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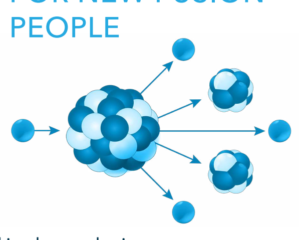
FUSION VS. FISSION - A PRIMER FOR NEW FUSION PEOPLE



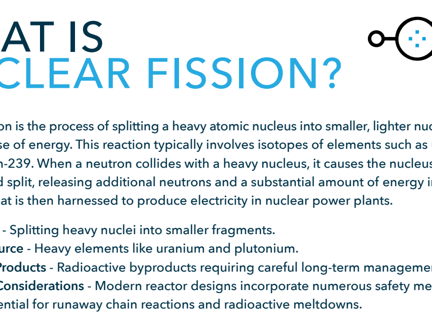
I started in the fusion industry without a background in plasma physics or nuclear energy to serve as a reference point. This blog was written by a layman in the fusion energy business for other laypeople starting in fusion energy. It results from reading other write-ups from organizations like Helion, Commonwealth Fusion Systems, BBVA, the Fusion Industry Association, and the DOE, plus some shameless use of Perplexity AI. Each source provides numerous simple and complex comparisons, so I wanted to share a basic primer of what new folks entering the market needed to know.

THE SIMPLE EXPLANATION-

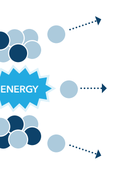
When people talk of nuclear energy, it is almost always fission energy they are referring to. Fission occurs when a neutron slams into a larger atom, forcing it to excite and split into two smaller atoms, also known as fission products. Additional neutrons are also released, which can initiate a chain reaction. When each atom splits, a tremendous amount of energy is released. Uranium and plutonium are most commonly used for fission reactions in nuclear power reactors because they are easy to initiate and control.

Fusion occurs when two atoms are squeezed together to form a heavier atom, like when two hydrogen atoms fuse to form one helium atom. This process powers the sun and creates vast amounts of energy - several times greater than fission.

Here is a short video from the DOE that provides a high-level overview.

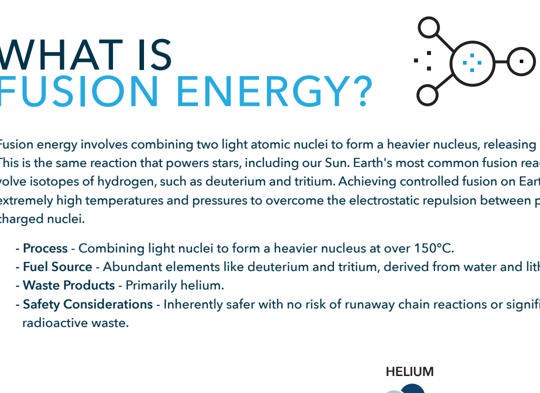


WHAT IS NUCLEAR FISSION?



Nuclear fission is the process of splitting a heavy atomic nucleus into smaller, lighter nuclei, accompanied by the release of energy. This reaction typically involves isotopes of elements such as uranium-235 or plutonium-239. When a neutron collides with a heavy nucleus, it causes the nucleus to become unstable and split, releasing additional neutrons and a substantial amount of energy in the form of heat. This heat is then harnessed to produce electricity in nuclear power plants.

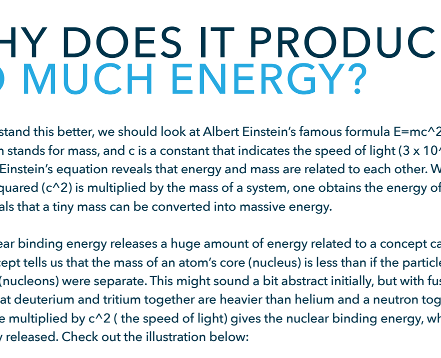
- **Process** - Splitting heavy nuclei into smaller fragments.
- **Fuel Source** - Heavy elements like uranium and plutonium.
- **Waste Products** - Radioactive byproducts requiring careful long-term management.
- **Safety Considerations** - Modern reactor designs incorporate numerous safety measures, but there is a potential for runaway chain reactions and radioactive meltdowns.



WHAT IS FUSION ENERGY?

Fusion energy involves combining two light atomic nuclei to form a heavier nucleus, releasing energy. This is the same reaction that powers stars, including our Sun. Earth's most common fusion reactions involve isotopes of hydrogen, such as deuterium and tritium. Achieving controlled fusion on Earth requires extremely high temperatures and pressures to overcome the electrostatic repulsion between positively charged nuclei.

