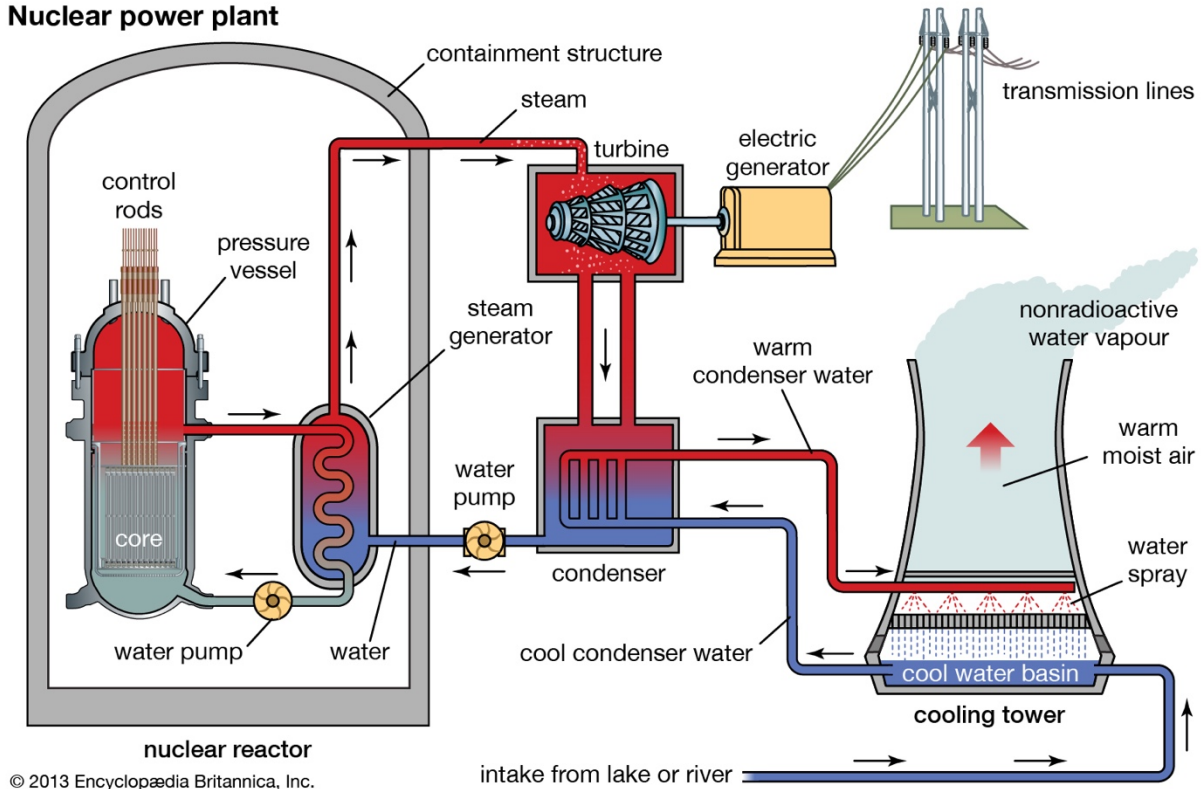


Alternative Power Generation.

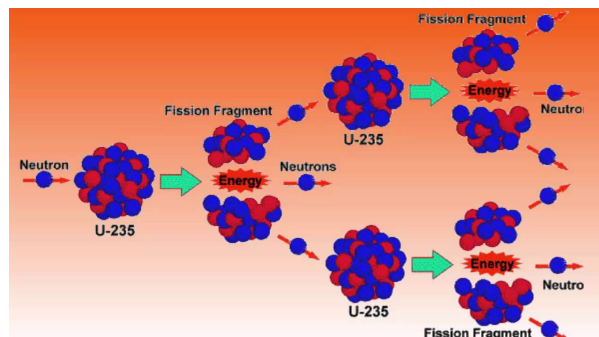
Dr Owen Williams – University of Wales TSD:

Power plants that depend on atomic energy don't operate that differently from a typical coal-burning power plant. Both heat water into pressurized steam, which drives a turbine generator. The key difference between the two plants is the method of heating the water.

