10. Monitoring and verifying the storage and disposition of fissile materials and the closure of nuclear facilities

Annette Schaper

I. Introduction

This chapter examines transparency in the process of the dismantlement of nuclear warheads and the resulting release of excess plutonium and highly enriched uranium (HEU). In order to reduce the risk of nuclear proliferation, these materials must be disposed of. There are various plans for the disposition of plutonium and HEU. HEU can be diluted with depleted uranium in order to obtain low-enriched uranium (LEU), which is not weapon-usable unless it is re-enriched. Two methods for the disposition of plutonium are being studied, primarily by the United States and to some extent by Russia: (*a*) vitrification together with high-level waste, and (*b*) fabrication to uranium–plutonium mixed oxide (MOX) fuel, with subsequent irradiation in nuclear reactors.[1] Before these methods can be applied, the fissile material is put into intermediate storage. The verification task is to ensure that the material is not re-used for military purposes.

The total amount of military plutonium worldwide has been estimated at about 250 tonnes and the amount of military HEU at about 1700 tonnes.[2] Some of this material has been declared excess to military needs by Russia and the USA—about 50 tonnes of plutonium for each country, and 500 tonnes of

[1] A number of influential studies of the disposition of weapon-usable plutonium have been carried out. See, e.g., US National Academy of Sciences (NAS), Committee on International Security and Arms Control (CISAC), *Management and Disposition of Excess Weapons Plutonium* (National Academy Press: Washington, DC, 1994); and NAS/CISAC, *Management and Disposition of Excess Weapons Plutonium: Reactor Related Options* (National Academy Press: Washington, DC, 1995). A French–German–Russian project for the building of a MOX pilot plant for Russian weapon-grade plutonium and the 1993 Russian–US HEU Agreement are among the most advanced projects. See Gesellschaft für Anlagen- und Reaktorsicherheit mbH, Siemens Aktiengesellschaft and Russian Ministry of Atomic Energy (Minatom), *Basisauslegung für eine Pilotanlage zur Produktion von Uran-Plutonium-Brennstoff aus waffengrädigem Plutonium und zum Einsatz dieses Brennstoffs in Kernreaktoren* [Principal design of a pilot plant for the production of uranium–plutonium fuel from weapon-grade plutonium and for the use of this fuel in nuclear reactors], Final report, 28 Feb. 1997; and Bunn, M., *The Next Wave: Urgently Needed New Steps to Control Warheads and Fissile Material* (Carnegie Endowment for International Peace: Washington, DC, and Harvard University: Cambridge, Mass., 2000), available at URL <http://www.ceip.org/files/projects/npp/pdf/NextWave.pdf>.

[2] Albright, D., Berkhout, F. and Walker, W., SIPRI, *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities and Policies* (Oxford University Press: Oxford, 1997); and the Internet site of the Institute for Science and International Security (ISIS: Washington, DC), URL <http://www.isis-online.org>.

Russian and 174 tonnes of US HEU.[3] Only a few tonnes of US material have been placed under International Atomic Energy Agency (IAEA) safeguards.

There is a lack of transparency in military fissile materials. Although substantial quantities of fissile material are considered excess to military needs, only a small amount is under international monitoring.

II. Steps towards greater transparency in fissile materials

The major sources of proliferation-relevant material and technologies are in the nuclear weapon states (NWS). Although they apply national controls, these states are not obligated to adhere to international standards and the security of their nuclear materials does not have to be monitored by an international agency. Proliferation risks have increased substantially since the end of the cold war because of the large quantities of fissile materials excess to military requirements, as have the risks of the diversion of fissile material in warhead dismantlement and material transport, storage and disposition processes. The dangers are particularly acute in Russia, which is in the process of transforming its nuclear control system. The security of the Russian nuclear production complex is believed to be far below Western standards and is in danger of deteriorating even further, exacerbating the risk of the proliferation of sensitive material and technologies.[4] All these factors contribute to the urgency of devising appropriate control measures.

The safeguards agreements between the non-nuclear weapon states (NNWS) and the IAEA have greatly reduced the danger of nuclear proliferation.[5] They have introduced high standards for facility and material protection, control and accounting (MPC&A). The lack of similar standards in the NWS poses major dangers. Universal international safeguards would promote both a security culture and high standards and should therefore be a long-term goal of nuclear arms control.

IAEA full-scope safeguards on nuclear materials in the NNWS, in all their nuclear activities, are key mechanisms for verifying compliance with the 1968 Treaty on the Non-proliferation of Nuclear Weapons (Non-Proliferation Treaty, NPT). In conformity with the 1971 NPT Model Safeguards Agreement, full-

[3] ISIS Internet site (note 2). The 174 tonnes of US HEU correspond to 100 tonnes of weapon-grade uranium equivalent.

[4] Potter, W. C., 'Before the deluge? assessing the threat of nuclear leakage from the post-Soviet states', *Arms Control Today*, vol. 25, no. 7 (Oct. 1995), pp. 9–16; Schaper, A., 'Nuclear smuggling in Europe—real dangers and enigmatic deceptions', eds V. Kouzminov, M. Martellini and R. Santesso, *Proceedings of the International Forum on Illegal Nuclear Traffic: Risks, Safeguards and Countermeasures*, UNESCO Science for Peace Series, vol. 4: *Illegal Nuclear Traffic: Risks, Safe-guards and Countermeasures* (UNESCO: Venice, 1998); and Orlov, V. A., 'Accounting, control, and physical protection of fissile materials and nuclear weapons in the Russian Federation: current situation and main concerns', Paper presented at the International Seminar on Material Protection Control and Accounting in Russia and the Newly Independent States, sponsored by the Deutsche Gesellschaft für Auswärtige Politik, Bonn, 7–8 Apr. 1997.

