Proliferation of Nuclear Weapons and Nuclear Safeguards

by

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PREFACE

This report provides an introduction to selected issues related to nuclear weapons proliferation and the physical protection and material control, accounting and safeguards of nuclear materials. Prepared for faculty and students, it should be read in conjunction with the companion report, “Technological Issues Related to the Proliferation of Nuclear Weapons.” This and the companion report are derived from selected works by the author and his colleagues, Christopher E. Paine and Matthew G. McKinzie, at NRDC.

So long as intrinsically dangerous activities may be carried on by nations, rivalries are inevitable and fears are engendered that place so great a pressure upon a system of international enforcement by police methods that no degree of ingenuity or technical competence could possibly hope to cope with them.

—from "A Report on the International Control of Atomic Energy" [the "Acheson-Lilienthal Report"] March 16, 1946.

I. Introduction.

Two kinds of measures are employed to ensure that special fissionable and other nuclear weapon related materials are not used for illicit purposes: (a) physical security and (b) material control and accounting. Similar measures are employed by banks and other financial institutions to protect money and other securities. A bank does not rely solely on physical security, i.e., its guard force, door locks, vaults, etc., in part because these measures alone cannot provide adequate protection against embezzlement. Money control and daily balancing of the accounts are required to provide both protection against the “insider” threat and timely detection of inventory discrepancies. Similarly, to protect nuclear materials one must have both adequate physical security and adequate material control and accounting. Physical security of nuclear materials has been entrusted to the states. Material control and accounting is both a state function and a function delegated to International Atomic Energy Agency (IAEA).

The international safeguards regime is a collection of treaties, agreements and commitments applied to peaceful uses of nuclear energy designed to reduce the likelihood that special fissionable and other materials, services, equipment, facilities, and information are used in any way as to further any military purpose. The Non-Proliferation Treaty (NPT), the IAEA safeguards, the Treaty on the Prohibition of Nuclear Weapons in Latin America (Tlatelolco Treaty), the Trigger List, and the Zanger Committee are all part of this regime.

During the past 40 years, or so, this regime has had its successes and failures. Several countries initiated and subsequently shutdown their nuclear weapons development efforts, and the Non-Proliferation Treaty (NPT) has been signed by all but a handful of countries and extended indefinitely. The spread of nuclear weapons as of 1998 appears to be limited to eight countries, namely, the United States, Russia, United Kingdom, France, and China—the five countries that are declared nuclear weapon states under the NPT—and Israel, India, and Pakistan, none of whom have signed the NPT or joined the IAEA.

In addition there are several non-nuclear weapon states who are currently seeking, or who have recently sought, a nuclear weapons capability, including Iraq, North Korea, Iran, and Libya; and there is at least one non-state terrorist group in this category. No doubt there are other so-called nascent nuclear weapon states that are taking steps now to reduce the time period to acquire nuclear weapon should a decision be made in the future to do so. Thus, in the foreseeable future—well into the next century—it will be important to retain an effective safeguards regime to ensure that civil nuclear activities are not used for weapon purposes.

During the past decade the international safeguards regime has been marked by three glaring failures. First, is the failure by the IAEA and other elements of the international safeguards regime to detect in a timely fashion the Iraqi nuclear weapons program and its relationship to nuclear activities under IAEA safeguards. The scope of the Iraqi weapons program was only divulged as a consequence of the Gulf War and its aftermath, to the extent that the scope is known. The international community, through the IAEA and its 93+2 program, has taken important steps to strengthen international safeguards to lessen the likelihood of another

Iraq, primarily by giving the IAEA wider latitude to inspect undeclared nuclear facilities. It remains to be seen how effective these improvements will be.

Second, is the failure to implement an effective IAEA safeguards program in North Korea immediately after it became a party to the NPT in 1985. Thus, for several years thereafter North Korea actively pursued a nuclear weapons program in violation of the Treaty without being detected. As a consequence of this delay, the international community now finds itself having to reward North Korea with two light water reactors to entice North Korea to halt its illegal plutonium production program.

Third, is the failure to prevent the diversion of kilogram (kg) quantities of weapon-usable nuclear materials—plutonium and highly-enriched uranium (HEU)—from civil nuclear facilities in Russia following the collapse of the Soviet Union. The international safeguards regime cannot provide timely warning of a diversion of significant quantities of nuclear weapon-usable materials from the civil nuclear programs in Russia and other states of the former Soviet Union to any number of states or non-state groups seeking nuclear weapons.

There is neither adequate physical security nor adequate material control and accounting of nuclear weapon-usable materials in Russia and other newly independent states. In this instance it has not even dawned on the leadership of the international civil nuclear community that this in large measure is a problem of their own making. The nuclear community was not responsible for the collapse of the Soviet Union; but the availability of large inventories of inadequately safeguarded weapon-usable fissile material is a direct consequence of the international nuclear community's promotion of the use of HEU in civil research and test reactors, the commercial separation of plutonium in reprocessing plants, and the use of plutonium fuels in civil reactors. Moreover, unlike in the case of Iraq, the international nuclear community has failed to mobilized itself and put in place adequate safeguards to ensure that diversion of plutonium and HEU from civil nuclear programs cannot happen in the future under similar circumstances.

In addition to these most glaring examples there have been numerous examples of the failure of various nuclear export control regime to prevent nuclear weapon-related materials, services, equipment, facilities, and information from being used further military purposes.

In spite of 93+2 and other improvements in IAEA safeguards, the United States does not believe IAEA safeguards are adequate and ultimately does not rely on them. The clearest evidence for this is the U.S. opposition to the sale of civil power reactors to Iran by Russia. Iran has signed the NPT; the Russian-made VVER-1000 reactors use a non-weapon usable low-enriched uranium fuel; the fuel would be returned to Russia; and while in Iran the fuel would be under IAEA safeguards. Nevertheless, the United States has actively opposed this sale and the sale of a research reactor fueled with 20%-enriched uranium, claiming that Iran is sponsoring terrorism, receiving technology for its missile program from Russian agencies, and pursuing a nuclear weapons program.

Matters would be far worse, were Iran to follow the Japanese example and announce that it was pursuing a closed fuel cycle, the construction of a pilot reprocessing plant, and the stockpiling of plutonium for civil purposes.

