Nuclear Weapons and the Nuclear Fuel Cycle

Dec 3 2013
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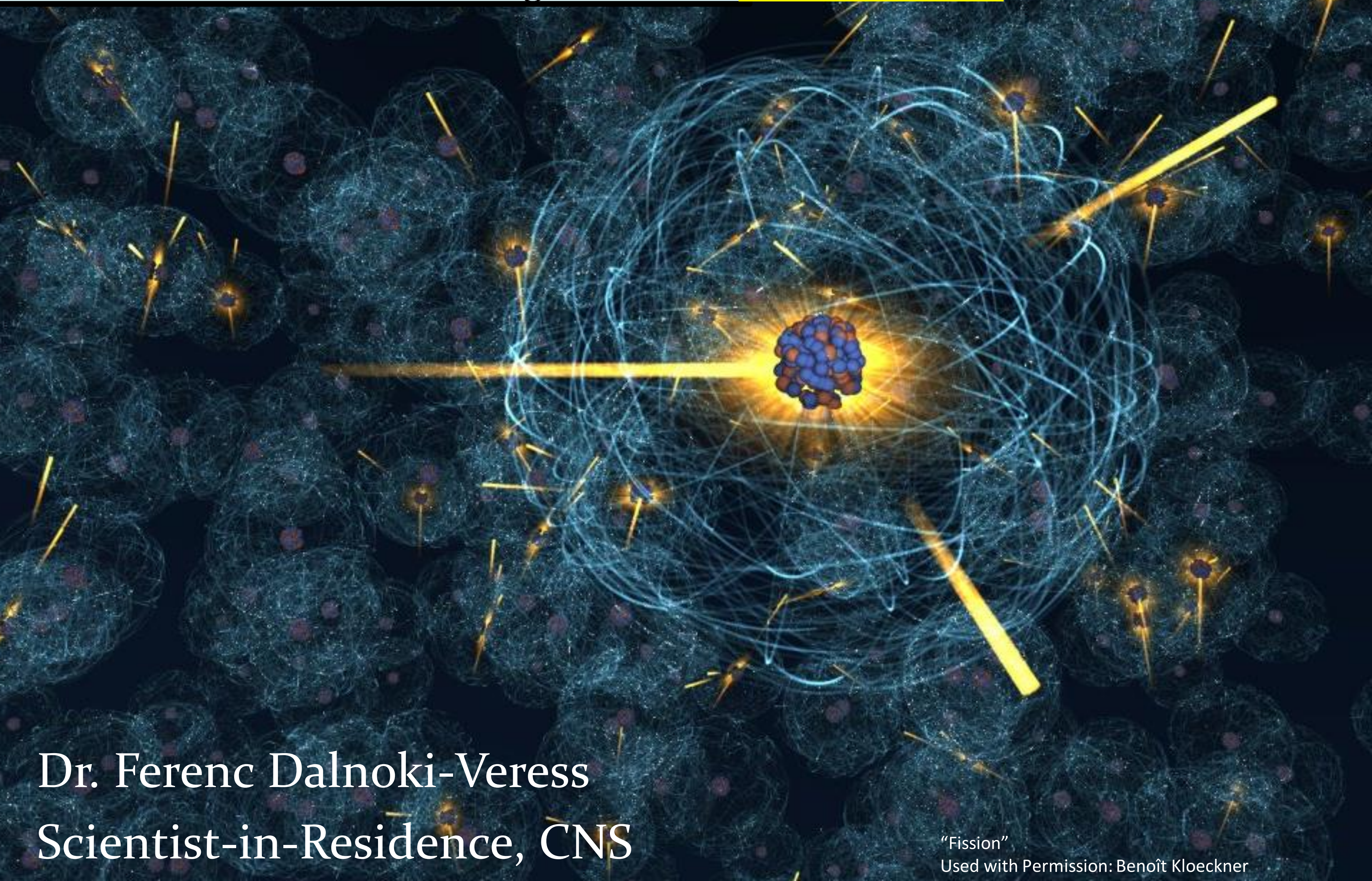

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“Fission”
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Outline

- Atoms, radioactivity
- Fission as a way of producing energy
- Military application of nuclear materials
- Civilian application of nuclear materials
- **The Nuclear Fuel Cycle** & How the military application is intertwined with the civilian application.

Modern View of the Carbon Atom

Much Less Dense Cloud

Electron cloud = 6 electrons

1% of the time we find a carbon-13 atom. It has 7 neutrons because number of particles = 6 (protons) + 7 (neutrons) =13

6 protons
6 neutrons

We say this is the isotope carbon-12

Hard Dense Center

Carbon-12 and carbon-13 are isotopes of carbon. **Chemically** behave like carbon but behave differently in **nuclear reactions**.

Chemistry vs Nuclear Physics

Atoms bond to form molecules = Chemistry

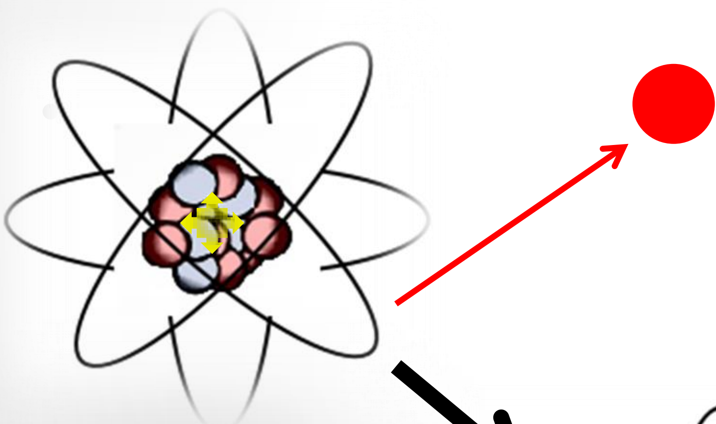
Let energy be represented by E=E(CHEM)

Nuclear world E(NUCLEAR) $=10^6$-10^8 E(CHEM)

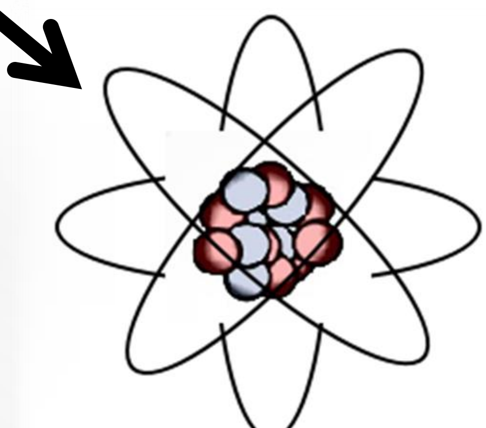
Protons and neutron bound in the nucleus =Nuclear Physics

Radioactive Materials

- Radioactive describes the property that some isotopes will over time decay (or change) to a different isotope (could even be a different element).



Bundle of energy
= Different **particles**
with different properties.



More Stable

Radioactive Decay

If we wait long enough it will all become Ba-137

The more energy you have the more damage you can do.

http://www.wylio.com/credits/Flickr/4700028173

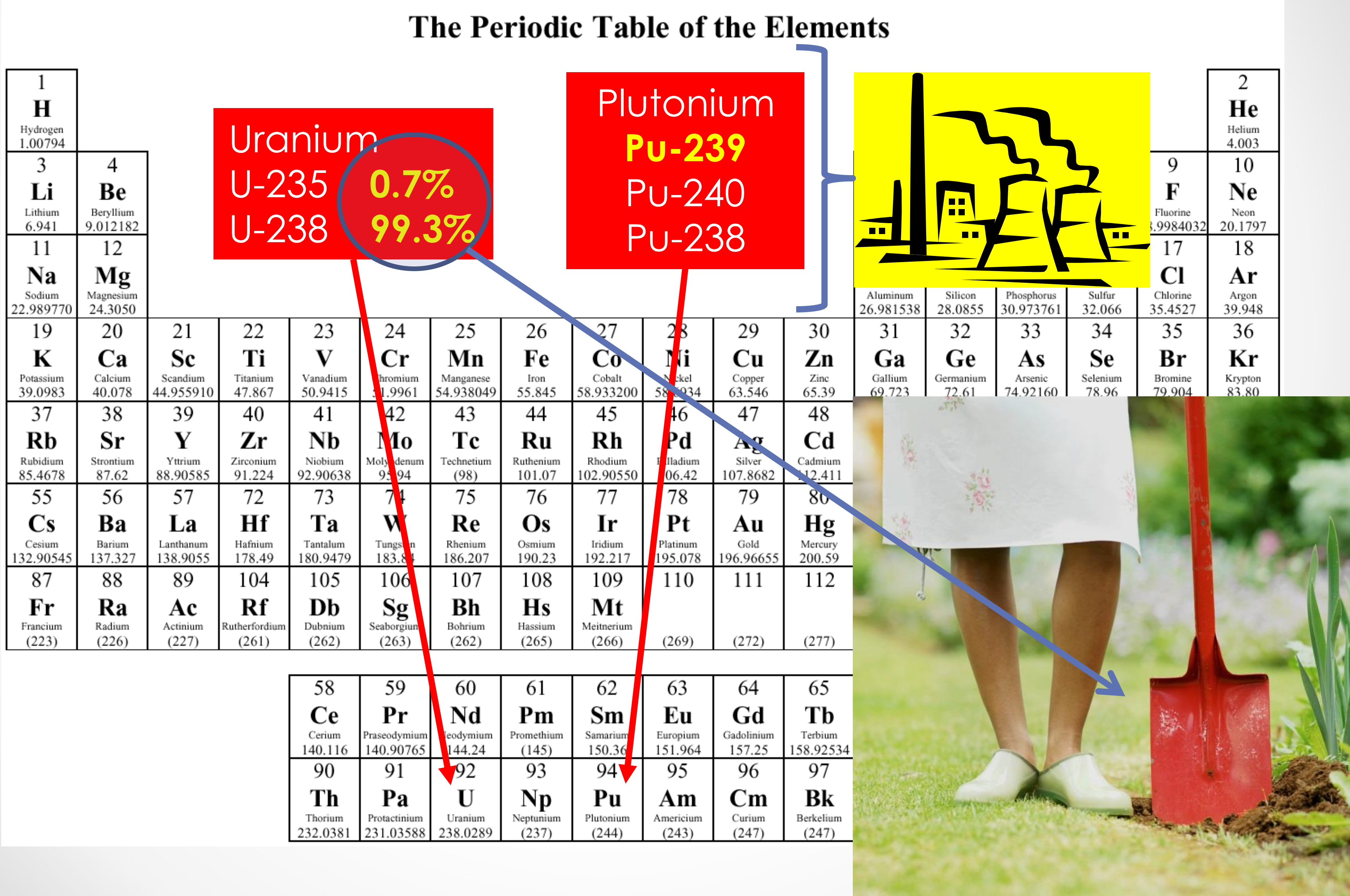
The more bullets you have the more damage you can do.

But actually radioactivity is everywhere

Radioactivity is everywhere but is it dangerous?

