ATOMS FOR WAR/ATOMS FOR PEACE

by Tom Cochran

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I'd like to spend a few minutes going through some physics' fundamentals of nuclear reactors and weapons, and then, deal with the nuclear fuel cycle: where the uranium goes once it leaves Saskatchewan; how it is processed prior to going into reactors; and, what's done with the products afterward. Finally, I'll go into who's who in the nuclear proliferation business; namely, which countries are doing what today.

I. THE FUNDAMENTALS OF THE PHYSICS OF NUCLEAR REACTORS

We start with a statement that actually drops out of the Theory of Relativity discovered in 1905 by Albert Einstein. Simply, the mass equivalent of energy or the energy equivalent of mass can be transposed, one into the other. Einstein demonstrated that matter has energy in it, and therefore, can actually be changed into energy. For example, if you take a uranium atom, weigh it, and then proceed to pull the constituents apart and weigh them individually, you will discover that the individual neutrons and protons weigh more than the weight of the original atom. The difference is the energy that binds the atom together. We call it the binding energy.

Those who have read a page or two ahead in their freshman's physics' text know that the interest in this is in the fact that you can take a uranium atom, split it into two fragments and release about one million electron volts (MEV) for every neucleon in the atom - or about 200 MEV for an entire uranium atom. Most of that energy is released as the energy or movement of the fusions fragments itself. Some of it comes out as X-rays, some of it as the velocity or energy of the neutron.

The interesting fact that was recognized in 1939 was that there is an enormous amount of energy released just by splitting apart one uranium atom. As soon as this was recognized, people theorized that perhaps more than one neutron would come out. That would enable one to produce a chain reaction, and if that were in fact possible, one could develop a fairly sizable bomb. Immediately, the physicists who realized this recommended to their colleagues that they should quit public discussion of this matter. They met and had Einstein write Roosevelt. The result was the launching of the "Manhattan Project".

Another frightening aspect is the fact that the atom does not split right in half. It usually splits into a heavy fragment and a light one: the result being Strontium 90, Cesium 137, Krypton 85 and so forth. These are the ones that are biologically attractive, and frequently cause cancers when taken into the human body.

One can plot a curve of the uranium atom, as a function of the velocity or energy of the neutron causing a fission, to interpret the probability that one will get a fission or, a neutron absorbed by the uranium atom. It would be a very complex curve and a higher probability of absorption occurs after you slow the neutron down. The fact that these curves are complicated and differ, whether one is talking about Uranium 235 or Plutonium 239, provides a rich area of work for reactor physicists and allows them to design reactors the way one designs cars. There are all sorts of variations; one can put in all kinds of moderators, different kinds of fuels and so forth, and end up with different kinds of reactors. That's what makes a Canadian CANDU different from the lightwater reactor that's prevalent in the United States.

The final thing to mention in the way of physics, before getting into more interesting things, is that, on the average, 2½ neutrons are released every time a uranium atom is fissioned. Sometimes its 2 neutrons, sometimes 3, but on the average it is 2½. Ninety-nine per cent of the time, they come out promptly - in one billionth of a billionth of a second (10^{-12} second). The other .75% of the time, the neutrons kind of "pop" out of the fission fragments. They come out much later. These are called delayed neutrons. If there were no delayed neutrons, when a chain reaction was set up, and the reactor was made critical, the reactor would run away very quickly. The period of the reaction, or the time as you progressively increased the power level of the reactor, would be so short that you would have no control over the reactor. You would have a nuclear bomb instead of a nuclear reactor. The overall average time period for neutron to be released, when the delayed neutrons are averaged in with the prompt neutrons, is more like a tenth of a second. That is slow enough that it enables one to control a reactor. Therefore, the only difference between a bomb and a reactor in this regard is that for a bomb you try your best to get the criticality due only to the prompt neutrons. Therefore, the reaction takes place very quickly.

II. THE NUCLEAR FUEL CYCLE

Now I'd like to talk a little bit about the fuel cycle. With the present system that reactors are operating on, the first step in the nuclear fuel system is the mining of uranium. It is mined and the uranium ore is sent to the mill where 99.8% of the material, which is simply sandstone or rock that goes with uranium, is removed and put on a tailings pile by the side of the mill. The 0.2% which is uranium comes out in a chemical form known as yellowcake, or ~~U-308~~ U_3O_8 (made up of U-238 and U-235). That is sent to a facility to be converted to uranium hexaflouride (UF_6). This refinery is the type of facility that they attempted to construct locally (at Warman, Saskatchewan). I understand that the people here suggested that they do something else!

