HEU as weapons material – a technical background[1]

1. What is HEU?

Natural uranium consists of 0.72 % uranium-235 (U-235) and 99.27 % U-238 in addition to small quantities of other uranium isotopes. In order for a uranium assembly to be capable of undergoing a nuclear chain reaction, the uranium must be sufficiently enriched in U-235. This means that the fraction of U-235 nuclei must be increased. Different uses of uranium require different degrees of enrichment. *Natural uranium* may be used in reactors moderated by heavy water or graphite. *Low-enriched uranium (LEU)* is enriched uranium in which the fraction of U-235 is less than 20 %. Most nuclear power plants use uranium fuel enriched to about 3–5 %. This material cannot be used for nuclear explosives. *Highly enriched uranium (HEU)* is defined as uranium enriched to a minimum of 20 % U-235. Civilian uses of HEU include power generation, propulsion and research reactors, and production of radioisotopes. *Depleted uranium* is a waste product from the enrichment process. It typically contains about 0.2–0.5 % U-235.

2. How to obtain HEU.

In the *enrichment* process, the fraction of U-235 is increased from the original 0.72 % to whatever the application in question requires. Several enrichment methods exist; generally they utilise the small mass difference between U-235 and U-238 and require large facilities with sophisticated and expensive equipment. Enrichment is considered to be the most demanding step in the production of nuclear weapons, and is beyond the technical capabilities of most non-state actors. When HEU is used in a reactor, the spent fuel that is eventually removed from the reactor will still contain a relatively large fraction of U-235. This means it is possible to recover the remaining HEU from the spent fuel by *reprocessing* it. Some spent nuclear fuel is highly radioactive, making it difficult to extract the remaining uranium. However, many civilian facilities have spent HEU fuel assemblies that are old (and therefore significantly less radioactive) or only lightly irradiated, thereby making them vulnerable to theft or diversion.

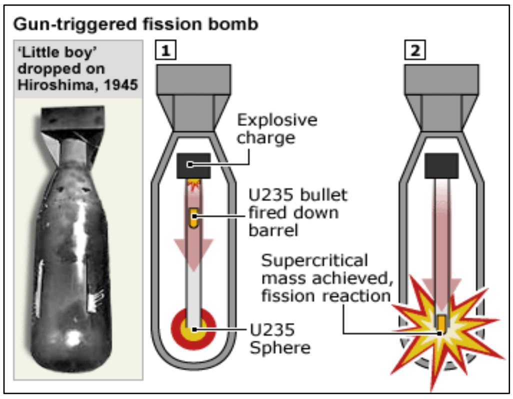

Figure 1. Gun type nuclear weapon (http://nuclearweaponarchive.org/Library/Brown/)

3. HEU and nuclear weapons.

All nuclear weapons require a fissile material such as HEU or plutonium. Due to its relatively low background of spontaneous fission neutrons, HEU is considered much more suitable than plutonium for use in an improvised nuclear device (IND). The low spontaneous fission rate facilitates the IND design by the fact that the probability of a predetonation is relatively low. This allows for the use of a gun-type IND, which is far easier to design and build than an implosion type device. The latter requires for example a high quality explosive lens (made of conventional explosives) and more sophisticated detonation equipment. HEU appears in many forms, including gas (UF_6), uranium oxides

[1] This briefing has been prepared by the Norwegian project secretariat, consisting of The Norwegian Defence Research Establishment (FFI), Institute for Energy Technology (IFE), Norwegian Institute of International Affairs (NUPI) and the Norwegian Radiation Protection Authority.

and uranium metal. Making uranium-based IND requires casting of highly enriched uranium metal into proper shapes. For that reason, the most attractive form of HEU for the purpose of nuclear terrorism is metallic HEU. Other forms of HEU would necessitate difficult chemical processing in order to convert the material into uranium metal. The Hiroshima bomb ("Little Boy", as seen in Figure 1) was a crude, gun-type nuclear weapon based on 64 kg of 80 % enriched uranium. The yield of this weapon was about 13 kt.[2] It is reasonable to assume that a terrorist, aiming to construct an HEU-based IND, would pursue a design somewhat similar to, or equally crude as this first nuclear weapon. Note that even a not very "successful" IND may lead to very serious consequences. For example, just 1 % of 13 kt would constitute an enormous explosion.

