Book Review:

Plutonium – How Nuclear Power's Dream Fuel Became a Nightmare

By Frank von Hippel, Masafumi Takubo, Jungmin Kang
Introduction by Mohammed El Baradei, past Director General of the IAEA
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Book review by Gordon Edwards, Peace Magazine, July 2020, pp. 28-29

In the beginning was the atom, and the atom was uranium. And uranium begat plutonium, the saviour and destroyer of worlds.

This is an excellent book about plutonium, the primary nuclear explosive material in the world's nuclear arsenals, and – according to the beliefs of a whole generation of nuclear proponents – an ideal future fuel for a nuclear-powered world.

With great lucidity, the authors describe the history of the nuclear age as an abortive effort to make the difficult transition from uranium to plutonium as the principal energy resource of the future. Facts are communicated in a calm, matter-of-fact, easy-to-understand manner. The failure of the "breeder reactor" concept and the resulting accumulation of huge stockpiles of separated plutonium is meticulously documented.

The book concludes with a powerful appeal to put an end to plutonium separation of any kind, whether civilian or military, in order to prevent the world from drifting toward unparalleled catastrophe.

The authors take nothing for granted. They explain the necessary background (summarized below) in exemplary fashion. Their main mission is to give a detailed but succinct country-by-country account of the history of plutonium separation and breeder aspirations.

Uranium is the only naturally occurring material that can be used to make an atomic bomb or to fuel a nuclear reactor. But less than one percent of uranium atoms are able to perform these tasks – those with an atomic mass of 235. Such atoms are "split" when struck by a neutron, giving off two or three more neutrons in the process. If one or more of those extra neutrons splits another uranium-235 atom, and this occurs repeatedly, a self-sustaining chain reaction will be achieved. Enormous energy is released as the powerful forces holding the atomic nucleus together are unleashed.

Heavier uranium atoms have atomic mass 238. They are 143 times more abundant than their lighter twins, but they cannot be used as an explosive or as a fuel. So, to make an atomic bomb from uranium, the proportion of uranium-235 atoms must be greatly enhanced to produce "highly enriched uranium" (HEU - 20 to 95 percent). Fortunately, enrichment is difficult and time consuming, requiring technology not readily available to most would-be proliferators.

One cannot make an A-Bomb from "low enriched uranium" (LEU) (less than 20 percent uranium-235). LEU can serve as a nuclear fuel if one uses a "moderator" to slow down the neutrons, but commercial uranium reactor fuel (LEU) is not a proliferation risk. HEU is weapons-usable; LEU is not.

Plutonium is another matter.

Plutonium is a human-made element. Whenever an atom of uranium-238 absorbs a stray neutron it is transformed into an atom of plutonium. Plutonium is a more powerful nuclear explosive than uranium-235, and a superior nuclear fuel as well. It can be chemically separated from irradiated uranium fuel – an operation called "reprocessing". Reprocessing poses a proliferation risk, as any type of separated plutonium is immediately weapons usable.

The authors explain that from 1940 to 1975, nuclear power advocates were convinced that scarce uranium-235 supplies would be exhausted within a few decades. By transforming the more abundant uranium-238 atoms into plutonium, the fuel supply could be extended for many centuries. But how?

When a plutonium atom is split by "fast" (unmoderated) neutrons, the extra neutrons given off are especially numerous. This numerical advantage is key to the "breeder" concept. If plutonium fuel is fed into a "fast reactor" – one with no moderator – stray neutrons impinging on a blanket of uranium-238 will create even more plutonium atoms than those that are fissioned. Such reactors are called "breeders".

The net gain in nuclear fuel only works with plutonium fuel. When uranium-235 atoms split they do not give off enough stray neutrons to make this "breeding" possible, even in a "fast reactor". Plutonium came to be seen as a dream fuel. Every country using nuclear power wanted a reprocessing plant and a fleet of breeder reactors.

But the dream became a nightmare when India exploded its first atomic bomb in 1974 using plutonium from a peaceful research reactor – a gift from Canada. It was suddenly made clear that allowing plutonium separation will enable any nation to build its own arsenal of nuclear weapons. Any war, anywhere, could turn into a nuclear war. How to prevent this nightmarish eventuality?

Plutonium-based fuel is also a serious proliferation risk. Anything commercially traded will eventually fall into the hands of criminals or terrorists. The plutonium can be chemically extracted and used to make powerful nuclear weapons. Washington or London could be destroyed without a clue as to who did it. Plutonium is also an extraordinarily effective carcinogen when inhaled; it would make for a chilling radiological dispersal weapon – a so-called "dirty bomb".

President Carter, trained as a U.S. naval nuclear engineer, initiated the end of reprocessing and plutonium use in America. He failed to achieve such a ban in the rest of the world, however.

Fortunately, fate intervened. Prototype breeder reactors in America, Britain, France, and Japan turned out to be accident-prone and prohibitively expensive; one after another, breeder programs failed and were abandoned. The liquid sodium metal coolant frequently caught fire on contact with air or water. Russia had some success with its "fast reactors", but did not run them as breeders.

Nevertheless, plutonium separation continues and stocks of separated plutonium keep growing in China, France, India, Japan and Russia. With no breeders to use it as fuel, plutonium is incorporated into MOX (mixed oxide fuel) to supplement uranium in the existing fleet of moderated reactors. But MOX is five times more expensive than LEU. Meanwhile, nuclear power has plateaued worldwide, uranium is plentiful and prices are low. The rationale for breeders has evaporated. Analysis reveals that all purported benefits of removing plutonium from irradiated fuel are chimerical: waste repositories will not be smaller or safer or cheaper due to reprocessing.

These concerns are relevant to developments in Canada today. New Brunswick is investing $10 million dollars in two "small" reactor designs (SSR and ARC-100) predicated on the reprocessing of CANDU irradiated fuel and the breeder concept.

Both New Brunswick reactors are inspired by old breeder reactor designs in the USA built before 1965. The Moltex SSR reactor is a "molten salt" design inspired by the MSER (Molten Salt Reactor Experiment) at Oak Ridge Tennessee, and ARC-100 reactor is a liquid sodium metal design inspired by EBR-II (Experimental Breeder Reactor II) built in Idaho.

This book is highly recommended. The entire remarkable story of plutonium is told with crystal clarity and detailed scholarship, fully referenced with helpful end notes. A compelling case is made to end all plutonium separation activities and to secure existing stocks. The object is to ensure that this material is not available for incorporation into tens of thousands of new nuclear weapons, or diverted for nuclear terrorism.

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