Helium-3
The energy source of tomorrow?

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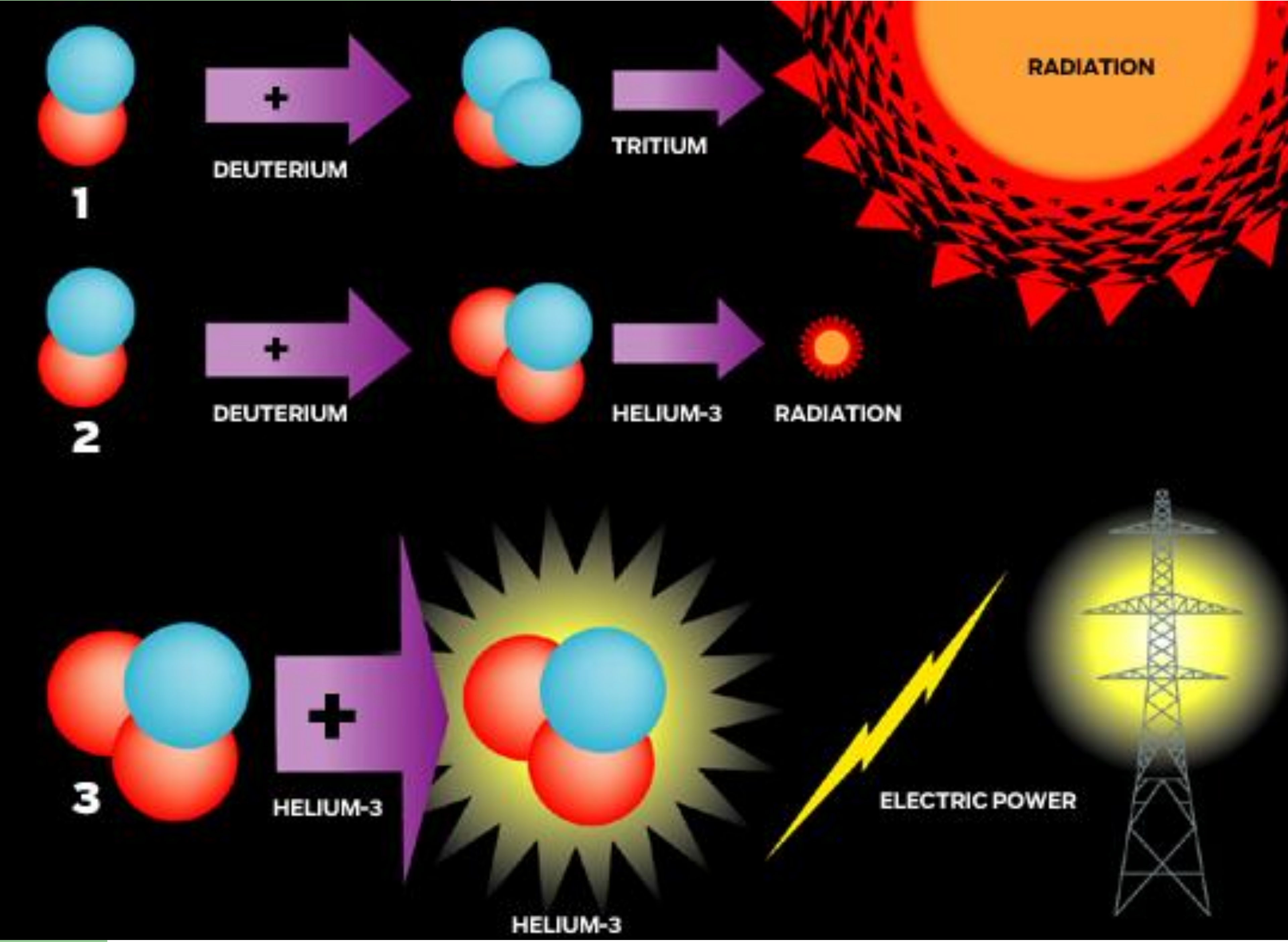

RADIATION
+
DEUTERIUM
TRITIUM
1
+
DEUTERIUM
HELIUM-3
RADIATION
2
3
+
HELIUM-3
HELIUM-3
ELECTRIC POWER

Problems with the D-T fuel cycle

The Deuterium-Tritium fuel cycle has some inherent problems that might be extremely difficult to overcome:

