Fission, Fusion and Efficiency (The Three Fs)

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www.ccnr.org/fission_fusion_and_efficiency_2022.pdf

Nuclear energy refers to energy that comes directly from the atomic nucleus. There are two ways to release nuclear energy in massive amounts, nuclear fission and nuclear fusion.

Nuclear Fission:

Nuclear fission takes the very heaviest element found in nature, uranium (U), and “splits” the atoms in a “nuclear chain reaction”. A relatively rare form of uranium (uranium-235) is the ONLY material found in nature that can sustain a nuclear chain reaction. So without uranium-235 to begin with, there would be no nuclear weapons of any kind and no nuclear fission reactors either.

Plutonium is a derivative of uranium that is created inside every operating nuclear reactor. It can also be used for bombs or for fuel. See the one-page fact sheet that I have prepared. www.ccnr.org/Uranium_&_Plutonium_2022.pdf .

The "high level" radioactive wastes from fission come about mainly because of the hundreds of varieties of broken pieces of uranium atoms that are extremely radioactive; these are called the “fission products”. In addition, neutrons needed to keep the chain reaction going are responsible for creating dozens of other radioactive waste materials – the transuranic elements (heavier than uranium) and the activation products. See “Nuclear Waste 101”.

Transuranic elements are extremely toxic. They result from uranium-238 atoms (the kind of uranium that is not chain-reacting). Uranium-238 atoms absorb neutrons without splitting becoming heavier and far more dangerously radioactive than the uranium that produced them.

"Activation products” on the other hand are created when stray neutrons collide with ordinary non-radioactive atoms like nickel, iron, cobalt, carbon, hydrogen. When neutrons are absorbed, these non-radioactive atoms are “destabilized” and become radioactive — hydrogen becomes “tritium” (radioactive hydrogen), stable cobalt-59 becomes highly radioactive cobalt-60, non-radioactive iron becomes radioactive iron, and so on. That’s why dismantling a nuclear power plant creates large volumes of long-lived radioactive waste due to activation — as well as radioactive contamination by fission products and transuranic elements that have leaked out of damaged fuel bundles.

Nuclear Fusion:

Nuclear fusion is very different. Fusion takes the very lightest element found in nature, hydrogen (H), and “fuses” its atoms together to make heavier atoms. This is what takes place in the sun and the stars; these celestial objects are essentially “burning hydrogen” in a nuclear fusion process. In actuality, the fusion reactions planned on earth use “heavier-than-usual” hydrogen atoms, called “deuterium” (D, twice as heavy as H) and tritium (T, three times as heavy as H). Deuterium and tritium are chemically almost identical to ordinary hydrogen, but have different masses.

Because there is no “splitting” of atoms with nuclear fusion, there are no fission products. And because there is no uranium present, there are no transuranic elements created. So there is very much less variety of nuclear wastes from nuclear fusion than from nuclear fission.

The one exception is “activation products”. There are lots of activation products because of the much more energetic neutrons from the fusion reaction compared with fission. In particular there is an enormous amount of tritium produced, and there is inevitably going to be a great deal of tritium (radioactive hydrogen) released to the environment — far more than you would get from a fission reactor. Because hydrogen is one of the basic building blocks of all organic molecules, this radioactive material (tritium) easily infiltrates into all living things and there is no way to “filter it out” of air or drinking water. It enters the body through inhalation, ingestion, and absorption through the skin.

Why Commercial Fusion Has not Arrived:

From the beginning of the nuclear age 80 years ago, it has been known that nuclear fusion releases a lot more energy than nuclear fission.The problem is that nuclear fission can start at room temperature, and then it generates a lot of heat — but nuclear fusion cannot even start until the temperature is about 100 million degrees. This is very hard to achieve on Earth.

During the world war 2 atomic bomb project, some people (like Edward Teller) wanted to go directly for a more powerful bomb based on fusion. It is often called an “H-Bomb” because it fuses isotopes of hydrogen together. Such a bomb is 50, 100, 1000 or more times more powerful than the Hiroshima bomb. These are the kinds of bombs that are used in strategic nuclear weapons like the warheads on ICBMs (Inter-Continental Ballistic Missiles).

But every H-Bomb (also called a “thermonuclear” weapon) has to use a small “fission bomb” based on plutonium in order to raise the temperature to 100 million degrees so that the fusion reaction can be ignited. When H-Bombs are dismantled, all the superpowers have do is remove the plutonium “triggers” and the thermonuclear weapons are rendered harmless.

However, on Earth, for peaceful purposes, the question is – how do you get the fusion reaction started? And how do you keep the fusion reaction contained once it starts? Since any earthly material will melt or vaporize at such temperatures, the idea is to use a container that is not made of material but only electromagnetic forces. In particular, powerful electric and magnetic forces can make a kind of “electromagnetic bottle” that can theoretically contain the fusion plasma. It is literally a “force field”. This is what happens in a Tokamak.

“Plasma” is considered the fourth state of matter — solid, liquid, gas, and then plasma. For many decades now, scientists have been trying to use electromagnetic bottles to contain the plasma that results when hydrogen gas is heated to such extremely high temperatures that the protons and electrons become completely separated from each other, creating a hot plasma, using concentrated laser beams to achieve such high temperatures.