- **Process** - Combining light nuclei to form a heavier nucleus at over 150°C.
- **Fuel Source** - Abundant elements like deuterium and tritium, derived from water and lithium.
- **Waste Products** - Primarily helium.
- **Safety Considerations** - Inherently safer with no risk of runaway chain reactions or significant radioactive waste.



WHY DOES IT PRODUCE SO MUCH ENERGY?

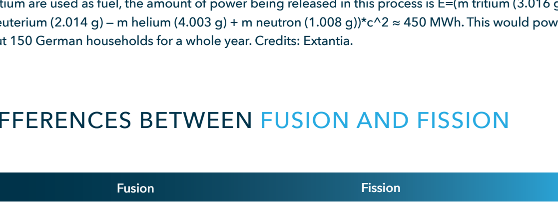
To understand this better, we should look at Albert Einstein's famous formula E=mc^2. E stands for energy, m stands for mass, and c is a constant that indicates the speed of light (3 x 10^8 meters per second). Einstein's equation reveals that energy and mass are related to each other. When the speed of light squared (c^2) is multiplied by the mass of a system, one obtains the energy of that system. This reveals that a tiny mass can be converted into massive energy.

The nuclear binding energy releases a huge amount of energy related to a concept called "mass defect." This concept tells us that the mass of an atom's core (nucleus) is less than if the particles that the core is made of (nucleons) were separate. This might sound a bit abstract initially, but with fusion, it effectively means that deuterium and tritium together are heavier than helium and a neutron together, and the mass difference multiplied by c^2 (the speed of light) gives the nuclear binding energy, which is the amount of energy released. Check out the illustration below:

WHY DOES IT NUCLEAR FUSION RELEASE SO MUCH ENERGY

Because of a concept called "Mass defect". Mass defect is the difference between the particles'individual mass and the actual mass of an atom's nucleus. Let's see how it works.

$E = mc^2 \approx 450$ MWh



"Mass defect" explained

- Dueterium and tritium together are heavier than helium and a nuetron.
- The 0.018 g difference seems small but 16 additionasl zeros are added by multiplying with the speed of light squared.
- This reveals that a tiny amount of mass can be converted inyo a huge amount of energy.

Sources: NSTA, NiST

Nuclear fusion releases massive energy due to the "mass defect." Assuming ±2 g of deuterium and ±3 g of tritium are used as fuel, the amount of power being released in this process is E=(m tritium (3.016 g) + m deuterium (2.014 g) – m helium (4.003 g) + m neutron (1.008 g))*c^2 ≈ 450 MWh. This would power about 150 German households for a whole year. Credits: Extantia.

