

SHORT TITLE: *Proliferation dangers associated with nuclear medicine*

Proliferation dangers associated with nuclear medicine: getting weapons-grade uranium out of radiopharmaceutical production

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Abstract

Abolishing the threat of nuclear war requires the outlawing of nuclear weapons and dismantling current nuclear weapon stockpiles, but also depends on eliminating access to fissile material (nuclear weapon fuel). The near-universal use of weapons-grade, highly enriched uranium (HEU) to produce radiopharmaceuticals is a significant proliferation hazard. Health professionals have a strategic opportunity and obligation to progress the elimination of medically-related commerce in HEU, closing one of the most vulnerable pathways to the much-feared 'terrorist bomb'.

Keywords: *Highly enriched uranium, Medical imaging, Nuclear medicine, Nuclear weapons, Radiopharmaceuticals*

Introduction: nuclear bomb fuel in the health sector

Nuclear weapons imperil civilisation. Notwithstanding the threats posed by global warming and resource degradation and competition, nuclear weapons alone have the capacity to render the planet uninhabitable, exterminate much of the human population and severely damage most ecosystems in the space of a few short hours. In addition to nuclear war, deliberate or accidental, involving nuclear weapons states new or old, the other outstanding nuclear detonation scenario derives from 'non-state actors'.

Recently the United States was urged to lead in the creation of ‘a world without nuclear weapons’ by former Secretaries of State Henry Kissinger and George Schultz, former Defense Secretary William Perry and Senator Sam Nunn. These senior statesmen proposed a programme of urgent steps that would lay the groundwork for a world free of the nuclear threat. Of particular and immediate relevance to the medical profession, they advocated ‘... phasing out the use of highly enriched uranium in civil commerce and removing weapons -usable uranium from research facilities around the world and rendering the materials safe.’ [1]. Similar calls have been made by the Weapons of Mass Destruction Commission chaired by Dr Hans Blix [2] and International Atomic Energy Agency (IAEA) Director Dr Mohamed ElBaradei [3].

The health care industry has an important role in the highly enriched uranium (HEU) market, as the bulk of the radioisotopes used in diagnostic medical procedures are currently derived from HEU. Fortunately, there are no technical obstacles to converting to low enriched uranium sources for these radiopharmaceuticals. Health care professionals are thus strategically positioned to hasten the phase-out of medical commerce in HEU and so terminate one of the most vulnerable pathways to the much-feared ‘terrorist bomb’.

Apart from its use in production of radioisotopes, HEU has been used to fuel plutonium and tritium production for nuclear weapons, is still used in some civilian and military research reactors and for naval propulsion reactors in nuclear submarines, ice-breakers (Russia) and aircraft carriers (US).

Some physicists and international security experts have raised concerns about such continued, readily avoidable use of HEU in settings with considerable risks of theft

and diversion. Two important recent papers have documented the proliferation dangers associated with using HEU to produce medical isotopes [4,5]. However, these important matters have received scant attention from physicians, their professional organisations, and health authorities. In this paper, we summarise the issues for health care professionals and recommend concerted action by medical organisations to minimise the significant but avoidable contribution that their clinical practice inadvertently makes to nuclear proliferation dangers.

HEU: present danger

Nuclear weapons are fuelled by the fission of highly enriched uranium (in which the isotope U-235 fraction has been enriched, typically from 'natural' 0.7 per cent to over 90 per cent) or the byproduct isotope plutonium-239, inevitably produced in nuclear reactors when U-238 nuclei absorb neutrons. Without enrichment of uranium or reprocessing of spent reactor fuel to extract plutonium, there is no nuclear explosive threat. When there is sufficient fissile material for the neutrons generated by each fissioning atom to cause more than one additional fission, the critical mass is exceeded, and the rapidly escalating chain reaction causes a nuclear explosion. The key to a nuclear bomb is getting a supercritical amount of nuclear material together fast enough so that a substantial amount of explosive energy is released before the bomb – its nuclear material converted into an expanding gas - blows itself apart. The critical mass decreases with the inverse square of the density, so if for example the fissile material can be squeezed to twice its normal density, only a quarter as much material is needed (Table 1) [6]. Nuclear weapons are either pure fission explosives, like the Hiroshima and Nagasaki bombs, or two-stage