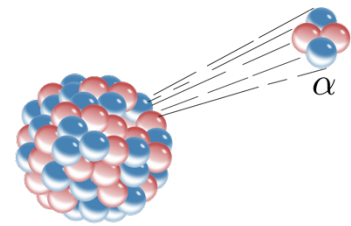
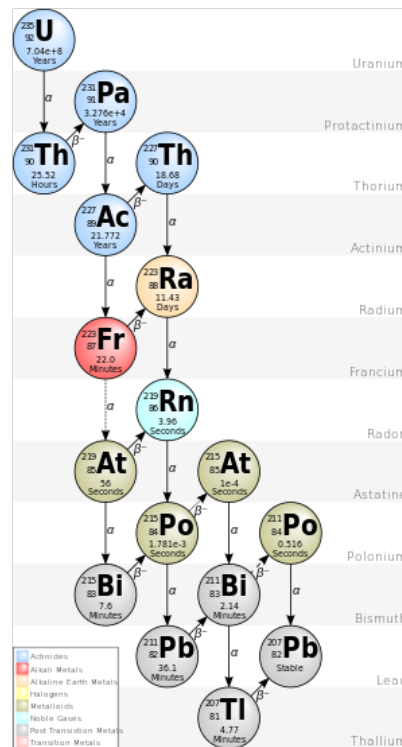
Nuclear power plant



While coal-powered plants burn fossil fuels, nuclear-powered plants depend on the heat that occurs during nuclear fission, when one atom splits into two and releases energy. Nuclear fission happens naturally every day. Uranium, for example, constantly undergoes spontaneous fission at a very slow rate. This is why the element emits radiation, and why it's a natural choice for the induced fission that nuclear power plants require.



Uranium is a common element on Earth and has existed since the planet formed. While there are several varieties of uranium, uranium-235 (U-235) is the one most important to the production of both nuclear power and nuclear bombs.



U-235 decays naturally by alpha radiation: It throws off an alpha particle. It's also one of the few elements that can undergo induced fission. Fire a free neutron into a U-235 nucleus and the nucleus will absorb the neutron, become unstable and split immediately.

The decay of a single U-235 atom releases approximately 200 MeV.

$$U_{235} = (200 \times 10^6) \times 1.6 \times 10^{-19}$$

$$U_{235} = 3.2 \times 10^{-11} J$$

That may not seem like much, but there are lots of uranium atoms in a kg of uranium.

$$U_{235} \text{ atoms} = (6.022 \times 10^{26}) \div 235$$

$$U_{235} \text{ atoms} = 2.56 \times 10^{24}$$

So we get:

$$U_{235} = (2.56 \times 10^{24}) \times 3.2 \times 10^{-11}$$

$$U_{235} = 8.2 \times 10^{13} J/kg$$

The splitting of an atom releases heat and gamma radiation, or radiation made of high-energy photons. The two atoms that result from the fission later release beta radiation (superfast electrons) and gamma radiation of their own.



But for all of this to work, scientists have to first enrich a sample of uranium so that it contains 2 to 3 percent more U-235 [source: World-nuclear.org]. Three percent enrichment is sufficient for nuclear power plants, but weapons-grade uranium is composed of at least 90 percent U-235. The process of enriching uranium is done via a centrifuge after a gas has been created from the uranium. The force of the centrifuge separates the U-235 atoms from the U-238 atoms. At first, there is only a slight increase in the concentration of U-235 atoms, so the process has to be repeated several times in the centrifuge to increase the enrichment. Making weapons-grade uranium is very difficult and expensive, which is one reason so few countries have nuclear weapons. But these barriers are not insurmountable.

