.S. (15 MT)

FIGURE 44

THREE-STAGE FUSION WEAPONS DESIGNS

SCHEMATIC OF A 3-STAGE FUSION WEAPON

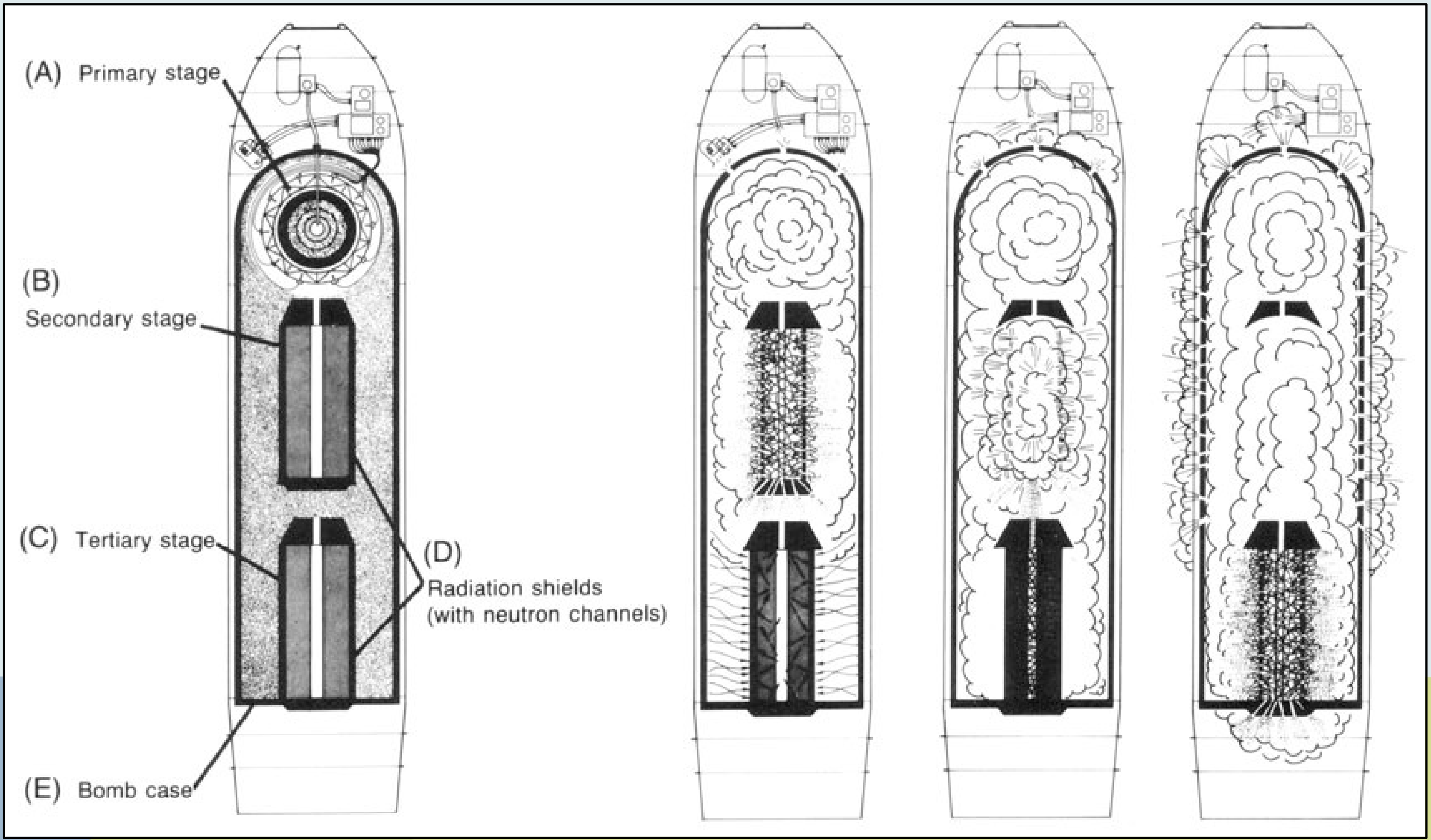


FIGURE 45

EXAMPLES OF 3-STAGE FUSION WEAPONS

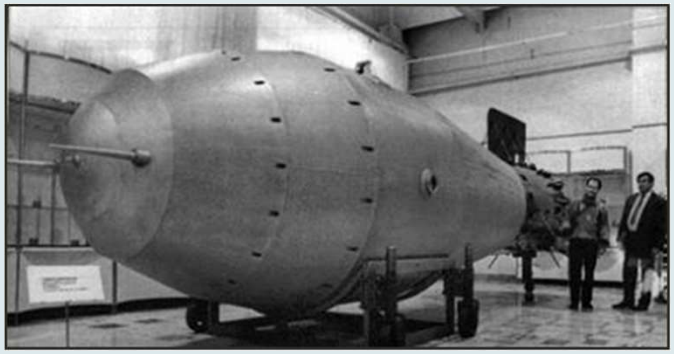


FIGURE 46
Mark-41
Only 3-Stage Fusion Weapon Deployed by the U.S
25 MT

FIGURE 47
Tsar Bomba
The Largest Fusion Device Detonated, Ever

THERMONUCLEAR WARHEADS, BOTH LARGE AND SMALL

The 8F675 warhead was the most powerful nuclear bomb ever deployed by the USSR with a maximum yield of 25 megatons. It was deployed from 1976-1986

W 76-2
Estimated yield 5-7 KT
Deployed 2020

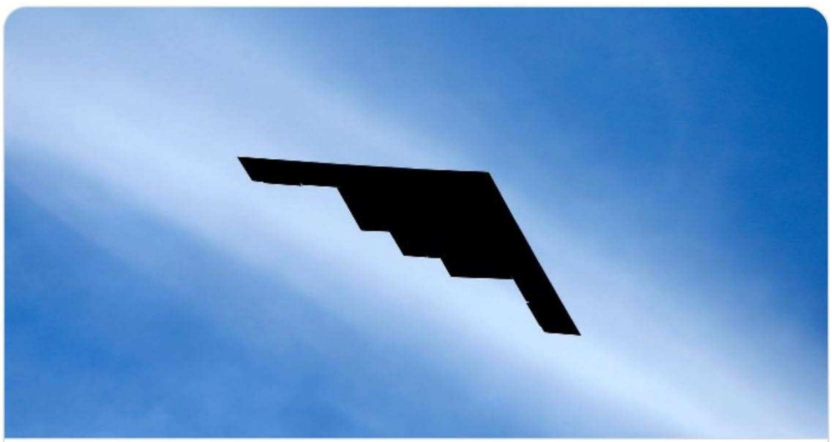
MARK 53 NUCLEAR BOMB, RETIRED 2011

The Mark 53 was a two-stage, thermonuclear bunker-buster bomb. After the retirement of the Mk. 41, it was America's most powerful nuclear weapon with a yield of 9 megatons. 50 of the bombs were retained as part of "Enduring Stockpile" until 2011.