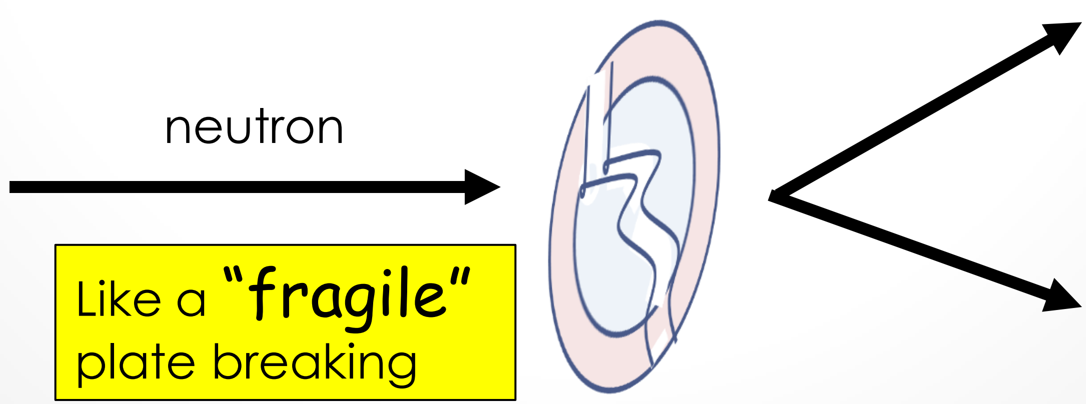
Nuclear reactors or weapons use a special class of isotopes that exhibit a strange property called fission

Everything starts with U-235: One of Two Elements that Fission



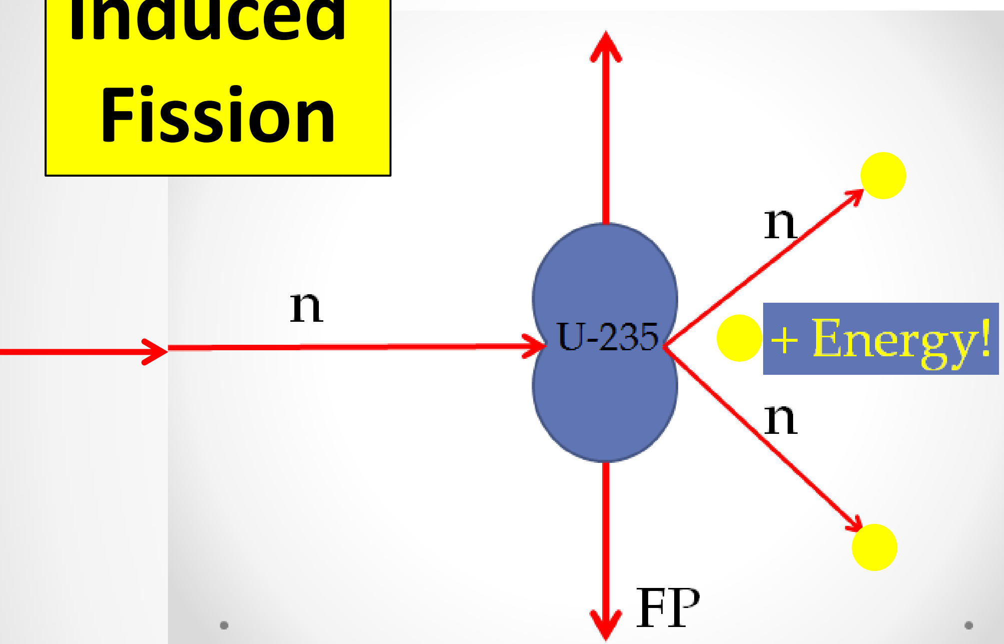
Nuclear Weapons Use Fission to Generate Energy

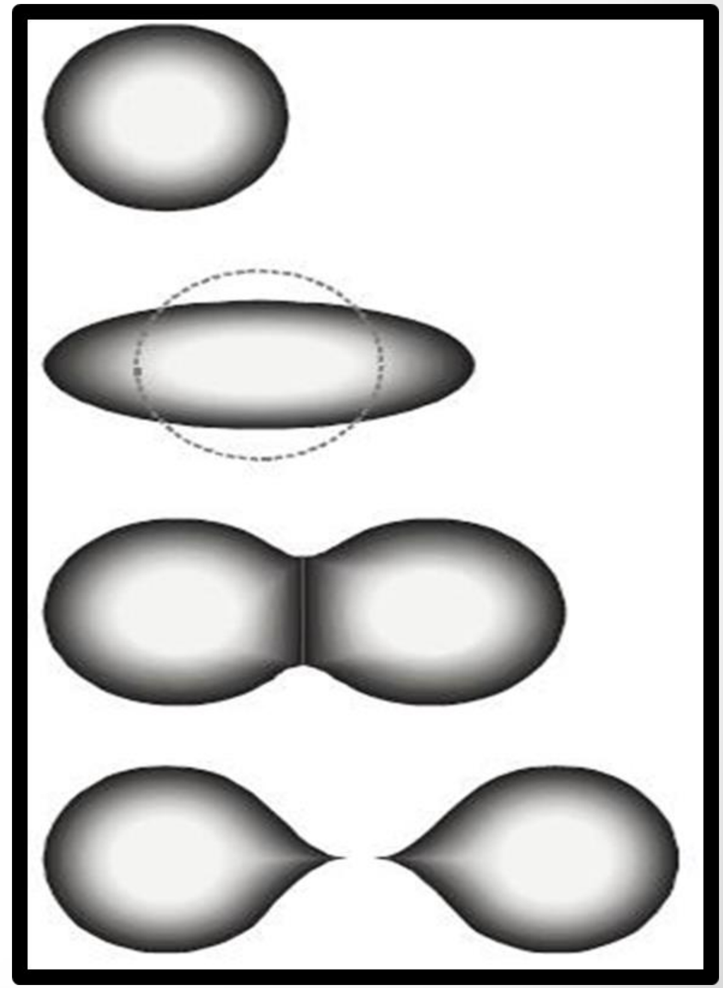
- Some isotopes instead of decaying by emiting particles they split into two or three, and in the process emit neutrons and an incredible amount of energy.
- These isotopes are so large and unstable that you only need a small kick to break them.



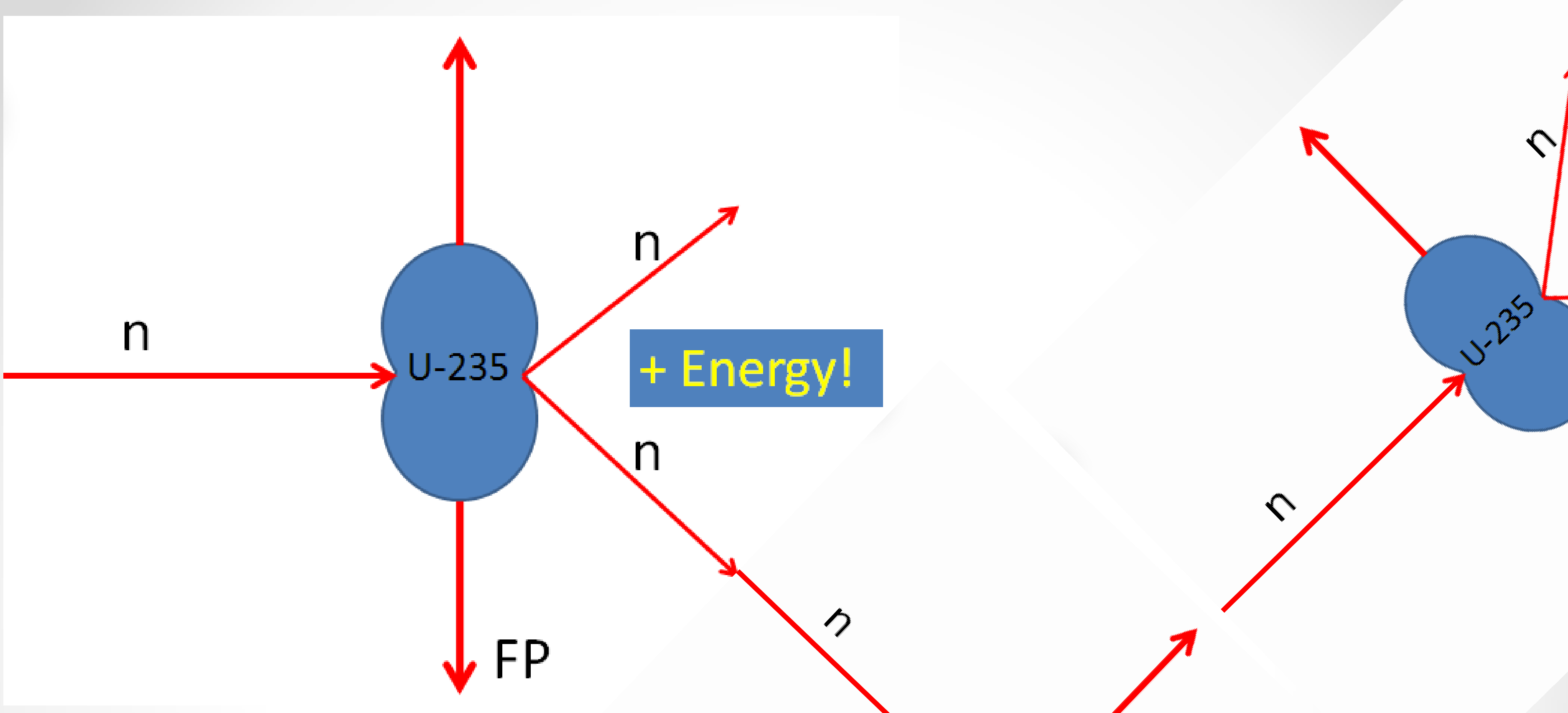
Fission Process

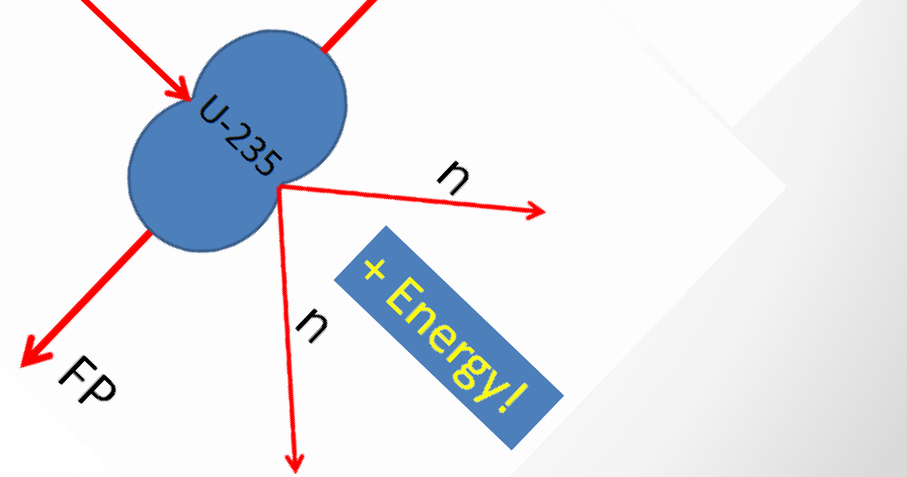
Induced Fission





Induced fission can occur where a neutron released can induce fission in another nucleus.

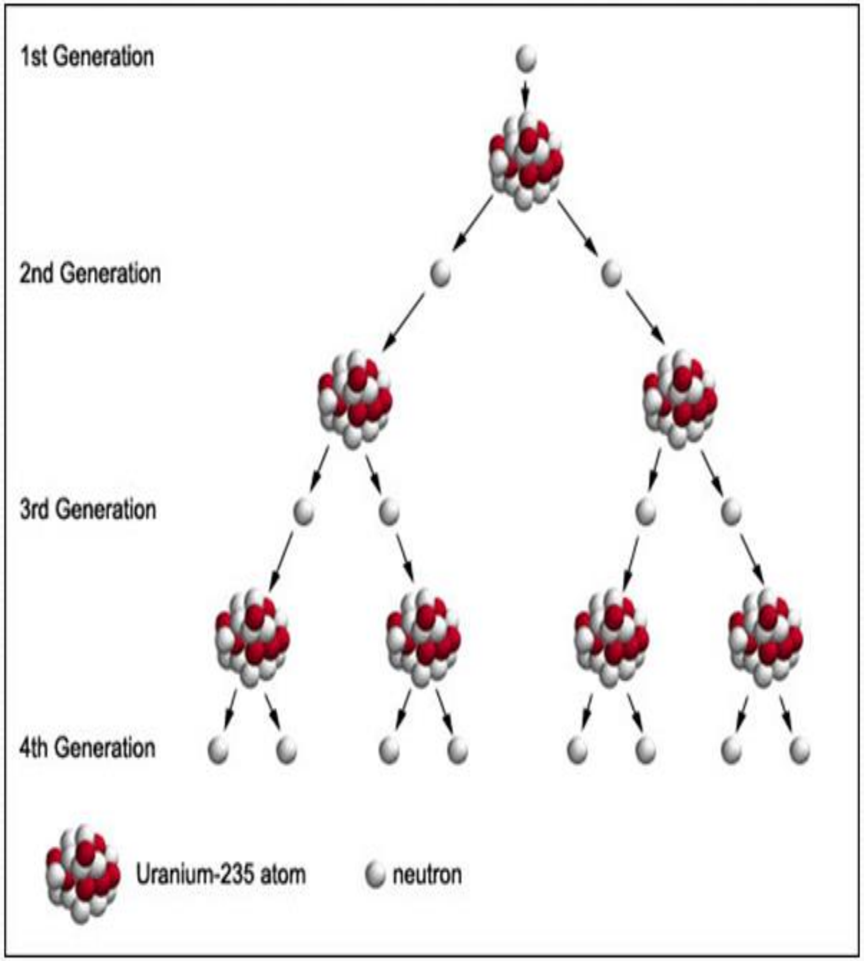




HERE IS WHAT IS INCREDIBLE

Start a chain reaction..