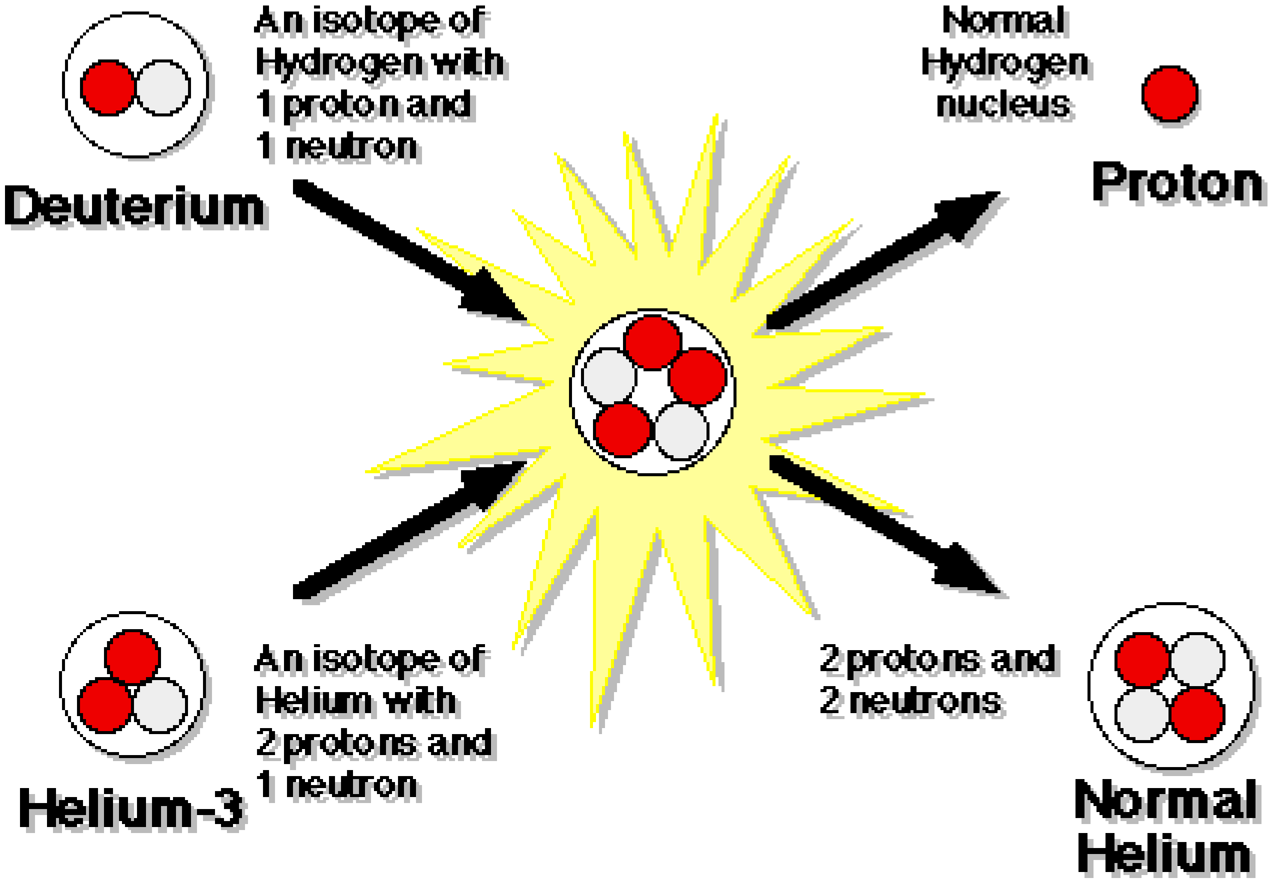
- It releases eighty percent of its energy in a stream of high-energy neutrons.
- This necessitates recapture of the neutrons and then inefficient thermal conversion of their energy to electrical power.
- These neutrons are highly destructive to anything they strike, including the containment vessel.
- Radiation damage to structures may weaken them and leave highly radioactive waste behind
- Tritium is a highly radioactive isotope of hydrogen that is hard to contain with the risk of release.

If not D-T then what?

- Twenty years ago a group of scientists met at a retreat south of Madison, Wisconsin to discuss the problems with the Deuterium-Tritium fuel cycle for fusion. They talked over what the options are for a better fuel. Helium-3 is what they came up with.