MEGATON BOMBS ARE STILL A POLICY CONTROVERSY

NPEC
@NuclearPolicy

House-Senate debate emerges on upgrading America's largest nuclear weapon, the 1.2 megaton B-53 gravity bomb



B-83 86'ed? Not if GOP can help it.
politico.com

11:36 AM · Sep 22, 2021 · Twitter for iPad

B-83 nuclear bomb

ADDITIONAL VARIATIONS ON FUSION WEAPONS DESIGNS

W66 DEPLOYED IN THE 70S (DECOMMISSIONED EARLY 80S) W70 DEPLOYED IN THE 70S AND RETIRED 1992

Enhanced Radiation weapons, also known as “neutron bombs,” are two-stage fusion weapons with the non-essential uranium removed to minimize the fission yield.

They were developed in the 1950s, deployed in the 1970s, and retired in the 1990s.

W66 Warhead

COBALT BOMB NEVER DEPLOYED

A cobalt bomb is a two-stage fusion weapon with a cobalt "jacket." It was developed in the early 1960s, but was not deployed.

VARIABLE YIELD WEAPONS

	Yield	Length	Diameter	Weight	Delivery	
B61 Gravity Bomb	0.3 – 340 kt	3.56 m	33 cm	320 kg	Aircraft	
B83 Gravity Bomb	Low kt – 1.2 mt	3.7 m	46 cm	1,100 kg	Aircraft	
W80 Warhead	5-150 kt	80 cm	30 cm	130 kg	AGM-86 ALCM	