The proliferation issues related to civil nuclear power have been recognized for almost two decades:

- very small quantities of plutonium (Pu) and/or highly enriched uranium (HEU) are needed for a nuclear weapon;
- it is very difficult to provide adequate security for separated plutonium and HEU at bulk-handling facilities (e.g., nuclear fuel enrichment, reprocessing and fabrication facilities) where separated plutonium and HEU are is found in non-discrete forms; and
- stockpiling of these materials in non-weapon states provides a dangerous breakout capability.

The lack of adequate security of weapon-usable materials in Russia, the need to dispose of large stocks of fissile materials from retired weapons, the impact that civil plutonium stockpiles will have on elimination of nuclear weapons, and the growing recognition that we must address the long-term proliferation risks associated with spent fuel once the protection afforded by the radioactive fission products has decayed away, represent new dimensions to these issues.

II. The Amount of Plutonium and/or Highly-Enriched Uranium Needed for a Nuclear Weapon is Very Small

After more than half a century of living with nuclear weapons there is still considerable misinformation about the fissile material requirements for nuclear weapons. The 22 kiloton (Kt) yield Nagasaki weapon was constructed with only 6.1 kilograms (kg) of weapon-grade plutonium (WGPu). As noted in Section III.E of the companion report, "Technological Issues Related to the Proliferation of Nuclear Weapons," had this weapon been fabricated with three kg of WGPu, its yield would have been about one kiloton—still a very damaging explosion with the potential to kill tens of thousands of people, depending on the population density and physical characteristics of the targeted area. Many tactical nuclear weapons that were in the U.S. nuclear arsenal had yields in the kiloton, and even sub-kiloton range.

By today's standards the Nagasaki bomb is considered a "low-technology" nuclear weapon design. A non-nuclear weapons state today can take advantage of the wealth of nuclear weapons design information that has been made public over the past 50 years, and do better. As little as one to three kg of WGPu and as little as three to eight kilograms of HEU are needed to construct a nuclear device with a yield of one kiloton. Modern boosted fission primaries with yields in the range of 5-20 Kt are constructed with about 3 kg of WGPu.[1]

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[1] See "Technological Issues Related to the Proliferation of Nuclear Weapons," Section III.F.

III. Existing Physical Security Measures at Many Nuclear Facilities Provide Insufficient Insurance Against Theft of Weapon-Usable Nuclear Materials

Adequate physical security measures are essential to prevent the theft of fissionable material. As noted previously, under the present international safeguards system these are entrusted to the individual nation state, which in turn may delegate the task to private commercial entities licensed for the purpose.

One difficulty in providing adequate physical security is that theft of materials can involve a collusion of individuals, including the head of the guard force, the head of the company, or even the state. Despite having guards at every bank, employees at the Bank of Credit and Commerce, Inc. (BCCI) were able to steal millions of dollars from bank customers because the thieves were running the bank—the collusion was at the top. If the threat includes the potential for collusion involving the guard force and facility managers, providing adequate physical security becomes extremely difficult.

Of course the principal role of physical security is completely reversed when the collusion involves elements of the government itself. In this case the primary mission of the security apparatus is to **hide** the program from outside scrutiny. It is now known that at various times in the past, the governments of the United States, Japan (during World War II), Soviet Union, United Kingdom, France, China, Israel, India, South Africa, Sweden, Argentina, Brazil, Taiwan, Pakistan, North Korea, South Korea, Iraq and Libya have had secret nuclear weapons development programs at one time or another.

For nuclear weapon-usable materials to be safely used in commerce, the institutions that must prevent their misuse must function reliably over the history of the respective commercial industries.[2] Moreover, these institutions have to function reliably on a global basis. The situation in Russia makes it abundantly clear that this has not been possible. Today Russia has no effective judiciary, its economy is characterized by graft, corruption and organized crime extorts payoffs from a substantial fraction of the private businesses, and the physical security over Russia's weapon-usable fissile material is demonstrably inadequate.

Russia has the largest stocks of weapon-usable fissile material of any nation—some 200 t of plutonium and 1200 to 1400 t of HEU. Most of this spread among 15,000 to 25,000 intact nuclear weapons at scores of weapon storage locations. Physical security over nuclear weapons in Russia appears to be considerably better than at more than 50 additional sites where weapon-usable fissile materials are processed and/or stored. These sites are associated with nuclear warhead assembly and component manufacture; fuel cycle facilities associated with weapon material production, naval and civil reactor fuel; research and test reactors; and basic nuclear research. In the Soviet Union, prior

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[2] Pu-239 has a half-life of 24,000 years, and U-235 has a half-life of 700 million years. The lifetimes of weapon-usable materials greatly exceed the lifetimes of modern man and civilized society.

to its breakup, the security at about a dozen of the defense related sites relied heavily on guarding not only the facilities, but also the secret towns and cities where the nuclear work force resides. These large "closed" areas are anathema to a democratic society.

Since the collapse of the Soviet Union there have been several cases where quantities, a few hundred grams to a few kilograms, of weapon-usable fissile material has been illegally removed from civil research and naval fuel facilities, and on some case not recovered until it left the country. Low-enriched uranium fuel has been stolen. Four tonnes (t) of beryllium contaminated with gram quantities of HEU was stolen from a Russian nuclear facility at Obninsk, and subsequently recovered by Lithuanian authorities in Vilnius.

IV. IAEA Safeguard Measures are Incapable of Detecting Diversion of Weapons-Usable Fissile Material From Several Important Types of Nuclear Facilities

The international community's principal tool for penetrating the secrecy of nuclear facilities is the authority of the IAEA to conduct inspections and require adherence to strict material accounting and control procedures, collectively referred to as "safeguards." These inspections and requirements are meant to provide timely detection of the diversion of significant quantities of weapons-usable material.

Given the small quantity of fissile material need to make a bomb, highly accurate material accounting and control measures are essential to determine whether a theft has taken place, and to provide timely warning to prevent the material from being used for illicit purposes. It is well established—from experience at existing civil and military chemical separation (reprocessing) plants, naval fuel facilities, and mixed-oxide fuel facilities—that it is extremely difficult (we would argue impossible) to provide in practice adequate material control and accounting, at bulk handling facilities where large amounts of nuclear weapons-usable material are processed in the form of liquids, gases and/or powders.