- In fact, helium-3 is the perfect fusion fuel. It can produce an incredible amount of power with absolutely no radioactivity. And a helium-3 fusion reactor won't have the same containment issues either.

Deuterium-Helium-3



Deuterium-Helium-3

$$D + {}^{3}He \longrightarrow p(14.7\ MeV) + {}^{4}He\ (3.7\ MeV) + 18.4\ MeV$$

Because D-He-3 Fusion involves 3 protons as opposed to 2 with DT Fusion, the amount of heat required for good fusion parameters is 100 keV. This is about 10 times greater than the amount needed for DT fusion. At the Naka Fusion Center in Japan, scientists set the world record for the hottest plasma in their advanced tokamak JT-60. This plasma reached 520,000,000 Kelvin, which corresponds to ion energies of 50 keV. Thus the energy requirements for helium-3 fusion are not insurmountable.

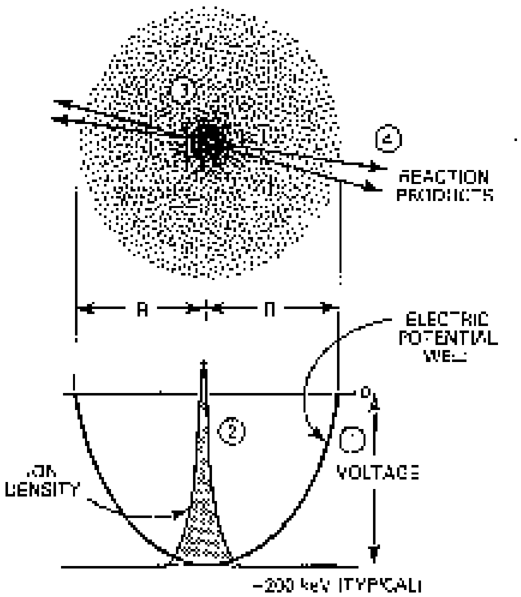
Deuterium-Helium-3

D-He-3 reactions produce no high energy neutrons, and consequently the activation of metals is drastically reduced. (Stray D-D reactions will generate some neutrons)

Another significant benefit of using Deuterium and Helium-3 fuels is that the reaction products, being charged particles, can be manipulated by electric and magnetic fields and can consequently be used for direct energy conversion which is far more efficient than thermal conversion.

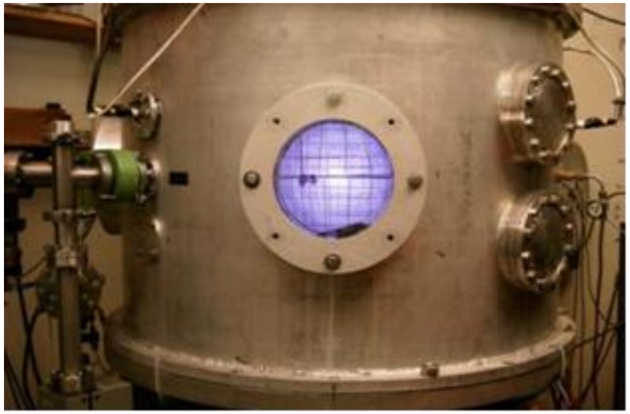
IEC
Inertial Electrostatic Confinement

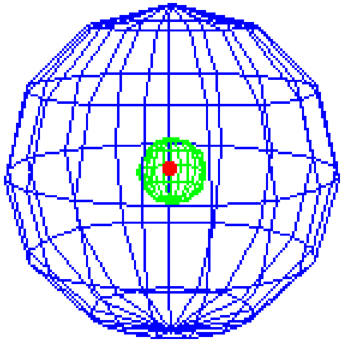
- Concept:
  - Using electric fields to accelerate nuclei
- Potential with D-D, D-T, D-3He, 3He-3He
- Two common approaches
  - Gridded – direct applied voltage
  - Polywell – voltage derived from electron cloud



IEC

- UW-Madison leads research in grid IEC
  - Inner sphere and outer sphere
  - Potential depth ~100kV
  - Needs only ~60mA of current compared to ~1MA in Tokamaks