The ~~U-308~~ U_3O_8, which is a solid, is converted to UF_6, which is a gas if heated to 130 degrees. A gas is needed to operate a gaseous diffusion plant. Gaseous diffusion is simply a process by which one can enrich the amount of U-235 atoms present in the uranium. In natural uranium, about 0.7% of the atoms are U-235. The other 99.+% are the isotope U-238. U-238 doesn't fission with slow neutrons so it doesn't make for a very good fuel, in that form. Reactors are actually operated with U-235 component.

Some reactors will only operate if you enrich the concentration of U-235 atoms. Once enriched, you get a product which is about 3% enriched in U-235. The leftover material which contains about 0.2% U-235 is called the enrichment tails. These are simply stored. (We'll come back to those later.) One needs another chemical conversion before one manufactures fuel - it has to be converted into uranium oxide. This is done in a separate facility or a combination of facilities, that is, the chemical conversion could be done in one part, and then the fabrication into fuel rods could be done separately. In any case, it's then put into a reactor. In the particular reactor that I have been describing, the fuel sits for about three years. Each year you would unload about a third of the fuel. By this time, about two-thirds of the U-235 atoms would have been burned up. They will have now been fissioned, and so fresh fuel will be required to replace the spent fuel. The spent fuel has also been contaminated by all the fission products and those products, in effect, poisoned the reactions. This is another reason for the removal of the spent fuel.

The fuel is very hot, both thermally and radioactively, because of all the radioactive fission products in it, so it is stored in a "swimming pool" by the reactor - a spent fuel storage pool. Eventually, it will go to the federal wastes repository, none of which exist in the world as yet (they're still trying, they say).

In an expansion to the fuel cycle for the same reactor, a reprocessing step has been added. After the spent fuel has cooled about 120 days, it is sent off to a chemical reprocessing plant to recover its unused uranium. Remember only two-thirds of the uranium was fissioned or burned. With a reprocessing plant, the rest can be recovered, sent back and re-enriched. At the same time, in this reactor, about 97% of the uranium atoms are U-238 atoms which do not fission. They do something else. The U-238 still captures neutrons some of the time and converts them into U-239 which decays into Neptunium-239, and then into Plutonium 239 (Pu-239). Pu-239 is a very interesting isotope. For all practical purposes, it behaves in reactors and bombs just like U-235. Therefore, one can use this fuel to make weapons. Again, the fission products are removed at this stage, encapsulated somewhere and stored in the fictitious federal repository.

The Canadian reactor, the CANDU, is identical, except that it is designed to avoid enrichment of the uranium. It uses natural uranium as fuel. This is an advantage. However, there are some disadvantages. More fuel must be used, the reactors cost more, and so forth. These are some of the cost trade-offs that must be weighed when one is deciding whether one buys or builds a lightwater or a CANDU reactor. CANDUs have other advantages when it comes to production of Plutonium for weapons. I'll get to that later.

A reactor is a reactor, whether it be for commercial use or for naval submarines. The fuel cycle for a naval reactor is almost identical to that of the light water reactor. It's a naval reactor because they don't want to build a reactor that's as large as a five-storey building. To make a reactor compact enough to get it into the hull of a submarine, the fuel must be enriched up to 97%, or at least, highly enriched uranium must be used. Therefore, the fuel cycle of a naval reactor is essentially the same as described, except that more money is spent in terms of enriching the uranium.

Spent fuel from the US nuclear submarines is sent to a reprocessing plant in Idaho where the uranium that has not been burned up in the fuel is recovered to be reused. It will not be used, however, in the submarines. It will be reused for another purpose which we will get to later. The fictitious repository in this particular case is some steel tanks in Idaho where they're storing the waste products.