While there are numerous shortcomings in the design and implementation of IAEA safeguards, we focus here on four technical flaws: (a) the IAEA's "significant quantity" (SQ) values are technically flawed—they are far too high; (b) detection of the diversion of a SQ amount applies to a material balance area, instead of the entire facility, or even country; (c) the IAEA cannot adequately safeguard large reprocessing plants and some other bulk-handling facilities; and (d) the IAEA's timely detection criterion cannot be met.

A. The IAEA's Definition of "Significant (i.e., Explosive) Quantities" for Plutonium and HEU Nuclear are Technically Incorrect.

For safeguards purposes the IAEA defines a "significant quantity" (SQ) of nuclear material as "the approximate quantity of nuclear material in respect of which, taking into account any conversion process involved, the possibility of manufacturing a nuclear explosive device cannot be excluded."[3] Significant quantity values currently in use by the IAEA are given in Table 1.[4]

The SQ values were recommended to the IAEA by a group of experts, namely, the IAEA's Standing Advisory Group for Safeguards Implementation (SAGSI), and "relate to the potential acquisition of a first nuclear explosive by a non-nuclear weapon state."[5] The direct-use values in Table 1, that is, 8 kg of plutonium, 8 kg of uranium-233, and 25 kg of HEU, are also referred to by the IAEA as "threshold amounts," defined as "the approximate quantity of special fissionable material required for a single nuclear device."[6] The IAEA cites as a source for these threshold amounts a 1967 United Nations document.[7] The IAEA states,

> "These threshold amounts include the material that will unavoidably be lost in manufacturing a nuclear explosive device. They should not be confused with the minimum critical mass needed for an explosive chain reaction, which is smaller.[34]
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> [34] Using highly sophisticated techniques available to NW States, the critical mass and the corresponding threshold amount can also be significantly reduced, but these are special cases that need not be considered here."

As evidenced from Figures 1 and 2 in Section III.D of the companion report, "Technological Issues Related to the Proliferation of Nuclear Weapons," the direct-use SQ or threshold values currently used by the IAEA are technically indefensible. For decades the IAEA has set invalid technical thresholds for the minimum quantity of nuclear material needed for a nuclear weapon, even for a low-technology first nuclear explosive by a non-nuclear weapon state, including consideration of unavoidable losses.

First, the current 8 kg SQ value for plutonium is consistent with assuming a 24 percent loss in fabricating a solid 6.1 kg plutonium core similar to the Trinity device or the Nagasaki bomb—equivalent to losing the outer 0.4 cm of the 4.5 cm core during casting and machining. This degree of imprecision seems exceptionally high for the numerically controlled techniques now available in the commercial marketplace.

Second, as noted earlier, if one took the same *Fat Man* design, first tested at the *Trinity* site in New Mexico and dropped on Nagasaki in 1945, and simply substituted a three kg plutonium core for the 6.1 kg core that was used in 1945, the yield of this device would be on the order of one

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[3] *IAEA Safeguards Glossary, 1987 Edition*, IAEA, IAEA/SG/INF/1 (Rev. 1), 1987, p. 23.

[4] Ibid., p. 24.

[5] Thomas Shea, ``On the Application of IAEA Safeguards to Plutonium and Highly Enriched Uranium from Military Inventories," IAEA, (June 1992, with additions: December 1992).

[6] *IAEA Safeguards Glossary*, p. 23.

[7] *Effects of the Possible Use of Nuclear Weapons ...*, United Nations, A/6858, 6 October 1967.

Kt, still a very respectable atomic bomb that could create catastrophic losses in dense urban areas. Thus, based on this evidence alone the IAEA is in error to assert that "highly sophisticated techniques available to NW States" are needed to make nuclear weapons with "significantly reduced" quantities of materials.

Third, as discussed in Section III.E of the companion report, since the early 1950's, the nuclear weapon states have been producing nuclear weapons with yields of several kilotons range from as little as 2 kg of plutonium. The so-called "highly sophisticated techniques available to NW States" referenced by the IAEA were known to U.S. weapons designers in the late-1940s and early 1950s—and are now available to anyone with the patience and skills to search the open technical literature. Nuclear devices using very small quantities of plutonium and HEU—so-called "fractional crit" weapons—with yields on the order of one Kt were tested during the Ranger series in 1951.

Finally, a well advised safeguards program for a given country or group of countries would set the "significant quantity" levels at values less than the minimum amount needed for a weapon, to guard against the fact that materials can be diverted from more than one source. The practice of setting higher levels to account for manufacturing losses is likewise imprudent, particularly in view of the fact that a significant fraction of these "losses" are technically recoverable. In sum, *safeguards apply to all non-weapons countries, irrespective of their technological sophistication, and safeguards effectiveness should be assessed with this fact in mind*.

Many IAEA-member countries, including Israel, India and Pakistan and several that are not declared nuclear weapon states, such as Japan, Germany, South Korea, have highly developed nuclear infrastructures, and must be considered technologically sophisticated. Israel is presumed to have deployed boosted fission weapons, and possibly two stage thermonuclear weapons. India claims to have tested a two stage thermonuclear device this year. This is certainly credible given that it has been 24 years since its first nuclear weapon test in 1974. Even for countries that are in general not sophisticated technologically, such as North Korea, the key technical information needed to establish a program for achieving substantial compression via implosion techniques is now accessible in the unclassified literature. The quantities defining safeguards significance, therefore, must be based an the assumption that the proliferator has access to "advanced" (i.e., at least 1950's era) technology. Whatever the nonproliferation "disinformation benefit" that may have flowed from the IAEA is mistaken SQ values in the past, it is now far too late in the proliferation game to base the international nuclear control regime on flawed technical premises. As a consequence, the IAEA's significant quantities should be lowered at least 8-fold to the values in Table 2.

B. Detection of the Diversion of a SQ Amount Applies to a Material Balance Area, Instead of the Entire Facility, or Even Country

To improve material control, large facilities that process or store nuclear weapon-usable materials are subdivided into numerous “material balance areas.” The inventories and inventory differences within individual balance areas can be significantly smaller than those for the entire facility. The IAEA SQ limits are applied to the separate material balance areas. It must be recognized that this approach does not afford adequate protection against state sponsored diversions or a collusion of individuals who can remove materials from separate material balance areas.