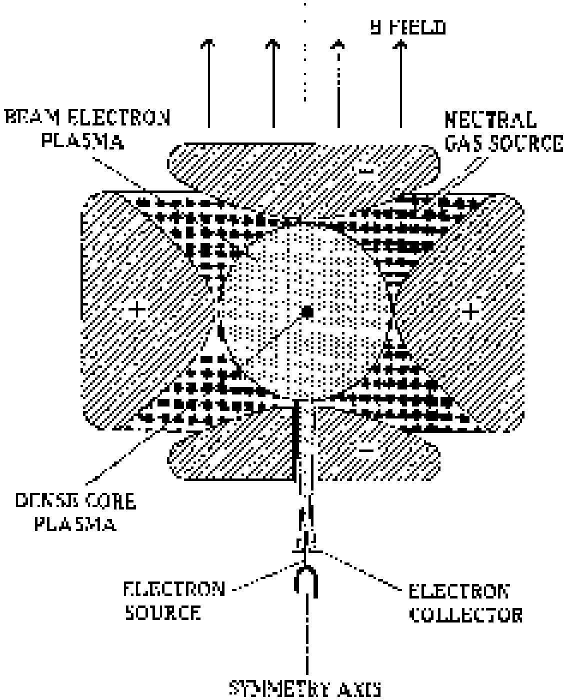




IEC

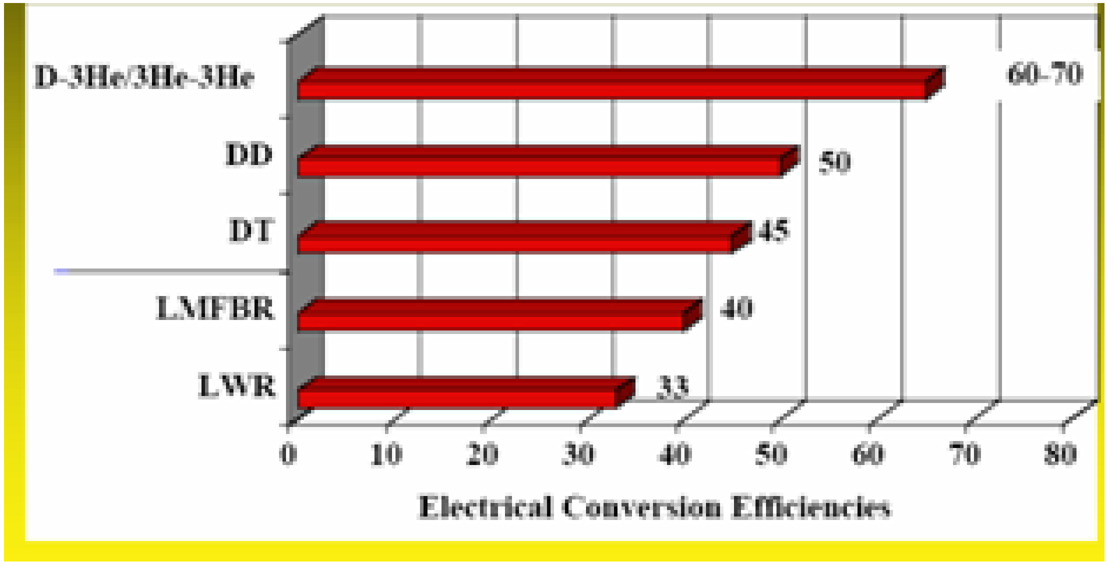
- The Polywell
  - Excess electron cloud from injection
  - Solenoids create magnetic confinement field
  - Intrinsically steady-state

- Most current project: WB-6
  - Has produced a fusion rate of 10^9/sec (D-D)
  - Only needed 12.5kV driving to produce 10kV well



IEC

- Energy Conversion:
  - IEC has most potential for direct energy conversion (charged products)
    - Efficiency ~70%-80%
    - Some loss due to escaping voltage well
  - Thermal cycle still optional
    - Efficiency ~30%



IEC

- Current Issues/Disadvantages:
  - Limits on core densities
  - For gridded IECs, heat flux
  - For Polywell, electron confinement
  - Feasibility of direct energy conversion

IEC

- Advantages
  - Relatively simple design (UW-Madison's ~2' in diam.)
  - Easily accelerates ions to massive energies
    - Energies of 100keV realistic for D-3He
  - Limited loss of plasma/reactants
  - Low ash accumulation
  - Design allows for easy fuel injection