Chain Reaction



Total energy produced is equivalent to number of fissions which increases exponentially (2,4,8,..) as the number of generations increase

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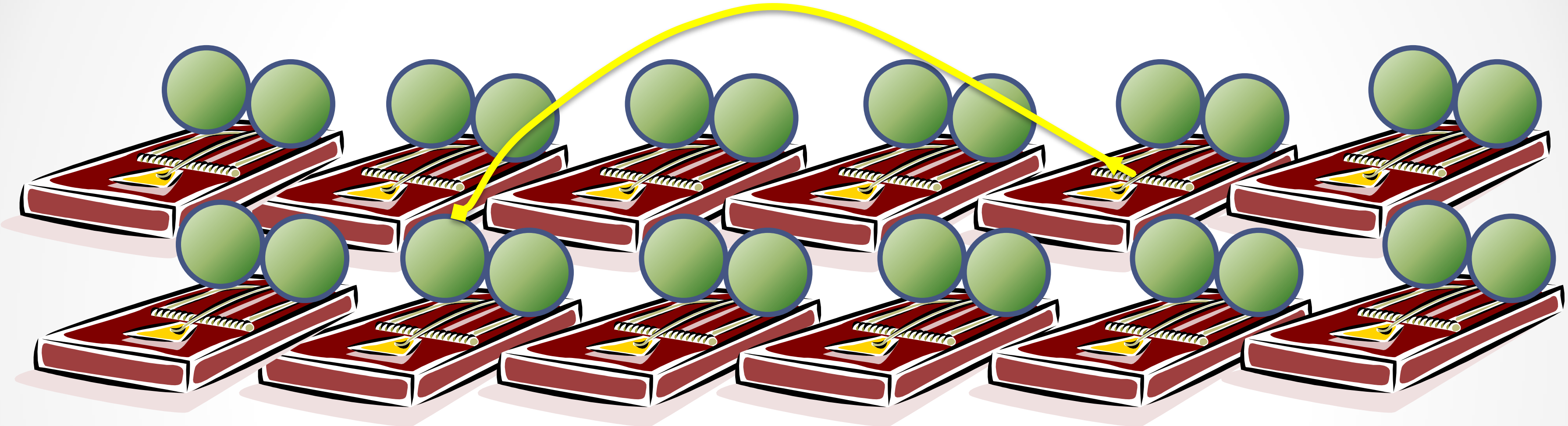
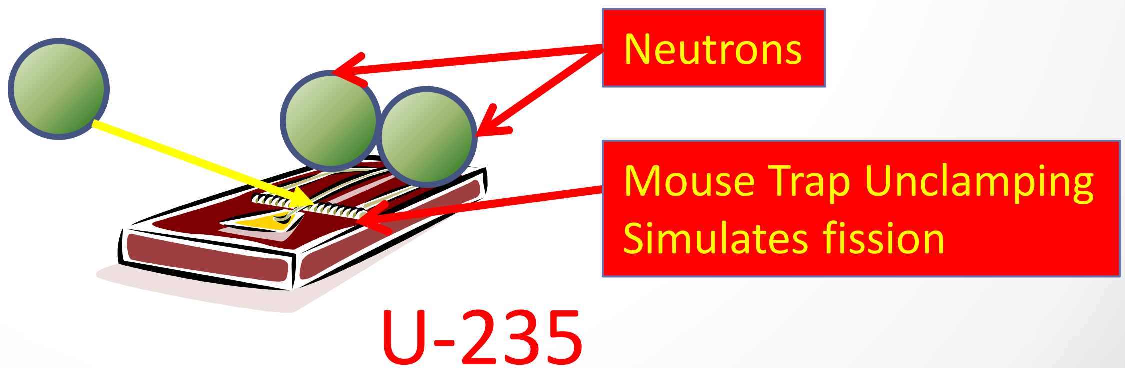
Left behind are the many **fission products** (that are Produced) and tend to be radioactive for hundreds of years.