C. The IAEA Cannot Adequately Safeguard Large Reprocessing Plants and Some Other Bulk-Handling Facilities

In the parlance of nuclear material accounting, the inventory difference (ID) is defined as:

$$ID = BI + I - R - EI,$$

where BI is the beginning inventory, EI is the ending inventory, and I and R are, respectively, the material added and removed during the inventory period.[8] For the minimum amount of diverted plutonium (assumed by the IAEA to be the SQ value—currently 8 kg of plutonium) to be distinguished from measurement noise with detection and false alarm probabilities of 95% and 5%, respectively, it can be shown that 3.3 σ_{ID} must be less than the SQ value, where σ_{ID} is the uncertainty in the inventory difference.[9] This means if the SQ value for plutonium were lowered to one kg, σ_{ID} should not exceed about 300 grams.

At reprocessing plants that handle tons of weapons-usable plutonium, σ_{ID} is dominated by the error in measuring the plutonium input into the plant, which is about one percent of the throughput. The Japanese Tokai Mura reprocessing plant, one of the smallest plants in the West, has an average output of about 90 t of heavy metal per year (tHM/y), and the LWR spent fuel processed has an average total plutonium content of about 0.9 percent. Thus, σ_{ID} for Tokai Mura is about 8 kg of plutonium per annual inventory. Even if inventories were taken every six months, σ_{ID} would be about 4 kg, which is too high by today’s standard and more than an order of magnitude too high if the SQ value were lowered by a factor of eight as we propose. One simply cannot detect the diversion of several bombs’ worth of plutonium annually from Tokai Mura. The inventory difference would be larger at the plants in the United Kingdom and France since they have a greater throughput of plutonium.

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[8] In the literature "inventory difference" (ID) is sometimes called "material unaccounted for" (MUF).

[9] Marvin Miller, "Are Safeguards at Bulk-Handling Facilities Effective?, Nuclear Control Institute, Washington, D.C., August 1990.

Material accounting and control at Russian plants handling nuclear fuel in bulk form is rudimentary at best. The RT-1 chemical separation plant at Chelyabinsk-65 has a capacity of about 400 tHM/y, and until 1991 had been operating at about 200 tHM/y. Therefore, the situation at RT-1 would be two to six times worse than at Tokai Mura, even if it were brought up to current western standards.[10] It is difficult to imagine running a bank in which you counted the money only a few times a year, and then only counted the notes larger than one-hundred dollars . Yet the Russian nuclear establishment sanctions the commercial use of nuclear weapons-usable material under safeguards that are no better.

D. The Timely Detection Criterion Cannot be Met

Detection time (the maximum time that should elapse between diversion and detection of a significant quantity) should be in the same range as the conversion time, defined as the time required to convert different forms of nuclear material into components of nuclear weapons. For metallic plutonium and HEU, the conversion time is 7-10 days; for other compounds of these materials, 1-3 weeks. These times are already much shorter than the period between inventories at any fuel reprocessing plant operating today. Thus, there can be no assurance that the primary objective of safeguards—the timely detection of significant quantities of plutonium—is now being, or can be, met.

To meet the timely detection criteria, reprocessing plants would have to undergo clean-out inventories every few days, or weeks. But this would reduce their annual throughput—and utility—practically to zero. It would also drive up the cost of reprocessing. Plutonium recycle, the use of mixed-oxide (MOX) fuel in standard commercial LWRs, is already uneconomical due to the high costs of reprocessing and MOX fuel fabrication even when conducted without a technically adequate level of safeguards. Similarly, the cost of the fast breeder reactor (FBR) fuel cycle is greater than that of the LWR operating on the once-through cycle without plutonium recycle.

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[10] According to Evgeni Dzekun, chief engineer of the Mayak civil reprocessing plant at Chelyabinsk-65, a plutonium input-output balance for the plant is calculated every 3-4 months when the plant is cleaned out between reprocessing campaigns. About one percent of the plutonium is lost to waste streams, and a lesser amount to plateout in the plant's plumbing. The ID is typically 15 kilograms of Pu per campaign, amounting to a total ID of about 3% percent of throughput. In other words, the ID is almost twice the IAEA's significant quantity for plutonium. According to Dzekun, if the ID in a given campaign is larger than can be explained by measurement errors, a "special investigation" is carried out, but what this consists of is not known. To assure detection of an 8 kg. diversion at this plant with 95% confidence and a 5% false alarm rate, 3.3 x ID must be less than 8 kg., so this plant apparently falls short of the minimum IAEA standard by a factor of six. If 4 kilograms is regarded as the amount needed for a weapon, then the “safeguards” at Mayak need to be improved by a factor of twelve in order to provide confident detection of diverted material. See “Report on an International Workshop on the Future of Reprocessing, and Arrangements for the Storage and Disposition of Already-Separated Plutonium” (Moscow, 14-16 December 1992) by F.von Hippel, Princeton University, and T.B. Cochran, C.E. Paine, Natural Resources Defense Council, January, 10, 1993, p. 5.

In Western Europe and Japan, consideration has been given to Near-Real-Time Accountancy (NRTA) as a means of improving the sensitivity and timeliness of detection. NRTA involves taking inventories at frequent intervals, typically once a week, without shutting down the facility. It and similar concepts are likely to be opposed by operators due to the added costs that would be imposed. In any case the methods and adequacy of practical NRTA system implementation are open questions.

A case in point is Japan's Tokai Plutonium Fuel Production Facility (PFPF) where MOX fuel has been fabricated for Japan's Joyo and Monju fast-breeder reactors since 1988. The PFPF's production line consists of 17 interconnected glove boxes monitored by unattended, tamper proof instruments, such as neutron coincidence counters. Following an April 1994 inspection conference with the IAEA, Japanese sources disclosed that on the order of 70 kg of plutonium was “held up” in the remotely monitored process line, and that the uncertainty in the NRTA system's measurement of this hold-up material exceeded at least 8 kg, enough material for several nuclear explosive devices. Japan’s Power Reactor and Nuclear Fuel Development Corporation (PNC) agreed to design new glove boxes that reduce the amount of plutonium deposited in the process line, but astonishingly the IAEA did not order the immediate shutdown of the plant and a comprehensive clean-out inventory. Given that 1-2 kg is sufficient for a weapon, the IAEA's intervention was technically four years too late to provide timely warning of a theft or diversion had a subsequent physical inventory demonstrated that kilogram quantities of plutonium remained unaccounted for. This initial application of NRTA, and the IAEA's sluggish response to the difficulties encountered, does not justify confidence in successful implementation of NRTA techniques in larger and more complex facilities with vastly greater flows of material.