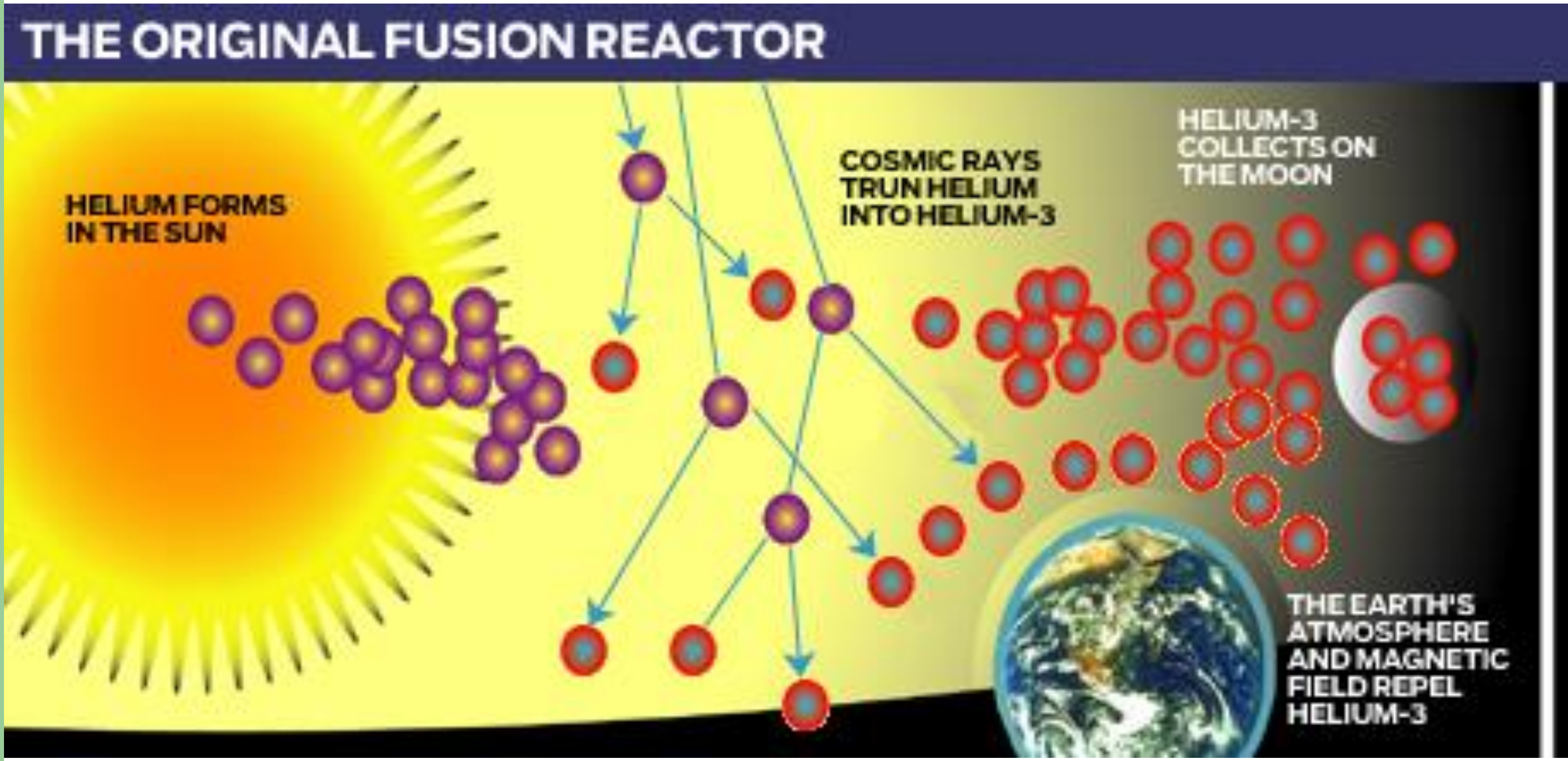
Helium-3 Manufacturing

- **Helium-3 is a byproduct of tritium decay**, and tritium can be produced through neutron bombardment of lithium, boron, or nitrogen targets.
- Current supplies of helium-3 come, in part, from the dismantling of nuclear weapons where it accumulates; approximately 150 kilograms of it have resulted from decay of US tritium production since 1955, most of which was for warheads.
- **Roughly eighteen tons of tritium stock are required for each ton of helium-3 produced annually by decay.**
- The production rate is $\mathbf{N\gamma = N\, t_{1/2} / (\ln 2)}$.
- Note that any breeding of tritium on Earth requires the use of a high neutron flux, which proponents of helium-3 nuclear reactors hope to avoid. Furthermore, **the production and storage of huge amounts of the gas tritium appears to be uneconomical.**

Lunar Supplies

Samples collected in 1969 by Neil Armstrong during the first lunar landing showed that helium-3 concentrations in lunar soil are at least 13 parts per billion (ppb) by weight. Levels may range from 20 to 30 ppb in undisturbed soils. Quantities as small as 20 ppb may seem too trivial to consider. But at a projected value of $40,000 per ounce, **220 pounds of helium-3 would be worth about $141 million**.