chain reaction – nature of tremendous energy released from a nuclear bomb

A Useful Analogy



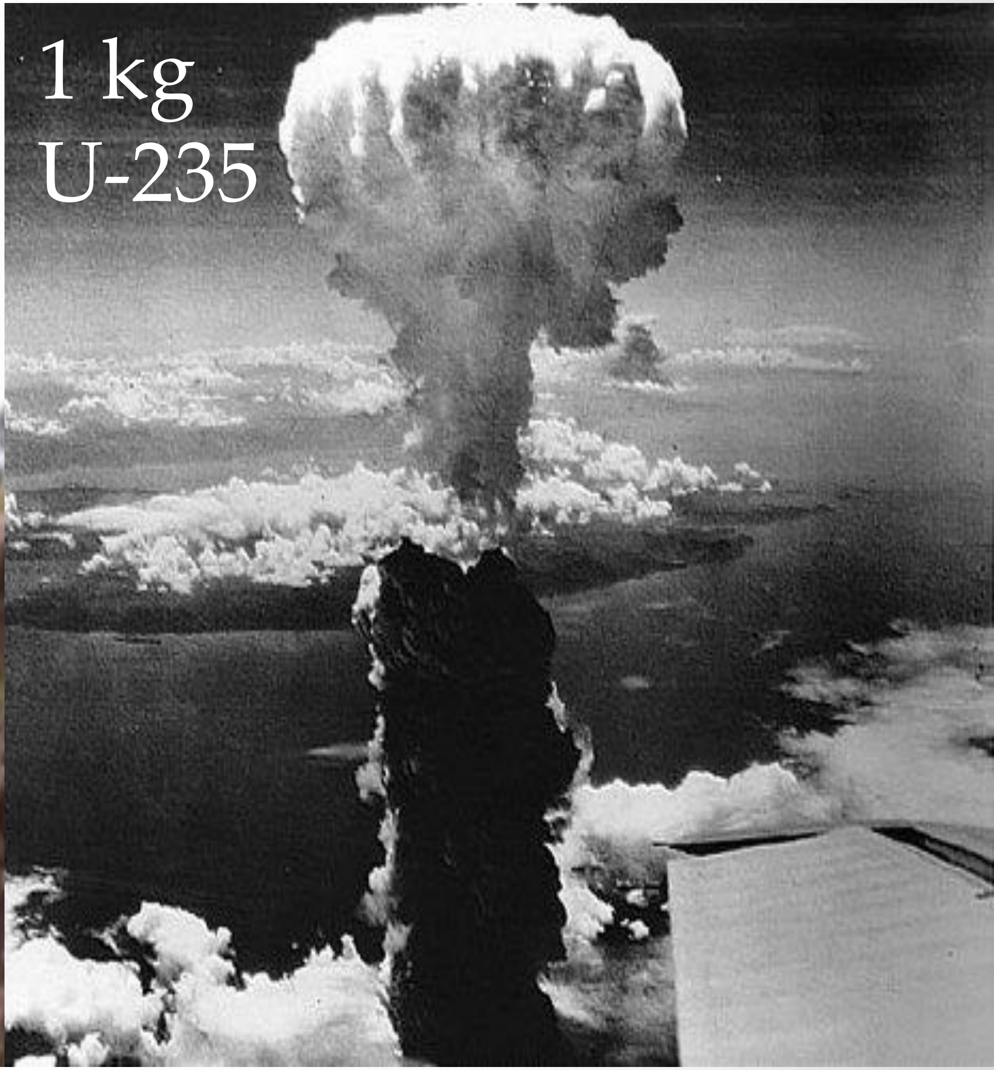
U-235 Density
HIGH
FAST



Uncontrolled Reaction

http://www.youtube.com/watch?v=Pmy5fivI_4U
http://goo.gl/t5QyUJ

The Nuclear Difference

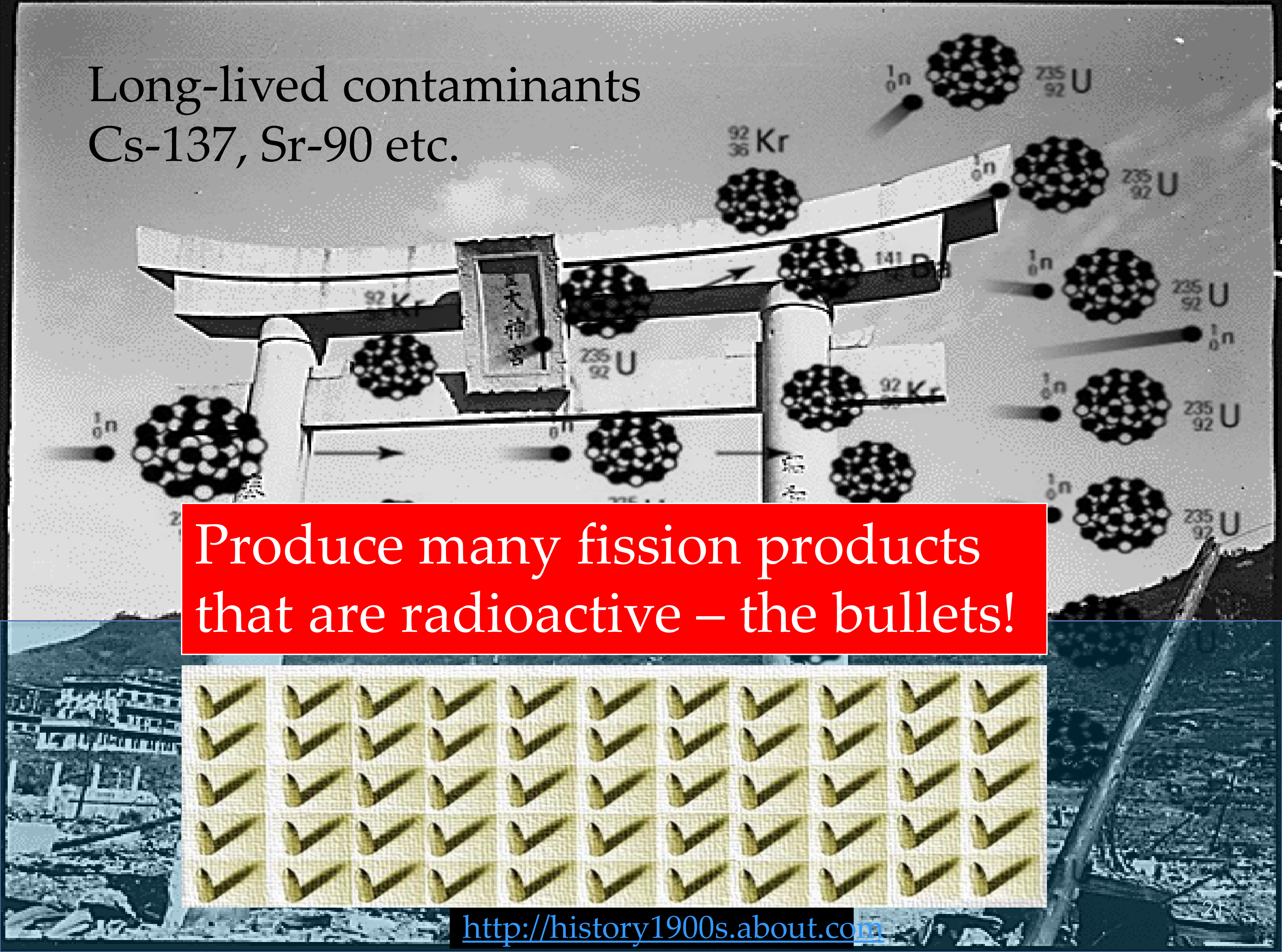


Yield = 0.000001 kt TNT

Yield = 15 kt TNT

The Nuclear Advantage

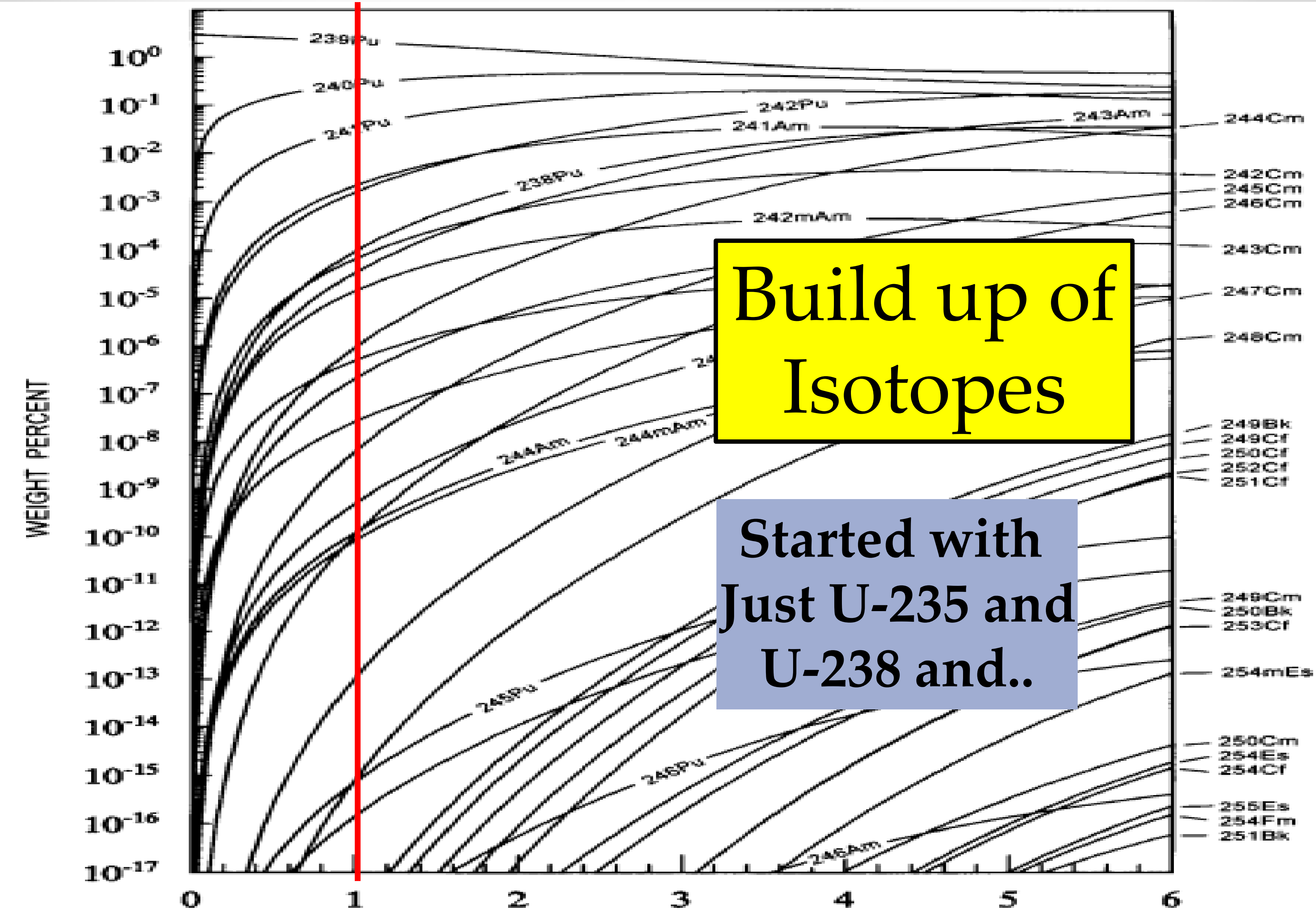
	Chemical	Fission
Reaction	$C+O_2 \rightarrow CO_2$ Burning Coal Bonding to form molecules	n + U-235 → Ba-142+Kr-85 + 2 n's Splitting the atomic nucleus
Inputs	Coal	UO2
Reaction Temp	700 C	500 C
Energy Released/kg	1	63,000



Long-lived contaminants
Cs-137, Sr-90 etc.

Produce many fission products that are radioactive – the bullets!

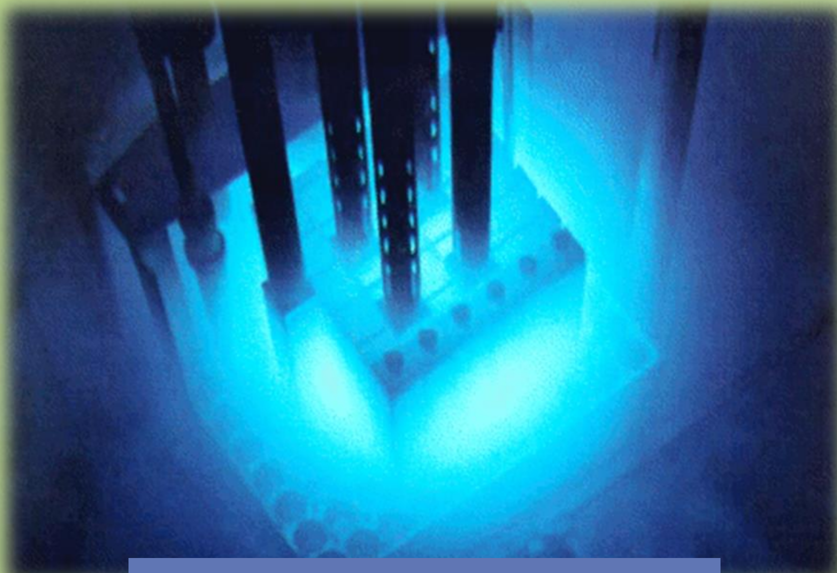
http://history1900s.about.com



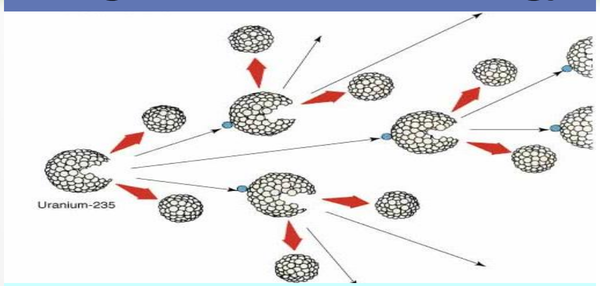
Irradiation Time in Years 3% U-235 Fuel

Peaceful vs Weapons

Power Reactors: LEU



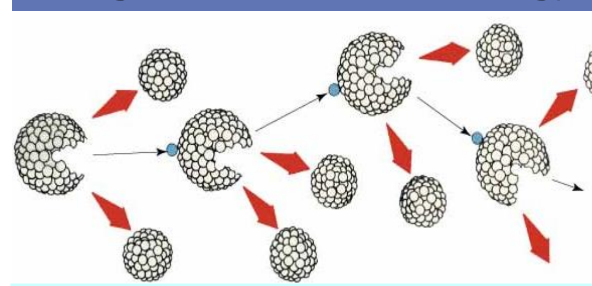
Large Amount of Energy



Slow, Controlled
Release of Energy

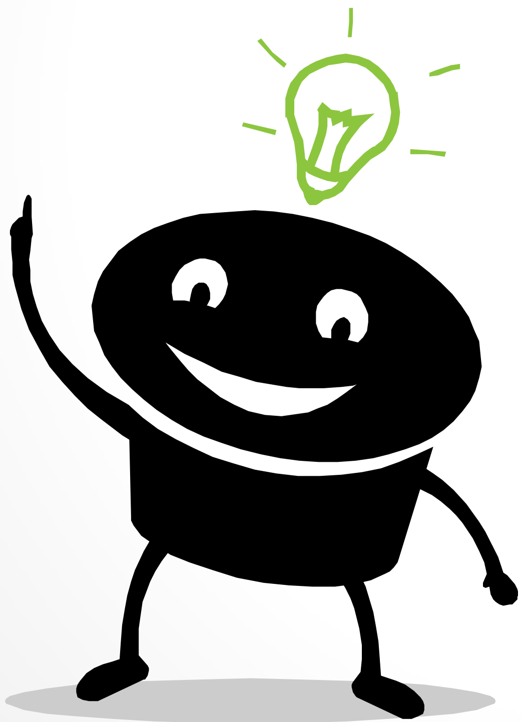
NW: HEU,Pu

Large Amount of Energy



FAST , Uncontrolled
Release of Energy

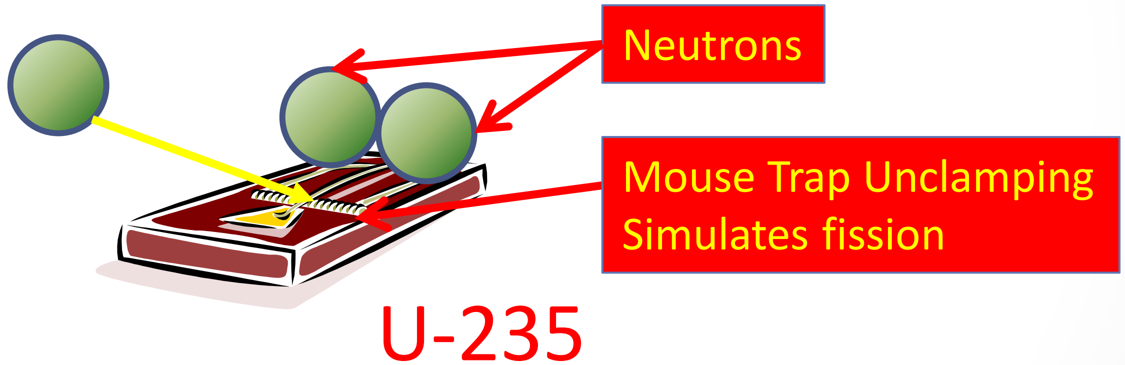
Nature of the energy in a reactor or nuclear weapon is the same!



A nuclear reactor is essentially a slowly, controlled, exploding nuclear weapon.