Another fuel cycle is that which the US uses in producing Plutonium and Tritium for nuclear weapons. Again, we begin with the mining of the uranium ore. It goes to the mill where the yellowcake is removed and then on to the refinery to be converted into UF_6. The UF_6 is enriched up to about 60%. This enriched uranium, plus the uranium from the submarines' spent fuel, is then converted into fuel elements that are put into the production reactor. These fuel elements are used solely to provide the neutrons in the production reactor and keep their critical reaction going. At the same time, depleted uranium tails, that were 99.8% U-238, are taken from the tailings pile at the enrichment plant. These are made into fuel elements and put into the reactor to absorb the neutrons. That's the whole purpose of this reactor, to absorb neutrons from these fuel elements and produce plutonium.

Similarly, we can take enriched lithium and absorb neutrons. Lithium, in nature, is normally predominantly Lithium-7. We enrich the Lithium - 6 component, make fuel elements that are a lithium-aluminum alloy, drop them in and produce tritium by absorbing neutrons in lithium-6. The lithium-6 absorbs the neutrons and splits into tritium and a helium atom. Tritium and plutonium are used to manufacture the warheads for the weapons.

Now, in the US case, I'm sure you'd be interested to know, between 1942 and 1970, the AEC purchased about 325 thousand tons of uranium in the form of yellowcake. About 23% of that, something like 57 thousand metric tons was purchased from Canada. The US was making nuclear fission weapons out of both plutonium and highly enriched uranium. It was a little cheaper to enrich the uranium up to about 95% than it would have been to produce the plutonium through the above-mentioned process. So the US produced about ten times as much highly enriched uranium for weapons as they did plutonium for weapons. In 1964, they had so much highly enriched uranium for weapons that they quit producing it although they continued to produce some plutonium. By 1964, approximately 30% of the uranium that was used either directly for weapons or to produce plutonium for the weapons was Canadian uranium. I would say, as a rough number, approximately one third of the US arsenal is of Canadian origin. There are some 26,000 weapons in the US arsenal today. About 9,200 of those are part of the strategic nuclear force, the remainder are tactical weapons, naval weapons and so forth. We'll talk about some of those later.

Just one more piece of trivia. In the United States at one time there were about 14 of these reactors: 13 of them producing weapons grade plutonium; 8 graphite reactors at Hanford and 5 heavy water reactors, similar to the CANDU, located at the Savannah River plant in South Carolina. In the mid-60s to 1970 most of the production reactors were shut down. In fact, all were shut down at Hanford, all of them graphite reactors. Two of the heavy water reactors at the Savannah River plant were shut down. For the past ten years or so the US has continued to operate three production reactors to produce plutonium and tritium, at the Savannah River plant. The scale back occurred at about the same time that the purchases of Canadian uranium by the AEC went to zero. The mining also probably dried up here at about that time.

III. THE PROBLEM OF PROLIFERATION

It's useful to divide the nuclear proliferation problem into two types: what is normally referred to as 'vertical proliferation', that is, the increasing numbers of warheads by the super-powers, or in other words, the arms race; and 'horizontal proliferation', which is the spread of nuclear weapons capability to what would otherwise be non-nuclear weapons countries.

Within the discussion of 'vertical proliferation', the US has about 26,000 warheads. There are roughly twice as many as that in the world. If you do some crude arithmetic, 26,000 is about one for every 900 US citizens. The number of warheads that are being, or are likely to be produced, in the United States in the next decade, is about 16,000. Just count up the new missile systems: the cruise missiles, the MX, the new missile warheads for the Trident submarines and so forth. At the same time about half of the US stockpile will become obsolete; they will tear down about 13,000 warheads and there will be a net increase of about 3,000 warheads in the next decade. It comes out to about a warhead a day, net, or 4-5, gross.

The Defense Department did some studies last summer, all classified, of course. The weapons production side of the Department of Energy concluded that if we need all those new cruise missiles and so forth, we are going to need more plutonium and tritium, particularly tritium, to build neutron bombs. Neutron bombs are thermo-nuclear devices that use tritium and deuterium as the thermo-nuclear component. Therefore, the Department of Energy concluded that we need to restart some of these production reactors. They have and Congress has approved it. One of the additional reactors at the Savannah River plant that was on stand-by is being prepared so that it can be turned on at very short notice. A dual-purpose reactor at Hanford, that has actually been producing plutonium for the US research and development Breeder Program, is also being converted so that it produces weapons grade plutonium. If you decide to deploy neutron bombs, all of the complex at the Savannah River plant will be maximized to produce tritium. It will take that entire complex just to provide the tritium for the neutron bomb.