[5] Under the NPT (as well as the 1967 Treaty of Tlatelolco, the 1985 Treaty of Rarotonga, the 1995 Treaty of Bangkok and the 1996 Treaty of Pelindaba), the NNWS must accept IAEA safeguards to demonstrate the fulfilment of their obligation not to manufacture nuclear weapons.

scope safeguards—also referred to as INFCIRC/153-type safeguards—are designed to create assurances that material is not being diverted.[6] The principal method used is comprehensive material accountancy, complemented by surveillance and control techniques. In 1997 the IAEA member states adopted new safeguards arrangements in the Model Additional Safeguards Protocol (INFCIRC/540) to strengthen and improve the efficiency of the safeguards system.[7] While traditional IAEA safeguards aimed to ensure that illegal diversion of materials at declared facilities had not taken place, the strengthened safeguards aim to facilitate the IAEA's detection of undeclared activities at an early stage. The measures apply not only to potential recipient NNWS but also to potential supplier states, which include the NWS.

There is also a trend towards internationalization of the control and security of nuclear material in the NWS.[8] Several statements of intent have been made, for example, the declaration of the Group of Eight (G8) industrialized nations at the 1996 Nuclear Safety and Security Summit: 'We pledge our support for efforts to ensure that all sensitive nuclear material (separated plutonium and highly enriched uranium) designated as not intended for use for meeting defence requirements is safely stored, protected and placed under IAEA safeguards . . . as soon as it is practicable to do so'.[9] The Guidelines for the Management of Plutonium, which were agreed between the most important plutonium-using states in 1997 and incorporated in INFCIRC/549, state that: 'These guidelines apply to the management of all plutonium in all peaceful nuclear activities, and to other plutonium after it has been designated by the Government concerned as no longer required for defence purposes'.[10] An objective of the guidelines is to create maximum transparency. The NWS also made a commitment to increase transparency in excess fissile material at the 2000 NPT Review Conference: 'We are committed to placing as soon as practicable fissile materials designated by each of us as no longer required for defence purposes under the International Atomic Energy Agency (IAEA) or other relevant international verification'.[11] The Council of the European Union made a similar statement at this review conference.[12]

[6] IAEA, The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons (NPT Model Safeguards Agreement), INFCIRC/153 (Corrected), June 1972, available at URL <http://www.iaea.org/worldatom/Documents/Infcircs/Others/inf153.shtml>.

[7] IAEA, Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC/540, Sep. 1997, and subsequent corrections, available at URL <http://www.iaea.org/worldatom/Documents/Infcircs/Numbers/nr501-550.shtml>.

[8] Schaper, A., 'The case for universal full-scope safeguards on nuclear material', *Nonproliferation Review*, vol. 5, no. 2 (winter 1998), p. 69, URL <http://cns.miis.edu/pubs/npr/vol05/52/schape52.pdf>.

[9] Moscow Nuclear Safety and Security Summit Declaration, 20 Apr. 1996, para. 25, available at URL <http://www.g7.utoronto.ca/g7/summit/1996moscow/declaration.html>.

[10] IAEA, Communication Received from Certain Member States Concerning Their Policies Regarding the Management of Plutonium, IAEA document INFCIRC/549, 18 Mar. 1998, available at URL <http://www.iaea.org/worldatom/Documents/Infcircs/Numbers/nr501-550.shtml>. The guidelines are included as an attachment to the communications from states to the IAEA.

[11] Letter dated 1 May 2000 from the representatives of France, the People's Republic of China, the Russian Federation, the United Kingdom of Great Britain and Northern Ireland and the United States of America addressed to the President of the 2000 Review Conference of the Parties to the Treaty on the

The goal of universal international safeguards may seem unrealistic but it could be approached in discrete steps, each of which is a transparency-promoting measure. Several such steps are already being implemented or seriously considered, as described in the sections below.

The IAEA Strengthened Safeguards

The IAEA safeguards reform of 1997—embodied in INFCIRC/540 and known as the Strengthened Safeguards System[13]—constitutes a qualitatively new approach to monitoring and controlling fissile material.[14] It marked an important change in the philosophy of the IAEA safeguards regime. The revelations in the early 1990s of Iraq's clandestine nuclear weapon programme had exposed a number of important shortcomings in that regime.

The Additional Safeguards Protocol in INFCIRC/540 primarily addresses the completeness of states' declarations with the aim of ensuring the absence of undeclared nuclear material and activities. It gives IAEA inspectors the right to obtain from the parties to the Protocol more information than was previously required about all the parts of their nuclear fuel cycles, from uranium mines to nuclear waste. It also grants them more intrusive physical access to locations subject to safeguards as well as complementary access to undeclared sites. In addition, inspectors have stronger authority to use new verification techniques, such as collecting environmental samples for laboratory analysis, for the purpose of assisting the IAEA in drawing conclusions about the presence or absence of undeclared nuclear material or nuclear activities at a specific location.