Where does Lunar H-3 come from?



Lunar Supplies

The highest concentrations are in the lunar maria; about half the He3 is deposited in the 20% of the lunar surface covered by the maria.

There is an estimated total of **1,100,000 metric tonnes of He3** that have been deposited by the solar wind in the lunar regolith. Since the regolith has been stirred up by collisions with meteorites, we'll probably find He3 down to depths of several meters.

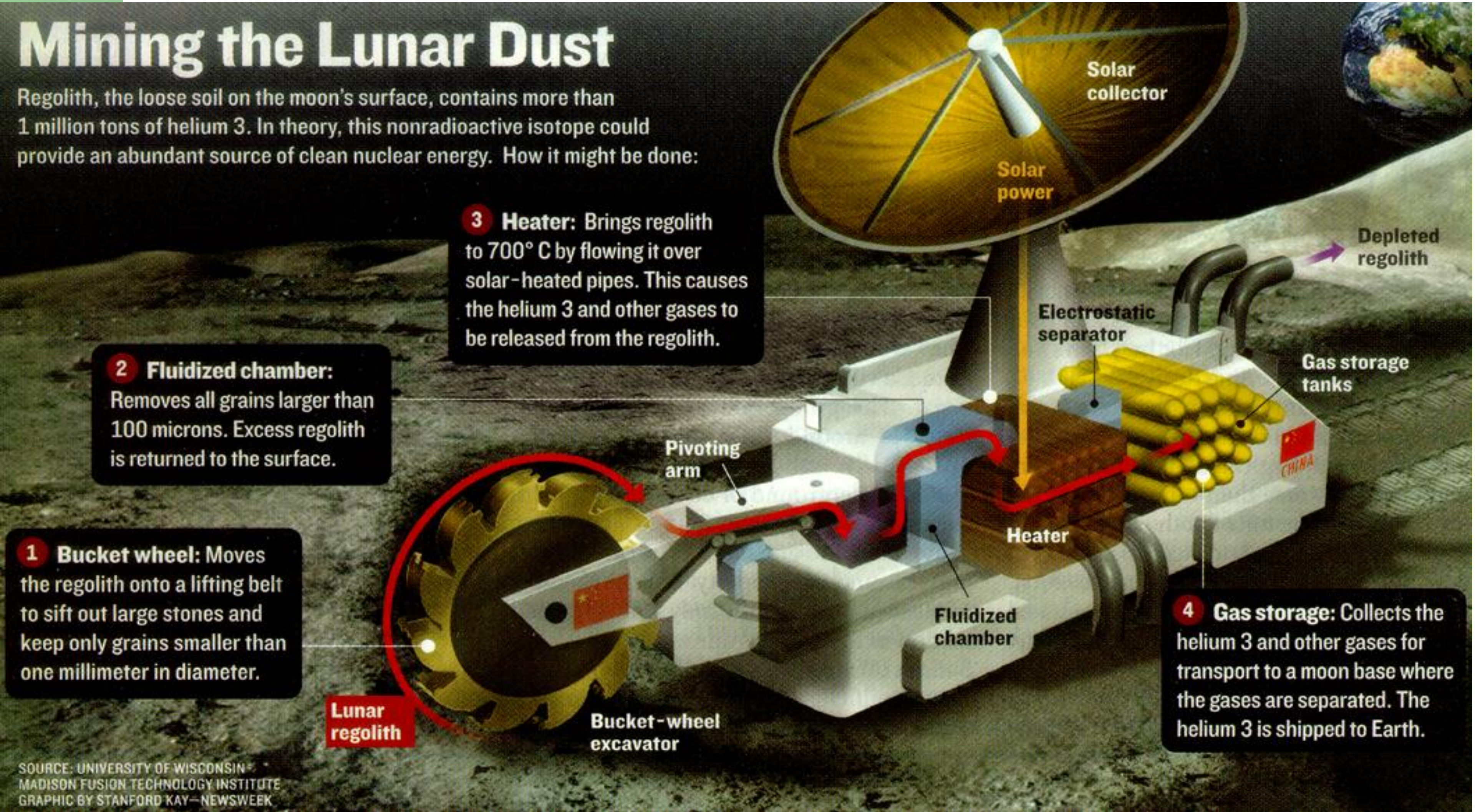
Lunar Supplies

Ouyang Ziyuan who is now in charge of the Chinese Lunar Exploration Program has stated on many occasions that one of the main goals of the Chinese Lunar program would be the mining of helium-3, from where **"each year three space shuttle missions could bring enough fuel for all human beings across the world."**

How much would it take to Power the United States?

- Digging a patch of lunar surface roughly three-quarters of a square mile to a depth of about 9 ft. should yield about 220 pounds of helium-3--enough to power a city the size of Dallas or Detroit for a year.
- About **25 tonnes of He3 would power the United States for 1 year** at our current rate of energy consumption.
- To put it in perspective: that's about the weight of a fully loaded railroad box car, or a **maximum Space Shuttle payload**.

Extracting Helium-3



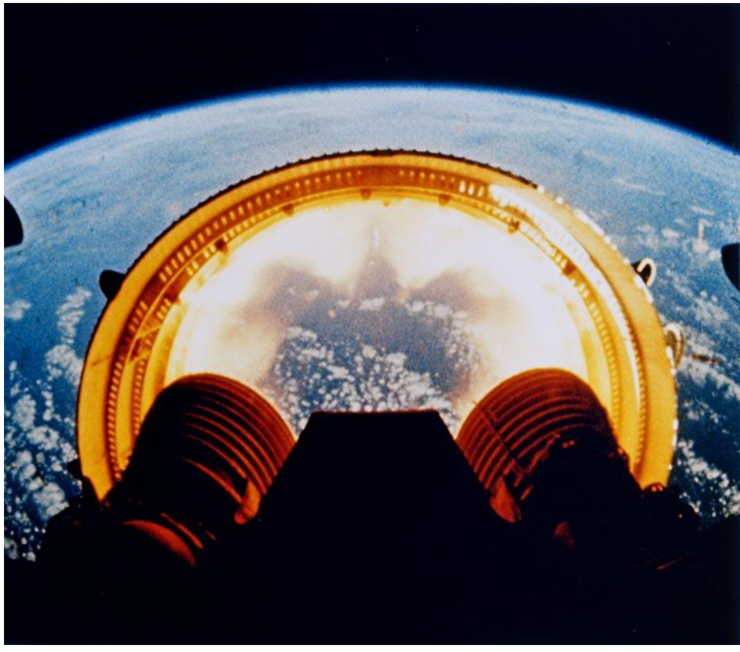
Extracting Helium-3

