Article 4: Linkages to Nuclear Weapons

Small modular reactors have a distinctive geopolitics. The countries of the world today include: the nine with established nuclear weapons programs (United States, Russia, United Kingdom, France, China, Israel, India, Pakistan, North Korea); many countries that are capable of developing nuclear weapons but say that they do not wish to; and other nations that for now are not capable of developing nuclear weapons.

Small modular reactors provide what one might call a lower price of admission to the nuclear weapons club. This is a two-step argument: a) the small modular reactor option lowers the investment required to build a first nuclear power plant and b) acquiring a first reactor brings with it the training of scientists and engineers, the acquisition of relevant infrastructure and capabilities, and sometimes even associated fuel-cycle facilities with potential weapons-related uses. Therefore, largely independent of any particular reactor technology, small modular reactors could challenge the traditional "nonproliferation" regime, which seeks to prevent any increase in the number of nations with nuclear weapons.

When a country that does not yet have nuclear weapons chooses to develop or acquire small modular reactors, one must consider both what it says it will do and what it could do. A declaration that it will not develop nuclear weapons notwithstanding, if a country has the capability to make nuclear weapons, political and military planners in other countries will have to take into account the possibility that this capability could well translate into an actual, even if clandestine, nuclear arsenal. Countries are not the only concern: the use of weapons-usable plutonium or uranium tempts fate at the subnational level as well, by creating opportunities for malevolent actions by individuals and sub-national groups.

Highly enriched uranium and plutonium are the connectors that link nuclear power and nuclear weapons. Uranium exists in nature but not in the highly enriched form that makes it usable for weapons, and plutonium does not exist in nature at all. The development of nuclear weapons requires either enriching uranium or separating plutonium.

Enriching uranium means using technology to create uranium that contains more of the rare nucleus of natural uranium, uranium-235 (U-235), relative to uranium-238 (U-238), than in natural uranium. In nature, only seven of every 1,000 nuclei of uranium are U-235 and almost all of the remainder is U-238. Today's fuel for large commercial pressurized-water reactors contains 30 to 50 U-235 atoms per 1,000 total uranium atoms; when it is above 200 per 1,000 (20 percent) U-235, the enriched fuel is considered "highly enriched" uranium. The level of uranium enrichment in today's weapons and in the reactors that power U.S. and U.K. submarines is greater than 90 percent. In the small modular reactors currently under discussion, the amount of enrichment of the uranium fuel ranges widely, but it is always kept below 20 percent (sometimes, just below). Indeed, since the late 1970s, designers of commercial nuclear power reactors of all sizes have accepted this 20 percent constraint on fuel enrichment.

A uranium enrichment facility can be reconfigured to provide any enrichment of U-235, however. It is therefore possible for a uranium enrichment facility designed to produce fuel for a reactor to be reconfigured to produce fuel for a bomb. Thus, uranium enrichment at the "front end" of the nuclear power fuel cycle where the reactor fuel is produced provides one of the two dangerous potential linkages between nuclear power and nuclear weapons.

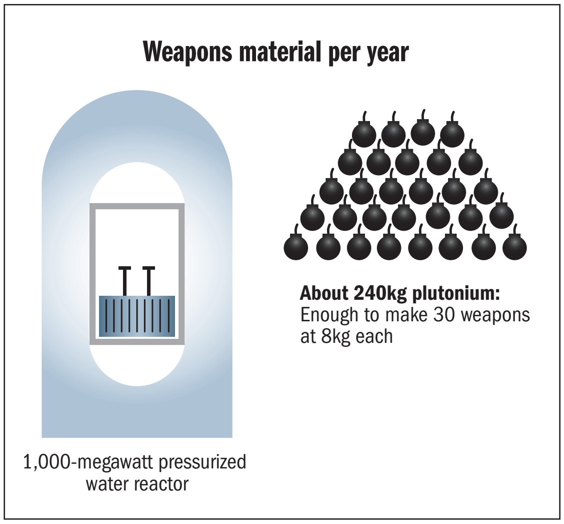

Figure 4.1: A nuclear reactor makes plutonium as it produces power. Plutonium that has been chemically separated from the spent fuel can be used to make bombs.