V. All Nuclear Weapons and Weapons-Usable Materials Should be Places Under Some Form of Bilateral or International Safeguards

Perhaps the greatest non-proliferation priority today is to improve the physical security and material accounting of warheads and weapons-usable materials in Russia. Russian nuclear weapons material, naval fuel, and civil reactor fuel facilities are highly integrated. Many of these facilities are old and cannot meet IAEA safeguard criteria. For these reasons Russian officials are unwilling to consider IAEA safeguards over these facilities at this time. Consequently, the most promising means of achieving the necessary improvements is through U.S.-Russian and other bilateral efforts.

The most promising approach is through a cooperative program involving the nuclear weapons laboratories in the United States and Russia. The Department of Energy (DOE) launched such a cooperative lab-to-lab program in April 1994, and it now covers material physical protection, control and accounting (MPC&A) at about 40 sites in Russia and another 13 in other states of the former Soviet Union. While this ongoing program has been highly successful, it is nevertheless limited by the shear magnitude of the problem and by lack of access to sensitive military sites.

What is needed is a comprehensive non-discriminatory global safeguards regime that covers all nuclear weapons and weapon-usable fissile material. Only then will the parties be forced to address methods for adequately safeguarding the most sensitive facilities and materials.

In the left-hand column of Table 3, are listed various categories of nuclear weapons, fissile materials, and weapons and fissile material facilities. The next four columns denotes the declared and undeclared weapons states—the US, Russia, United Kingdom, France, China, Israel, India and Pakistan. The last column denotes the non-weapon states. As seen from Table 3, all of the nuclear weapons and most of the fissile material facilities are not covered by the IAEA or even bilateral safeguards. As shown in Table 4, even with the objectives of a global cut-off in the production of fissile material for weapons, and with IAEA safeguards placed over fissile materials declared “excess” to national security requirements, all nuclear warheads and many fissile material inventories and production facilities will remain outside of any bilateral or international safeguards, including the weapons-usable material inventories in Russia. If we hope to achieve deep reductions in the global nuclear weapons arsenals we will need a comprehensive safeguards regime covering all nuclear weapons and weapon-usable materials. One of several possible comprehensive schemes is depicted in Table 5.

VI. Proliferation Risks Associated with Enrichment Plants

Diversion of HEU for unauthorized use from safeguarded enrichment plants designed to produce HEU can be difficult to detect because of the large inventory differences—a few percent of throughput. This diversion scenario is best resolved by an agreed ban on the isotopic separation of weapon-usable uranium, i.e., uranium enriched above 20% U-235.

Aside from direct diversion of HEU from a safeguarded plant, there are three additional technical paths for obtaining weapon-usable uranium through clandestine enrichment: (a) develop a new enrichment plant designed for HEU production, (b) alter an existing plant designed for low-enriched uranium (LEU) production, and (c) divert LEU for subsequent enrichment to HEU in a smaller enrichment plant. Some enrichment technologies, e.g., AVLIS, require relatively little space and consequently locating clandestine facilities represents a challenge to the IAEA and National Technical Means. Conversion of some enrichment technologies, e.g., centrifuge plants, is not a difficult operation physically, but could be detected by in-plant inspectors.

The diversion of LEU for subsequent enrichment also represents a potential breakout scenario and a challenging safeguards problem. Typical stocks of low-enriched uranium fuel (4.5% U-235) represent 71% of the “separative work” required to produce 80%-enriched uranium suitable for use in simple gun-type uranium weapons, such as the weapon which destroyed Hiroshima and the six weapons that were stockpiled by the former white minority government of South Africa. Since nuclear power based on the thermal reactor's “once-through” fuel cycle is likely to persist at least 40-50 years into the future—the expected lifetime of new nuclear plants currently approved for construction—close controls on enrichment as well as reprocessing capabilities will have to be maintained.

VII. Proliferation Risks Associated With the Closed Fuel Cycle

The United Kingdom, France, Russia, and Japan are reprocessing spent civil reactor fuel for waste management and to separate plutonium for recycle as a nuclear fuel in light water reactors and breeders. While France, Russia and Japan claim a continued interest in developing plutonium breeder reactors, their breeder programs are all moribund. Not only is there no adequate means of safeguarding large bulk handling facilities to prevent weapon-usable plutonium from being stolen, but also reprocessing of spent fuel and the recycling of plutonium[11] into fresh fuel for reactors permit non-nuclear weapons states to justify the acquisition and stockpiling of nuclear weapons-usable material—ostensibly for peaceful purposes. At the same time, without violating any international safeguards agreements, these countries can design and fabricate non-nuclear weapon components. By moving to a point of being within hours of having nuclear weapons—perhaps needing only to introduce the fissile material into the weapons—a nascent weapons state would have all of its options open. Under these conditions, international safeguards agreements can serve as a cover by concealing the signs of critical change until it is too late for diplomacy to reverse a decision to “go nuclear.” India recovered the plutonium for its first nuclear device in a reprocessing plant that was ostensibly developed as part of its national breeder program.

Acceptance of the plutonium breeder as an energy option provides the justification for the early development of a reprocessing capability by any country. A non-nuclear weapons country would always have the option to shift its “peaceful” nuclear program to a weapons program, but this would require the politically difficult decision to attempt evasion or overtly abrogate IAEA safeguards. Without national reprocessing facilities and breeder reactors, countries wishing to develop nuclear weapons capacity face very considerable political problems and cost. Obtaining large quantities of weapon-usable plutonium requires that they build one or more specialized production reactors and chemical separation facilities. By establishing their nuclear weapons option through a plutonium-using nuclear electric generation program, they can circumvent these obstacles.

Were plutonium fast breeder reactors ever to become economical—we seriously doubt this will happen—their deployment would entail staggering amounts of nuclear weapons-usable plutonium in the reactors and the supporting fuel cycle.[12] If only 10 gigawatts of electric capacity were supplied by breeders—hardly enough to justify the R&D effort in any country even if the

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[11] Or any other weapons material, such as highly enriched uranium or uranium-233.