Back to Nuclear Weapons

The Key to Nuclear Weapons is Managing the Neutrons

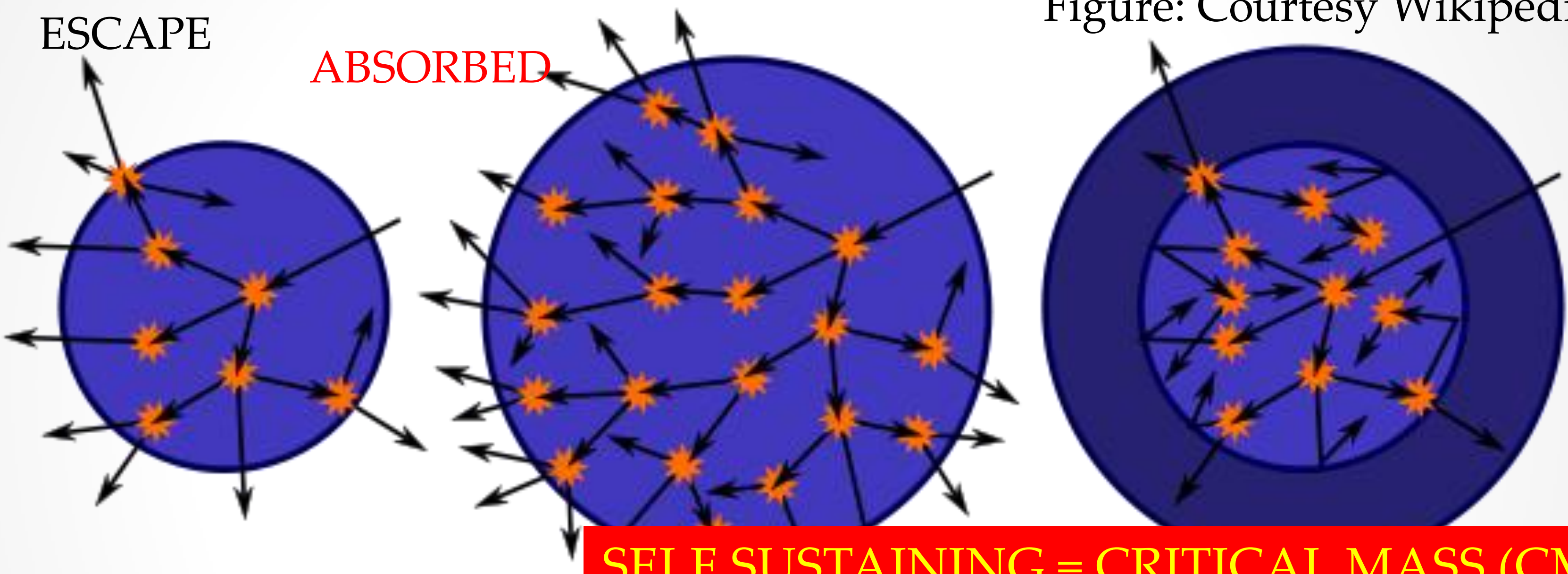


Make sure there are enough neutrons to continue the chain reaction
Want to make sure no neutrons escape.

How does one get an extremely fast chain reaction? **Increase the mass of material** so little neutrons escape from the chain.

Concept of Critical Mass

Figure: Courtesy Wikipedia



SELF SUSTAINING = CRITICAL MASS (CM)

FISSIONS STOPS AFTER SECOND GENERATION

FISSIONS SELF SUSTAINING

WITH REFLECTOR (CONFINING)

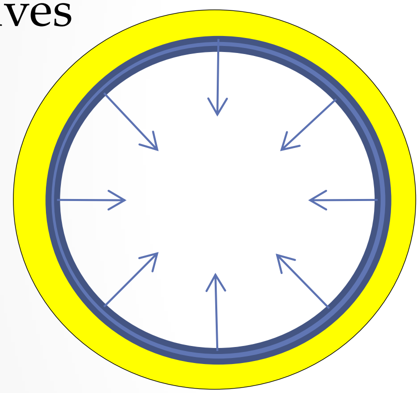
INCREASING FISSILE MATERIAL MASS

Once they come together they form a ***critical mass*** (enough material that on average more neutrons are produced then escape) and a chain reaction starts.

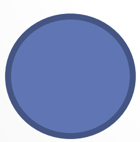
Two Types of Nuclear Weapons: Focus on Gun-Type

- 2 Ways of assembling nuclear material to attain critical mass

Explosives

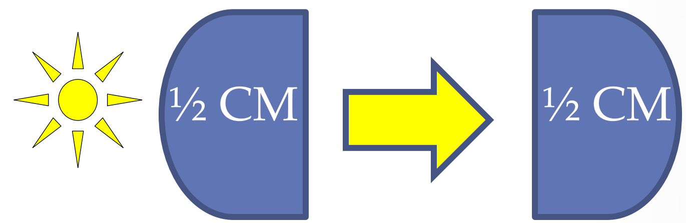


Compressed
= 1 CM



Implosion-Type
Nuclear Weapon

Explosives
High-Speed



Assembled
= 1 CM

Gun-Type
Nuclear Weapon

Testing is not necessary!

With modern weapons-grade uranium, the background neutron rate is so low that terrorists, if they had such material, would have a good chance of setting off a high-yield explosion simply by dropping one half of the material onto the other half. Most people seem unaware that if separate HEU is at hand it's a trivial job to set off a nuclear explosion . . . ***. even a high school kid could make a bomb in short order.***

Luis Alvarez, *Adventures of a Physicist* (Basic Books, 1987), p. 125.

Barrier 1: Obtaining HEU You can steal it OR You can produce it (enrich uranium)

New nations produce centrifuges which are 100 times less powerful then big commercial producers. A lot of technology, decades of research.

Producing HEU is Difficult

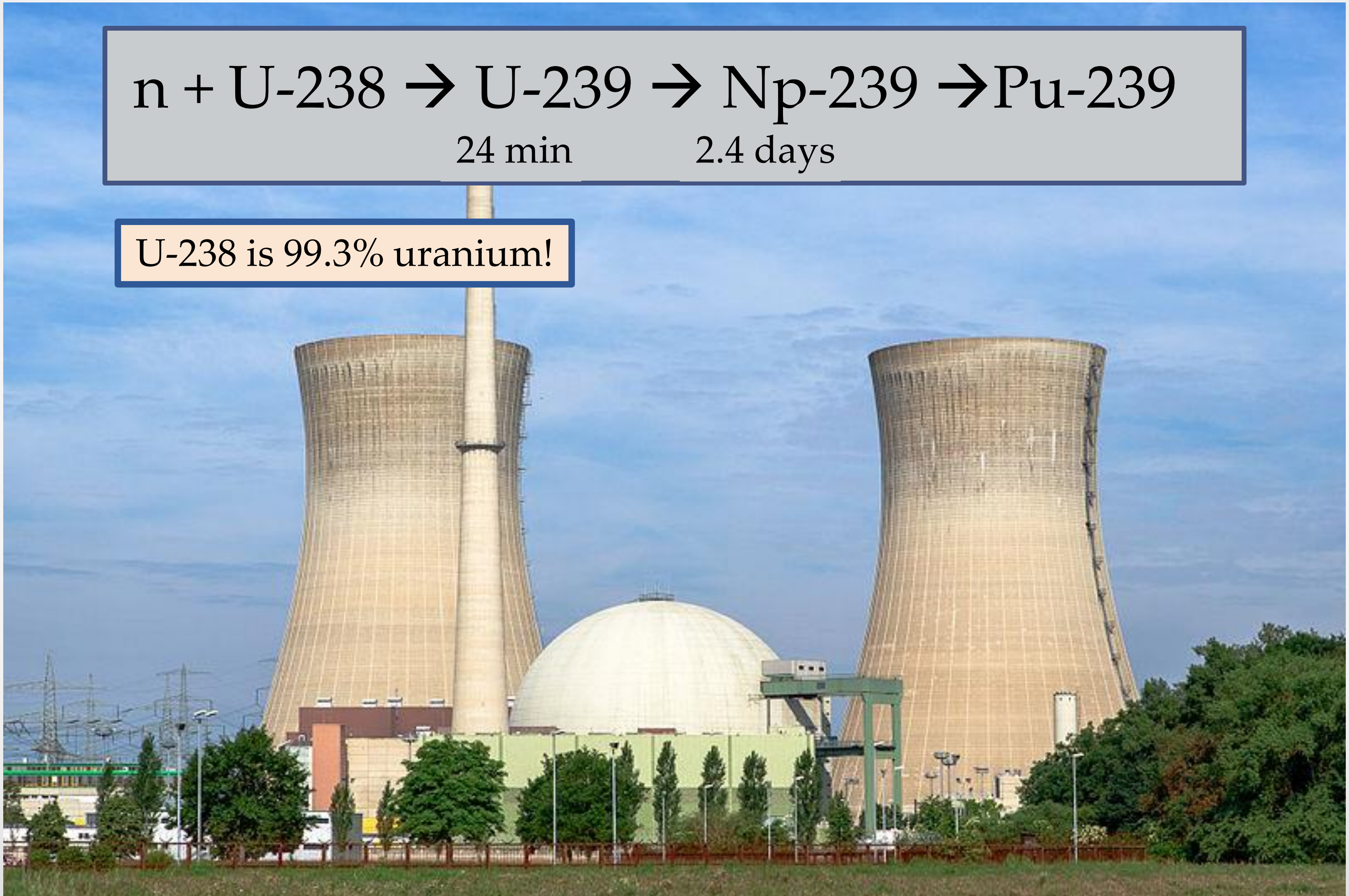
We can get HEU by enriching natural U what about Pu?

Plutonium is Easily Produced

n + U-238 $\rightarrow$ U-239 $\rightarrow$ Np-239 $\rightarrow$ Pu-239

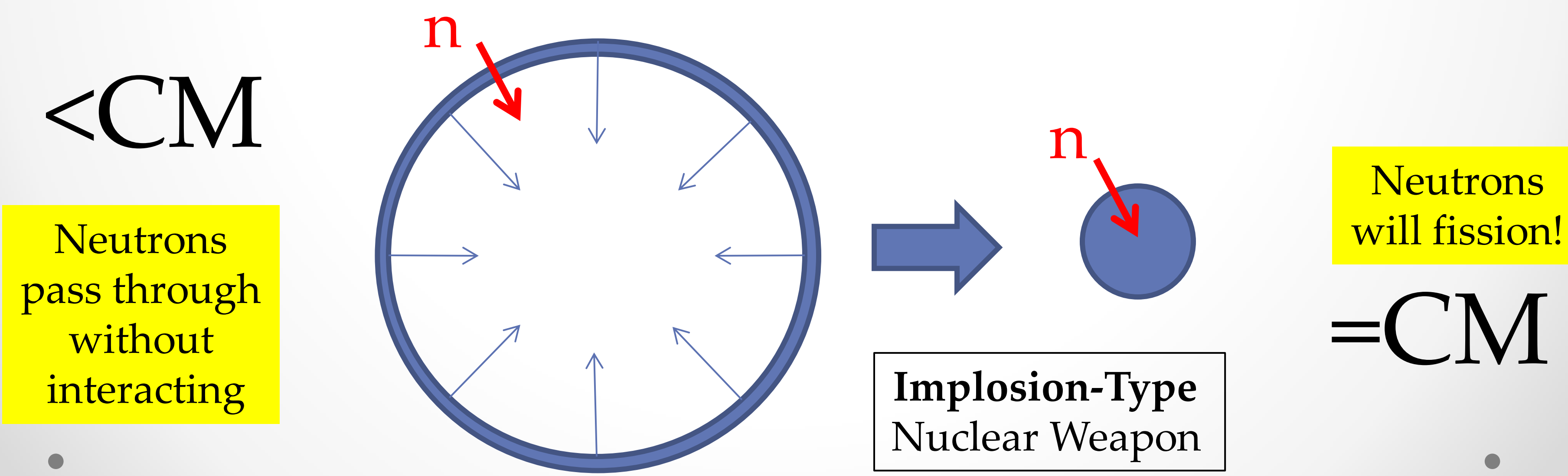
24 min 2.4 days

U-238 is 99.3% uranium!



Can I use Pu in a Gun-Type Weapon?

- No, **fortunately** can't use Pu in a gun type weapon
- Need a short period of time when there is no neutron, but Pu naturally gives off neutrons
- Need to find a super-fast way of assembling
- Implode a shell of Pu using explosives to reach CM



Barrier 2: Obtaining Pu is easy but you will need to test it and with global International Monitoring System (IMS), dozens of detectors around the world to detect nuclear explosions.

Summary

Material	Advantage	Barrier
U (HEU)	Testing not Necessary	Difficult to get HEU
Pu	Easy to Produce	Testing Necessary

How does this fit in with the Nuclear Fuel Cycle (life cycle of nuclear materials)?

- **Military** and **Peaceful** applications intersect!
- Need uranium for fuel in nuclear reactors
- Can produce plutonium from spent nuclear fuel (SNF)

Fuel Cycle in Detail..