4. HEU – critical mass.

Figure 2 shows the critical mass for a mixture of U-235 and U-238 as a function of the U-235 enrichment, assuming a bare, metallic sphere. The critical mass for 100 % enriched uranium is 47.5 kg, while it is approximately 750 kg at 20 % enrichment. Uranium enriched to 80% or greater might be considered *weapons quality*. However, nuclear weapons can be made with enrichment levels as low as 20%; higher enrichment levels are preferable because far less material is required to obtain critical mass (see part 4, below). Nuclear explosive devices will generally be made with a neutron reflector and/or a tamper. A reflector is typically a lightweight material with a high efficiency in reflecting neutrons back into the core, such as beryllium. A tamper is a heavy material which is used for slowing the expansion process, thereby making the chain reaction run longer. Examples of good tampers are natural or depleted uranium and tungsten. Due to their neutron reflecting ability, both reflectors and tampers will reduce the critical mass. As an example, a 10 cm natural uranium tamper will reduce the critical mass of a bare sphere of U-235 to less than one third: 15 kg.[4]

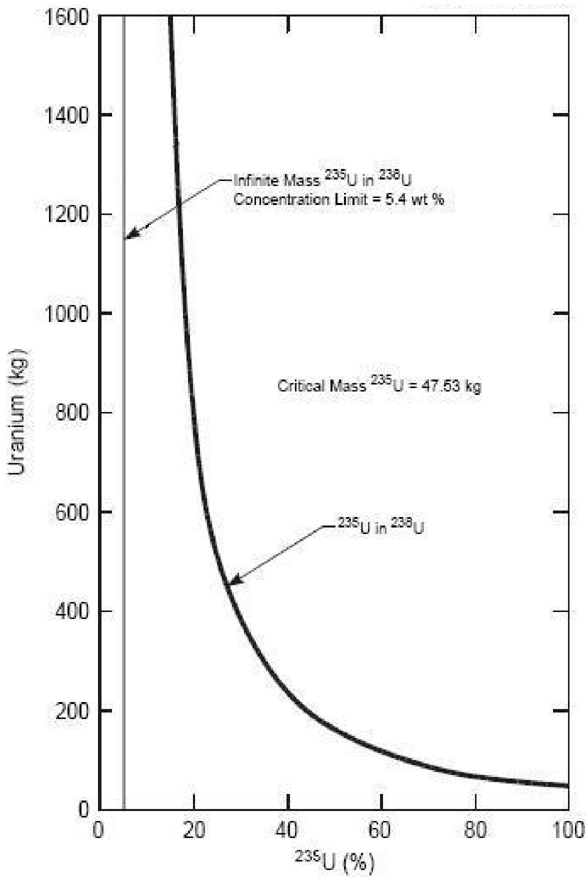

Figure 2. Critical mass for uranium-235 as a function of enrichment.[3]

[2] That is, it was equivalent to 13 thousand tonnes of the conventional explosive TNT.
[3] Modified from Forsberg C W, Hopper C M, Richter J L, Vantine H C (1998): *Definition of Weapons-Usable Uranium-233,* ORNL/TM-13517, Oak Ridge National Laboratory, Los Alamos National Laboratory and Lawrence Livermore National Laboratory, http://www.ornl.gov/sci/criticality_shielding/HopperPubs/DefWeaponsUsableU-233ORNLTM13517.pdf.
[4] Försvarets forskningsanstalt (FOA): FOA orienterar om kärnvapen, no 15 1990 (in Swedish).