In terms of 'horizontal proliferation', I want to talk about two major kinds of problems. The first is the reprocessing step. Once a reactor program and a civil reactor fuel cycle exists, and reprocessing is permitted in a country that is a non-nuclear weapons state, (plutonium is recoverable from a civilian reprocessing plant) then that country is what I would call a nascent nuclear weapons state. It is so close to having a bomb, it should really be considered a nuclear weapons state. The technology for manufacturing a bomb is more or less a low technology. It's easy to do. One simply needs to figure out how to squeeze that subcritical mass of plutonium and hold it together for a long enough period while it is super-critical. This is done by surrounding it with high explosives and detonating it uniformly, and then simply imploding the plutonium. The sophistication is the weapons design really comes down to how one does ~~what~~ most efficiently - how one gets the maximum compression and holds it together for the longest period of time.

That technology is fairly simple. In order to make a weapon with a yield comparable to the Hiroshima or Nagasake ones, one needs only a matter of weeks, as long as one has the fissile material. So once again, if this type of recycling is allowed, that is, if plutonium is recovered at a reprocessing plant and stored in a non-weapons state - that state can have a weapons option in very short order. The time period, in fact, is so short that if it decided to take the nuclear weapons route, the time it would take would be too short for other countries to bring any diplomatic pressures to bear.

A term one often hears in the non-proliferation jargon is 'timely warning'. We try to ensure that fuel cycles are designed and deployed so that one maintains timely warnings. That way, one will be able to identify a country that is moving to a weapons option and still have time to bring some sort of diplomatic pressure or sanctions against that country. Similarly, the reprocessing plant does not have to be in the country. If plutonium is simply shipped to another country for use as fuel in one of their civilian reactors, it would have the same effect. It would provide a country with weapons usable material.

There are a number of research reactors that use highly enriched uranium, which is a weapons usable material. If you have provided a country with a stockpile of highly enriched uranium in excess of twenty kilograms they, in effect, could have the weapons option in short order. All they need is to design the weapon and insert the material. (This is a slight simplification but the problem does exist.)

The breeder reactor is one which uses plutonium instead of enriched uranium as fuel. It avoids a step in the fuel cycle by simply recycling plutonium, inserting tails, and breeding plutonium faster than you can burn it up in the fission process.This is possible because when plutonium fissions, almost three neutrons are produced per fission. You only need one of those to go on and produce another fission to complete the chain reaction. You have an excess of almost two neutrons and if the reactor is designed efficiently, you can breed more than one plutonium atom for every one you fission. The problem with the breeder, of course, is that it requires the reprocessing step. Every year two and a half tonnes (two tonnes = 2000 kg.) are taken out. At five kg. per weapon, that is the equivalent of four hundred weapons per year for each breeder reactor of, roughly, 1,000 megawatts. A commercial reprocessing plant, if it handled 1,500 metric tonnes a year, would process fuel from about sixty breeders. If you run on a breeder fuel economy, you're approaching the equivalent of 10,000 nuclear weapons worth of plutonium from each reprocessing plant. Imagine that spread around the world, the stuff being made a legitimate article of commerce, being shipped to non-weapons countries. All the countries participating in this breeder fuel cycle, in effect, become nuclear weapons states. That is the nub of the proliferation problem. Once you move to the plutonium fuel cycle with breeders, or even reprocessing and recycling the plutonium in light water reactors, you get the same effect.

IV. WHO'S WHO IN THE PROLIFERATION BUSINESS

,Now, let's talk about who's who in the proliferation business. About five or ten years ago, if someone asked which countries had nuclear weapons, the answer would have been five: the US, the USSR, the United Kingdom, France and China. Israel probably would not have been named because most of us were not aware that by that time they had diverted some highly enriched uranium from a plant in Pennsylvania and had started developing nuclear weapons. Actually, whether or not this is fact is still in dispute in the United States. I really don't think that it is much of a dispute. It's clear that the CIA believes the diversion took place. The US Department of Energy, which more or less had responsibility for the facility, still maintains that they have no evidence of it taking place.