Uranium Mined only **0.7% U-235**

U Enriched to 3-5%

Fabricated into **U** Fuel

SNF has **Pu**

Disposed Back to Ground

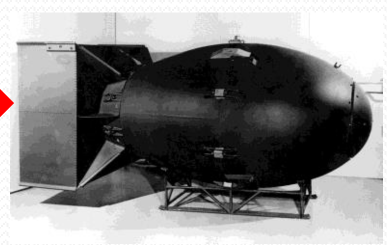
U-235 HEU

2 Routes to the Bomb!

Pu Removed (Reprocessing)

Pu-239

U Further Enriched to 90+%



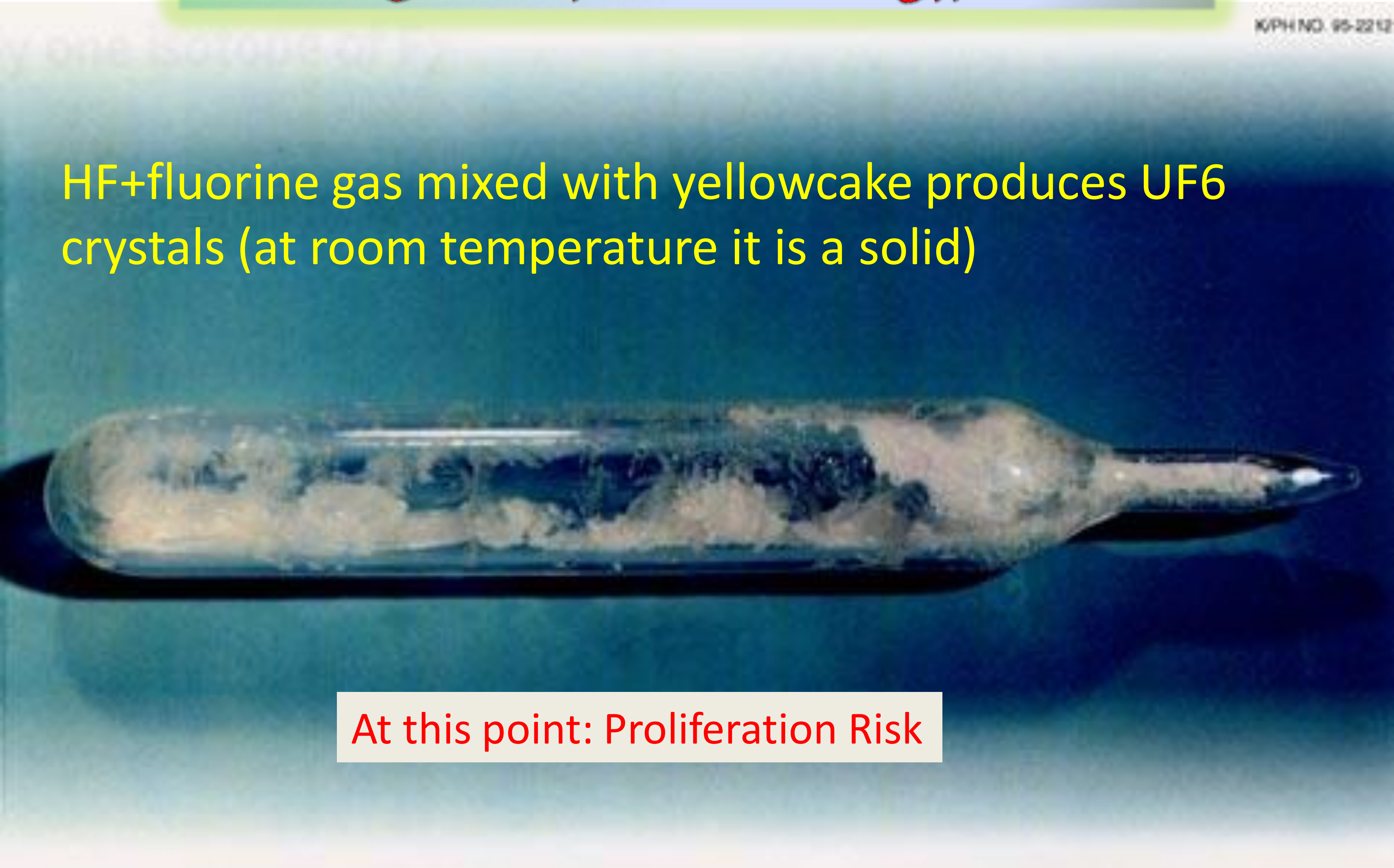
Major producers: Canada, Australia, Kazakhstan, Russia..

First Step: Mining and Conversion
Ore to Yellowcake to UF_6

Ore is crushed and processed into yellowcake.

Yellowcake converted to UF_6

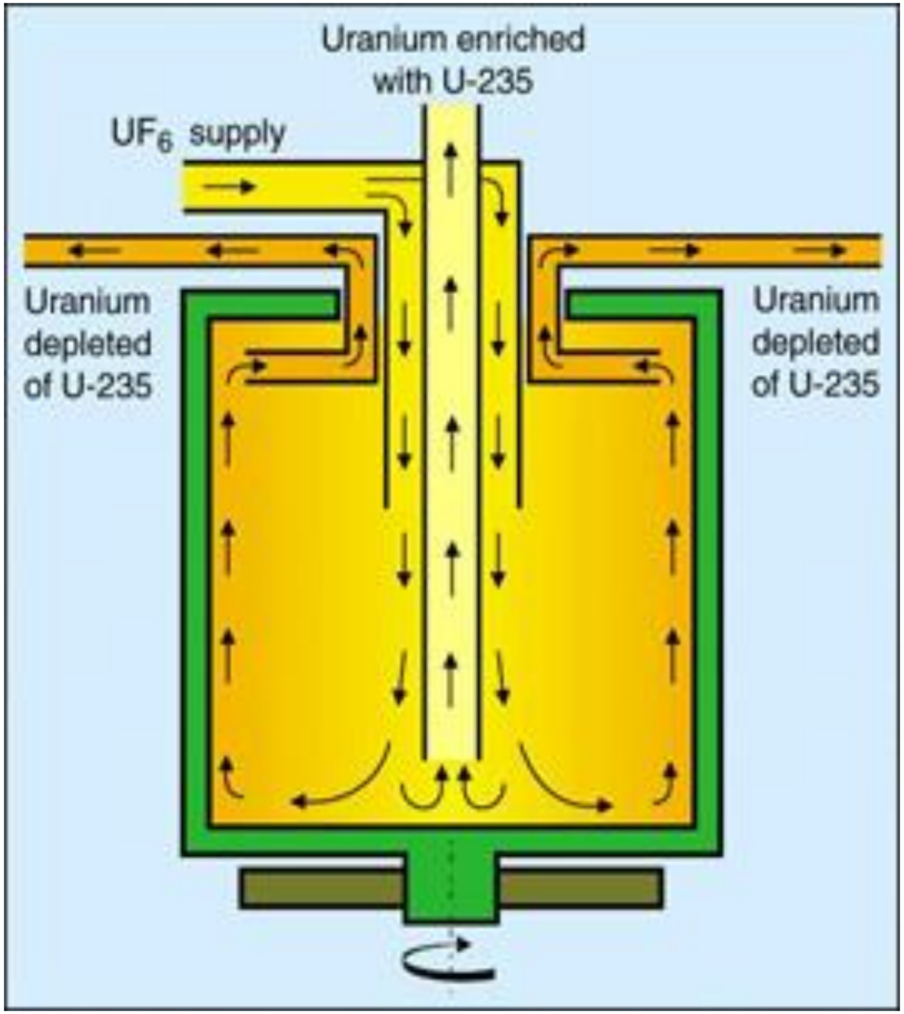
First Step: Mining and Conversion
Ore to Yellowcake to UF6



HF+fluorine gas mixed with yellowcake produces UF6 crystals (at room temperature it is a solid)

At this point: Proliferation Risk

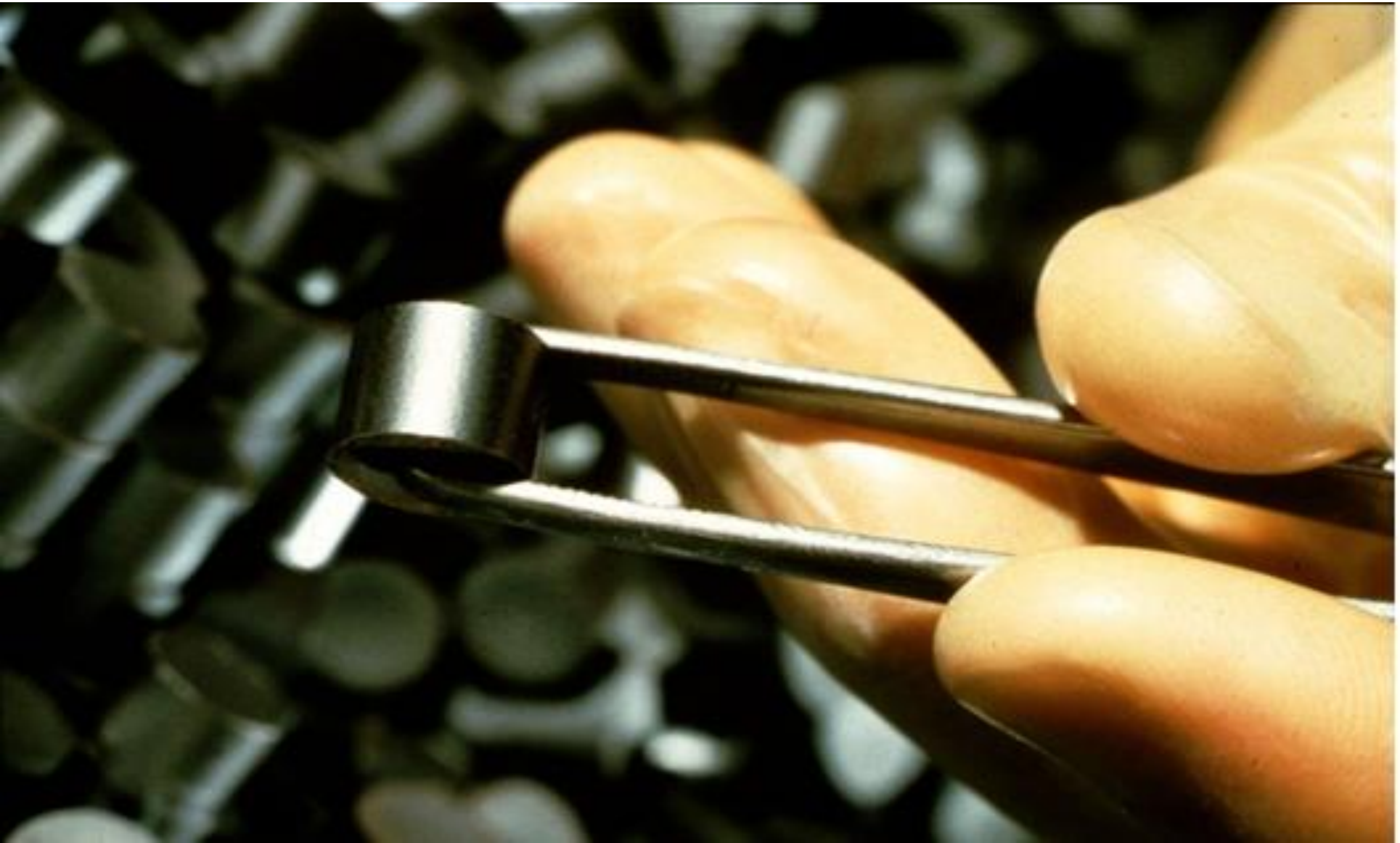
Second Step: U is Enriched



- Use small 1% difference between UF6 with U-235 and U-238.
- Gas is "spun" in a supersonic centrifuge, forcing lighter U-235 to the top, where it can be "scooped off"
- This demands high strength materials and precision engineering.

