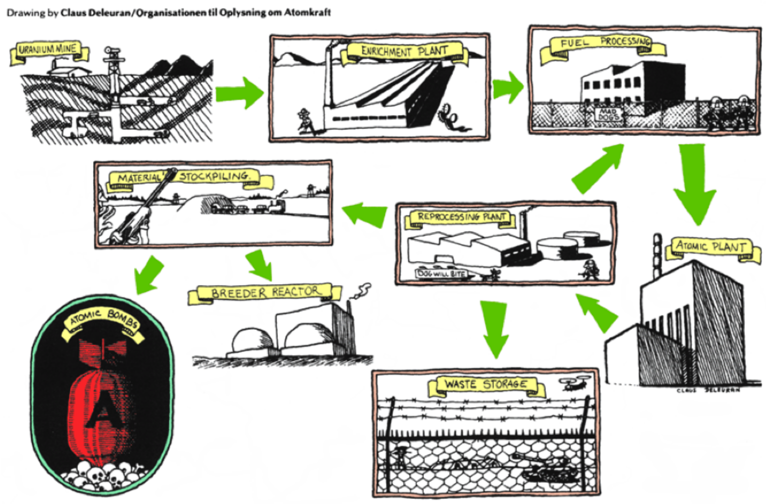
PS 114S. International Security in a Changing World

The Science of Nuclear Weapons: A Cheat Sheet[1]

1 Nuclear Fuel Cycle

Q. What is the nuclear fuel cycle?[2]

Figure 1: Nuclear Fuel Cycle



The nuclear fuel cycle is a process used to describe how natural uranium is used to produce nuclear energy. Uranium is a naturally-occurring element that can be mined relatively easily. After mining, states must purify or transform the natural uranium to get it ready to produce nuclear energy. Natural uranium is milled to extract the uranium from the ore to create a uranium oxide concentrate commonly known as *yellowcake*.

After milling, the yellowcake is not ready to be placed in a reactor yet since it is primarily ^{238}U and the fissile material required for a reaction is ^{235}U. Next, uranium ore is next placed in a centrifuge to enrich it or concentrate the amount of the fissile isotope relative to others. Once the enrichment process reaches a certain concentration level, the uranium is placed in fuel pellets which are then combined together to form fuel rods.

Fuel rods are placed in a light-water reactor where a controlled nuclear reaction can take place. The reactor produces electricity and heat as well as waste and poor-bomb grade plutonium which needs to be properly disposed of. After the reaction, reprocessing can occur in which waste is separated from materials which can be re-enriched or used for use in other weapon production. Waste is to be safely disposed of; poor-bomb grade products can be reprocessed and enriched again to extract further energy. Bomb-grade uranium from the reaction can be used for weapon stock-piling where scientists and engineers may assemble a weapon.

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[2]Source: No Clear Reason: Nuclear Power Politics, Edited by the Radical Science Collective, Free Association Books, London, England, Vol. 14, page 81, 1984.

Q. What is the difference between the uranium path and plutonium path to the bomb?

The uranium path to the bomb is easier in the sense that acquiring HEU is easier than bomb-grade plutonium. The uranium path requires enriched uranium for bomb-grade uranium. The plutonium path does not require enriched uranium as it can use a HWR or GGR to produce bomb-grade plutonium much faster. Uranium paths are the most common ways to produce commercial nuclear energy so it makes less sense when states claim a right to peaceful enrichment and nuclear energy when they are also building technology to produce a plutonium bomb.

Q. Why is there a controversy over the "right to enrich?"

Once you have the technology to enrich, you also have the technology to make a nuclear weapon. Countries which want the right to pursue peaceful uses of nuclear energy typically ask for the right to enrich uranium for nuclear energy. This is problematic, however, as countries which have the capacity to make low enriched uranium (LEU) by default also have the capacity to make high enriched uranium which is weapon-grade. The international community must depend on the state's good will and promise that they will not create weapon-grade uranium with their enrichment capabilities, but this is difficult to regulate. This was one of the problems in Iran's early nuclear program.

Some countries, like Iran and North Korea, argue there is a double-standard in which countries the international community "trusts" to enrich peacefully (like Japan) and countries not allowed to do it. As a result, North Korea, for example has pursued the plutonium path to the bomb which does not require an enrichment step.