thermonuclear (or hydrogen) bombs, in which a fission ‘primary’ generates the energy to ignite a ‘secondary’ in which hydrogen isotopes undergo nuclear fusion. Advanced nuclear weapons utilize a variety of design features to increase their explosive power, make them lighter and more compact, more robust, reliable and more predictable in explosive yield. These features include neutron reflectors, typically made of beryllium (or, potentially, uranium or lead – the latter widely available and highly malleable) and boosting with a mixture of the heavy hydrogen isotopes deuterium and tritium, which at about 100 million degrees produce a burst of neutrons that boost the fraction of fissile material fissioned and the explosive power. A thick reflector will reduce the critical mass by a factor of two or more [7]. Modern thermonuclear weapons generally contain both plutonium and HEU [8].

[TABLE 1 ABOUT HERE PLEASE]

Fission weapons can use either a gun-type assembly method, with one subcritical mass being fired down a barrel into another subcritical mass; or implosion, in which a sphere of fissile material is compressed by high explosive lenses distributed around the sphere and triggered simultaneously. HEU can be used in either gun or implosion weapons; plutonium requires the implosion design. The Hiroshima bomb was of gun-type (Figure 1), using 60 kg of 80 per cent enriched HEU. The Nagasaki bomb was made of plutonium in an implosion design, like most modern nuclear weapons.

[FIGURE 1 ABOUT HERE PLEASE]

Rather than a sophisticated military weapon able to be delivered by missile or combat aircraft, terrorists are likely to be satisfied with a simple nuclear weapon with a high probability of exploding, somewhere in the kiloton range, more likely delivered by ship or van or assembled on site. Gun-type bombs are simple and do not require testing or a neutron generator – these were the type of weapons built and stockpiled clandestinely by the *apartheid* regime in South Africa [8]. They are well within the capabilities of technically unsophisticated states, subnational groups and international terrorist organisations such as *al Qaida* [10]. One subcritical HEU mass could potentially be dropped down a cylinder from a height of a one or more stories to collide with another subcritical mass. The trade-off for simplicity is the larger quantity of HEU required (Table 1).

In 2001, the IAEA defined a ‘significant quantity’ of fissile material as the amount required to make a first-generation Nagasaki-type implosion bomb, including losses expected during production. It stated these significant quantities as 8 kg for plutonium (of any composition less than 80 per cent PU-238) or 25 kg of U-235 contained in HEU [11]. However, depending on weapons design and explosive power, modern nuclear weapons may require as little as 1 to 3 kg of plutonium or 5 to 10 kg of HEU (Table 1). The mass of uranium required for a weapon also depends on the degree of enrichment of U-235 above the 0.7 per cent contained in natural uranium (Figure 2) [12]. The definition of HEU as uranium enriched to greater than 20 per cent U-235 - which the IAEA considers a ‘direct use’ material - is based on what is felt to be required for a weapon of practical size. Apart from the simple robust nature of gun-type

construction of a bomb containing HEU, there are other aspects that may make HEU the preferred nuclear weapon material for terrorists. The radioactivity of uranium, even HEU, is low, enabling uranium metal to be handled by hand, and the radiation is easily hidden by even modest shielding, making smuggling extremely difficult to detect [10]. Although smaller quantities of plutonium would be required, plutonium is more radioactive, harder to handle and easier to detect. In terms of a practical perspective on the quantities of fissile material used in the Hiroshima and Nagasaki bombs, 60 kg of weapons grade HEU could easily fit into a five litre container, and 6 kg of weapons-grade plutonium would fit easily into a 400 ml drink container [10]. Dividing the material into two or three packages would reduce the danger of criticality.