For every ton of Helium-3 extracted from lunar soil nine tons of oxygen, water and other life-sustaining substances, as well as six tons of hydrogen useful for powering fuel cells, would be yielded. These materials are ideal for sustaining manned mining outposts or even settlements as well as producing fuel for rockets.

The Payoff

Let's suppose that by the time we're slinging tanks of He-3 off the moon, the world-wide demand is 100 tonnes of the stuff a year, and people are happy to pay $3 billion per tonne. That gives us gross revenues of $300 billion a year.

To put that number in perspective: that rate of income would provide for the launch of a Saturn V style rocket every day for the next 10,000 years.



Medical Applications

- P + Nitrogen gases/Water => C-11, N-13, O-15
- Carbon-11 => used to diagnose renal and prostate cancers
- Oxygen-15 & Nitrogen-13 used in respiratory examinations; esp. PET scans
- All above have $\mathbf{t}_{1/2}$ <20 min
- Availability:
  - Cyclotrons – too big, too few

Conclusions

- Using He-3 as fusion fuel:
  - More efficient electrical conversions
  - Low (negligible) levels of radioactivity
    - Only neutrons from chance D-D fusion in D-3He fuel
    - Little to no activation of nearby structures
    - No radioactive fuel needed (No Tritium!)
- If priced at ~$1 Billion/ton, He-3 has Energy cost ~equal to oil at $7/barrel
- In terms of stored energy, He-3 on the Moon has ~10x as much as all economically viable supplies of fossil fuels on the Earth

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