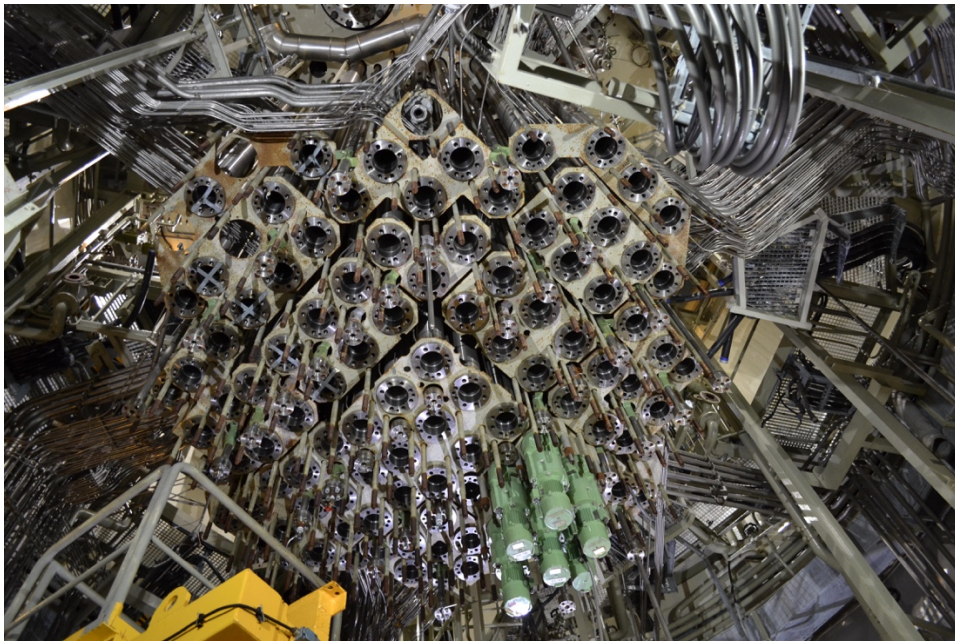


In order to turn nuclear fission into electrical energy, nuclear power plant operators have to control the energy given off by the enriched uranium and allow it to heat water into steam. That steam then drives turbines to generate electricity.

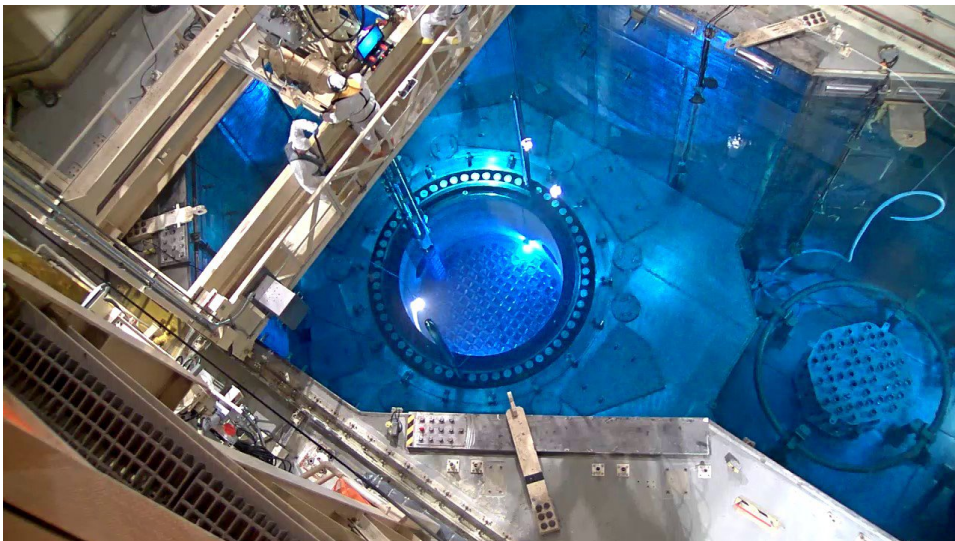
Enriched uranium typically is formed into 25 mm pellets, each with approximately 10mm diameter. Next, the pellets are arranged into long rods, and the rods are collected together into bundles. The bundles are submerged in water inside a pressure vessel. The water acts as a coolant. Left to its own devices, the uranium would eventually overheat and melt.



To prevent overheating, control rods made of a material that absorbs neutrons are inserted into the uranium bundle using a mechanism that can raise or lower them. Raising and lowering the control rods allow operators to control the rate of the nuclear reaction. When an operator wants the uranium core to produce more heat, the control rods are lifted out of the uranium bundle (thus absorbing fewer neutrons). To reduce heat, they are lowered into the uranium bundle. The rods can also be lowered completely into the uranium bundle to shut the reactor down in the event of an accident or to change the fuel [sources: Nosowitz, World-nuclear.org].



The uranium bundle acts as an extremely high-energy source of heat. It heats the water and turns it to steam. The steam drives a turbine, which spins a generator to produce power.



In some nuclear power plants, the steam from the reactor goes through a secondary, intermediate heat exchanger to convert another loop of water to steam, which drives the turbine. The advantage to this design is that the radioactive water/steam never contacts the turbine. Also, in some reactors, the coolant fluid in contact with the reactor core is gas (carbon dioxide) or liquid metal (sodium, potassium); these types of reactors allow the core to be operated at higher temperatures [source: World-nuclear.org]

Once you get past the reactor itself, there's very little difference between a nuclear power plant and a coal-fired or oil-fired power plant, except for the source of the heat used to create steam. But as that source can emit harmful levels of radiation, extra precautions are required.



