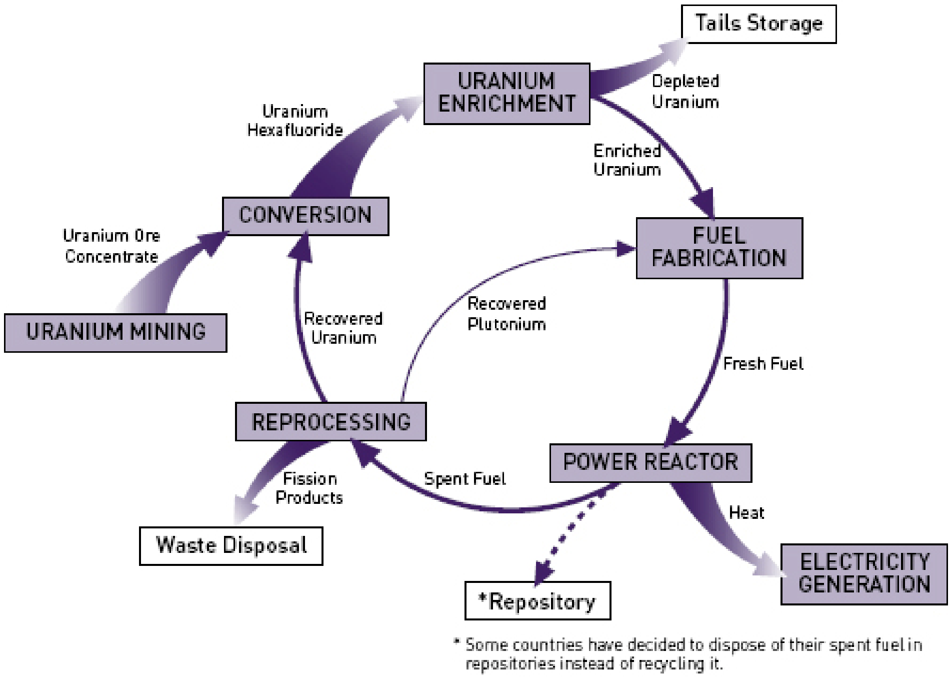
REPORT OF THE
INTERNATIONAL COMMISSION ON
Nuclear Non-proliferation and Disarmament

INFORMATION SHEET
No 2

What the Commission Report says on:

THE NUCLEAR FUEL CYCLE: BASIC TERMINOLOGY FOR NON-SPECIALISTS



A. NUCLEAR MATERIALS

Uranium occurs naturally. To be useable, uranium ore (containing as little as 0.1 per cent uranium, sometimes less) has to be *mined*, then *milled* and processed to produce a uranium oxide concentrate ('yellowcake'). Yellowcake is then *converted* into uranium dioxide which can be used as fuel in some reactors (see "heavy water reactors" below), but for most purposes into uranium hexafluoride gas (UF_6) and then *enriched*. The final step in the process is the fabrication of fuel assemblies (usually ceramic uranium oxide pellets encased in metal tubes).

"Enrichment" means increasing the concentration of the isotope uranium-235, and reducing that of uranium-238. Natural uranium consists primarily of these two isotopes, but only U-235 is capable of undergoing *fission*, the process by which a neutron strikes a nucleus, splitting it into fragments and releasing heat and radiation. ("Isotopes" are forms of the same element differing from each other in relative atomic mass but not their chemical properties, or putting it another way, atoms that have different numbers of neutrons in each nucleus but the same atomic number, i.e. number of protons in each nucleus.)

Low enriched uranium (LEU), used as the fuel (to heat water to steam to drive turbines) in most power generating reactors, involves increasing the natural concentration of U-235 (0.7 per cent) to between 3 and 5 per cent.

The full text of *Eliminating Nuclear Threats: A Practical Agenda for Global Policymakers,* Report of the International Commission on Nuclear Non-proliferation and Disarmament, Co-chairs Gareth Evans and Yoriko Kawaguchi (November 2009), is available at www.icnnd.org

ICNND Secretariat: Dept of Foreign Affairs and Trade, ACT 0221, Australia **E** icnnd@dfat.gov.au **T** +61 2 6261 1111
Tokyo Office: Ministry of Foreign Affairs, Tokyo 100-8919, Japan **E** j-icnnd@mofa.go.jp **T** +81 3 5501 8221

High enriched uranium (HEU) is defined (for percentage of U-235 has been increased to 20 per cent or greater. *Weapons-grade uranium* is usually described as that enriched to 90 per cent or higher U-235.

