Fission, Fusion and Efficiency (The Three Fs)

Gordon Edwards, November 7, 2022.
www.ccnr.org/fission_fusion_and_efficiency_2022.pdf

for commentary about the December "FUSION BREAKTHROUGH" see p.6 and onwards

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 nucleus and its electrons become completely separated from each other, creating a hot plasma, often using outside sources – neutral particle beams and electromagnetic pulsations – to help achieve such incredibly 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.

[Note: On Dec 12 2022 a US nuclear weapons laboratory claimed to be the first to achieve “net energy” from a fusion reaction. This is discussed from page 6 on.]

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 same promise has been repeated at least 16 times.)

But this promise is and always has been very diffficult to keep. One of the problems: how do you prevent 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 extremely 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 the 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.

for commentary about the December "FUSION BREAKTHROUGH" see p.6 and onwards

FUSION BREAKTHROUGH AT A NUCLEAR WEAPONS LAB

A short commentary on the "fusion breakthrough" on December 5, 2022, announced on December 12 2022.

Jubilation is felt because, for the first time in over 60 years of effort costing many billions of dollars, a greater amount of energy came out of an extremely short-lived fusion reaction than the amount of energy needed to trigger it in the first place. The net energy gain was about 50 percent.

The experiment took place at the Lawrence Livermore National Laboratory, a pre-eminent weapons Laboratory in California once directed by Edward Teller.

It all happened very quickly. “The energy production took less time than it takes light to travel one inch,” said Dr. Marvin Adams, at the NNSA. (NNSA = National Nuclear Security Administration)

Here are a few details

1) In an earlier email (www.ccnr.org/fission_fusion_and_efficiency_2022.pdf) I described the “magnetic confinement” concept, whereby an electromagnetic force field holds a very hot plasma of hydrogen gases inside a doughnut-shaped torus (typical of the Tokamak and its close relatives). In this case, “very hot” means about 150 million degrees C.

But the breakthrough that is being ballyhooed now, since Tuesday December 13, is a different kind of process altogether, using a concept called “inertial confinement”.

The experiment involved a small pellet about the size of a peppercorn. This pellet contained, in its interior, a mixture of deuterium and tritium gases, two rare hydrogen isotopes. In the experiment, the pellet’s exterior was blasted by x-rays triggered by a battery of 192 very powerful lasers, all targeted on the inner walls of a cylinder made of gold. The lasers generated x-rays on contact with the gold atoms, and those x-rays were focussed by the curving cylindrical walls on the little peppercorn-sized pellet in the middle of the gold cylinder.

The x-rays heated the outer shell of the pellet to more than three million degrees, making the exterior of the pellet explode outwards, and (by Newtons “action-reaction” principle) causing the inner gases to be compressed to a very high density at an extremely high temperature, presumably to over 100 million degrees. It is a high-energy kind of implosion, causing fusion to occur in the very centre. The peppercorn “pops”.

2) The experimenters input 2.05 megajoules of energy to the target, and the result was 3.15 megajoules of fusion energy output – that is over 50% more energy than was put in (for a net gain of 1.1 megajoules). This suggests that the fusion reaction inside the pellet may have triggered other fusion reactions.

How much energy is that? Well, a typical household uses about 100,000 megajoules of energy per year, or an average of 273 megajoules per day. So 1.1 megajoules is not much. But it is greater than the input energy.

The Tokamak project now under construction in France for the ITER project, using magnetic confinement, is expected (hopefully) to have a net energy gain factor of 100.

Earlier this year, in February 2022, the UK JET laboratory announced that they had managed to have a fusion reaction last for five seconds. The reaction produced 59 megajoules of energy, but without a net gain in energy.

3) Most of the news stories about this event state, erroneously, that fusion reactors will not produce any radioactive wastes. This is untrue.

It is true that fusion reactors will not produce high-level nuclear waste (irradated nuclear fuel), but It is expected that fusion reactors will release an enormous amount of tritium (radioactive hydrogen) to the environment — far more than is currently released by CANDU reactors, which in turn release 30 to 100 times more tritium than light water fission reactors.

Moreover, because of neutron irradiation, the structural materials in a fusion reactor will beome very radioactive. The decommissioning wastes will remain dangerously radioactive for hundreds of thousands of years.

4) Many experts believe it will take at least 20-30 years to have a prototype fusion reactor in operation, even if things go quite well, and more decades will be required to scale it up to a commercial level. Thus, fusion energy will be largely irrelevant to the climate emergency we are now facing as all of the critical decision points will have passed before fusion is available.

And, of course, there are no guarantees even then.

As one commentator sardonically remarked, « fusion energy is 20 years away, it always has been, and perhaps it always will be ».

SERVICING THE THERMONUCLEAR WEAPONS STOCKPILE

In my opinion, the most important thing about the fusion “breakthrough" is neither the over-hyping nor the under-hyping of the story, but the misrepresentation of the nature of the research as energy related rather than weapons related — disguising the fact of the fundamentally military rather than civilian rationale and applicability of the entire fusion Ignition facility located at the Lawrence Livermore National Laboratory, a long-standing weapons lab.