A concrete liner typically houses the reactor's pressure vessel and acts as a radiation shield. That liner, in turn, is housed within a much larger steel containment vessel. This vessel contains the reactor core, as well as the equipment plant workers use to refuel and maintain the reactor. The steel containment vessel serves as a barrier to prevent leakage of any radioactive gases or fluids from the plant.

An outer concrete building serves as the final layer, protecting the steel containment vessel. This concrete structure is designed to be strong enough to survive the kind of massive damage that might result from earthquakes or a crashing jet airliner.

These secondary containment structures are necessary to prevent the escape of radiation/radioactive steam in the event of an accident. The absence of secondary containment structures in Russian nuclear power plants allowed radioactive material to escape in Chernobyl.

According to the Nuclear Energy Institute, the power produced by the world's nuclear plants would normally generate 2.2 billion tons (2 billion metric tons) of CO₂ per year if they depended on fossil fuels. In fact, a properly functioning nuclear power plant actually releases less radioactivity into the atmosphere than a coal-fired power plant. That's because when coal is burned for electricity, fly ash (which contains very concentrated amounts of uranium and thorium) is released. This fly ash has 100 times more radioactivity than the radioactivity released by a nuclear power plant producing the same amount of energy. Plus, nuclear energy comes with a far lighter fuel requirement. Nuclear fission produces roughly a million times more energy per unit weight than fossil fuel.

But there are many negatives as well. Historically, mining and purifying uranium hasn't been a very clean process. Even transporting nuclear fuel to and from plants poses a contamination risk. And once the fuel is spent, you can't just throw it away. It's still radioactive and exposure to this waste can cause radiation sickness, cancer or even death, depending on how much radiation you absorb. According to the U.S. Government Accountability Office, the U.S. has accumulated 80,000 metric tons of nuclear waste generated by power plants, most of which was still stored at company sites, as the federal government struggles to come up with a better solution.

And as if this weren't bad enough, nuclear power plants produce a great deal of low-level radioactive waste in the form of shoe covers, wiping rags, equipment and other materials.

Remember, at the heart of every nuclear reactor is a controlled environment of radioactivity and induced fission. When this environment spins out of control, the results can be catastrophic.

For many years, the Chernobyl disaster stood as a prime worst-case example of nuclear malfunction. In 1986, the Ukrainian nuclear reactor exploded, spewing 50 tons (45 metric tons) of radioactive material into the surrounding area, contaminating millions of acres of forest. The disaster forced relocation of 150,000 people, and eventually caused thousands to die from cancer and other illnesses.



Chernobyl was poorly designed and improperly operated. The plant required constant human attention to keep the reactor from malfunctioning. Yet even a well-designed nuclear power plant is susceptible to natural disaster.

On Friday, March 11, 2011, Japan experienced the largest earthquake in modern history. A programmed response at the country's Fukushima-Daiichi nuclear facility immediately descended on all of the reactor's control rods, shutting down all fission reactions within 10 minutes. Unfortunately, however, you can't shut down all radioactivity with the flip of a switch.



The March 2011, quake manifested a deadly tsunami, which destroyed the backup diesel generators that powered the water coolant pumps the facility had turned to after it couldn't get power from Japan's grid. These pumps circulate water through the reactor to remove decay heat. Uncirculated, both the water temperature and water pressure inside the reactor continued to rise. Furthermore, the reactor radiation began to split the water into oxygen and volatile hydrogen. The resulting hydrogen explosions breached the reactor building's steel containment panels.

Simply put, the Fukushima-Daiichi facility had many countermeasures in place to shut down operations in the event of severe seismic activity. They just didn't count on losing power to their coolant pumps.

Plants such as Japan's Fukushima-Daiichi facility, Russia's Chernobyl and the United States' Three Mile Island remain a black eye for the nuclear power industry, often overshadowing some of the environmental advantages the technology has to offer.