Plutonium occurs naturally only in minute quantities and is essentially a man-made element. Plutonium is produced by reactors as a normal by-product when some of the neutrons released during fissioning are captured by uranium-238 atoms: some of the plutonium is itself fissioned, but a proportion remains in *spent fuel assemblies* in different isotopic forms (including Pu-239, Pu-240 and Pu-241), which can be extracted and used as a nuclear fuel.

In the case of standard *light water reactors*, the plutonium contained in the spent fuel is typically about 60-70 per cent Pu-239, described as *reactor-grade*; *heavy water reactors,* by contrast, can be used to produce Pu-239 in weapons-grade concentrations (but the brief irradiation required to achieve this is inefficient for power production). *Weapons-grade plutonium* has 93 per cent or more Pu-239.

Fissile Material. This expression usually refers to high enriched uranium (HEU) and separated plutonium (i.e. plutonium separated from spent fuel through reprocessing).

B. ENRICHMENT PROCESSES

These are of four main types:

(1) Gas centrifuge: UF_6 gas is pumped into a series of rotating cylinders: the centrifugal force draws heavier molecules (containing U-238) toward the outside of the chamber while lighter U-235 molecules remain in the centre. Standard centrifuge enrichment is easily modified to produce HEU, and the modifications can be concealed.

(2) Gaseous Diffusion: UF_6 containing U-235 and U-238 is compressed and fed into a semi-permeable vessel. Since lighter molecules travel faster than heavier ones, molecules consisting of U-235 will escape from the vessel faster than those of U-238.

(3) Electromagnetic enrichment: The different paths of the U-235 and U-238 isotopes as they pass through a magnetic field allow them to be separated and collected.

(4) Laser: A laser of a particular wavelength is used to excite U-235 atoms to the point that they can be separated from U-238 (or vice versa).

C. REACTORS

There are two basic types of fission reactor – "thermal" (in wide use) and "fast neutron" (now limited in number, but expected to be important in the future):

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(1) **Thermal reactors.** These use a *moderator* to slow neutrons to the optimum ("thermal") speed to cause fission, viz. a material that slows neutrons without capturing them. The usual materials are light water, heavy water and graphite:

*Light water reactors***:** The most common reactors in operation today, light water reactors use ordinary water as a coolant and moderator. Because this is a relatively inefficient moderator these reactors require low enriched uranium as fuel. From a non-proliferation standpoint, light water reactors are preferable to heavy water reactors for two reasons: first, removing the fuel (to extract the plutonium by-product) requires shutting down the reactor (easily noticed); secondly, it is difficult to produce plutonium with a high proportion of Pu-239.

*Heavy water reactors***:** These reactors use as coolant and moderator water containing an elevated concentration of "heavy hydrogen" (also known as deuterium) - hydrogen atoms which contain a neutron in their nucleus in addition to the usual proton. This allows the use of natural (non-enriched) uranium as fuel. Heavy water reactors produce significant quantities of plutonium, and are capable (though not in commercial use mode) of producing Pu-239 in weapons-grade concentration.

Gas-graphite reactors: These use gas (CO2 or helium) as the coolant and graphite as the moderator. They can operate on natural or low enriched uranium. Examples include the early "Magnox" reactor, the Advanced Gas-cooled reactor currently used in the UK, and the German-designed "pebble-bed" reactor under development in South Africa and China.

(2) Fast neutron reactors. These use high energy ("fast") neutrons to cause fission. They do not use a moderator, relying instead on fuel of higher fissile density (typically 20-30 per cent plutonium). The coolant is a material that neither absorbs nor slows neutrons, either molten metal (to date, sodium) or gas (helium). The principle is use of high energy neutrons to convert the predominant uranium isotope U-238 to plutonium. Fast neutron reactors can be operated in three modes:

Plutonium burners: these consume more plutonium than they produce.

Equilibrium mode: in these, plutonium production and consumption are in balance.

Plutonium breeders: these produce a surplus of plutonium available for fuelling additional reactors.

Both breeding and equilibrium modes are self-sustaining, in the sense that once operating they provide their own fissile material requirements and only require additional "fertile" material, i.e. natural or depleted uranium.

[Section 5, Box 5-2]