As Frank von Hippel (of Princeton University) pointed out in a recent letter,

"The National Ignition Facility is currently funded by the nuclear weapons program. The deal with the weapons labs in 1993 was that they would continue to get as much money if they stopped insisting on doing nuclear test explosions as they were getting for testing and developing new weapons. They agreed and the US has not tested since 1992.

"Each lab got to choose what research tools they would like. Livermore chose the National Ignition Facility. Its purpose is to test the nuclear-weapon design codes with small nuclear fusion explosions produced by implosions by lasers rather that the X-rays produced by the first stage explosion of a nuclear warhead.
"But the labs are insatiable and Livermore is notorious for its hype. Remember the dream of bomb-powered X-ray lasers that were promised to shoot down

Soviet warheads, which persuaded Reagan to launch his "Star Wars" program? So Livermore is now touting its $3 billion toy as the energy technology of the future. Anything is conceivable but that is such a huge extrapolation that no one but a fraudster would make it."

In the context of climate change, the big difference between solar and fusion is that one works and one doesn't. Moreover the one that works is predicated on helping humankind achieve a truly sustainable future while the one that doesn't work is largely dedicated to perpetuating and perfecting weapons of mass destruction.

When I invited Mr. Bolton to address my class ("Energy and the Environment") to talk about his work with the Tokamak fusion reactor at Varennes (just south of Montreal) I asked him whether there was any military interest in his work. He seemed quite surprised by my question and said, "No, certainly not. My research on fusion energy has nothing to do with the military." But a week later, when I spoke with him on the telephone, he confided to me that he had thought about my question and was surprised to realize that the only other scientists who had expressed any interest in his work over the years were folks who worked at weapons labs in the US and elsewhere.

When General Groves supervised the World War II Atomic Bomb Project it was under the auspices of the US Department of War. The military learned the political power of euphemisms and later renamed it the Department of Defence. Meanwhile the Nuclear Weapons department is euphemistically called the Department of Energy.

Both fusion and fission advocates are hoping to grab as large a share as they can of the trillions of dollars being made available by governments around the world for fighting climate change, and so they have adopted similarly euphemistic language and promotional hype – dubbing their favorite research projects as "clean", "renewable" and "promising" technologies that may be "essential" to deal with the climate crisis, thereby taking money away from proven technologies that are faster and cheaper to deploy and will undoubtedly make a significant impact on reducing greenhouse gases by 2030, like solar and wind. Neither new fission nor new fusion will have any discernible effect by 2030, and I wager very little effect by 2050 as well. And so the can is kicked down the road for a few more decades. The International Energy Agency has predicted that, over the next few years, 90 percent of all new electrical capacity installed worldwide will be due to these two renewable and proven tehnologies – technologies that nuclear proponents have routinely derided.

Resources:

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1. Clean Energy or Weapons?
What the 'Breakthrough' in Nuclear Fusion Really Means

M.V.Ramana, The Wire, India, December 15, 2022
https://science.thewire.in/the-sciences/clean-energy-weapons-breakthrough-nuclear-fusion-explained/

Excellent article by M. V. Ramana explaining clearly the military motivation behind the so-called fusion breakthrough

”When anthropologist Hugh Gusterson asked a senior official about the purpose of the laser programme, he said, 'It depends who I'm talking to… One moment it's an energy program, the next it's a weapons programme. It just depends on the audience'. "
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2. The Energy Department's fusion breakthrough: It's not really about generating electricity

By John Mecklin | Bulletin of Atomic Scientists | December 16, 2022
https://thebulletin.org/2022/12/the-energy-departments-fusion-breakthrough-its-not-really-about-generating-electricity/#post-heading
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THE "FUSION BREAKTHROUGH"
INEXHAUSTIBLE ENERGY OR THERMONUCLEAR WEAPONS?

The recent discussion of the significance of the "fusion breakthrough", and its misrepresentation as a monumental game-changer on our way to commercial fusion energy, deserves the attention of Canadians. The hype seems clearly designed to distract people's attention away from the tens of billions of dollars being spent annually on maintaining and modernizing the USA's enormously destructive fleet of thermonuclear weapons. People should be speaking up about this.

There is no great harm in being pro or anti nuclear power as an energy strategy, but when the pro-nuclear side is willing to embrace thermonuclear weapons as a useful step on the way to peaceful fusion energy, alarm bells start going off in my head.

On a purely scientific level, it is a far-fetched and unsupportable stretch to compare the "fusion breakthrough" at Lawrence Livermore National Laboratory (LLNL) with the 1939 Joliet-Curie discovery of "extra neutrons" in the case of nuclear fission — as if these discoveries were of equal importance in practical terms. The discovery of extra neutrons emitted following the fission of a uranium atom IMMEDIATELY made a nuclear chain reaction possible — and the rest (building the first A-Bombs) was just a design problem. In fact Joliet-Curie himself took out several patents right away, related to fission — includiing military patents.