Most of you are aware that India exploded a nuclear weapon, in 1974.

That weapon was a plutonium bomb., India simply claimed that it was a peaceful nuclear device, not a bomb at all! Of course, there is no difference - physically they are the same with respect to everything but the outer casing. The type of lunchbox you put it in seems to make a difference to the Indians - that is, whether to call it a weapon or a Peaceful Nuclear Explosion (PNE). The plutonium for this 'PNE'came from the Cyrus research reactor which was provided by Canada. The US had trained the Indian scientists under the Atoms for Peace program. The spent fuel from the reactor was reprocessed in the Trembay reprocessing plant which was part of their so-called breeder program.

Pakistan is the second country that is clearly moving towards a nuclear weapons option. One of their scientists, a man named Khan, stole the plans for a gas centrifusion enrichment plant from the plant where he worked in Holland, a plant owned by the Dutch, British and Germans. The Pakistanis proceeded to try and put the plant together through the purchase of components on the open market. They bought a large number of components before the whistle was blown by the British. They are actually proceeding toward a weapons option along three parallel directions: 1)Using enrichment process technology; 2)Using a pilot reprocessing plant that they purchased, I believe, from the Belgians; and 3) They also attempted to purchase a larger plant from the French in the mid-70s. The French provided the design, but with US pressure by the Carter administration, cancelled the deal. The Pakstanis are still trying to use the design by buying equipment. They are buying it from the Italians and others and importing it as fertilizer plant equipment. It's designed so that they don't get a critical reaction when the plutonium is chemically processed and recovered. In order to ensure that sufficient plutonium does not get into the vat to go critical in the plant rather than the weapon, particular sizes of vats must be designed.

The Pakistanis are getting their uranium from a mine in Niger. It's operated by Cogema, a French company that also has some mining interests in Canada, I'm told. The arrangement Cogema has with Niger allows Niger a piece of the action. They have two mines there and Cogema's share of the uranium is safeguarded by the International Atomic Energy Agency (IAEA). Since the Niger government is not a part of IAEA, their uranium goes to Libya and then is transshipped to Pakistan.

A couple of years ago the Natural Resources Defense Council, who I am representing here tonight, brought some legal action, related to the shipment of fuel for the Tarrapore reactor, following the explosion of the Indian weapon. We wanted to know what information the US State Department had before it at the time of the explosion. They were approving these shipments of fuel after 1970 and even into 1974. We have a law in the States caled the Freedom of Information Act where you simply write the government agencies and ask for any information they have on such and such. With the exception of classified material, they must supply the information. One document was discovered at Department of Energy. It was a CIA document. It was forwarded to the CIA and the agency office marked two paragraphs for release. By some clerical error the entire document,except for the two paragraphs, was released. This document turned out to be the National Intelligence Agencies estimate of who's who in the proliferation business. In the mid-70s, it pointed out, Taiwan was proceeding with the nuclear weapons option clearly in mind. The document also discussed the fact that Israel already had nuclear weapons and the evidence for that. In Taiwan, which also has a Canadian reactor, they were attempting to build a reprocessing plant in a nuclear facility that backed up their military facility where they do all their space research. They share all the same computers; there were pipes running under the fence and so forth. The US blew the whistle because we had leverage over Taiwan in terms of supplying military equipment. We forced them to abandon the effort. Having no information from Taiwan since then, I do not know what their current status is.

South Korea is a country, in many respects, similar to Taiwan in this regard. They attempted to buy a reprocessing plant from the French. That was another case where the US brought diplomatic pressure and forced the South Koreans to abandon that program. In 1977, the Carter administration, in an attempt to bring some control to all of this, announced that the US policy would be to defer indefinately any commercial reprocessing in the country. The clear implication was that the US would try to convince other countries to take similar steps.

Since 1974, Canada has always been in the forefront in trying to toughen up some of the bilateral agreements with other countries to try to force countries that she does business with to implement full-scope safeguards over all their nuclear facilities if they are going to buy Canadian reactors. Other countries, particularly France and Germany, have been much more reluctant to tighten up their safeguards in the same way the US tried to do. They basically refused to go along with the idea of stopping or indefinitely postponing reprocessing in their own countries.