As for plutonium, it is created within the uranium fuel assemblies at all nuclear power plants, but there it is collocated with intensely radioactive materials (see Figure 4.1). Therefore, if the plutonium is to be used subsequently, further steps have to be taken at the “back end of the fuel cycle” to “reprocess” the spent fuel after it leaves the reactor. There are many methods to carry out such reprocessing, and all of them make plutonium much more accessible, whether for inclusion in new fuel or for use in weapons (see Figure 4.2).

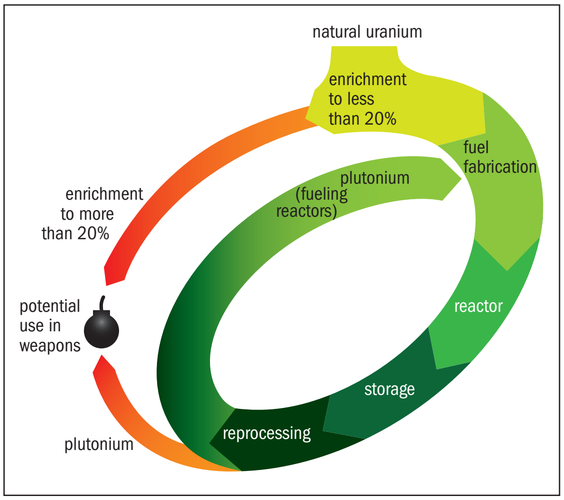

Figure 4.2: Two routes to bombs create risks for nuclear power.

In summary, the primary risks of nuclear power for creating the capacity to make weapons derive less from the design of the reactors themselves and more from the chain of activities associated with processing of the fuel, in particular, the enrichment of uranium at the front end and the treatment of spent fuel at the back end. A country wishing to have nuclear power plants could choose to forgo indigenous enrichment and reprocessing, either because it wants to ease the concerns of other countries that it might be developing nuclear weapons or simply to avoid the cost and trouble of enrichment and reprocessing. If it decides not to enrich, it has to arrange for another country to provide its low-enriched uranium. At the back end, there is no need for fuel to be reprocessed. It can be stored and eventually disposed of in a deep underground repository. However, even if a country commits to not reprocessing its spent fuel, the presence of nuclear reactors in the country provides what has been termed “breakout potential,” the ability to withdraw from such a commitment and to produce weapons-usable plutonium from its fuel, potentially building a nuclear arsenal (see Figure 4.3).

Below, for each of the four categories of small modular reactors presented in Article 2, we briefly

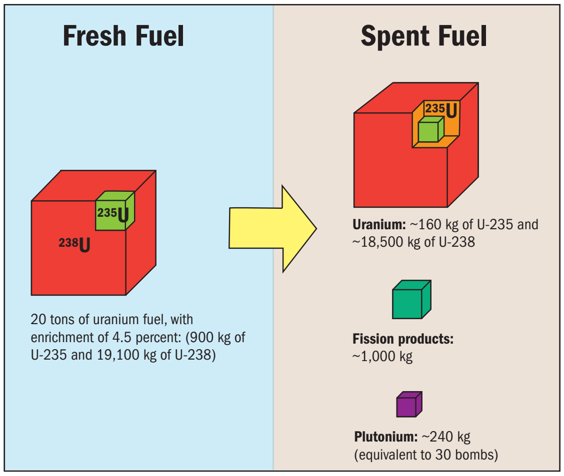

Figure 4.3: Annual flow of material through a 1,000-megawatt pressurized-water reactor. Figure adapted from http://www.laradioactivite.com/en/site/images/CompositionCUen.jpgimages/CompositionCUen.jpg

examine its nuclear weapons potential, considering both its fuel cycle and the geopolitical implications of its currently intended use.

Family 1: Ready to Build. Today’s light-water reactor technology can be relatively robust against use to produce material for nuclear weapons. Uranium is enriched only to 3 to 5 percent U-235, and reprocessing of spent fuel is optional. As a result, small modular reactors that copy the dominant fuel cycle of commercial large reactors, i.e., with no reprocessing of used fuel, will not create new linkages to nuclear weapons. Quantitatively, for the same amount of power production, small modular reactors belonging to Family 1 could require about 50 percent more fuel to move through the reactor, relative to today’s large commercial light-water reactors, partly as a result of the small modular reactor fuel being replaced all at once and the large reactor fuel being replaced one-third at a time. Thus, for generating the same amount of electrical energy, small modular reactors may require more uranium to be mined, processed, and enriched.