[FIGURE 2 ABOUT HERE PLEASE]

The most difficult challenge for a terrorist organisation seeking to build a nuclear weapon or improvised nuclear device is obtaining fissile material, either plutonium or highly enriched uranium (HEU). In 2002, the US National Research Council warned that ‘crude HEU weapons could be fabricated without state assistance’, noting that ‘the primary impediment that prevents countries or technically competent terrorist groups from developing nuclear weapons is the availability of [nuclear material], especially HEU’ [13].

Meanwhile, abundant evidence exists that:

... terrorist groups have been trying aggressively to obtain nuclear materials, primarily from the enormous stockpiles of the Former Soviet Union. In December

1994, Czech police seized 4 kg HEU. ... In October 2001, Turkish police arrested two men with 2.56 pounds of weapons grade uranium. Since 1993, the IAEA has reported 175 cases of nuclear trafficking, 18 involving HEU or plutonium. ... *Al-Qaida* agents have tried to buy uranium from South Africa, and have made repeated trips to three central Asian states to try to buy weapons grade material or complete nuclear weapons [14].

The IAEA Illicit Trafficking Database has documented more than 650 instances of intercepted smuggling of radioactive materials over a decade; 18 cases of seizure of stolen plutonium or HEU have been confirmed [15]. Some additional examples include [7,16]:

- 40 kg of weapons grade uranium seized in Odessa in Dec 1993;
- in 1994, German police seized more than 400 g of plutonium arriving from Moscow;
- in October 2001 the Russian Ministry of Defence reported two recent terrorist attempts to break into nuclear storage sites;
- in April 2006 Russian police arrested a foreman of the Elektrostal nuclear fuel fabrication facility and co-conspirators for stealing 22.2 kg LEU (this facility processes large amounts of HEU) [17].

An obvious question is how many more thefts and smuggling events have not been detected. Former CIA Director Porter Goss told the US Congress in 2005: 'There is sufficient [Russian] material unaccounted for so that it would be possible for those with

know-how to construct [a] nuclear weapon' [18]. But as of 2005, only 54 per cent of the buildings in the former Soviet Union holding nuclear material had received comprehensive security upgrades [19]. IAEA Director General Dr Mohamed ElBaradei estimated in March 2006 that regarding protection of nuclear material, '... perhaps 50 per cent of the work has been completed' [20]. Moreover, IAEA experts have observed that current technology is unlikely to detect a shielded nuclear device on a truck or boat [21].

HEU and radiopharmaceuticals

Current isotope production is well documented [4,5]. The four major competitors in the international medical isotope marketplace provide over 95 per cent of the global supply (from seven different reactors): MDS Nordion (Canada), TycoHealthcare / Mallinckrodt (Netherlands), Institut National des Radioéléments (Belgium) and NECSA/NTP (South Africa). Their most important product by far is technetium-99 (Tc-99m), which is used in 25 million medical imaging procedures annually, constituting at least 80 per cent of medical isotope usage worldwide. Tc-99m is the favoured isotope tracer in bone scans, thyroid scans and increasingly in cardiac function assessments. Tc-99m has a short half-life ($T_{1/2} = 6$ hours), so most nuclear medicine departments purchase its precursor, molybdenum (Mo-99, $T_{1/2} = 66$ hours) from which they then generate their Tc-99m, ensuring a steady and reliable supply.