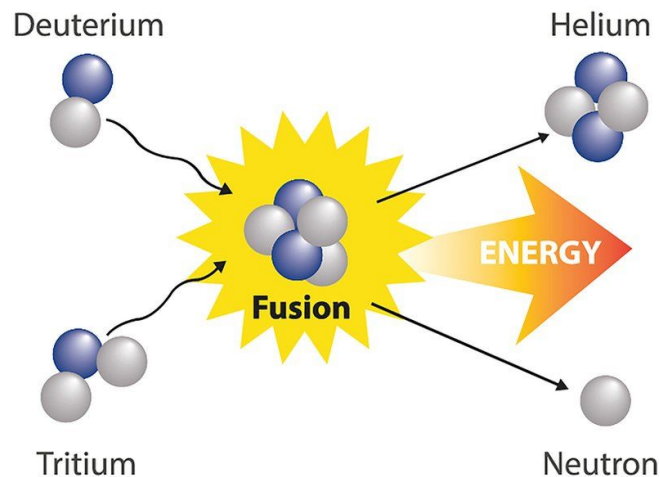


Nuclear Fusion

Dr Owen Williams – University of Wales TSD:

The prospects for developing nuclear fusion as a feasible source of energy have significantly improved, say experts.

The UK government has recently announced an investment of £200m to deliver electricity from a fusion reactor by 2040.

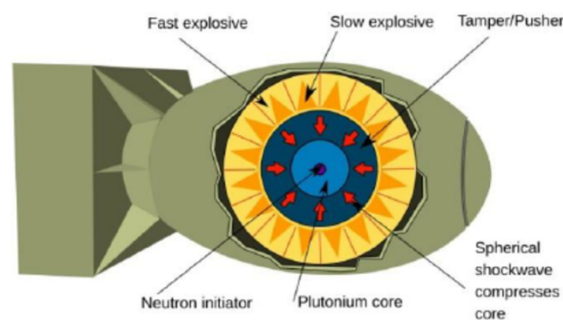


Private companies and governments have claimed they aim to have demonstration models working within five years.

With the price of wind and solar continuing to drop, experts say these existing renewables might offer a more economical and timely method of tackling climate change and generating energy than an unproven technology like fusion.

Nuclear fusion is an attempt to replicate the processes of the Sun on Earth. It differs significantly from nuclear fission, which has been our only way of getting electricity from atoms since the 1950s.

Fission has proven to be hugely expensive. It generates large amounts of radioactive waste and raises serious concerns about safety and the proliferation of weapons.



So what exactly is fusion?



The basic idea is to take a type of hydrogen gas, heat it to more than 100 million degrees until it forms a thin, fragile cloud called a plasma, and then control it with powerful magnets until the atoms fuse and release energy.

Potentially, it can generate power that is low carbon, with much smaller amounts of waste. It also comes without the danger of explosions.

To deliver the fusion concept, countries have focused their energies on a major international co-operative effort called Iter.



The giant Iter site in southern France aims to have its first plasma generated in 2025

The Iter project involves 35 countries and, right now, it is constructing a huge test reactor in southern France.

The plan is to have the first plasma generated in 2025. However, getting from this step to producing energy is extremely difficult.

Iter has also been beset by long delays and budget overspend which means it is unlikely to have a demonstration fusion power plant working even by 2050.

"One of the reasons that Iter is late is that it is really, really hard," said Prof Ian Chapman, chief executive of the UK Atomic Energy Authority.

"What we are doing is fundamentally pushing the barriers of what's known in the technology world. And of course you reach hurdles and you have to overcome them, which we do all the time and Iter will happen, I am completely convinced of it."



General Fusion believe their approach to fusion will work within five years

Until Iter is up and running in 2025, the UK based Joint European Torus (JET) remains the world's largest fusion experiment.

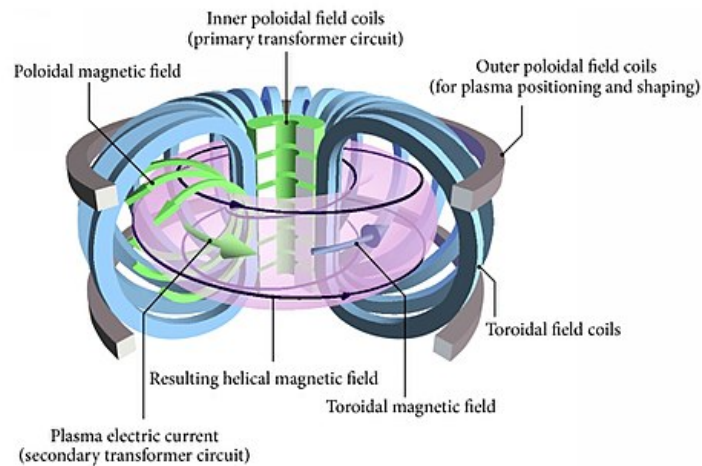
It has secured EU funding until the end of 2020, but what happens after that, and the participation of the UK in Iter after Brexit remain unclear.