FIGURE 48
Currently Deployed Variable Yield Weapons

APPENDIX: HOW MUCH FISSILE MATERIAL IS NEEDED TO FUEL DIFFERENT NUCLEAR WEAPONS DESIGNS

NUCLEAR WEAPON YIELD VERSUS PLUTONIUM MASS FOR PURE FISSION WEAPONS

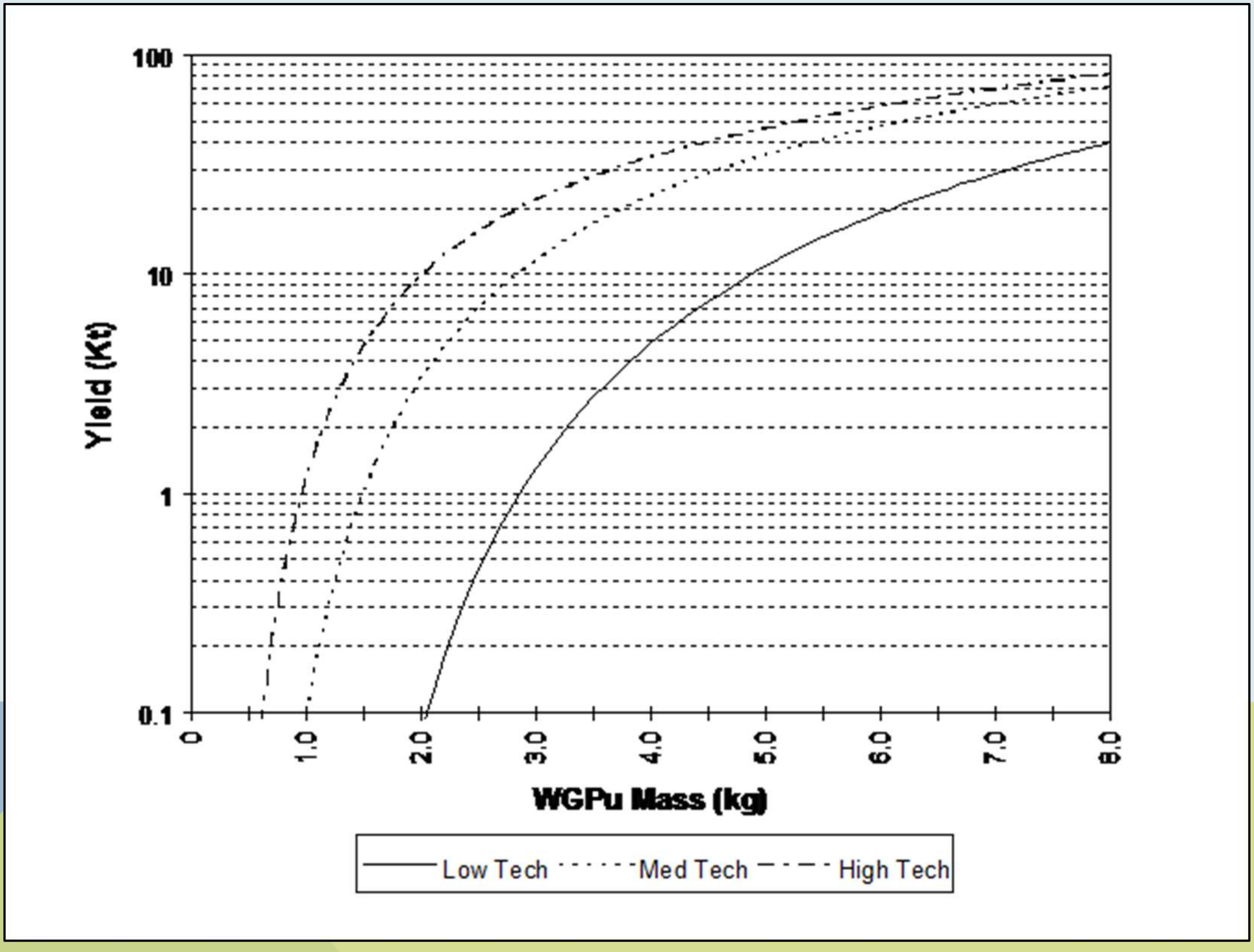


FIGURE 49

NUCLEAR WEAPONS YIELD VERSUS HEU MASS FOR PURE FISSION WEAPONS

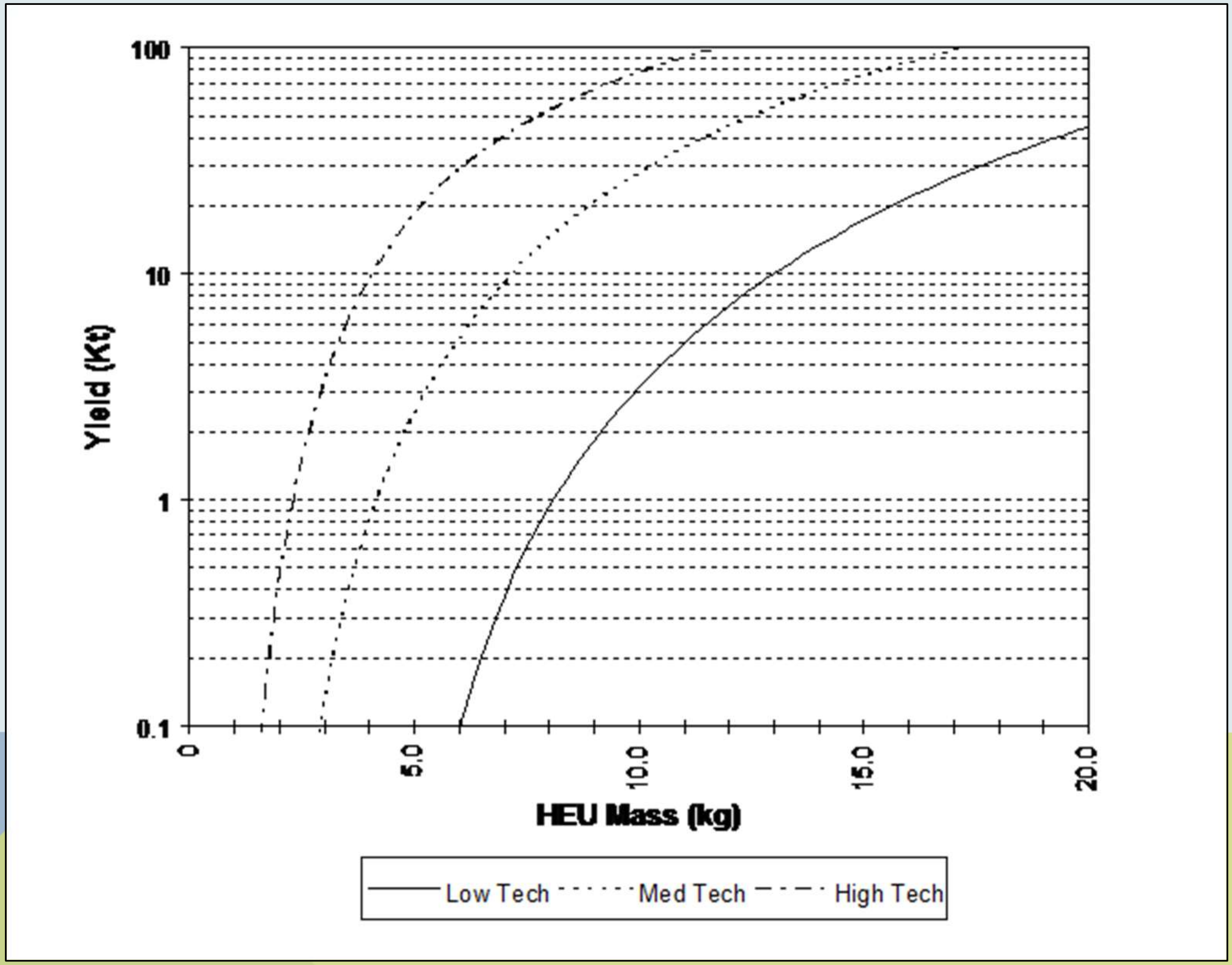


FIGURE 50

APPROXIMATE FISSILE MATERIAL REQUIREMENTS FOR PURE FISSION NUCLEAR WEAPONS

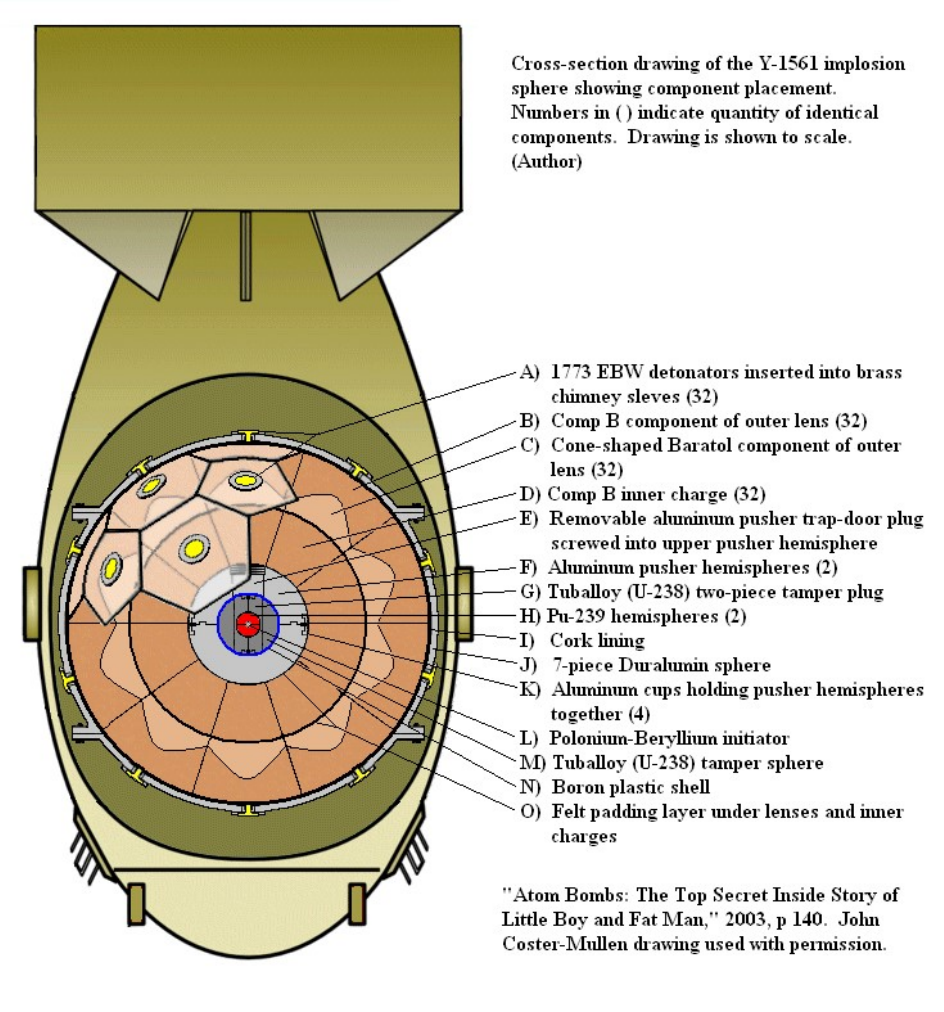
