The Nuclear Fuel Cycle

Nuclear energy exhibits great potential as a low-carbon energy source, but carries inherent risks of diversion to weapons-related uses. At its core, the nuclear fuel cycle includes the various industrial processes associated with the production of electricity from uranium in nuclear reactors. However, some of the industrial processes more easily open the door to produce the fissile material essential for a nuclear weapon. Collection of sufficient quantities of fissile material is the most difficult step for would-be proliferators, explaining why there is such great attention given to enrichment and reprocessing technology that can produce such material.

There are seven activities involved in the life cycle of turning natural uranium into a useful fuel to generate electricity (the front end of the fuel cycle) and finally into either a disposable waste or the used fuel can be recycled through a process known as reprocessing. Together, these options are known as the back end of the fuel cycle. The ability to reuse spent fuel is what makes it a cycle, rather than a linear process.

1. Mining: uranium ore is extracted from the ground. The uranium found in nature contains only 0.7% of the isotope uranium-235 (U-235), which is useful in weapons and for fueling civilian reactors, while 99.3% is uranium-238 (U-238), which is not useful.

2. Milling: the ore is processed to produce “yellowcake,” a uranium concentrate.

3. Conversion: the yellowcake is transformed into uranium hexafluoride gas, which is the feedstock for centrifuges. This gas is still considered “natural uranium.”

4. Enrichment: as the uranium hexafluoride gas is fed into the centrifuges, its concentration of U-235 increases, while correspondingly decreasing the concentration of U-238.

5. Fuel fabrication: the enriched uranium is converted into powder, processed into ceramic pellets, and inserted into fuel rods, which are then arranged into fuel assemblies to power nuclear reactors.

6. Storage: after being used in the reactor, the depleted fuel — now mostly U-238 — is usually stored in a spent fuel pool.

7. Reprocessing: since only a small percentage of the potential nuclear energy is used up in a normal reactor cycle, some users recycle the spent fuel, recovering or “separating” the uranium and plutonium for reuse. The cycle can continue on and on, but because uranium is quite abundant, it is cheaper and easier to simply mine more uranium for the U-235 isotope than it would be to reprocess for it.

Contrary to most common misconceptions, all of these steps are elements of a peaceful nuclear fuel cycle. None of these steps inherently signals an intent to develop nuclear weapons. However, the two most threatening processes are enrichment and reprocessing because mastery of either process creates the potential to later procure fissile materials for a nuclear weapon.