Under the Additional Protocol, states are required to submit 'expanded declarations' on nuclear fuel cycle technologies such as centrifuge enrichment technology. Exports and imports of such technologies must also be declared, as well as ongoing research activities. The IAEA has established a computerized system for the storage and retrieval of safeguards-relevant information from open

Non-Proliferation of Nuclear Weapons, NPT/Conf.2000/21, URL <http://disarmament.un.org/wmd/npt/2000doclist.htm#Documents>.

[12] European Union, 'Council common position of 13 Apr. 2000 relating to the 2000 Review Conference of the Parties to the Treaty on the Non-proliferation of Nuclear Weapons', *Official Journal L 97*, 19 Apr. 2000, Document 400X0297, Article 2 (2i), available at URL <http://europa.eu.int/eur-lex/en/archive/2000/l_09720000419en.html>.

[13] See note 7. This reform was previously called 'Programme 93 + 2'. The programme was launched in 1993 to strengthen the effectiveness and improve the quality of IAEA safeguards and was to present recommendations within 2 years. Although the consultations between governments and the IAEA were not completed in 2 years, the programme was supported by the 1995 NPT Review and Extension Conference. See Zarimpas, N., 'Nuclear verification: the IAEA strengthened safeguards system', *SIPRI Yearbook 2000: Armaments, Disarmaments and International Security* (Oxford University Press: Oxford, 2000), pp. 496–508; and 'Strengthening of International Atomic Energy Agency safeguards', [n.d.], *Australian Peace and Disarmament Newsletter* (Department of Foreign Affairs and Trade), URL <http://www.dfat.gov.au/isecurity/pd/947/947_11.html>.

[14] Progress in applying the strengthened safeguards has been slow. As of 2 Dec. 2002, Additional Protocols to IAEA safeguards agreements were in force for 28 states. IAEA, 'Strengthened Safeguards System: status of Additional Protocols', URL <http://www.iaea.org/worldatom/Programmes/Safeguards/sg_protocol.shtml>.

sources in order to facilitate its interpretation of the expanded declarations and to help build state proliferation or non-proliferation profiles.

The IAEA is to negotiate Additional Protocols with the NWS, which will lead to the implementation of selective measures in their civilian nuclear facilities. All the NWS have presented papers on how these measures can be implemented, but they differ in the degree to which greater transparency is accepted.[15] The new measures have not been entirely integrated into the existing safeguards system. Its success will depend on the willingness of states to offer increased transparency in their civilian nuclear complexes. Although the measures that the NWS will implement are quite modest, the reform must be seen as an important first step that acknowledges the need for universal safeguards application.

The Trilateral Initiative

Another positive step towards introducing nuclear controls in the NWS is the 1996 IAEA–Russian–US Trilateral Initiative. The objective of the Trilateral Initiative is to create assurances that steps taken in conjunction with the reduction of nuclear arsenals are irreversible.[16] When it is implemented, this initiative will constitute major progress towards the establishment of enhanced transparency in fissile materials. Special technical provisions are being developed that will allow the NWS to submit dismantled nuclear weapon components or other classified forms of fissile material to verification without giving IAEA inspectors access to information on the design or manufacture of the weapons. This calls for security arrangements for access and inspections that are very different from those applied in the NNWS. Since 1998, substantial progress has been made in developing and testing verification equipment. This is an important step towards the goal of introducing full-scope safeguards in the NWS. It will grant the IAEA an unprecedented role and might also trigger additional efforts to redesign and convert facilities to types that are more suitable for safeguards operations.

A Fissile Material Cut-off Treaty

A multilateral Fissile Material Cut-off Treaty (FMCT) would facilitate the application of safeguards, or at least the rudiments of safeguards, in the NWS.[17]

[15] These papers have not been published but have been presented to several governments. The papers of China and Russia were the least positive towards enhanced transparency in civilian nuclear facilities.

[16] IAEA, 'IAEA verification of weapon-origin fissile material in the Russian Federation and the United States', IAEA General Conference, Press Release PR 99/10, 27 Sep. 1999, URL <http:///www.iaea.or.at/GC/gc43/gc_pr/gcpr9910.html>; and Shea, T., 'Verification of weapon-origin fissile material in the Russian Federation and the United States', *IAEA Bulletin*, vol. 41, no. 4 (1999), p. 36, available at URL <http://www.iaea.org/worldatom/Periodicals/Bulletin/Bull414/article7.pdf>. See also chapter 11 in this volume on possible future roles for the IAEA.

[17] The term Fissile Material Cut-off Treaty is used in this chapter because it is the most commonly used term. This does not imply any recommendation as to the scope of the treaty, which is contested in the Conference on Disarmament. See, e.g., Johnson, R., 'FMT: breakthrough at last at the CD', Sep. 1998, URL <http://www.acronym.org.uk/fmctaug.htm>. See also Schaper, A., *A Treaty on the Cutoff of Fissile*

The fact that this treaty has been on the agenda of the Conference on Disarmament (CD) for several years with little progress is not directly related to matters of substance. While the FMCT has become an important symbol for nuclear disarmament efforts, its most important benefit would be to introduce verification measures in the NWS in order to ensure that they are not producing or diverting fissile materials for military purposes. This is similar to the verification task of the IAEA in the NNWS under the NPT. The principal difference under an FMCT verification regime would be that the NNWS would not be allowed to possess unsafeguarded materials from past production, while the NWS might eventually be allowed a 'black box' of materials previously excluded from safeguards. It is not clear whether the treaty will cover only the future production of weapon-usable materials or if it will also include previously produced materials. Even if the treaty is limited to a ban on future production, it is essential to ensure that material is not falsely declared as past production. If civilian material is excluded, it could eventually be declared as past production and diverted to military use. Ideally, all civilian and military fissile material produced after the entry into force of an FMCT should be placed under safeguards.