Q. What does North Korea have to do with this?

As Professor Hecker mentions in lecture, North Korea has mastered the plutonium and uranium fuel cycles meaning they have the technology for both the *front-end of the fuel cycle* and the *back-end of the fuel cycle*. That is, they have the capacity to make both plutonium-based nuclear weapons (which have a greater destructive capacity than uranium-made nuclear weapons) and uranium-based weapons.

2 Check your understanding

- Why do some countries argue in favor of the "right to enrich?" What are the benefits?
- Why do some countries argue against the "right to enrich?" What are some disadvantages to it?
- Should countries have a "right to enrich?"
- If countries should have a right to enrich, how should the international community police or monitor states to prevent any potential abuse?
- Does North Korea's nuclear program set a dangerous precedent? What can the international community do about it?

Terminology	
Uranium: A naturally-occurring element that can be mined across the world. Most natural uranium is composed of ^{238}U; only 0.7% is ^{235}U, the fissile isotope that forms the basis of a nuclear reaction.	**Plutonium:** An element formed from uranium through neutron bombardment; the fissile isotope is ^{239}Pu. Weapon-grade plutonium is defined as ¿93% concentration of ^{239}Pu.
Uranium Bomb: Easier to assemble than plutonium bomb; the possession of 4-25 kg of HEU is sufficient to make a nuclear weapon.	**Plutonium Bomb:** More lethal capacity due to radiation; harder to assemble than uranium bomb; the possession of 4-8 kg of Pu is sufficient to make a nuclear weapon.
Enrichment: A process used to increase the concentration of certain uranium isotopes in natural uranium to make it usable for nuclear energy or weapons purposes through isotope separation	**Right to Enrich:** A state's belief that they have the right to enrich uranium under Article IV of the NPT which guarantees signatories access to nuclear technology for peaceful uses
Highly-Enriched Uranium (HEU): Uranium with greater than 20% concentration of ^{235}U or ^{233}U. Colloquially known as 20% enriched uranium; uranium enriched at and beyond this level is weapon-grade	**Low-Enriched Uranium (LEU):** Uranium with less than 20% concentration of ^{235}U or ^{233}U. LEU is commonly enriched to 3-5% concentration for use in commercial nuclear power reactors; it is not usable for weapons at this stage, but **once a state has the technology or capability to generate LEU, it also inherently has the ability to make HEU**
Front End Nuclear Fuel Cycle: The mining, milling, and enrichment procedures used to turn natural uranium into enriched uranium for energy or weapon purposes	**Back End Nuclear Fuel Cycle:** The reprocessing, waste disposal, and byproduct extraction after a controlled nuclear reaction; waste include heat, energy, and poor bomb-grade uranium which can be reprocessed to higher enrichment levels to become weapon-grade
Centrifuge: An equipment used to facilitate enrichment or isotope separation through centrifugal force; gas centrifuges are used to enrich natural uranium to LEU or HEU	**Reactor:** Device used to initiate and control a sustained nuclear reaction often with enriched uranium; the reactor is used to produce nuclear energy with byproducts like electricity, waste, and poor bomb-grade plutonium. Other reactors may use unenriched uranium which can lead to further isotope separation and the create of bomb-grade plutonium
Light-Water Reactor (LWR): A nuclear reactor which uses normal H_2O as a coolant and neutron moderator around the fuel rods; they are the work-horse reactors in commercial nuclear power production	**Heavy-Water Reactor (HWR)/Graphite Gas-Cooled Reactor (GGR):** Nuclear reactors which use gas cooling techniques or heavy-water (D_3O^+) as a coolant; they do not require enriched uranium so enrichment and centrifuges processes are less important; they also produce weapon-grade plutonium and force the removal of spent fuel continuously thereby posing a higher safety hazard
Fissile Material: Description in arms control and nuclear policy used to describe materials specifically used in the fission primary of nuclear weapon creation; all fissile materials are fissionable	**Fissionable Material:** Any material capable of sustaining a nuclear fission chain reaction through the splitting of the atom (a nuclear reaction); not all fissionable materials are fissile
Fuel Rods: a collection of uranium fuel pellets; these are combined with other fuel rods to create fuel elements or fuel assemblies and then placed in the reactor core for the nuclear reaction	**Spent Fuel:** Fuel rods which no longer have enough fissionable uranium to efficiently produce nuclear power