	WEAPON-GRADE PLUTONIUM (KG)			HIGHLY-ENRICHED URANIUM (KG)		
Yield	**Technical Capability**			**Technical Capability**		
(kt)	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
1	3	1.5	1	8	4	2.5
5	4	2.5	1.5	11	6	3.5
10	5	3	2	13	7	4
20	6	3.5	3	16	9	5

** Values rounded to the nearest 0.5 kilogram*

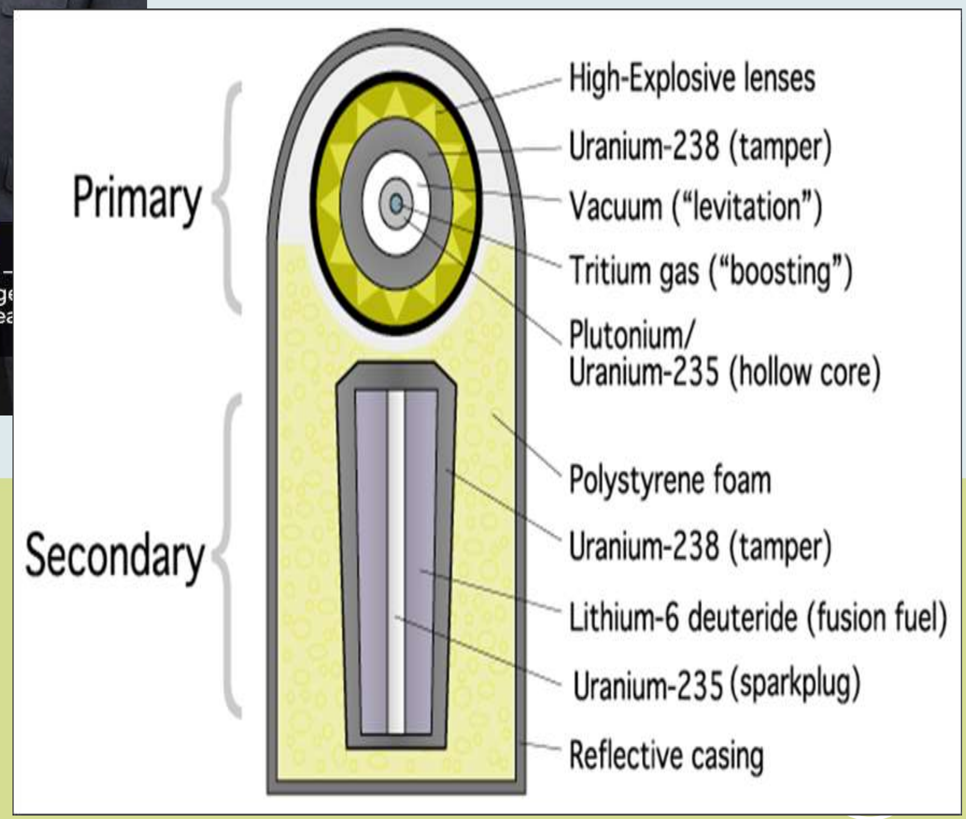
FIGURE 51

ADDITIONAL SLIDES

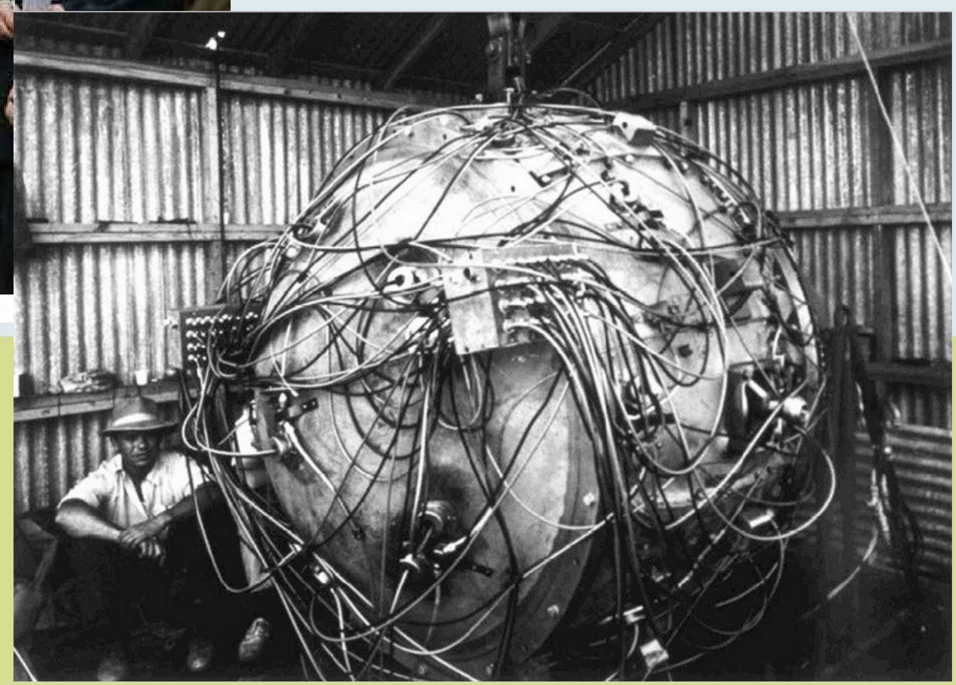
FIRST N. KOREAN TESTS WERE IMPLOSION FISSION WEAPONS