All four big producers use neutron bombardment of HEU targets in their production reactors to generate Mo-99. These targets are distinct from the fuel for the reactor. This process only consumes up to three per cent of the available U-235 (about 10 g), so the 'used' target is still bomb-grade material. As about 85kg HEU is used for these

targets each year globally and the targets are not recycled, large amounts of weapons-usable material – enough for many Hiroshima-size bombs - are now stockpiled in multiple relatively poorly-secured commercial locations. MDS-Nordion imports about 20 kg of weapons-grade HEU into Canada from the US each year; the European producers use weapons-grade HEU from another nuclear weapons state (France, Russia, or the United Kingdom), or HEU imported from the US prior to the 1992 Schumer amendment to the US Atomic Energy Act, which encouraged HEU users to switch to LEU. South Africa is using HEU that it produced for weapons prior to 1991 [4].

Low enriched uranium (LEU, containing less than 20 per cent U-235) targets, which are not viable for weapons production, are eminently suitable for Mo-99/Tc-99m production. The smaller producers in Argentina, Indonesia and Australia are currently using LEU targets (enriched to 19.75 per cent or less U-235), but their global market share is still small [4].

Even though there is no technical impediment to conversion from HEU to LEU target processing, none of the big players are currently using LEU or planning to convert.

Among currently operating isotope producing reactors, only the BR2 Reactor in Belgium (Mallinckrodt) and the SAFARI Reactor in South Africa continue to use HEU as *fuel* as well as target material.

Many other important medical isotopes are generated in non-reactor facilities such as cyclotrons and other spallation sources. These include thallium-201 (Tl-201, $T_{1/2} = 73$ hours) for testing cardiac function, fluorine-18 (F-18, $T_{1/2} = 110$ minutes) used in PET scanning, and indium-111 (In-111, $T_{1/2} = 2.8$ days) for specialist diagnostic studies, such as brain studies, infection and colon transit studies. Other reactor-produced, but much

less commonly used, medical isotopes are xenon-133, strontium-89 and iodine-131. The same issues discussed here pertain to all reactor-produced isotopes. Furthermore, several investigators have demonstrated potential non-reactor routes to Mo-99/Tc-99 production, but there are no current commercial projects developing these further [22].

While technetium currently retains a significant place in medical imaging, and an increasing role in cardiac perfusion studies, some of its traditional imaging roles (such as bone and lung scanning) are being superseded by newer technologies, in particular Positron Emission Tomography (PET) and Magnetic Resonance Imaging (MRI), which eliminate the need for isotopes sourced from nuclear reactors altogether [22], and modern CT scanning incorporating helical, multidetector, high resolution and multislice features.

Converting to LEU

In June 2006 the Norwegian government, in cooperation with the International Atomic Energy Agency, hosted an international symposium on minimization of use of HEU in the civilian nuclear sector. The technical experts at the Oslo symposium reached consensus that:

- conversion from HEU to LEU fuels and targets is possible in most instances;
- no future needs for HEU have been identified; and
- current conversion programmes have been quite successful [23].

Participants observed that improving physical protection requirements for HEU to the necessary levels is often far more expensive than decommissioning or converting reactors to use LEU. For example, in the United States security costs at the eight national nuclear laboratories increased by US\$500 million per year since 11 September 2001, leading to a

decision to shut down or convert some reactors to LEU simply to cut costs [5].

Several presentations attested to the fact that there is no technical impediment to the conversion to LEU fuel and targets. George Vandegrift, from the Argonne National Laboratory in Illinois, USA, observed that: 'Conversion from HEU to LEU targets is technically feasible in *all* current processes' (his emphasis) [24]. He examined the successful conversion programmes in Argentina and Indonesia and found no negative effect on 'product purity, product yield, or operating costs'. These findings were emphasised by Professor Jose Goldemberg, Co-Chair of the International Panel on Fissile Materials, in his report of the 'Technical Workshop on HEU Minimisation': 'The conversion of radioisotope production, specifically Mo-99, to LEU is technically feasible, and ... remaining obstacles to conversion of this activity are chiefly of commercial nature.' [23]

A recent assessment of the commercial viability of conversion to LEU targets concluded that the cost to consumers in most applications would be in the order of a one to two per cent increase. The authors also noted that there could be a very large cost saving associated with using LEU targets by eliminating the very high security costs necessitated by HEU storage and transport [5].