The French, particularly, have been staunch in their refusal because they have their own breeder reactor program. The French see their breeder program much like they see their Concorde. There is a lot of national prestige in their breeder program and since breeders require reprocessing, they are very reluctant to suggest that reprocessing is in any way dangerous.

Another of the countries that are very troublesome in the proliferation business is Switzerland. The Swiss have been in Pakistan, helping them to build their own reprocessing plant. The Swiss government simply refused to pressure the companies to force them back out of that work several years. It is not clear, even today, whether they have fully withdrawn.

Argentina is a good example of a nascent nuclear weapons state. She is building an independent fuel cycle, obtaining her energy independence in the nuclear business. Argentina is buying heavy water CANDU type reactors that don't require enrichment plants. The Argentines also have the reprocessing technology to reprocess the spent fuel, recover the plutonium and, either recycle it into useful fuels in those reactors or make weapons out of it. At the moment, Argentina simply declares that all of those activities are for peaceful purposes and therefore, simply avoids any diplomatic pressures that other countries impose on them. It's much like the case of India, who exploded a weapon. If Argentina goes the weapons route, it is important to recognize that Brazil will probably follow suit.

Another country to keep an eye on is Iraq. Iraq is building the back end of the fuel cycle, the reprocessing facilities, before constructing any power reactors. They purchased a research reactor that the Israelis purportedly blew up during its fabrication in France. The French rebuilt it and sent it to Iraq. The US tried to put pressure on the French not to provide highly enriched uranium - something like a bomb's worth, in the form of fresh fuel. The Iraqis complained that they had already signed a contract for the highly enriched uranium, not the low enriched uranium. They got the highly enriched uranium.

When the Iraqi - Iranian war broke out, the reactor facility (not the reactor itself, but the facility) was bombed by two phantom jets. There is all kinds of speculation as to which country those planes actually came from. Iraq does not have any nuclear scientists. We evidently forgot to train them in our Atoms for Peace program, so they are relying on the Italians. Their chief scientist on this project was an Egyptian, who was shot in Paris along with his girl friend who was a witness to the event. There is some reason to believe the Israelis do not want the Iraqis to get too far in their endeavour. At the time of the Iraqi = Iranian war the IAEA, which was responsible for the enriched uranium , asked to go in and inspect. They were turned down with Iraq denying them access because they were at war. (The inspection program has completely broken down in that regard.)

There is one more country to watch: South Africa. South Africa clearly has nuclear weapons. They have an indigenous program with enrichment based on technology supplied by the Germans. As you may recall, they were caught trying to test a weapon in the desert, first by the Soviets, and then confirmed by US satellites. Of course, one does not have to test the fission weapons anymore. One can do all the tests one needs just on the chemical explosions and predict with total confidence, whether or not the weapon will have sizeable yield.

You may also recall the September 22, 1971 event in the South Atlantic. There is still debate over whether or not that was, in fact, a nuclear device. A panel of scientists convened by the Office of the Science and Technology Policy analyzed the data and concluded that it was probably not a nuclear device. The CIA, the Defense Intelligence (DIA) and the Naval Research Laboratory director believe that it was a nuclear device. It would have been a low yield device. As of about six months ago, there was not any evidence on whose it was, whether South African or a collaboration between South Africa and Israel. Of course, speculation can run rampant as to whether it was neutron bomb or an Israeli bomb or whatever.

If the Pakistanis build the Islam bomb using reprocessing technology, in all likelihood, it will again be through the aid of a CAnadian reactor. The only indigenous source of spent fuel that is availabe in Pakistan is a small CANDU reactor near Karachi. They would probably take the spent fuel from that reactor if they decided to go that route rather than the enrichment route and I understand that they are having trouble with the enrichment route.

This concludes my presentation.

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June 8, 1981

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Dear Tom,

Please find enclosed a copy of the CONFERENCE PROCEEDINGS, for ATOMS FOR WAR & PEACE - THE SASKATCHEWAN CONNECTION, complements of the Inter-Church Uranium Committee.

A transcript of your oral presentation is included in the Proceeding along with those given by the other resource people.

With Hope for Peace,

Carmen Milenkovic

(Ms) Carmen Milenkovic
ICUC