Although today’s light-water reactors and related technologies have no need for fuel reprocessing, France, Russia, India, Japan, and the United Kingdom have built reprocessing into the fuel cycle for their commercial reactors. (The United Kingdom, however, will be ending its reprocessing program over the next several years and is now focusing on how to dispose of its plutonium stockpile.) Fuel from small modular reactors based on today’s pressurized-water reactors might be reprocessed as well.

Family 2: Succeeding the Second Time Around. Given the lack of operating experience, the risks of weapons couplings for high-temperature and molten-salt reactors, large and small, are poorly understood, but there are no obvious consequences of moving to smaller scale. (Having a larger number of individual reactors in place for the same power output, one could argue, creates more separate opportunities for mischief.) In comparison with light-water reactors, a much larger volume of used fuel from high-temperature reactors would need to be handled to obtain the same quantity of plutonium. However, the level of uranium enrichment used by various high-temperature reactors is higher (the uranium fuel is roughly 10 percent U-235) than in light-water reactors.

With molten-salt reactors, the most worrisome issue from the point of view of weapons linkage is the continuous processing of fuel, which is integral to reactor operation. Continuous processing facilitates the extraction of weapon-usable materials (plutonium or uranium-233) from the fuel. In contrast, reprocessing of spent fuel from pressurized-water reactors is optional.

Family 3: Reducing the Burden of Nuclear Waste. These reactors would be fueled by the spent fuel of (for example) pressurized-water reactors, from which most fission products have been removed. Even if separation of weapon-usable plutonium during fuel preparation were renounced initially, a country could add the relevant additional steps to acquire separated plutonium at a later time if desired. One of the small modular reactors in this category is a small version of the full-scale integral fast reactor, currently marketed as the PRISM; the continuous reprocessing integral to this reactor concept could produce nuclear weapons material (separated plutonium), even though that is not how the system is supposed to operate.

Family 4: Comes with Fuel for a Lifetime. In order to operate for decades, small modular reactors with lifetime cores must start with a higher loading of fissile material than reactors that are refueled periodically; generally, this means that the uranium enrichment level will be higher. To achieve lifetime cores, these reactors generate at least as much new fuel as the fuel they consume, which requires the amount of plutonium in the reactor to increase continually. One 200-megawatt lifetime-core reactor could contain on the order of 1,000 kilograms of plutonium after seven years and almost 3,000 kilograms of plutonium after 30 years (see Figure 4.4). By comparison, about 150 kilograms of plutonium would be contained in the spent fuel discharged periodically from a 200-megawatt pressurized-water reactor (typical refueling periods for small modular reactor designs range from 14 months to 48 months; see Table 7.1).

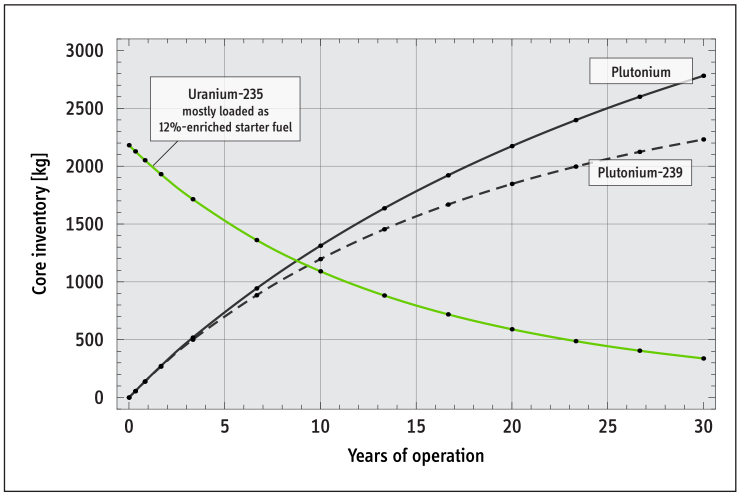

Figure 4.4: Build-up of plutonium in a 200-megawatt lifetime core-reactor (Family 4).