To give some sense of certainty, the UK government recently announced £220m for the conceptual design of a fusion power station by 2040.

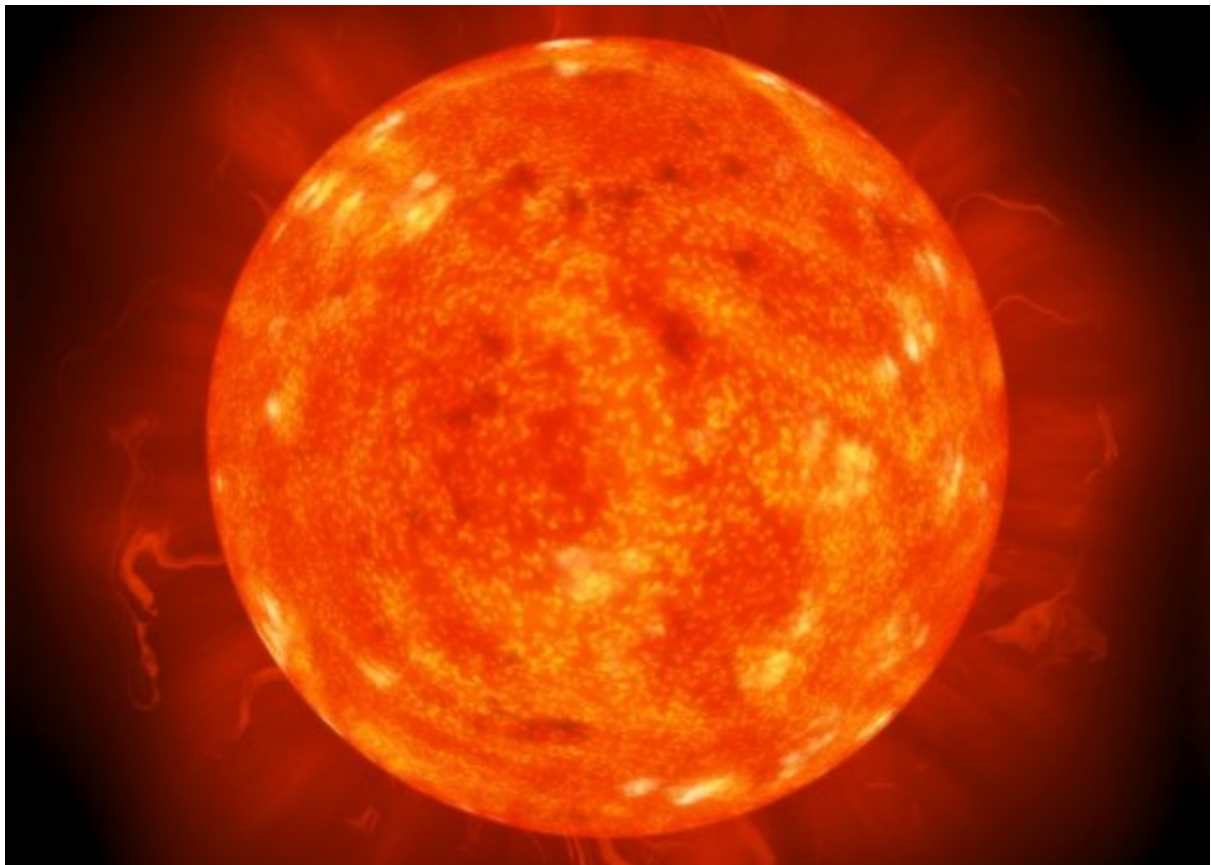
Over the next four years, researchers based at Culham in Oxfordshire will develop designs for a fusion power plant called Step or Spherical Tokamak for Energy Production.

How will the UK make fusion work?

The most widely known approach to making fusion happen involves a doughnut shaped vacuum chamber called a Tokamak. Hydrogen gas is heated to 100 million degrees C at which point it become a plasma. Powerful magnets are used to confine and steer the plasma until fusion occurs.