DIFFERENCES BETWEEN FUSION AND FISSION

	Fusion	Fission
Energy Creation Process	Combines two light atomic nuclei to form a heavier nucleus, releasing energy.	Splits a heavy atomic nucleus into smaller nuclei, releasing energy.
Energy Output	Potentially releases more energy per unit mass than fission, making it a highly efficient energy source.	While efficient, it does not match the energy density achievable through fusion.
Fuel Sources	Utilizes abundant light elements like deuterium and tritium. For example, just one pound of fusion fuel equals 10 million pounds of coal.	It relies on heavy elements such as uranium-235 and plutonium-239, which are far less abundant and require extensive mining and enrichment processes.
Waste Products	Produces primarily helium, a non-radioactive and harmless gas, with minimal radioactive by products.	Generates significant amounts of radioactive waste that must be carefully managed and stored f or long periods to prevent environmental contamination.
Safety & Environmental	It cannot cause a runaway meltdown and produces no long-lived radioactive waste, making it a cleaner and safer energy source.	Carries risks of meltdowns and produces hazardous radioactive waste, posing long-term environmental and safety challenges.
Technical Challenges	Fusion requires extremely high temperatures (over 100-150 million degrees Celsius) and precise plasma confinement, making it significantly more difficult to achieve and sustain.	Fission is technologically mature with established methods for energy generation, though safety and waste management remain concerns.
Regulation	The US Congress passed the ADVANCE Act, which defines fusion machines as particle accelerators and codifies their regulation under NRC's byproduct material framework.	The Nuclear Regulatory Commission (NRC) regulates nuclear fission under Part 50 of the Code of Federal Regulations (CFR). The NRC is an independent agency that licenses and regulates the civilian use of atomic energy to protect the public, the environment, and national security.
Applications	Fusion is primarily in the experimental stage, with projects like ITER aiming to demonstrate feasibility. Commercial fusion energy has not yet been realized.	Fission is widely used in current nuclear power plants globally, providing a substantial portion of low-carbon electricity.
Energy source	Commercial fusion power plants will create the precise conditions needed for fusion to happen on Earth and ultimately generate power. High temperatures and pressures create and sustain a plasma, bringing the atoms close enough to fuse. The challenges of achieving and maintaining these conditions are what make fusion so hard, but they also ensure its safety. The fusion process can be stopped at any time and will simply cease on its own when conditions aren't perfect. A chain reaction is physically impossible in fusion, which means there is no risk of a runaway chain reaction or meltdown.	Splitting a heavy atom creates lighter atoms plus neutrons. When other atoms absorb the neutrons, they split and release more neutrons. This creates a chain reaction that must be carefully controlled in a nuclear reactor. Even when the reactor is shut down, the smaller atoms continue to radioactively decay, generating continued heat that safety systems must dissipate to avoid a fuel meltdown.
Fuel	Fusion can be productively performed with different fuels. Three potential fuel combinations are proton and boron, deuterium and tritium, ordeuterium and helium-3. Protons and deuterium are both found in waterand are naturally abundant. Boron is also naturally abundant– from existing surface mines in the U.S. and other countries. Tritium, which requires special handling, is a byproduct of other nuclear processes. In the short term, it can come from fission power plants. As commercial fusion scales, fusion companies and researchers are developing ways to produce this fusion fuel in a fusion machine from other elements. Helium-3 can be produced from deuterium-deuterium fusion.	Uranium, the main fuel for fission, is common,though the uranium isotope U-235 required forpower generation is rare and requires miningand enrichment before it can be used as fuel.Processing the raw materials into morec oncentrated U-235 fuel for power generation requires a regulated facility and specializedhandling.
Regulations	Fusion facilities will be regulated like particle accelerators, thousands of which are already operating in hospitals and other facilities around the world. They require appropriate shielding to protect workers, the public, and the environment from radiation. Standard industrial safety processes will be in place for fusion. Fusion is inherently safe as there is no risk of meltdowns or runaway chain reactions and no presence of high-level radioactive materials to create and sustain the fusion reaction.	Every fission facility requires a lengthy and costly licensing and permitting process to ensure that the plant will operate safely.
Byproducts	Fusing atoms together creates new atoms and releases energy, either as charged particles or as neutrons and charged particles. The resulting atoms are most commonly isotopes of helium, an inert gas familiar to us through balloons. Many fusion approaches will use and/or produce tritium, a low-level radioactive byproduct that requires shielding and storage. These fusion approaches will use tritium in a closed fuel cycle, meaning that the tritium will be produced and consumed in the plant. Some other fusion approaches do not use any tritium, which significantly reduces the quantity of radioactive byproducts. Neutrons from the fusion process activate the walls of the plasma vessel, which must be safely stored at the end of its operational life. These fusion-activated materials are low-level radioactive waste and pose a much lower risk than high-level radioactive materials from fission power plants. Radiation levels from fusion waste decrease significantly faster, too. Scientists and companies are researching newer materials to reduce activation levels as well as ways to recycle these materials after some period of time to be reused in fusion power plants.	Some of the byproducts fission creates are highly radioactive, requiring shielding and long-term storage. They are contained within the nuclear fuel and taken out of the reactor as spent fuel, which is high-level radioactive waste. Nuclear waste from fission must be safely stored for a long time, up to one million years. It requires specialized management. It can be recycled into more fuel, but that requires additional processing.

References:

https://www.energy.gov/ne/articles/fission-and-fusion-what-difference
https://www.helionenergy.com/articles/why-fusion-is-not-nuclear/#:~:text=Fusion%20combines%20two%20light%20nuclei,implications%20for%20the%20two%20processes.
https://www.bbva.com/en/sustainability/what-are-the-differences-between-nuclear-fission-and-nuclear-fusion/
https://www.fusionindustryassociation.org/learn-about-fusion-energy/faqs/#:~:text=Fission%20energy%20is%20created%20by,cannot%20cause%20a%20runaway%20meltdown.
https://cfs.energy/devens-campus/faq
https://www.orano.group/en/unpacking-nuclear/nuclear-fission-and-nuclear-fusion-what-you-should-know
https://medium.com/extantia-capital/why-fusion-is-not-a-vc-case-692849c8cf70
https://theconversation.com/whats-the-difference-between-fusion-and-fission-a-nuclear-physicist-explains-240438
https://energycentral.com/news/mil-evening-report-what%E2%80%99s-difference-between-fusion-and-fission-nuclear-physicist-explains
https://www.zapenergy.com/how-it-works#:~:text=Fusion%20has%20the%20potential%20to,a%20couple%20of%20shipping%20containers.
https://medium.com/extantia-capital/understanding-the-hype-fusion-101-aa60c49eed15