The recent "fusion breakthrough" is not at all in the same category in terms of practical importance. There are no immediate consequences of this "breakthrough" that will instantly bring peaceful nuclear fusion that much closer to realization.

In terms of the military mission of the National Ignition Facility (NIG) it is a monumental event for them to finally accomplish what they have been striving to do since the very beginning — ignition! -- having spent $10 billion in the process. It is indeed a triumph of engineering. Finally, they have succeeded in igniting a tiny pellet of fusion fuel for 85 nanoseconds. It was essentially a miniaturized nuclear fusion explosion on a tiny scale.

The rationale and the design of this experiment was, and is, entirely military, as an integral part of the Nuclear Stockpile Stewardship Program. It was in fact a miniature nuclear fusion detonation.

How does this simplify the work of fusion energy researchers? Not at all.

As the interview with Bob Rosner in the Bulletin of Atomic Scientists shows, relating the fusion "breakthrough" to fusion energy is "BS" (Rosner's phrase).

Mechlin (the author of the BAS article says -

Mechlin: "I spoke this week with Bob Rosner, a physicist at the University of Chicago and a former director of the Argonne National Laboratory who has been a longtime member of the Bulletin's Science and Security Board....

Rosner: ". . . the people working on energy (and who pay for the ongoing research) had nothing to do with this project. The folks who succeeded so splendidly in attaining ignition and self-sustained fusion on December 5 were not part of DoE's fusion energy program (which sits in the DoE Office of Science Office of Fusion Energy Sciences); they're working instead for the National Nuclear Security Administration (NNSA), which manages our nation's nuclear weapons stockpile."

Later in the article comes this exchange:

Mecklin: "The news coverage and how it was put out, though—it was all about, you know, electricity generation from fusion."

Rosner: "It's basically—it's BS, right? That's how we started our chat..."

https://thebulletin.org/2022/12/the-energy-departments-fusion-breakthrough-its-not-really-about-generating-electricity/#post-heading

The real importance of the "fusion breakthrough", in terms of peaceful fusion energy research, is not scientific but political. The resulting euphoric wave of self-congratulations (deserved) and extrapolation to fusion energy (undeserved) was a boon to help pry more billions of dollars out of the treasuries of several countries in order to keep the money flowing for this very expensive and very long-term research into commercial fusion energy which is still far far away.

An article in Nature magazine demonstrates that non-physicists (such as the authors of the Nature article, who are trained in scientific journalism and public relations) are easily taken in by the unjustified fusion energy hype being ballyhooed in the media by pro-nuclear enthusiasts. See https://www.nature.com/articles/d41586-022-04440-7

But even in their article, the fundamental "BS" aspect is revealed. It's more about the money than it is about the science, as shown in the following paragraph:

"NIF [National Ignition Facility] was not designed with commercial fusion energy in mind — and many researchers doubt that laser-driven fusion will be the approach that ultimately yields fusion energy. Nevertheless, Campbell thinks that its latest success could boost confidence in the promise of laser fusion power and spur a programme focused on energy applications. 'This is absolutely necessary to have the credibility to sell an energy programme,' he says.

Selling. Thatt's what it's all about. Salesmanship.

I am willing to bet that the overwhelming majority of competent scientists in the fusion field would give a near-zero probability of this particular type of laser-driven fusion experiment having any applicability at all to commercial fusion energy, but those same people are probably delighted at the positive PR fallout that comes with the hype, because it promises to secure more public money for their work.

This same attitude is consistent with the current hype surrounding Small Modular Nuclear Research Reactors in Canada. The SMNR promoters need to use PR to create a sense of "credibility" in order to "sell an energy programme", which I (and many others) predict will prove to be far too costly and much too slow to make a dent in climate change for at least the next two or three decades. After that, it will be too late anyway.

Essentially, the climate crisis presents an opportunity for these SMNR startup companies to obtain government funding for their favourite research projects. It's a kind of shotgun approach covering a bewildering variety of previously proposed reactors that have, in the past, failed to be successfully commercialized - liquid sodium reactors, molten salt reactors, pebble-bed reactors, plutonium-fuelled reactors, breeder reactors, etc. etc.

I believe that now is the time for us to prioritize quenching our carbon emissions, quickly and cost-effectively, using energy efficiency investments and renewable energy deployments, rather than embarking on a multifaceted nuclear technology research program that may or may not produce results decades later. And nuclear fusion is NOT going to save the day.

Canada's nuclear cadre has struck out before with Small Nuclear Reactors that simply didn't work. Remember the two 10-megawatt (thermal) MAPLE reactors that were stillborn at Chalk River some 20 years ago? Or the 10-megawatt (thermal) Mega-Slowpoke District Heating Reactor that AECL could not even give away, free of charge? Or the 250-megawatt (electrical) Gentilly-1 reactor that operated for a total of 180 days over several years without ever producing a single kilowatt-hour of off-site electricity? These failures should teach us a sobering lesson.

Moral: Don't count your nuclear chickens before they are hatched.

Gordon Edwards.