[12] With a plutonium breeder economy the quantity of plutonium involved would be enormous. The plutonium inventory in a commercial-size breeder is about 5 t, of which 3.5 t is fissile - sufficient for 800 atomic bombs using 6 kg Pu each. A Russian BN-800 breeder reactor would require over 4 t. Although the net amount of plutonium produced in a fast breeder reactor annually is generally less than that produced in a conventional thermal power reactor of the same size, one-third to one-half of the FBR fuel must be removed annually for reprocessing, plutonium recovery, and remanufacture into fresh fuel. Since the fuel will be outside of the reactor for 3.5 to 7 years the plutonium inventory needed to support a single commercial-size plutonium breeder is 11-22 t - sufficient for 1800 to 3600 atom bombs using 6 kg Pu each.

economics were otherwise favorable—the plutonium inventory in the reactors and their supporting fuel cycle would be on the order of 100-200 t—sufficient for 17,000 to 33,000 nuclear weapons each using 6 kg of plutonium. By comparison, U.S. nuclear weapons stockpiles in 1987 consisted of 23,400 warheads, and the WGPu inventory, most of which was in weapons, was about 85 t. The Russian warhead plutonium stockpile consists of an estimated 135-170 t of WGPu in a total stockpile which peaked in 1985 at about 45,000 warheads.

Moreover, about one half of the plutonium created in a breeder reactor is bred in the blanket rods. The burnup of the blanket material is low. Consequently, the resulting plutonium is weapon-grade, with a Pu-240 concentration lower than that used in U.S. and Russian weapons. Thus, any non-weapons country that has large stocks of breeder fuel, has the capacity to produce a ready stock of weapon-grade plutonium. It only has to segregate and reprocess the blanket assemblies separately from the core assemblies.

Consequently, remaining breeder research and development programs, if not deferred altogether, should be limited to conceptual design efforts only, with an emphasis on advanced proliferation resistant fuel cycles that do not require mastery of the technology for isolating and fabricating weapons-usable nuclear materials. To the extent that this is politically impossible, sufficient plutonium has already been separated to meet the needs of R&D programs, so at a minimum there is no requirement to continue separating plutonium for this purpose. In this connection it should be noted if plutonium breeders some day prove to be economically competitive, and if the breeder fuel cycle can be safeguarded with high confidence under stringent international controls, then commercial deployment could begin with cores of non-weapons usable 20% enriched uranium. *In other words, there is no need to accumulate a stockpile of separated plutonium today to insure the possibility of deploying breeders at some point in the future.*

VIII. Civil Plutonium Stockpiles Are a Potential Barrier to Achieving Deep Reductions in the Global Nuclear Arsenals

The accumulation of large stockpiles of separated plutonium and weapon-usable expertise in nominally civil programs will act as a barrier to deep reductions and eventual elimination of nuclear weapons held by declared and undeclared weapon states. As of the end of 1997, Japan had accumulated 24 t of separated plutonium, of which 19 t was stored on France and the United Kingdom and 5 t stored in Japan.[13] One need only ask how far China, for example, might be willing to go in accepting limits on, or reductions in its nuclear weapons stockpile if Japan is poised to accumulate an even larger inventory of weapons-usable fissile materials in pursuit of a civil plutonium program with no clear commercial rationale. Similarly, Russia's continued operation of three reprocessing plants and Russia’s committed to the deployment of BN-800 type breeder reactor and a closed fuel cycle fuel, could abort U.S. political support for continuing toward very deep reductions and ultimate abolition of nuclear weapons stockpiles. The lack of such a commitment by

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[13] *Nuke Info Tokyo*, July/Aug. 1998, p. 5.

the United States and other nuclear weapons states, could, in turn, lead to continued erosion of the nonproliferation regime. Hence the need to forthrightly address the mistaken legitimacy afforded civil plutonium programs under the current system of international controls. In any case, nations having civil nuclear energy programs with closed fuel cycles can make an important contribution to the disarmament process by deferring further separation of plutonium until the global inventories of plutonium are substantially reduced.

France, the United Kingdom, Japan and Russia continue to separate plutonium at a far greater rate than it is being burned in existing reactors. France and the U.K. are separating about 20 t of Pu per year, but only 9 t were recycled into fuel in 1997.[14] The U.K stockpile of separated civil plutonium (i.e., not fabricated into fuel or in use in reactors) now stands at 50 t and is projected to grow to 100 t by 2010.[15] The global inventory of separated civil plutonium is now an estimated 170 t—some 3.6 times the 47 t of plutonium reserved by the United States for weapons and comparable to stocks of plutonium reserved for weapons by all nuclear powers.

IX. Plutonium Economics

Development efforts worldwide have demonstrated that plutonium fast breeders are uneconomical—unable to compete with thermal reactors operating on a once through uranium cycle—and that breeders will remain uneconomical for the foreseeable future. The putative benefits of the plutonium breeder, associated with its ability to more efficiently utilize uranium resources, are not diminished if commercial breeder development is postponed for decades, and the spent fuel from existing conventional reactors is stored in the interim. As thoroughly documented by the Nuclear Control Institute, energy security in the nuclear sector can be achieved more cheaply and more quickly by stockpiling uranium.[16]

The use of plutonium in the form of MOX fuel in conventional power (“thermal”) reactors is likewise uneconomical, because the costs of using MOX fuel cannot compete with those of enriched fresh uranium fuel for the foreseeable future. A 1993 study by the RAND Corp. estimated that the price of uranium feedstock for enrichment would have to increase by a factor of 16 before plutonium recycle in LWRs become competitive.[17]

Assuming conservative reprocessing costs and an FBR/LWR capital cost ratio of 1.5, the yellowcake price would have to increase by a factor of 50 or more before the breeder becomes

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[14] Frank von Hippel, “How to Simplify the Plutonium Problem, *Nature*, July 30, 1998, p. 415.

[15] Ibid.

[16] P. Leventhal and Steven Dolley, "A Japanese Strategic Uranium Reserve: A Safe and Economic Alternative to Plutonium," Nuclear Control Institute, Washington D.C., January 14, 1994.