There was a Tokamak fusion reactor facility located at Varennes, just south of Montreal, and it was eventually sold and dismantled. Of course it never succeeded in getting a fusion reaction going. I had the director, Mr. Bolton, come and address my class of aspiring physicists, chemists and engineers. He told me, quite frankly, that he did not expect to see nuclear fusion in his lifetime, but he found the research fascinating and personally rewarding.

In fact, very short-lived fusion reactions have been accomplished — lasting for a second or two at first, then for a minute or two. But no one has ever yet achieved a self-sustaining fusion reaction that can continue for a lengthy period of time. In particular, no one has yet succeeded in getting more energy out of a fusion reactor than the amount of energy that had to be put in to make it start up.

Fusion Conclusion:

As long as I can remember, going back to my years in high school in the 1950s, we have been told over and over again that nuclear fusion is just around the corner and will be ready to go in five years. It has been a perpetually repeated promise. (80 years = 5 years times 16, so the promise has been repeated at least 16 times.)

But this promise is and always has been highly questionable. One of the problems: how do you keep the fusion reaction plasma from becoming turbulent and therefore too difficult to keep confined in the magnetic bottle? In order to be manageable the “doughnut shaped” Tokamak bottle has to have a well-behaved plasma circulating inside, with smooth streamlines rather than choppy turbulence (like rough waves in a storm).

Meanwhile, the fusion neutrons are three or four times more energetic than the fission neutrons and they cannot easily be contained, so there will be a lot of “neutron damage" to materials that are outside the magnetic bottle — i.e. the construction materials of the reactor itself, not to mention the tritium leakages that will occur. Neutrons not only make the construction materials very radioactive (hence creating long-lived radioactive waste, at a much "smaller" level than the used fuel waste from fission reactors however) but also makes those materials very much weaker by a process called "embrittlement".

Embrittlement takes place at a less intense pace in fission reactors, which is why the CANDU reactors have to be "retubed" at a cost of billions of dollars every 20 years or so, because the tubes become too dangerous (too weak) to keep using them. In the case of a fusion reactor, the plant may have to be rebuilt every five or seven years because of neutron embrittlement.

In order for nuclear fusion to become a realistic alternative, it will take a long time. First, it has to be shown to be technically feasible to achieve a self-sustaining fusion reaction. That is not yet the case. Second, it will have to be shown to lend itself to engineering practices that will successfully overcome the many difficulties involved in having the reactor operate 24/7 for many months at a time. Third, it will have to be shown to be commercially and financially viable. The probability that all of this can be accomplished by 2030 is absolutely nil, and by 2050 still very unlikely in my opinion.

Renewables and Efficiency:

Renewables are about 4 times cheaper than nuclear and about 4 times faster to deploy. They are also proven — there is no doubt that they work. Most new nuclear projects, both fission and fusion, have many dubious aspects. They are unproven and untested. They are slow to deploy.

Energy efficiency is even cheaper and faster than renewables. For example, converting from electric resistance heating to using heat pumps throughout Quebec would provide enough surplus electricity to run Quebec's entire transportation sector without building any additional power plants of any kind – an astonishing fact. This is just one example out of many.

So, given that the climate crisis is indeed an emergency, we should be investing in what is fastest and cheapest to get immediate benefits. That means energy efficiency and renewables. There is no way of knowing ahead of time just how successful this will be in terms of getting to 100% replacement of fossil fuels, but it is absolutely certain that it will reduce the greenhouse gas emissions significantly, giving any other energy technology a much lesser job to do.

Moreover, the payback time will be short — capital invested in renewables and efficiency will be recovered through energy savings in good time for further investments in more renewables, or in anything else. A simple strategy, based on common sense.

Instead, investing in nuclear, now, locks up capital for decades without providing any benefits at all until the reactors are finished and ready to go. That represents decades of delay in which GHG emission are increasing unabated. During this time th climate crisis is getting worse. Even when the capital is eventually paid back, much of it has to be earmarked for the expensive job of dealing with the radioactive waste and the robotic dismantling of the radioactive structures. It is a technical and economic quagmire. Not only financial capital, but also political capital is essentially co-opted into the nuclear channel rather than what should be the first priority — reducing greenhouse gases quickly and permanently.

In Quebec, storage of renewable energy can easily be accomplished by using the existing dams. Pumped storage uses excess renewable energy to pump water uphill to generate electricity later on by letting the stored water run downhill when the sun or wind is not sufficient for the day's energy needs. But, what's even simpler with the existing dams, is just blocking the water flow when solar and wind are performing very well, and letting it flow if and when the other renewables are lacking in any way.

There are many advances being made in the realm of electrical storage, which will be needed anyway to electrify the transportation sector, no matter where the electricity comes from. Any improvements in energy storage will undoubtedly benefit the renewable much more than nuclear energy of any kind, since the only drawback of renewables is intermittency. Prioritizing renewables will simultaneously stimulate R&D in energy storage which will rapidly enhance the prospects for a sustainable energy future.