HEU and 'commercial viability'

However, all four major isotope suppliers have expressed concerns about the commercial viability of switching from HEU to LEU targets, as well as potential for supply disruption. Unfortunately, while incentives in the US Energy Policy Bill 1992 encouraged international suppliers of radiopharmaceuticals to convert their reactors to

LEU fuel and targets, the recent Burr Amendment (2005) to the Bill has weakened the capacity of the US to compel suppliers to do so. The Burr amendment was pushed through the US Congress on a wave of unfounded and commercially fomented concern about reduced supplies of medical isotopes supposedly threatened by conversion to LEU. The new law, passed after heavy lobbying efforts by Canadian medical isotope producer MDS Nordion, permits the export of US HEU to medical isotope producers even if they do not commit to convert to LEU, as was previously stipulated. The Reduced Enrichment Research and Test Reactor programme (RERTR) is an international programme to facilitate substitution of LEU for HEU in civilian research reactor fuel and radioisotope production targets. In 2003 Nordion stopped co-operating with the RERTR LEU target development project, primarily on economic grounds. Nordion continues to produce isotopes with a decades-old reactor and processing facility, which rely on targets of HEU (about 20 kg per annum) supplied by the US. Nordion's current stockpile exceeds 45 kilograms of unirradiated HEU, enough for several nuclear weapons [25].

Medical responsibility

Unlike the technical experts, policymakers at the Oslo Symposium were unable to agree on a clear path forward, although they acknowledged the terrorism threat posed by HEU and the desirability of conversion. Resistance to risk-reducing conversion is economic: the big players are not keen to spend the money to convert to LEU. Several speakers at the policy workshops attempted to address this. Laura Holgate, Vice President of the Nuclear Threat Initiative, encouraged the creation of a global norm, de-legitimising civil HEU possession and use, noting that without such a norm, arguments about convenience,

economic impact, and a misplaced sense of prestige would continue to thwart efforts to reduce the threats [26]. Lars Van Dassen, deputy head of the International Cooperation Program at the Swedish Nuclear Inspectorate, proposed the creation of an international code of conduct against the production, trade and use of civilian HEU [27].

The health sector has potential leverage and an important responsibility in this issue as a significant end user in HEU commerce [5]. Nuclear medicine departments that purchase HEU-derived radiopharmaceuticals, and the clinicians they serve, are subject to the big suppliers' stranglehold on the supply market and thus inadvertently enable and contribute to the persistence of an exposed and unnecessary nuclear proliferation pathway.

Meeting future medical isotope needs

Medical needs do not require further production of either HEU or LEU

There are vast stockpiles of HEU around the world – between 1400 and 2000 tons – enough for tens of thousands of nuclear weapons [8]. More than 99 per cent of this is possessed by the nuclear weapon states. At the end of the Cold War, Russia declared 500 tons of HEU, and the US 226 tons, to be in excess of their requirements for weapons. By mid-2006, Russia had blended down about 275 tons and the US 60 tons to non-weapons usable LEU for reactor fuel [8].

Nuclear weapons must be abolished: to remove the most urgent threat of unprecedented acute catastrophic mortality and global devastation, to enable prospects for a sustainable human future and to fulfill legally binding obligations on all the nuclear weapon states [2]. Dismantling 27,000 nuclear weapons currently in existence will

liberate further quantities of HEU for disposal. After nuclear weapons are abolished, stocks of HEU (and plutonium in separated or separable form) will continue to pose serious proliferation, terrorist and accident risks, and as long as they exist will need to be kept under the highest possible level of physical security. In a nuclear weapon free world, HEU will have no legitimate role which could justify its inherent risks, and there will be overwhelming reasons to eliminate remaining stocks. In this context, even larger amounts of HEU would be available to be blended down to LEU. Currently, 85 kg of HEU is used annually to provide 95% of global usage of Mo-99 [4]. At this level, blending down just ten tons of HEU to LEU would create a stockpile that could support global medical reactor-based isotope needs for more than a century [5]. It is thus evident that even if HEU continued to be used to produce medical isotopes, no further production of HEU is required to meet global radiopharmaceutical needs.