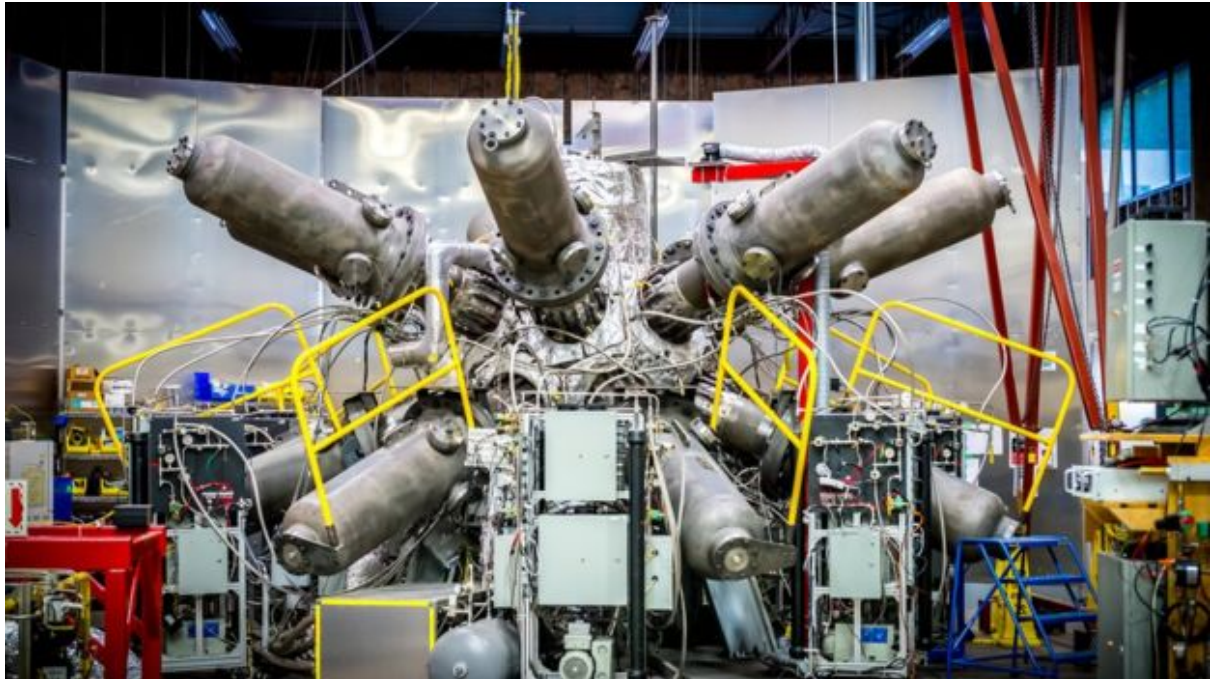
In the UK, researchers have developed a different form of Tokamak, that more resembles an apple core than a doughnut. Called a Spherical Tokamak, it has the advantage of being more compact, potentially allowing future power plants to be located in towns and cities.



Despite the hopes, no one to date has managed to get more energy out of a fusion experiment than they have put in.

Most experts are confident the idea will work, but many believe that it is a matter of scale. To make it work, you have to go large.

"I think fusion needs resources to really make it work," said Prof Ian Chapman from UKAEA. "You could do that within a company or a country, but you really need to have the requisite scale and resources."



"When ITER works, and I say when, not if, it will be a step change for fusion and you will see massive investment come into the field."

Will renewable energy make fusion redundant?

The UK has committed to Net Zero emissions by 2050 which will require the deployment of wind and solar on a massive scale. Some argue this should be a greater priority for Britain, rather than spending large sums on experimental fusion reactors.

"The cost of renewables has shot down while the cost of the world fusion project, Iter has gone up and it now looks very unlikely they will be able to compete without new ideas," said Sir Chris Llewellyn Smith, a one time chair of the ITER council and a respected British physicist.

Nuclear Powered Cars?

Dr Owen Williams – University of Wales TSD:

The advantages of nuclear-powered vehicles?

Nuclear power is cleaner than fossil power, causes few deaths, has higher power and energy density, and a single fuel rod lasts so long that you'd probably never need to refuel (plus, the space and weight saved from not having to carry fossil fuels would further increase efficiency and storage capacity).