Many different types of facilities and measures may be appropriate for inclusion in the verification regime, and a range of different materials should be considered in negotiations. Plutonium and HEU can be directly used for nuclear weapons, while other materials first need to undergo technical processes. For example, LEU must be further enriched. Different materials have different technical thresholds that must be crossed if they are to be used in nuclear weapons. Accordingly, the current scope of IAEA safeguards in the NNWS varies, and a future FMCT verification regime would have to allow for such variation. Decisions will have to be made as to which facilities and materials should be included in the regime.

In a minimalist, or 'focused', approach, only facilities for reprocessing and enrichment (i.e., those producing unirradiated plutonium or HEU) would be included in the regime. Reactors would not be included, and verification of enrichment plants producing only LEU would be limited to verification of their design in order to create assurances that HEU is not being produced. In this approach, verification would end with the irradiation of the material. The level of irradiation at which verification would cease would therefore have to be specified. However, after the termination of verification, a large portion of the original amount of plutonium or HEU would remain in the spent fuel and could be easily recovered through reprocessing. The verification method that creates the highest assurance that material is not diverted is material accountancy. If verification is terminated too early, comprehensive material accountancy is not

Material for Nuclear Weapons: *What to Cover? How to Verify?,* PRIF Reports no. 48 (Peace Research Institute Frankfurt (PRIF): Frankfurt, July 1997), available at URL <http://hsfk.de/downloads/prifrep48.pdf>; and Schaper, A., *Principles of the Verification for a Future Fissile Material Cutoff Treaty (FMCT)*, PRIF Reports no. 58 (PRIF: Frankfurt, Mar. 2001), URL <http://hsfk.de/downloads/prif58.pdf>.

possible and clandestine production at declared facilities could not be detected. The verification envisaged in this scenario is therefore not credible.

In a more credible approach, both reprocessing and HEU enrichment plants and nuclear reactors would be included in the regime, as would spent fuel from reactors since it contains plutonium. It would therefore be possible to detect clandestine production through the verification process. However, opposition to this proposal has been voiced on the ground that the costs would be high. On-site inspections are the most expensive part of verification, and frequent, regular visits to all light-water reactors would be costly. For example, if all the reactors in the NWS were inspected with the same frequency as those in the NNWS, the IAEA budget would have to be increased substantially.[18] The feasibility of a random inspection regime should therefore be considered. Depending on the technical characteristics of a reactor, different probabilities of detection within a certain time interval could be assigned, and inspections could take place at different frequencies. This arrangement would reduce the costs and still provide a relatively high probability of detection. Material accountancy based on reports of all spent fuel produced after the entry into force of an FMCT could be established by the verification authority and applied at every step until the defined termination point of verification. Material accountancy would have to be implemented nationally, by each state. The de facto NWS (India, Israel and Pakistan) would be obliged to submit information to the verification body.

A more comprehensive approach would incorporate material accountancy in the LEU-producing enrichment plants. The advantage would be a full accountancy of all uranium. The assurance against undeclared HEU production in a declared enrichment facility would be higher than that provided by the other approaches, and verification of the material balances at reactors could be completed because material accountancy would cover the entire output, not only that from reactors.

The need for comprehensive verification does not seem to be shared by all of the NWS, but even a modest scheme would set precedents and create an important basis for further changes. Verification at former production facilities would constitute a major milestone, and the experiences gained would build the confidence needed to implement additional measures. Proceeding with negotiations on an FMCT is therefore an urgent priority.

The Plutonium Management and Disposition Agreement

Under the 2000 Plutonium Management and Disposition Agreement (PMDA), Russia and the USA would each be committed to dispose of 34 tonnes of

[18] As of 31 Dec. 2001 there were 236 power reactors under IAEA safeguards, out of a total of 438 nuclear power plants worldwide. IAEA, *Annual Report 2001,* Table III, Facilities under Agency safeguards or containing safeguarded material on 31 December 2001, URL <http://www.iaea.org/worldatom/Documents/Anrep/Anrep2001/table_3.pdf>; and IAEA, 'Latest news related to PRIS [Power Reactor Information System] and the status of nuclear power plants', 1 Jan. 2002, URL <http://www.iaea.org/cgi-bin/db.page.pl/pris.main.htm>.

weapon-grade plutonium,[19] using the methods of irradiation in reactors, immobilization or any other method agreed by the parties. The PMDA regulates the quantities to be disposed of annually and calls for the development of an action plan for implementing technologies and accelerating the rate of disposition. In addition, it addresses cooperation with and assistance from other states, safety and security aspects, international financing and verification. The PMDA is important because it will be the first legally binding agreement on the disposition of weapon-origin plutonium. It therefore sets a precedent for further disarmament agreements and verification measures, including agreements between other NWS.

The PMDA verification provisions are disappointing, however, because they do not reflect the signatories' commitments to international transparency and IAEA verification and because the agreement is only bilateral. Article VII.3 states that 'Each Party shall begin consultations with the . . . IAEA at an early date and undertake all other necessary steps to conclude appropriate agreements with the IAEA to allow it to implement verification measures'. This formulation does not impose a strong obligation on the parties, and there is a risk that the IAEA might never be involved. Moreover, there is no mention of the Trilateral Initiative. The international community should urge both states to draw up a specific timetable for when and how the IAEA will be involved in verification of the PMDA and how to build on the progress made by the Trilateral Initiative.