Are dedicated isotope production reactors required?

One potentially important question which appears to have received insufficient attention is whether existing power reactors could be utilized to produce radioisotopes. The targets used to produce Mo-99 are placed in reactors for about one week [5]. Light water reactors used most widely for electricity generation are usually opened for refuelling only about once per year. However, 43 heavy water power reactors in use in Argentina, Canada, China, India, South Korea, Pakistan and Romania are refuelled continuously [28], and one or more of their fuel channels could potentially be used to irradiate targets to produce Mo-99. The same appears to be the case for the Advanced Gas Reactors in the UK. If a Mo-99 recovery facility were not located nearby, the irradiated targets would need to be

transported promptly to such a facility.

The current isotope production reactors in Canada, Europe and South Africa which in 2005 accounted for 95 per cent of global Mo-99 production in 2007 are aged between 42 and 50 years, and thus new production capacity is likely to be required within the next decade [4]. Given that each nuclear reactor is a significant investment with long-term recurrent costs and associated with significant accident, terrorist, waste and proliferation risks, minimising their number is desirable. According to the Intergovernmental Panel on Climate Change, 442 nuclear power plants were operational in December 2006, with a total installed capacity of about 370 gigawatts [29]. If medical isotope needs could be met by use or adaptation of a small number of these, dedicated new isotope production reactors may not be required.

A way forward

One of the oldest and most central ethical principles for doctors is the Hippocratic one: 'first, do no harm'. How many doctors are aware that they contribute to a nuclear proliferation and terrorist risk every time they order a nuclear bone or lung scan, or other procedure utilising an isotope produced using HEU, directly usable in a nuclear weapon? Almost certainly very few. How many of the patients involved are aware of this? Probably even fewer.

At its biennial Congress in Helsinki in September 2006, International Physicians for the Prevention of Nuclear War (IPPNW) resolved to advocate a shift from HEU to LEU for medical isotope production. Health professionals can help reduce the risk of nuclear weapons proliferation, especially by non-state terrorists, through the elimination

of medical HEU commerce, by:

- Educating and urging their national medical and nuclear medicine associations, specialist colleges and other professional organisations to advocate the elimination of HEU fuel and targets from the supply chain for medical isotopes;
- promoting a code of conduct against the production, trade, and use of civilian HEU, thereby contributing to a global norm de-legitimising civil HEU commerce;
- optimising use of appropriate non-ionising radiation imaging technologies, for example MRI or ultrasound;
- optimising use of appropriate non-reactor based ionising radiation imaging technologies, for example PET scanning;
- promoting research and development of non-reactor generation of isotopes currently sourced from reactors, in particular Mo-99;
- clinicians ordering diagnostic or therapeutic nuclear medicine procedures using reactor-based isotopes should ask their nuclear medicine providers where their isotopes come from, and urge a non-HEU source whenever possible. Some simple questions doctors can ask are:
 1. Where do your isotopes originate?
 2. Is it derived from HEU?
 3. If so, is there an alternative supplier not using HEU? If so, please use them. If not, what is the current supplier doing to convert to LEU?

Clinicians should consider and use alternatives to procedures which require reactor-produced isotopes whenever the care of their patients can be served as well or better by alternatives which either avoid ionising radiation altogether (such as ultrasound and MRI), utilise non-reactor isotopes (such as PET scanning), or utilise conventional X-rays (such as modern spiral CT scanning).