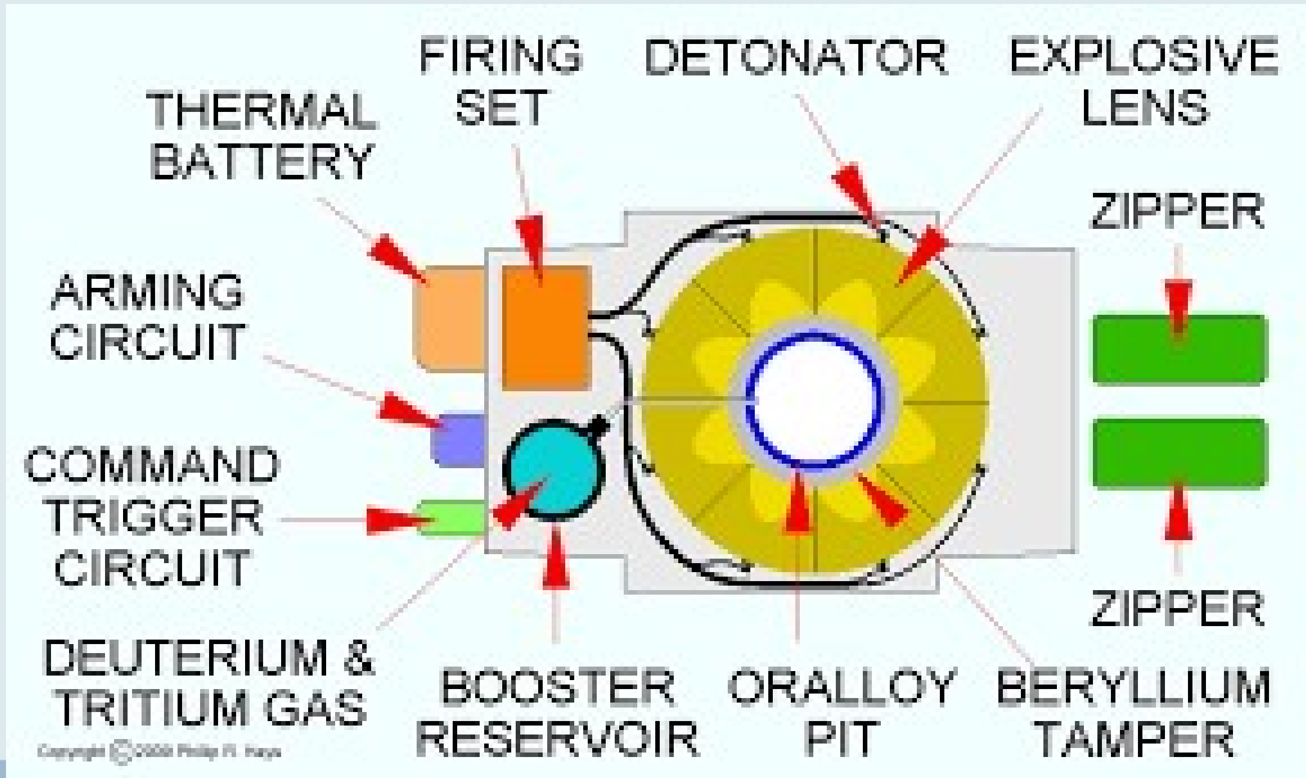
LATEST NORTH KOREAN CLAIM: A TWO - STAGE HYDROGEN BOMB?



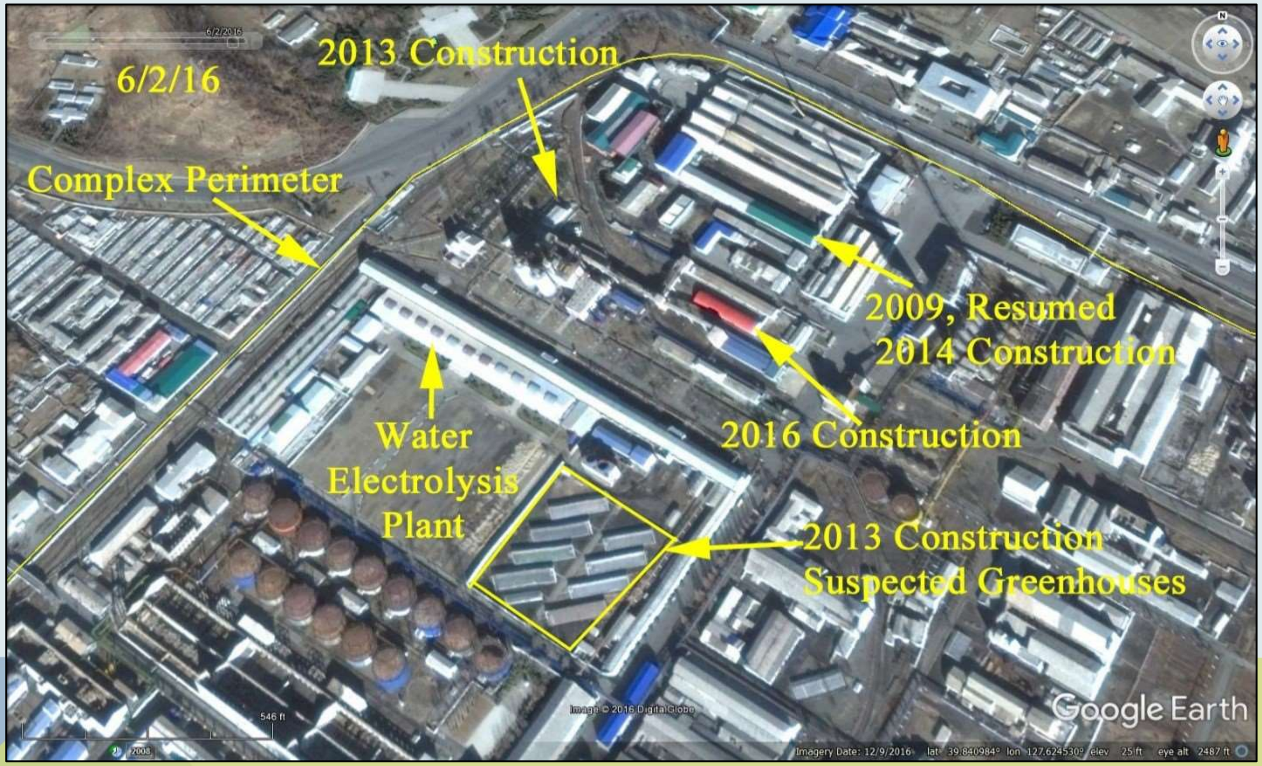
MINIATURE WARHEAD MOCKUP VS. 1945 US TRINITY SHOT