The goal of verification in the PMDA is simply to establish assurances that technical measures are being implemented as agreed. The agreement does not even mention the fact that transparency in nuclear disarmament is in the interest of the international community, even though it calls for assistance from other states. It should also stipulate that the parties must report on progress in their disposition of plutonium to ensure at least a degree of international transparency.

Large sections of the PMDA are devoted to the protection of sensitive information. The agreement mentions the use of information barriers during inspections and defines categories of sensitive information. In order to conceal the isotopic composition of excess plutonium, which is still regarded as secret, the agreement explains how excess plutonium may be diluted with 'blend stock' plutonium of a different isotopic composition, so that information about the original plutonium composition will not be revealed. This means that the quantity of plutonium to be disposed of will in fact be greater. Although these provisions for secrecy may be criticized as excessive, the decision to follow such a complicated procedure shows goodwill. On the one hand, the requirement for secrecy in the application of verification measures by the NWS must be respected if these states are to be expected to collaborate. On the other hand, they should be urged to accept, in principle, the need to advance transparency

[19] The US–Russian Agreement concerning the Management and Disposition of Plutonium Designated as No Longer Required for Defense Purposes and Related Cooperation, 1 Sep. 2000, available at URL <http://www.ransac.org/new-web-site/related/agree/bilat/pudisp-agree.html>. The PMDA had not entered into force as of Dec. 2002.

and move forward towards a universal verification system for all civilian fissile materials, including excess military materials.

III. Verifying the disposition of nuclear material

Pit storage

When warheads are dismantled, their fissile components—plutonium and HEU—are released in the form of pits. If these pits were further processed to convert the material they contain into oxide bulk forms, the disarmament process would become irreversible. However, Russia and the USA appear to be planning to place pits in intermediate storage, leaving at least part of the inventory intact. Since pits are countable items, such a storage procedure would have the advantage of facilitating verification at this stage.

The task of verification would be to ensure that real pits, not decoys, enter the storage plant. Because pits bear highly sensitive information, NWS will not allow them to be inspected. They must therefore be delivered to storage plants in sealed containers. It must be guaranteed that each container holds a pit and that each seal remains intact and is unambiguously identifiable.

There are various methods for applying seals, some of which are not costly. Many methods are being used or developed by the IAEA and the European Atomic Energy Community (Euratom). One is a forgery-proof method using fiber-optic seal tecnology. This would allow a pit storage facility to be monitored externally to account for every pit that enters or leaves for further processing.[20]

The NWS have carried out much technical work on such aspects of verification. However, although Russia and the USA have been engaged in technological cooperation on the verification of nuclear warhead dismantlement since 1995, the results of this cooperation have not been published.[21]

Processing of bulk material

All the options for material disposition that have been seriously considered so far—dilution of HEU with natural or depleted uranium, fabrication of MOX

[20] IAEA, *Safeguards Techniques and Equipment*, International Nuclear Verification Series no. 1 (IAEA: Vienna, 1995); Japan Atomic Energy Research Institute (JAERI), 'Research on safeguards technology', URL <http://inisjp.tokai.jaeri.go.jp/ACT95E/menu195.htm>; and Zheng, Y. T. *et al.*, 'The study of fiber-optic seal technology for arms control', Paper presented at the 8th International Summer Symposium on Science and World Affairs, Beijing, 23–31 July 1996.

[21] The principal partners in the Russian–US cooperation are the All-Russian Scientific Research Institute of Technical Physics (Vserossiyskiy Nauchno-Issledovatelskiy Institut Tekhnicheskoy Fiziki, VNIITF) in Chelyabinsk-70 and the US Sandia National Laboratories. The Russian laboratory was previously responsible for research and development of new nuclear weapons. Rubanenko, N. F., 'Nuclear weapons' transparent dismantlement', Paper presented at the International Pugwash Workshop, Snezhinsk, Russia, 11–13 Sep. 1997. See also chapters 5 and 9 and appendix 8A in this volume. A conference volume containing *c.* 50 contributions presented at a conference of both research institutes held on 18–22 Aug. 1997 has been made available only to the Russian and US governments.

fuel from plutonium and irradiation in reactors, and vitrification of plutonium with high-level waste—involve bulk material. Countable items, such as sealed containers with pits, would enter a facility, and some sort of bulk material, probably oxide powders of uranium and plutonium with various isotopic compositions and mixtures, would leave it for further processing.[22] Some additional bulk material would probably also enter the facility as blend stock for dilution in order to change the isotopic composition of the pits, which remains highly classified information. Only rough estimates could be made of the amounts of fissile material that enter the facility because the mass of the pits would remain unknown. Processes inside the facility could not be monitored because, again, sensitive information would be revealed.

Nevertheless, it is possible to verify fairly precisely the quantities and isotopic compositions of all materials leaving a facility. Methods for this purpose have been developed and tested by the IAEA and Euratom.[23] Reprocessing, enrichment and fuel fabrication (uranium and MOX) plants are examples of nuclear cycle facilities that handle bulk material. Nuclear reactors, in contrast, contain only fuel elements, which are countable and therefore much easier to verify.