[17] Brian G. Chow and Kenneth A. Solomon, *Limiting the Spread of Weapon-Usable Fissile Materials*, RAND National Defense Research Institute, Santa Monica, CA, 1993, p.36-38.

competitive. When might this happen? Most likely never, but surely at least 50 to 100 years away. On the timescale for technology development, a period of 50 -100 years is a very long time, during which more efficient fission options may emerge, to say nothing of advanced solar and new energy technologies not yet invented.

X. Impacts of Ongoing Nuclear Weapon Research

There are several ongoing developments related to modern nuclear weapon design that that will make it all the more important to control—we would say eliminate—the commercial use of direct-use fissile materials. Qualitative design principles of boosted weapons are now being published in the open literature.[18] But this pales compared to what we can expect early in next century in the way of openly available weapon design information.

The United States Department of Energy (DOE) is proposing to spend $4 billion to $4.5 billion annually—$60-67 billion over the next 15 years—on its nuclear weapons “Stockpile Stewardship and Management Program” (SSMP). In constant dollars this rate of expenditures is more than the United States spent on average during the Cold War when we were designing, testing and building new warheads and when the stockpile was typically about twice as large as it is today. The Stockpile Stewardship part of this DOE program is predicated on achieving a fundamental understanding of nuclear weapons behavior, and thus in many instances, unclassified advances in the scientific understanding of nuclear explosive phenomena.[19] The Stockpile Stewardship program seeks to sustain and even enhance U.S. capabilities, formerly dependent on nuclear explosive testing, to design and prototype nuclear weapons and “certify” changes to existing weapon types.

One of the objectives of DOE’s Stockpile Stewardship Program is to retain a cadre of scientist who are experts in the various nuclear weapon technologies. This is a principal objective of the inertial confinement fusion (ICF) program and the new National Ignition Facility (NIF) being built at Lawrence Livermore National Laboratory. In order to retain these scientist, DOE is relaxing the classification rules so that they can publish their research in the open literature. U.S. nuclear weapon scientists already are rapidly generating and releasing a wide range of data related to the design of nuclear weapons, including data on basic high energy-density physics, thermonuclear burn, chemical high explosive, and equations-of-state of higher atomic weight materials. Under the Stockpile Stewardship program, new experimental facilities, such as NIF, are being constructed to provide in the absence of explosive nuclear weapon

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[18] André Gsponer and Jean Pierre Hurni, “The Physical Principles of Thermonuclear Explosives, Inertial Confinement Fusion, And the Quest for Fourth Generation weapons,” International Network of Engineers and Scientist Against Proliferation, Technical Report No. 1, March 1998.

[19] Christopher E. Paine and Matthew G. McKinzie, “End Run: The U.S. Government’s Plan for Designing Nuclear Weapons and Simulating Nuclear Explosions under the Comprehensive Test Ban Treaty, NRDC, April 1998 (Rev. 1).

testing, nuclear weapon design data, and data to validate new weapon codes. Much of the data gathered in these facilities will be unclassified.

Another component of the Stockpile Stewardship program is the Accelerated Strategic Computing Initiative (ASCI), projected to cost some $4 billion between now and 2003. An objective of ASCI is to develop by 2003, computers that will be 100,000 times more powerful than today's supercomputers. With these new computer codes, DOE seeks to achieve a "virtual testing" capability, whereby vastly improved computer models of nuclear explosive performance, validated against past nuclear tests as well as experiments conducted in an array of powerful new above and below-ground testing facilities, are intended initially to offset, and perhaps ultimately to replace, the loss of data from underground testing. If current trends persist, we can anticipate that lower cost, more widely available, commercial computers will have the power and capacity of the supercomputers developed some ten years earlier.

Within the ASCI program, DOE has launched the Academic Strategic Alliances Program (ASAP), a partnership between the U.S. nuclear weapons program and the university community that will cost several hundred million dollars over the next five years. The contributions of ASAP to Stockpile Stewardship are in basic (but largely interdisciplinary) scientific research, computer hardware and software research for computer architectures based on massively parallel processing, and the union of these in simulation of complex systems. Under ASAP, for example, the California Institute of Technology will be assisting DOE in developing improved simulations of chemical high explosive detonations, shock compression of heavy metals, and the study of related hydrodynamic instabilities. Much of this work will be unclassified.

As the U.S. weapon program mature, we can anticipate that sometime within the first quarter of the next century, a tremendous amount of nuclear weapons design information and related computer design codes will be widely available in the open literature, and far more powerful computers will be widely available. Modern thermonuclear weapon designs will no longer be the sole purview of today's nuclear weapon states. Even in the absence of explosive nuclear testing, if there is to be any remaining technical barrier to obtaining nuclear weapons of sophisticated design, it will be in the form of constraints on the availability of direct-use nuclear material—separated plutonium and HEU.

XI. Conclusion

At the dawn of the nuclear age, the authors of the famous Acheson-Lilienthal plan for international control of atomic energy clearly recognized the inherent military potential of fissile materials used for ostensibly peaceful purposes. Indeed, they believed that no widespread use of nuclear energy for civil purposes was possible or desirable without international ownership and control of the full nuclear fuel cycle.

Today it remains the unanimous opinion of the weapons design and arms control communities that the pacing consideration in a country's acquisition of a nuclear weapon is not the capability to design a nuclear device, but the availability of fissile materials which can be turned to weapons purposes. Ending—as opposed to “managing”—nuclear weapons proliferation will likely prove impossible as long as: (a) production of HEU and chemical separation of plutonium for national security needs remain legitimate activities in a particular class of “nuclear weapon states;” and (b) the international safeguards regime permits civil nuclear fuel reprocessing in any state that asserts a peaceful interest in plutonium recycle and future deployment of plutonium breeder reactors for energy production.

With the end of the cold war, and the reductions in the superpower arsenals, the United States and Russia have huge surpluses of weapon-grade plutonium and highly-enriched uranium. Undoubtedly, there is no need for additional weapons plutonium production in other declared weapons states. *By completely renouncing the production, separation, and isotopic enrichment of weapons-usable nuclear materials, declared weapons states can put pressure on undeclared weapons states to do the same*. Weapon-usable fissile materials have no legitimate application in today's energy marketplace, and can always be produced in the future should the appropriate market and international security conditions emerge.