BOOSTED FISSION WEAPON DESIGN



SUSPECTED DPRK LITHIUM 6 PRODUCTION PLANT



DPRK COULD USE EITHER OF ITS REACTORS TO IRRADIATE LI6 TO PRODUCE TRITIUM

^{6}Li + Neutron = ^{3}H + ^{4}He + Energy

SUSPECTED DPRK TRITIUM EXTRACTION PLANT

BOOSTING: WEAPONS IMPLICATIONS

Higher yield to weight ratio warheads–missile delivered warheads

Potential to make more warheads from a given amount of fissile material

Potential arsenal size measured in hundreds before 2030

“Weapons-grade” plutonium no longer needed to make efficient bombs

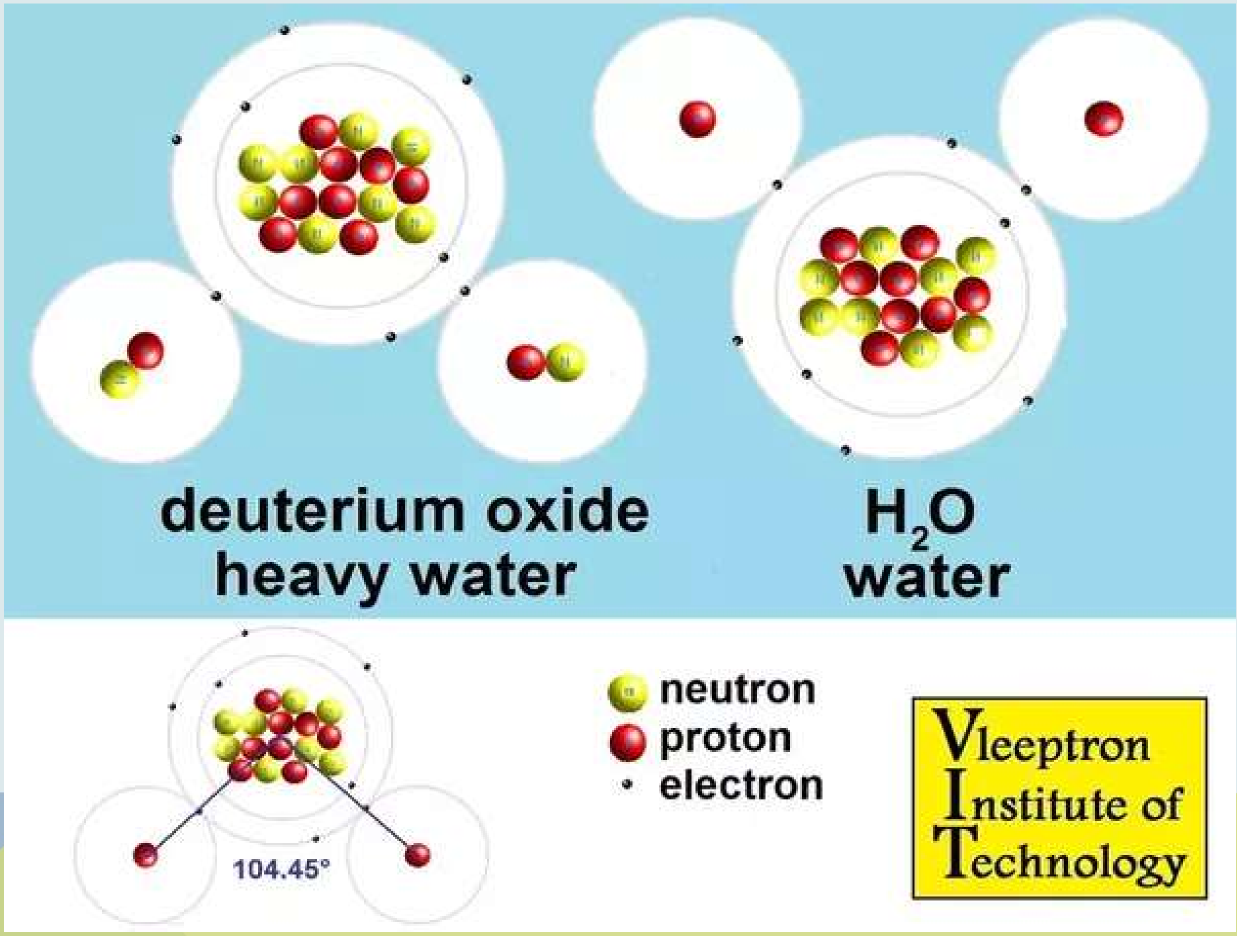
URANIUM ENRICHMENT LEVELS

Type	**Percentage U^{235}**
Natural Uranium	0.7%
Low Enriched Uranium (LEU)	0.7% - 20%
Reactor-Grade Uranium	3% - 5%
Highly Enriched Uranium (HEU)	> 20%
Weapons-Grade Uranium	> 90%