The basic approach to verification in bulk-handling facilities—such as MOX fabrication, reprocessing or vitrification facilities—is material accountancy, which verifies a detailed report by the owners, supplemented by containment and surveillance techniques. Normally, flows are measured at predetermined locations known as ‘key measurement points’ and samples are taken from various areas. Because some of the process flows might contain highly radioactive materials (e.g., when mixed with high-level waste), measurements take place behind radiation shielding and direct access is difficult. Extensive shielding and radiation protection measures make it more difficult to maintain an overview of all the potential diversion risks. The total content of fissile materials must be established to the extent possible through various measurements (e.g., mass of flows, isotopic compositions of samples and material accountancy of inputs). During the industrial process, nuclear materials used as feedstock may be changed isotopically, chemically and physically. Furthermore, some nuclear materials would become waste products, and minute quantities would be discarded in waste water or otherwise discharged. A common objective from the standpoint of both verification and financial considerations would be to keep the wastes and losses at the lowest possible levels and to maintain precise material accounts. If the material comes from unverified storage sites, the quantities involved must be measured independently. The output of fuel cycle plants consists of countable items, which are easier to verify.

[22] E.g., in the French–German–Russian project on plutonium disposition, the French–Russian contribution will be the fabrication of feedstock containing 30% plutonium oxide and 70% uranium oxide. The German–Russian contribution will be the fabrication of MOX from this feedstock. See note 1.

[23] Shea, T., ‘On the application of IAEA safeguards to plutonium and highly enriched uranium from military inventories’, *Science & Global Security*, vol. 3, nos 3–4 (1993), p. 223.

There are technical problems that would cause uncertainties in results. Errors in calculated plutonium content must be expected. They may stem from biases in solution measurements, time delays in sample analyses or measurement limitations owing to radioactivity. Similarly, the precision of material accountancy in civilian bulk-handling plants, especially reprocessing and enrichment plants, is limited. The limits are dependent on the thoroughness of safeguards, a fact which has a direct bearing on safeguards costs.

In the NNWS, implementation of safeguards is taken into account in the planning stage of a plant; verification of plant design can take place during construction.[24] This makes it much more difficult to pursue unmonitored diversion. Similarly, because plants for the disposition of excess weapon material have not yet been constructed, it would be possible to design and build them in a way that facilitates the implementation of international safeguards according to IAEA standards.

Verification as thorough as that described above would probably be applied only to facilities which do not handle fuel with the original pit isotopic composition. This means that material accountancy is likely to start after the material obtained from the dissolution of pits has been mixed with blend stock. However, an external monitoring regime for such 'black box' facilities should be put in place in order to obtain an account of the number of warheads and pits being destroyed and a rough estimate of the expected quantities of fissile materials. It is also recommended that the authorities in the NWS which are responsible for the facilities publish information on the average masses and average isotopic compositions of the pits in order to enhance the precision of such estimates. Such data would not reveal information that is proliferation-relevant but they would be beneficial for transparency.[25]

Reactor fuel and material for final disposal

Items leaving material disposition facilities would be either fresh fuel elements (LEU or MOX) or vitrified waste. The latter would be intermediately stored until it entered a final disposal site. Under the classic INFCIRC/153-type IAEA safeguards, the safeguards ceased when the material was practicably irrecoverable. Even after the 1997 safeguards reform, however, states are still required

[24] An example is the safeguards system at the new MOX plant at Hanau, Germany, that was developed before the plant was built. This plant never began operation, but there are plans to use its interior design in the French–German–Russian project for the building of a MOX pilot plant for Russian plutonium from dismantled warheads. See note 1.

[25] In the USA, the isotopic composition is classified as long as the material is in warhead component form. As soon as this form is modified, the masses and isotopic composition can be revealed. See Markin, J. T. and Stanbro, W. D., 'Policy and technical issues for international safeguards in nuclear weapon states', *International Nuclear Safeguards 1994,* vol. 2, Proceedings of the Symposium on International Safeguards, Vienna, 14–18 Mar. 1994, p. 639. See also US Department of Energy, Office of Declassification, 'Restricted data declassification decisions, 1946 to the present', RDD-7, 1 Jan. 2001, URL <http://www.fas.org/sgp/othergov/doe/rdd-7.html>. This document contains over 100 pages of technical details which are now declassified. In Russia, the isotopic composition of disarmament materials remains classified.

to submit information on material processed for final disposal. This requirement should also apply to the NWS, especially with regard to the disposal of material from nuclear disarmament.

Fuel elements would first enter a storage site and then be used in a reactor. It should be agreed internationally that, once material has been subjected to safeguards, it can no longer be removed, thus constituting an irreversible step. This implies that reactors using fuel made from disposition materials should be submitted to IAEA safeguards, as in the case of reactors in the NNWS. Because fresh and spent fuel elements are countable items, verification is much easier and cheaper than verification in bulk-handling facilities.

The verification goal at reactors is to provide assurance that there is no diversion of fresh or spent fuel.[26] Depending on the type of reactor, fresh fuel may consist of LEU, MOX, HEU or natural uranium. IAEA material accountancy and verification of fresh fuel are carried out by item counting and identification, non-destructive measurement and examination to verify the continued integrity of the item, assuming that the fuel has been received from an IAEA-safeguarded facility. However, when fresh MOX or HEU fuel originates from unsafeguarded facilities, additional measurements must be performed and the fuel must be maintained under seal or surveillance. Consequently, seal verification and/or surveillance evaluation must also take place.