Despite the fact that all types of plutonium in relatively small quantities, irrespective of their designation as civil or military, have an inherent capability to be used in weapons, the current nonproliferation regime allows national separation and acquisition of plutonium (and highly-enriched uranium) under an internationally monitored commitment of peaceful use. A more effective nonproliferation approach would be a global ban on the production, transfer, acquisition, or isotopic enrichment of separated plutonium, and on the isotopic enrichment of uranium to greater than 20% U-235.

The heavy commitment of U.K, France, Japan and Russia to spent fuel reprocessing and recycle of plutonium, and the lingering hopes of a future revival of the plutonium fast breeder program, have effectively barred consideration of such a simple and direct step as outlawing production and acquisition of weapons-usable fissile materials on a global basis.

While there are obvious technical advantages in such a comprehensive approach, tangible political progress will more likely be achieved in the near term by adopting ***parallel*** approaches that seek separate controls—in the initial stages at least—on the military and civil applications of weapon-usable fissile materials.

Table 1

IAEA Significant Quantities.

Material	Quantity of Safeguards Significance	Safeguards Apply to:
Direct-use nuclear material		
Plutonium	8 kg	Total element
Uranium-233	8 kg	Total isotope
Uranium enriched to 20% or more	25 kg	U-235 isotope
Indirect-use nuclear material		
Uranium (<20% U-235)	75 kg	U-235 isotope
Thorium	20 t	Total element

Table 2

NRDC's Proposed Significant Quantities.

Material	Quantity of Safeguards Significance	Safeguards Apply to:
Direct-use nuclear material		
Plutonium	1 kg	Total Element
Uranium-233	1 kg	Total isotope
Uranium enriched to 20% or more	3 kg	U-235 isotope

	WEAPON STATES					NON-WEAPON STATES
	US and Russia	UK, France, China	Israel	India	Pakistan	
MILITARY:	■	■	■	■	■	■
Warheads:	■	■	■	■	■	■
Operational						■
Reserve						■
Retired						■
Fissile Material:	■	■	■	■	■	■
In Warheads						■
Reserved for Warheads						■
Declared Excess	IAEA (limited)	None Declared	None Declared	None Declared	None Declared	■
Facilities:	■	■	■	■	■	■
Weapon Production						■
Material Production						■
Excess Material Storage	IAEA (limited)	None Declared	None Declared	None Declared	None Declared	■
NAVAL FUEL CYCLE:	■	■	■	■	■	■
Facilities			■	■	■	■
Fuel			■	■	■	■
CIVIL NUCLEAR:	■	■	■	■	■	■
Reactors			■	IAEA (limited)	IAEA	IAEA
Fuel Cycle Facilities			■	IAEA (limited)	IAEA	IAEA
HEU/Pu			■	IAEA (limited)	IAEA (limited)	IAEA
LEU			■	IAEA (limited)	IAEA	IAEA
Spent Fuel			■	IAEA (limited)	IAEA	IAEA

Table 3. Current safeguards.

	WEAPON STATES	NON-WEAPON S

	US and Russia	UK, France, China	Israel	India	Pakistan	STATES
MILITARY:	■	■	■	■	■	■
Warheads:	■	■	■	■	■	■
Operational						■
Reserve						■
Retired						■
Fissile Material:	■	■	■	■	■	■
In Warheads						■
Reserved for Warheads						■
Declared Excess	IAEA	IAEA	IAEA	IAEA	IAEA	■
Facilities:	■	■	■	■	■	■
Weapon Production						■
Material Production	IAEA	IAEA	IAEA	IAEA	IAEA	■
Excess Material Storage	IAEA	IAEA	IAEA	IAEA	IAEA	■
NAVAL FUEL CYCLE:	■	■	■	■	■	■
Facilities			■	■	■	■
Fuel			■	■	■	■
CIVIL NUCLEAR:	■	■	■	■	■	■
Reactors			■	IAEA	IAEA	IAEA
Fuel Cycle Facilities	IAEA	IAEA	■	IAEA	IAEA	IAEA
HEU/Pu	IAEA	IAEA	■	IAEA	IAEA	IAEA
LEU			■	IAEA	IAEA	IAEA
Spent Fuel			■	IAEA	IAEA	IAEA

Table 4. Cut-off of fissile material for weapons and excess stocks under IAEA safeguards.

	WEAPON STATES					NON-WEAPON STATES
	US and Russia	UK, France,	Israel	India	Pakistan	

		China				
MILITARY:	■	■	■	■	■	■
Warheads:	■	■	■	■	■	■
Operational	MONITORED	MONITORED	MONITORED	MONITORED	MONITORED	■
Reserve	MONITORED	MONITORED	MONITORED	MONITORED	MONITORED	■
Retired	MONITORED	MONITORED	MONITORED	MONITORED	MONITORED	■
Fissile Material:	■	■	■	■	■	■
In Warheads	MONITORED	MONITORED	MONITORED	MONITORED	MONITORED	■
Reserved for Warheads	MONITORED	MONITORED	MONITORED	MONITORED	MONITORED	■
Declared Excess	IAEA	IAEA	IAEA	IAEA	IAEA	■
Facilities:	■	■	■	■	■	■
Weapon Production	MONITORED	MONITORED	MONITORED	MONITORED	MONITORED	■
Material Production	IAEA	IAEA	IAEA	IAEA	IAEA	■
Excess Material Storage	IAEA	IAEA	IAEA	IAEA	IAEA	■
NAVAL FUEL CYCLE:	■	■	■	■	■	■
Facilities	MONITORED	MONITORED	■	■	■	■
Fuel	MONITORED	MONITORED	■	■	■	■
CIVIL NUCLEAR:	■	■	■	■	■	■
Reactors	IAEA	IAEA	IAEA	IAEA	IAEA	IAEA
Fuel Cycle Facilities	IAEA	IAEA	IAEA	IAEA	IAEA	IAEA
HEU/Pu	IAEA	IAEA	IAEA	IAEA	IAEA	IAEA
LEU	IAEA	IAEA	IAEA	IAEA	IAEA	IAEA
Spent Fuel	IAEA	IAEA	IAEA	IAEA	IAEA	IAEA

Table 5. One of several possible comprehensive safeguards schemes.