Sources: For weapons-grade U, see: World Nuclear Association, Uranium Enrichment, September 2015

For others, see: U.S. Department of Energy, “Nuclear Fuel Facts: Uranium,” accessed September 2015

DEUTERIUM HEAVY WATER



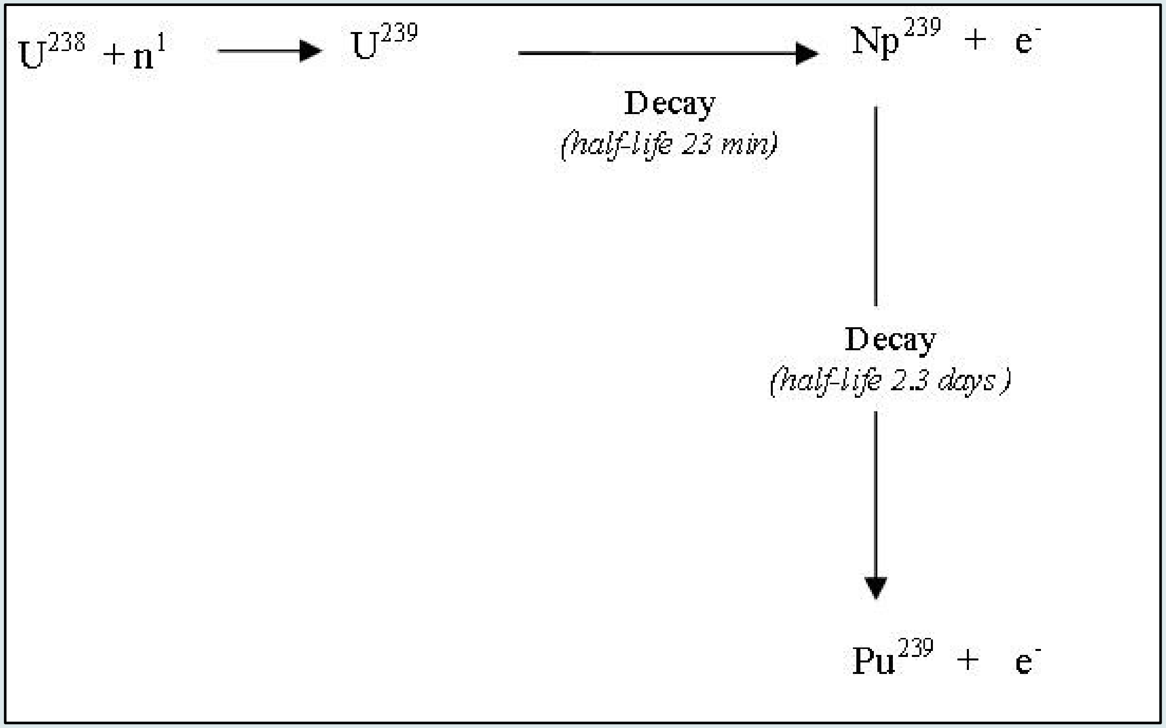
DEFINITIONS FOR GRADES OF PLUTONIUM

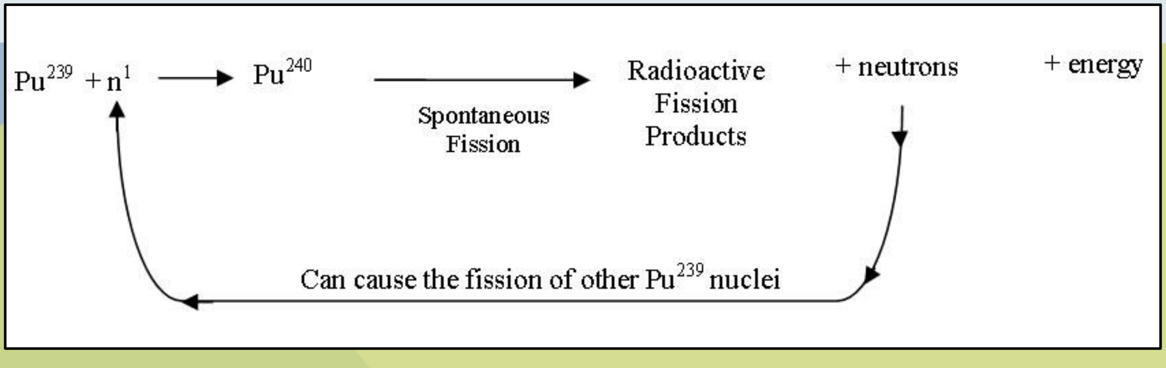
Type	Percentage Pu^{239}
Super-grade	>97%
Weapons-grade	>93%
Fuel-grade	80-93%
Reactor-grade	<80%

Sources: U.S. Dept. of Energy, "Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives," January 1997, pp. 37-39, available from http://www.ccnr.org/plute.html.

John Carlson, John Bardsley, Victor Bragin, John Hill, "Plutonium Isotopics - Non-Proliferation And Safeguards Issues," IAEA-SM-351/64, Canberra: Australian Safeguards and Nonproliferation Office, August 1997, http://fas.org/nuke/intro/nuke/O_9705.htm.