Similarly, the fuel in the reactor core must be verified. The methods may include item counting and serial number identification after refuelling has been carried out, but before the reactor vessel is closed. Under INFCIRC/153-type safeguards, inspectors are required to be present at all refuelling operations. An evaluation should be made of whether the overall number of inspections could be reduced by making some of them unannounced random inspections or by automating the monitoring and surveillance of fuel reloading and the resulting unchanged state of the core. The spent fuel pond must also be verified by, for example, observation, measurements of the Cherenkov radiation (a physical effect owing to radioactive decay under water) or surveillance of the sealed transfer gate.

Methods of verification

Containment and surveillance

The technical component of verification is the so-called containment and surveillance technologies. The equipment that the inspecting authorities will install in facilities includes seals, detectors, monitors and cameras to record any activity occurring in a particular area of a nuclear installation. It will allow the detection of undeclared movements of nuclear material and potential tampering with containment and/or surveillance devices. In light-water reactors, for

[26] Harms, N. and Rodriguez, P., 'Safeguards at light-water reactors: current practices, future directions', *IAEA Bulletin*, vol. 38, no. 4 (1996), URL <http://www.iaea.org/worldatom/Periodicals/Bulletin/Bull384/harms.html>.

example, cores are usually not opened more than once per year, so it is often possible to seal the head of the reactor's pressure vessel. The more sophisticated and automated an instalment is, the fewer on-site inspections would be needed to provide the same level of assurance that material has not been diverted. Automated data transfers to a verification agency would further reduce the need for on-site inspections.

Inspections

Verification is completed by inspections. Their purpose is to examine the operational status of a plant and the installed containment and surveillance equipment. In addition, verification of material accountancy is of particular importance. Physical inventories and streams of nuclear materials must be confirmed. The methods used to achieve the inspection goals depend primarily on the type of the facility and could include combinations of: (*a*) observations, measurements and tests to determine whether the design information is correct; (*b*) installation of containment and surveillance technologies; (*c*) installation of detection technologies for proscribed activities; (*d*) auditing of accounting records and comparison with reports submitted to the IAEA; (*e*) accountancy measurements (e.g. of the volume, concentration and enrichment of nuclear materials in streams), tracking the movement of solutions and taking samples in the case of bulk facilities (if material is in the form of countable items, such as those in a reactor, they must be counted, identified and examined by non-destructive means in order to verify their continued integrity); and (*f*) the taking of environmental samples as a means to detect additional undeclared operations.

Samples must be shipped to a laboratory for analysis—for example, in the case of international safeguards, to the IAEA Safeguards Analytical Laboratory in Seibersdorf, Austria. Measurement data taken from inspections and from laboratory analyses are used to establish an independent material accountancy which is compared with the operator's declaration.

INFCIRC/153 provides for ad hoc, routine and special inspections. Ad hoc inspections are conducted when an initial report must be verified or in the case of transfers. Routine inspections take place on a regular basis; the frequency of these inspections depends on the amount and kind of nuclear material in a facility. Special inspections take place only when the IAEA considers information to be inadequate. INFCIRC/540 allows access outside the nuclear sites, using the existing right of access at 'short notice' or 'no notice' during routine inspections. As a result of the formal definitions of the frequency of INFCIRC/153-type routine inspections, most inspections take place in power reactors and in states with large nuclear programmes where confidence in non-proliferation is already high, such as Canada, Germany and Japan. However, the costs for safeguards could be substantially reduced if routine inspections in reactors were to be replaced by a random system. The goal of verification is the deterrence of non-compliance by the risk of detection. The use of unannounced random inspections would contribute to this because the facility operator would need to be prepared for such inspections at any time. The absence of undeclared facility activities at the time of the inspection would provide assurance that there had been no such activities over the entire period since the last on-site inspection.

IV. Additional verification and transparency measures

The implementation of current and future disposition activities will be reinforced if the policy goal is global, transparent reduction. This could be achieved if the moratorium on the production of fissile materials for use in nuclear weapons that is currently observed by the NWS was codified in an FMCT. Although the CD has not started to negotiate a ban, some of the verification measures which are likely to be proposed are known. The crucial objective is the detection of undeclared activities. Another task would be verification of the closure of production facilities.

In the longer perspective, when progress has been made towards comprehensive nuclear disarmament, it will be important to pursue declarations of fissile material stockpiles, transparency measures and verification that undeclared materials no longer exist.

Detection of undeclared enrichment and reprocessing activities

Enrichment processes

The most important known enrichment processes are gas diffusion enrichment, gas centrifuge enrichment, jet nozzle enrichment, chemical enrichment, electromagnetic isotope separation (EMIS) and atomic vapour laser isotope separation (AVLIS).[27] Although it is unlikely that a new enrichment process will be developed, it would be impossible to conceal the clandestine use of such a process. Enrichment requires natural uranium or LEU as feedstock. If all the uranium in the world were to be accounted for through global transparency measures, its use for clandestine enrichment would be detected. A clandestine use would require the use of undetected stockpiles or the discovery of a new deposit. Thorough accountancy of uranium takes place in the NNWS and is verified by the IAEA. Unfortunately, similar safeguards do not exist in the NWS and in the non-parties to the NPT. However, there are other technical means for the detection of clandestine enrichment activities.