In the case of a nuclear car, you would probably be able to drive hundreds of thousands of miles before having to refuel. A nuclear warplane would stay up in the skies forever — or a commercial jetliner could fly all the way from London to Sydney without refueling.

Some of the biggest gains, though, would probably come from nuclear-powered cargo ships. The largest container ships, like those operated by Maersk, consume upwards of 10,000 litres of diesel *per hour*. It has been estimated that just 15 large container ships produce as much pollution as all of the world's billion-or-so cars combined — and there are *thousands* of container ships currently at sea. Nuclear cargo ships would put a serious dent in global greenhouse gas emissions.



The disadvantages of nuclear-powered vehicles?

With all that said, nuclear power isn't without its issues — and yes, there have been attempts in the past to make nuclear cars, planes, and ships.

The main problem, as you can probably guess, is radiation. Poor shielding could result in a messy end for the occupants of a nuclear vehicle, and any kind of containment leak would be bad news for the environment. Generally, the problem with good-enough shielding is that it tends to be heavy — and planes and cars aren't fans of extra weight.

Both the US and Soviet Union researched the possibility of nuclear-powered bombers during the Cold War. These bombers would carry thermonuclear bombs and would act as the perfect omnipresent nuclear deterrents.

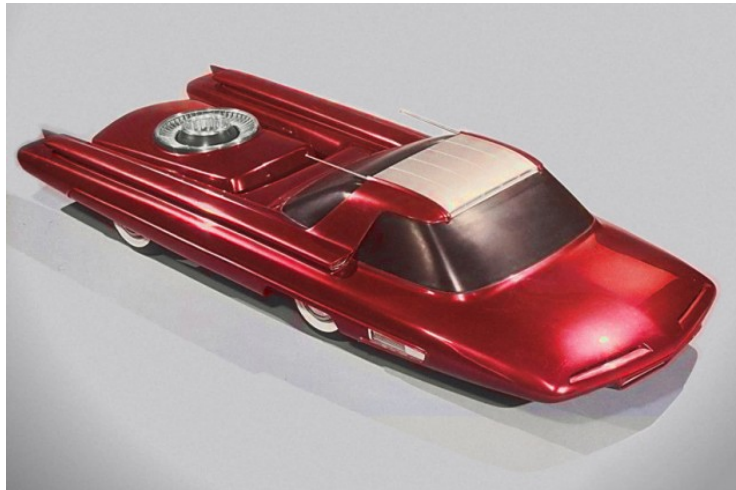


The NB-36H, 1958 — the only US aircraft to ever carry a nuclear reactor. But it only carried the reactor to test the feasibility of the added weight of the reactor and shielding; it didn't power the engines.

The heavy shielding requirement, plus the development of thermonuclear ICBMs and nuclear submarines in the 1960s, meant that these nuclear aircraft never took off.

The NS Savannah, one of the few nuclear-powered passenger ships ever built (by the US of course), dumped low-level radioactive waste into the ocean — the waste didn't actually harm the environment very much, but as you've probably realized by now, the media and public (and thus politicians) are hyper-sensitive when it comes to any kind of nuclear-related mishap.

Which brings us to cars. To this day, the closest we've ever come to a nuclear car is the Ford Nucleon, a 1958 scale model concept car that would've used a nuclear reactor paired with a steam engine (much like nuclear submarines or icebreakers).



At the time, there was no nuclear reactor small enough to squeeze into a car, and so it never became more than a concept. (As you can probably tell, the '50s and '60s — the heyday of optimistic nuclear research — were probably the last time that nuclear power wasn't despised by the public.)

The problem is, even as we sit on the cusp of super-clean fourth-generation (Gen IV) nuclear power, reactors are still really, really big. A small nuclear reactor is generally classified as anything that generates *less than 300 megawatts* of electricity. The combustion engine in your car, on the other hand, generates 150 kilowatts, or about 2,000 times less power. Even the smallest of modular Gen IV reactors, which pump out around 25 megawatts of electrical power, weigh about 50 tons. A lot of that is shielding, of course — but if you're going to be driving around at 100 mph with a nuclear reactor in the trunk, some strong shielding is probably a good idea.

For now, then, nuclear cars remain thoroughly unfeasible. They might not always be so, though. There is a definite trend towards smaller, safer, modular nuclear reactors — and there's no reason that trend won't continue. There's also the fact that no one has really *tried* to build a car-sized nuclear reactor, so it's no surprise that they generally weigh hundreds of tons.