PLUTONIUM AND THE PROBLEM OF PREIGNITION





*Reactor Plutonium Utility in Nuclear Explosives**

Bruce T. Goodwin, PhD

Senior Fellow, Center for Global Security Research, LLNL

NPEC
2017

*drawn from the work of Robert Selden

Lawrence Livermore National Laboratory

LLNL-PRES-801535

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Disinformation is rampant – from Japanese industry

No More Innocent Logic
"Plutonium Equals to Nuclear Weapons" (June 2016)

….To promote future global energy policy and accomplish the abolishment of nuclear weapons, uses of present LWRs must be promoted. ***The advocacy that nuclear weapons can be made from plutonium extracted from electricity generating power reactors would be a too innocent notion; and it would be a shame to take advantage of such oversimplified non-nuclear logic and use it as a political agenda. We must end this kind of nonsense***. Nuclear disarmament experts and politicians in nuclear-weapon states should have already known what we say here. http://www.cnfc.or.jp/index_e.html

The truth (see the following *'s) **however, is inconvenient**

Plutonium (Pu for short)

- **Plutonium is man-made, produced from Uranium in a reactor**
- **There are many isotopes of Plutonium. The length of time it is left in a reactor determines its isotopic composition**

Typical* Pu Isotopic Composition:

	238	239	240	241	242
Reactor grade Pu	1.5%	58%	24%	11.5%	5%
Weapons grade Pu	---	93.5%	6%	0.5%	---

*Reactor grade often defined as any Pu with more than 18% Pu-240

Fissile Material Properties Important to Bombs

- There are three aspects of fissile material important in nuclear explosives

  - Fissile material reactivity

    Critical Mass

  - Ease of handling

    Radioactivity and Heat Generation

  - Neutron background

    Spontaneous fission rate

Nuclear Reactivity

The most useful way to compare fissile materials for nuclear explosives is to compare fast neutron (or "prompt") critical mass:

Fissile material	critical mass (kg-bare sphere)
Weapons grade Pu	11 *
Reactor grade Pu	13 *
Uranium 233	16
HEU* 93.5% U-235	56

* Highly Enriched Uranium

The lower the critical mass,

the less material is needed per weapon

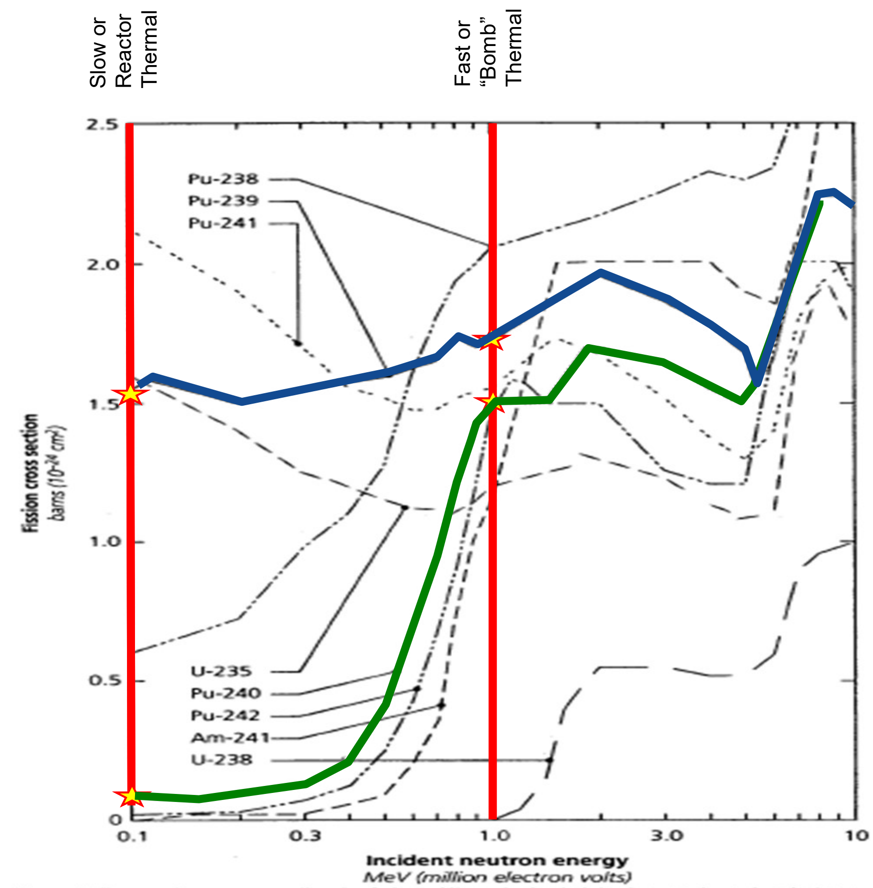


Figure 2: The neutron cross-section for fission of the principal plutonium and uranium isotopes (and americium-241, a decay product of Pu-241) against neutron energy.

Pu-240 has negligible fission with slow neutron…

…but is a *good* fissile material with fast neutrons…

…fast neutrons drive nuclear explosives

Handling

- **Now compare reactor grade Pu with weapons grade**

	Weapons grade	Reactor grade
Radioactivity (curies/gm)	3	10
Heat (watts/kg)	3	10
Neutrons emitted (n/sec/gm)	100	500

- **Radioactivity differences of several factors of ten would be needed to seriously inhibit handling** *
- **In newly built facilities, handling reactor grade is essentially the same as handling weapons grade Pu** *

Neutron Background

- **Neutron background is important in a nuclear explosion because it can influence when the explosive chain reaction starts**
- **A condition called “pre-initiation” has been widely cited as a key problem that reactor grade plutonium poses for creating a nuclear explosion**
- **The number of neutrons present depends upon the type of fissile material and comes from random, spontaneous fission**

  Neutron Output (n/sec/gm): 100(wpns) 500(reactor)

- **Pre-initiation results in a statistical distribution in yield between a predictable, fixed lowest yield and a maximum possible yield**

Conclusion

- A militarily useful first generation nuclear explosive using ***reactor grade plutonium*** can be designed to produce nuclear yield in the multi-kiloton range *

- With ***reactor grade plutonium***, the yield would be at least 1 kiloton * and ***more likely much higher***

This would have a destructive radius *much greater* than 1/3 that of the Hiroshima explosion *

What this means

- "A potential proliferating state or subnational group using designs and technologies no more sophisticated than those used in first-generation nuclear weapons could build a ***nuclear weapon from reactor grade plutonium*** that would have an assured, ***reliable yield of one or a few kilotons (and a probable yield significantly higher than that)"*** *

- "An ***advanced nuclear weapon states*** such as the United States and Russia, using modern designs, could produce ***weapons from reactor grade plutonium having reliable explosive yields***, weight, and other characteristics generally ***comparable to those of weapons made from weapons grade plutonium"*** *

* Quoted from: US Dept of Energy Publication "Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives, January 1997 http://www.osti.gov/scitech/biblio/425259