Nuclear reactors, including research reactors and those used to produce medical isotopes, pose proliferation, terrorist and accident risks and produce long-lived radioactive waste. Desirable goals for the healing professions are minimising negative consequences of the health care industry; promoting the highest benefit to risk ratio for health care practice; and dissociating, as much as possible, medical care from the world's most uniquely hazardous technology. It should cause health care professionals some disquiet that their care of patients currently, even if inadvertently, increases the risk of spread and use of the world's worst weapons of terror. In the longer run, a desirable goal for research and development of imaging and therapeutic modalities should be to find suitable alternatives to the use of reactor-generated isotopes, whether by use of isotopes produced by more benign means, or by different modalities.

Wherever and whenever feasible, nuclear medicine departments should procure isotopes produced without HEU, that is, currently from the Argentinian, Indonesian and Australian producers [4,5]. Where this is not currently feasible, they should encourage their supplier to convert to LEU and make it clear to their supplier that they plan to switch to a non-HEU source as soon as practicable.

Governments (of Belgium, Canada, France, the Netherlands and South Africa), and Euratom, should require HEU isotope production reactors within their jurisdiction to

promptly be converted to LEU targets. Any new isotope production facilities should be required not to utilize HEU. These governments' lack to date in addressing this avoidable nuclear proliferation and terrorist risk is inconsistent with their stated non-proliferation and anti-terrorist objectives.

The governments that supply HEU (France, Russia, South Africa, USA and UK) are in a strong position to encourage those they supply to switch from HEU to LEU for isotope production, and should be urged to institute compelling incentives – preferably coordinated - for producers to convert to LEU in the near future. Such measures could include a cut-off date of no more than one to two years for continued HEU supply, perhaps in combination with substantial and progressive escalation in the price charged for HEU.

In 2005, global peak production capacity for Mo-99 was estimated at 250 per cent of demand [4]. Producers currently using LEU have the capacity to increase their share of global supply, but only from five per cent to ten per cent (2005 data). Thus it is clear that conversion of the larger producers from HEU to LEU is needed.

The possibility of existing power reactors being utilised or adapted to produce isotopes should be further explored, potentially obviating the need for construction in the near future of dedicated new isotope production reactors.

The US National Academy of Sciences is currently undertaking a Congressionally-mandated study titled 'Medical isotope production without highly enriched uranium' [30]. This two-year project commenced in September 2006 and is due to be completed in two years. While this seems an unnecessarily long timeframe, it will hopefully investigate all relevant aspects including those discussed here and make

comprehensive recommendations which accelerate the removal of HEU from the production of medical isotopes.

Conclusion

Abolishing the nuclear weapons threat requires the outlawing and dismantling of nuclear weapons, but also depends on eliminating access to fissile material. The production of radiopharmaceuticals from HEU is both unnecessary and a significant proliferation hazard. Future use of reactor-sourced medical isotopes should be minimised as much as possible by enhanced efforts to further develop and utilise – whenever patient care would not be disadvantaged - alternative diagnostic and therapeutic modalities which do not exacerbate the most urgent global health threat. Because of the vast stockpiles of HEU which should be eliminated and can be blended down to LEU, medical isotope needs could be met without further mining and enrichment of uranium.

An IPPNW campaign to end medical reliance on bomb-grade uranium aims to eliminate one of the main potential sources of the much-feared 'terrorist bomb' by blocking one of the most vulnerable pathways to fissile material acquisition. It can also help re-awaken the profession and the public to the enormous and growing threat of nuclear weapons and the need for health professionals to actively and urgently engage in the elimination of this, the greatest immediate threat to planetary health and human well-being and survival.

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Table 1. Fissile material requirements for fission nuclear weapons

	Weapons-grade plutonium (kg)		Highly enriched uranium (kg)	
	Technical capability		Technical capability	
Yield (kt)	Low	High	Low	High
1	3	1	8	2.5
20	6	3	16	5

Source: Ref. 6.

Figure 1. Gun type fission nuclear weapon