Remove U-238 until desired ratio U-235/U-238 is reached

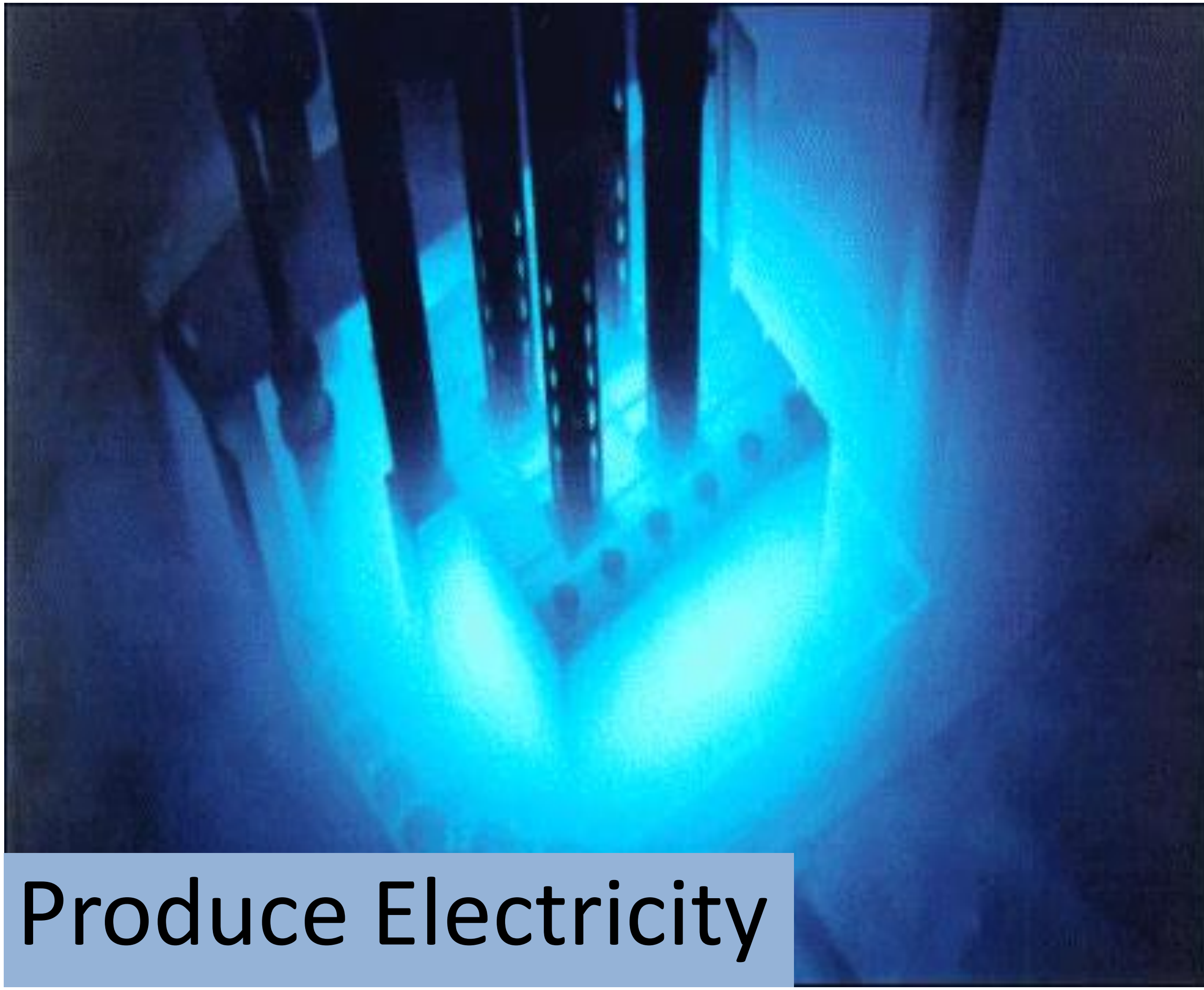
Third Step: Fuel Fabrication

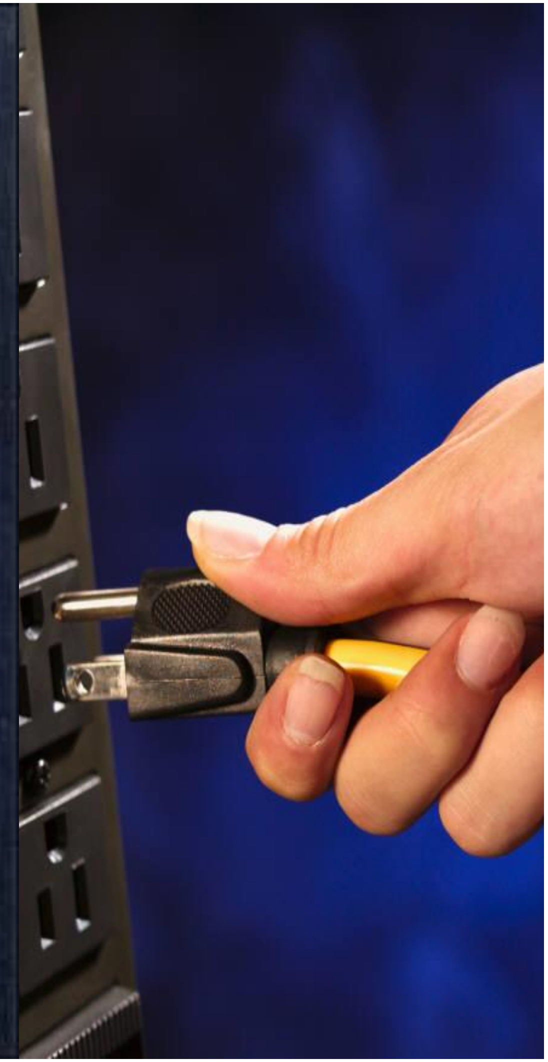


Third Step: Fuel Fabrication

Pellets are placed in fuel rods rods are combined into fuel assemblies

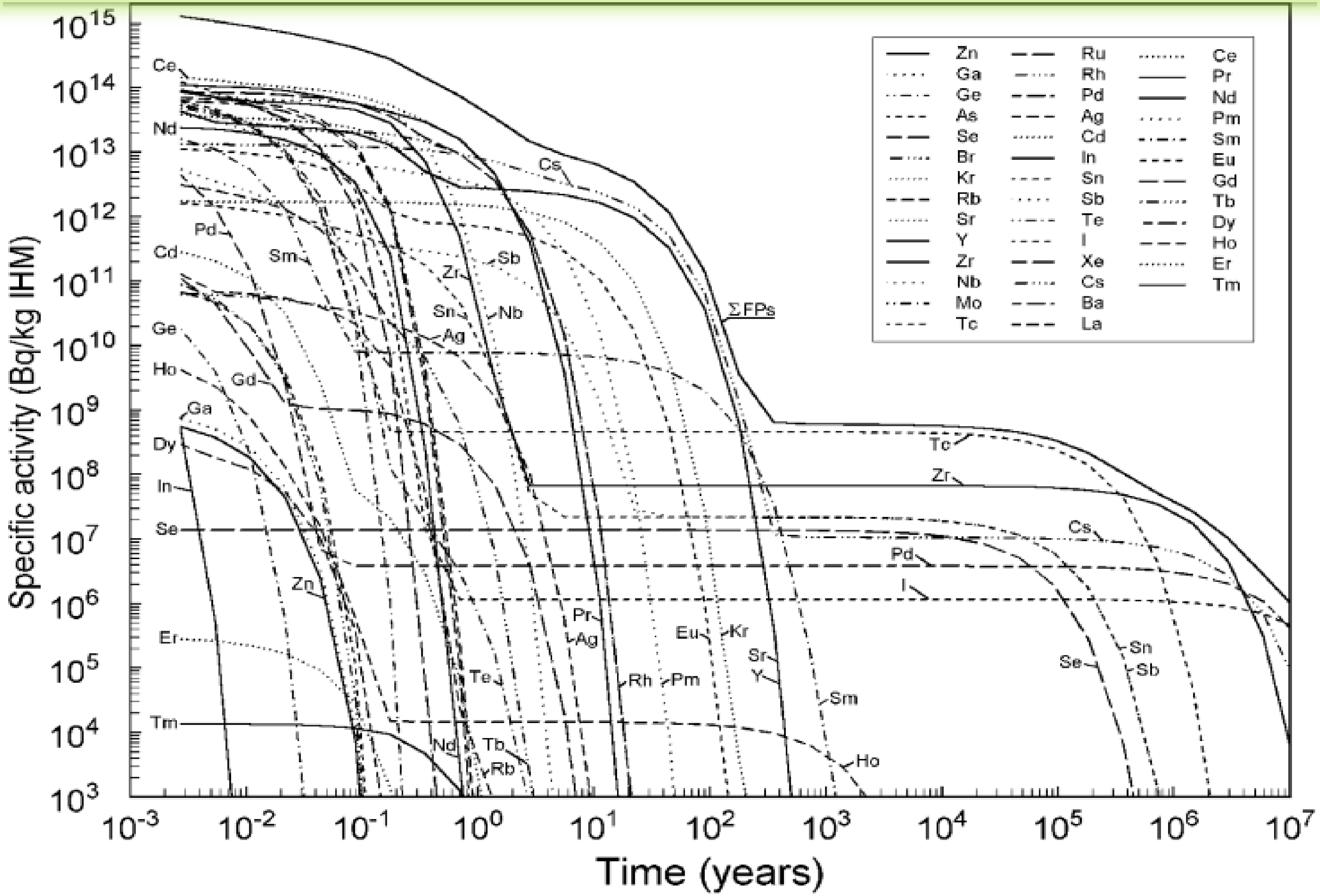
Fourth Step: Fuel is Loaded in Reactor



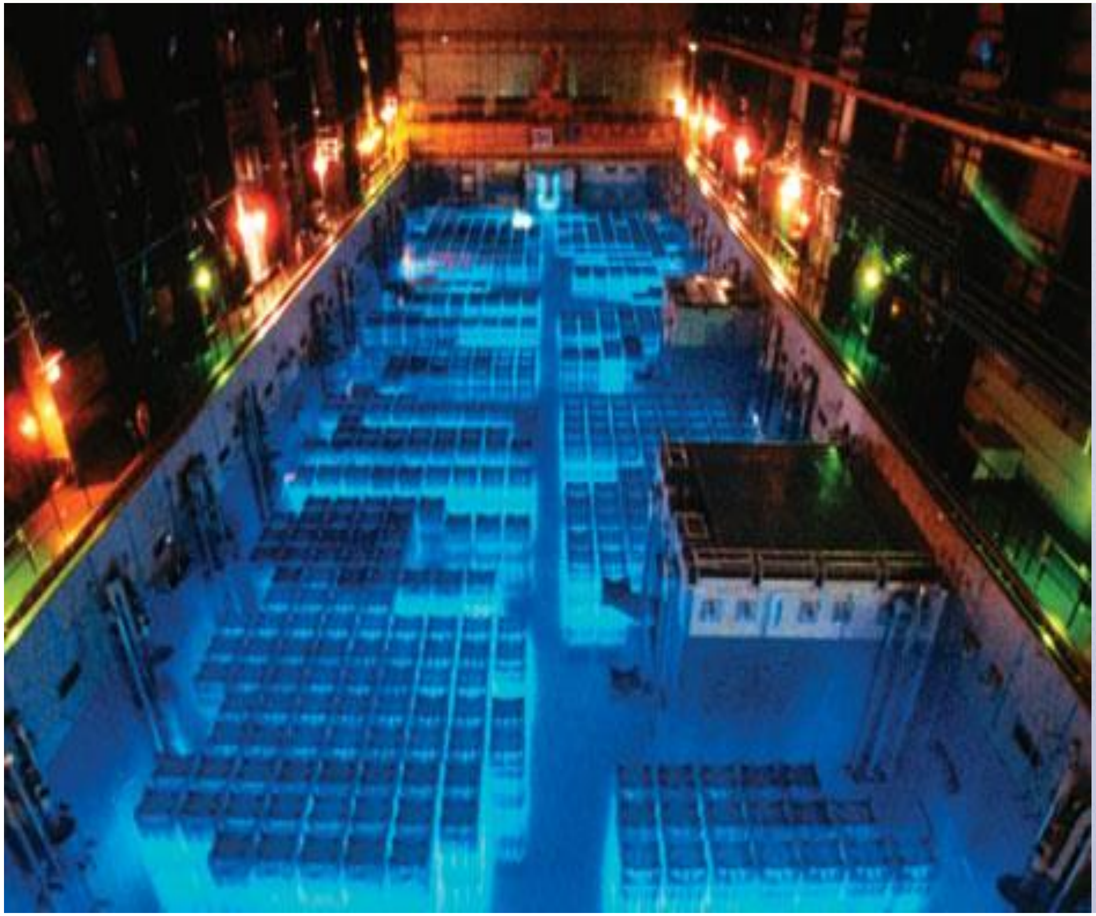


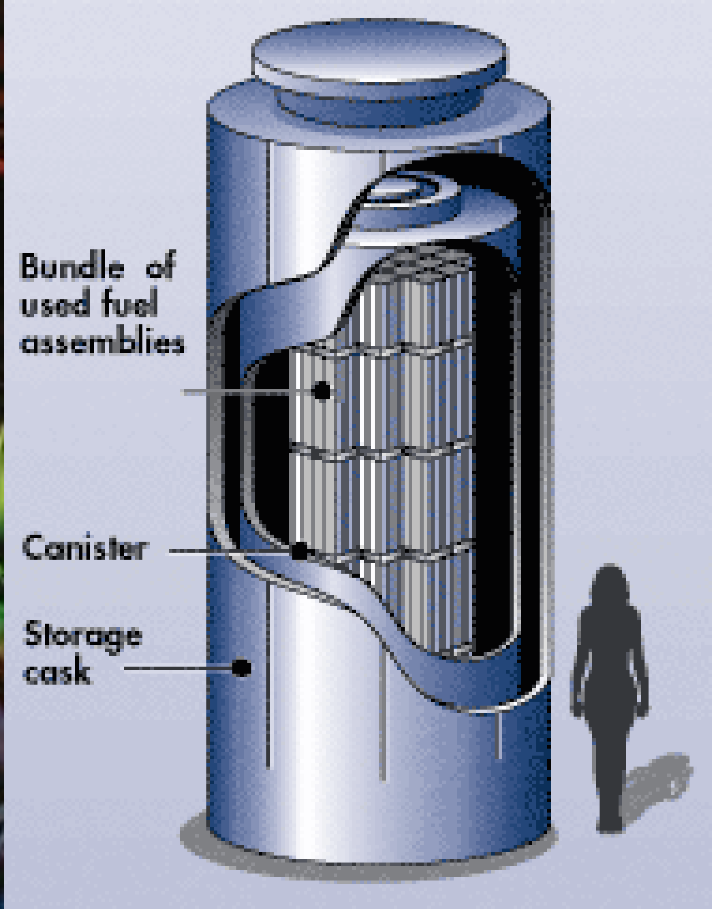
Produce Electricity

Fifth Step: Fuel is Removed from Reactor: Very radioactive and hot!



Fifth Step: Cooling Pond 5-10 Years then Dry Cask





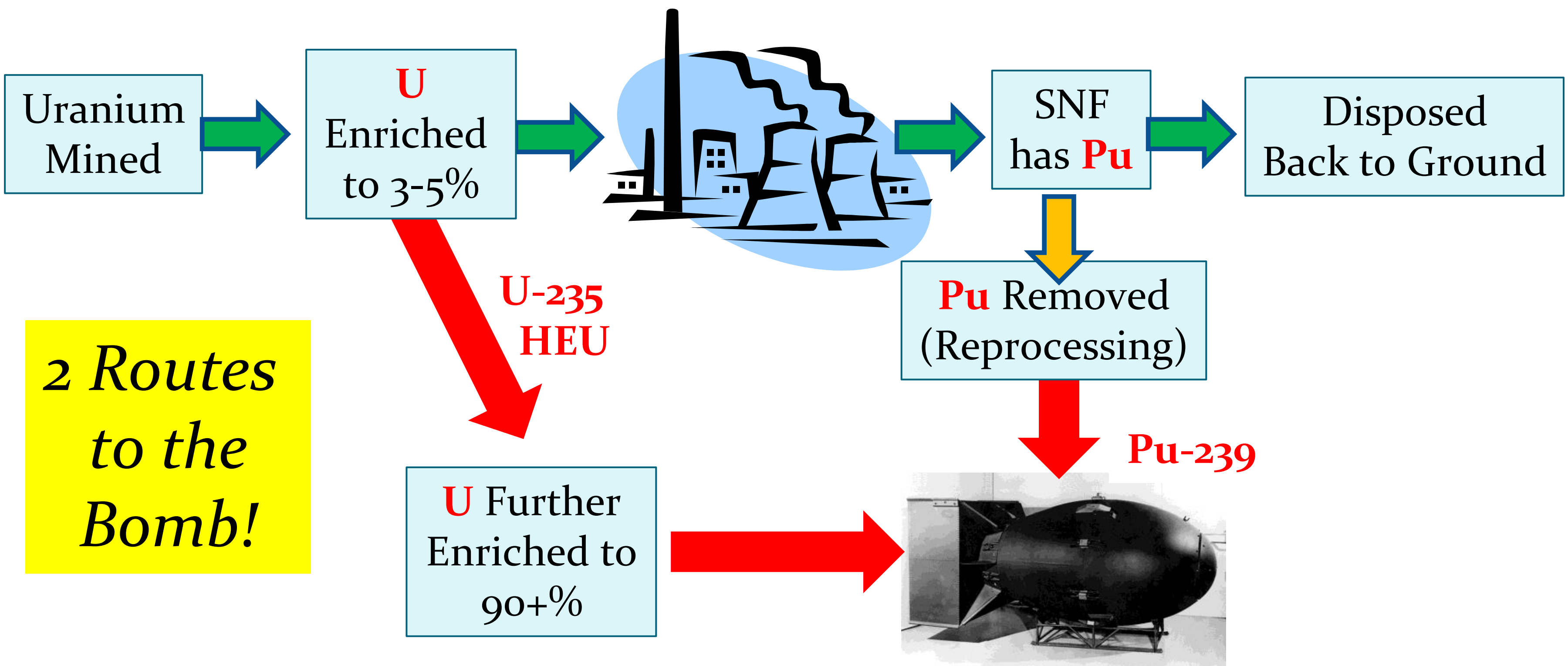
Future: emplaced in geological repository or other measures

So far no solution while we have **250k tonne of radioactive waste**

Permanent solution is desperately needed!

Summary

- **Military** and **Peaceful** applications intersect!
- Need uranium for fuel in nuclear reactors
- Can produce plutonium from spent nuclear fuel (SNF)



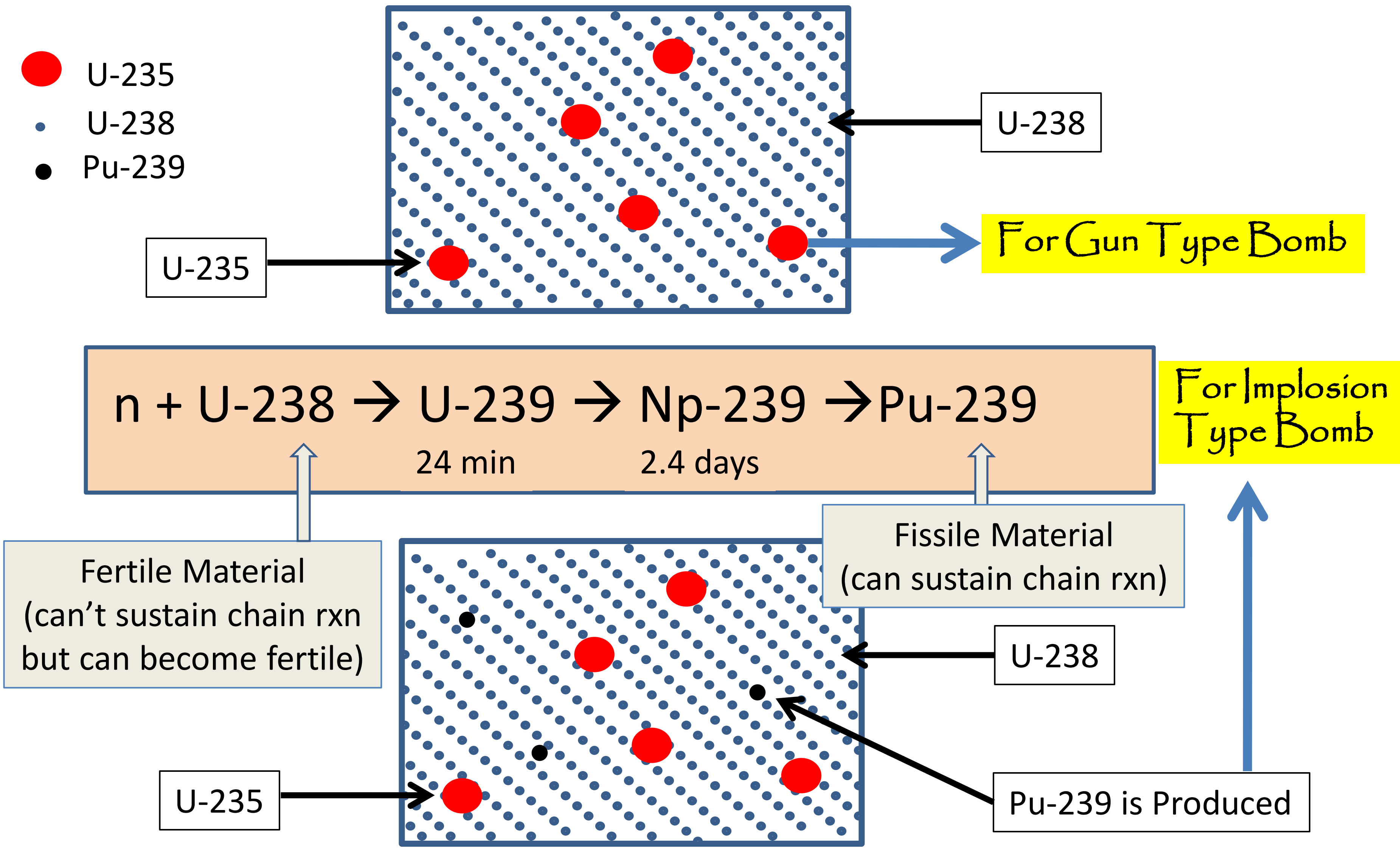
EXTRA SLIDES

Reprocessing of Spent Fuel: Closed Fuel Cycle

- Closed fuel cycle – recycle plutonium produced in other fuel
- “Russian policy is to close the fuel cycle as far as possible and utilize recycled uranium, and eventually also to use plutonium in MOX fuel. However, its achievements in doing this have been limited - in 2011 only about 16% of used fuel was reprocessed.”

  (WNA see: http://goo.gl/Zrtvn)
- The United States does not reprocess fuel although does advocate research in this area
- Controversial because of use of plutonium

Pu Production in Reactors



U-238 does not fission with slow neutrons but it can convert into Pu-239 which can.

The Nuclear Advantage

	Chemical	Fission	Fusion
Reaction	$C+O_2 \rightarrow CO_2$ Burning Coal Bonding to form molecules	n + U-235 → Ba-142+Kr-85 + 2 n's Splitting the atomic nucleus	D+T → He-4+n Bonding to form nuclei
Inputs	Coal	UO2	D_2+Lithium
Reaction Temp	700 C	500 C	1e8 C
Energy Released/kg	1	63,000	10 million