Most enrichment processes use the volatile chemical compound uranium hexafluoride (UF_6). Unless it is elaborately shielded, UF_6 can be detected by means of atmospheric measurements made adjacent to a plant or by laser imaging detection and ranging (LIDAR) techniques. LIDAR techniques examine laser light reflected by the atmosphere using spectral analysis methods and can iden-

[27] See, e.g., Federation of American Scientists, Special Weapons Primer: Weapons of Mass Destruction, 'Uranium production', [n.d.], URL <http://www.fas.org/nuke/intro/nuke/uranium.htm>.

tify traces of molecules. LIDAR can also be operated from satellites, but at present measurements are carried out by the national technical means (NTM) of some states.[28] There is no other application for UF_6 apart from enrichment. Atmospheric measurements can also detect whether HEU has been fabricated.

Some processes, in particular AVLIS and EMIS, do not use volatile materials and would be easier to conceal. However, EMIS would require large amounts of energy, which could be detected by means of infrared imagery, for example, from a satellite. (E.g., if Iraq's calutrons had been in operation, they would have been detected by NTM.) To hide the production of heat, an elaborate underground cooling system would have to be installed, which also requires a high level of energy, or the plant would have to be built as part of another facility. In the latter case, however, the ancillary systems would be visible. AVLIS is the enrichment method which would be the easiest to hide and extremely difficult to detect because it gives off little energy and releases no revealing gases. However, this process is the most sophisticated technically and could only be managed by a few industrialized states.[29] All enrichment processes leave traces of HEU, which are detectable in on-site inspections.

Reprocessing

The aim of reprocessing is the separation of plutonium and uranium from the radioactive fission products, which are all contained in spent nuclear fuel. The most effective and widely used process is plutonium and uranium recovery by chemical extraction. Initially, the spent fuel is crushed mechanically and then chemical separation processes are used. The central difference between an ordinary chemical factory and a reprocessing plant is the high level of radioactivity, which poses a danger for both the workers and the environment. Reprocessing plants must not only provide storage for fuel elements for years after removal from the reactor (so that most radioactive isotopes can decay) but also, and above all, implement extensive radiation protection measures.

Reprocessing releases several characteristic effluents that can be detected and monitored. They include particulate matter and gaseous fission products, which, to a greater or lesser degree, are radioactive, especially noble gases that cannot be bound chemically. Reprocessing produces far more emissions than the operation of a reactor or enrichment, and these emissions are likely to provide clear evidence of what is taking place. If detection is to be avoided, extremely sophisticated shielding measures are necessary in order to prevent the release of

[28] The USA has an extensive R&D programme to improve NTM, e.g., the Chemical Analysis by Laser Interrogation of Proliferation Effluents. Panofsky, W. K. H., Report of the Comprehensive Research and Development Review Committee for the US Department of Energy, Office of Nonproliferation and National Security, 8 June 1996.

[29] After many years of R&D, the building of a demonstration plant was begun in the USA but it was suspended in 1999. Lawrence Livermore National Laboratory, 'Advanced uranium enrichment project ends', News Release, 9 June 1999, URL <http://www.llnl.gov/llnl/06news/NewsReleases/1999/NR-99-06-05.html>. AVLIS will not be competitive and will not be used commercially. Knapik, M. and MacLachlan, A., 'USEC terminates AVLIS program, looks to silex, centrifuges; Richardson "surprised"', *Nuclear Fuel*, 14 June 1999.

revealing traces of radioactivity. Such traces can be distributed and detected over great distances.[30] Methods of detection include the taking of air samples or the use of LIDAR from aircraft or satellites. Shielding measures would only reduce, but not totally eliminate, the emissions and thus the risk of detection would remain.

Verifying the closure of facilities

If a state renounces the production of fissile materials for military purposes, the production facilities will be either closed down or converted to civilian use. Verifying that a facility is closed down is relatively simple because there are no operations. Traffic and movements can be detected by remote sensing. Inspectors can apply tags and seals to verify that the technical situation of a plant has not changed. Random, not necessarily frequent, inspections would deter cheating by creating the possibility that undeclared operations would be detected.

Warhead production facilities are a special case. Before intrusive inspections can take place, warhead dismantlement must have progressed so far that sensitive information can no longer be revealed. The remaining parts of the building that may still contain sensitive information can then be sealed. While inspectors can be banned from entering these parts of the building, they can inspect the seals to verify that such parts have not been accessed. Verification of operating civilian reprocessing and enrichment plants can be carried out with methods such as those described above.

A facility goes through several stages of operational status. When it is undergoing decommissioning, the frequency of inspections could be kept comparatively low, depending on whether operations could be resumed and on how much time would be needed to resume them. Inspections can often be replaced by the use of satellite imagery. In a fully decommissioned facility, the verification task is simpler. Theoretically, a stand-by facility can resume operations very quickly but, as long as it is not running, inspections are much easier than in an operating facility. In an operating facility, assurances must be provided, for example, that LEU enrichment facilities are not producing HEU and that the installations at reprocessing plants are operating as declared. The technical

[30] US Congress, Office of Technology Assessment (OTA), *Environmental Monitoring for Nuclear Safeguards,* OTA-BP-ISS-168 (US Government Printing Office: Washington, DC, Sep. 1995), available at URL <http://www.wws.princeton.edu/cgi-bin/byteserv.prl/~ota/disk1/1995/9518/9518.PDF>. Eight contributions to the Convention on Strengthened and More Cost Effective Safeguards of the IAEA Symposium on International Nuclear Safeguards, Session 7: Environmental Monitoring, Vienna, 13–17 Oct. 1997, are concerned with the measurement of radionuclines in the environment. The proceedings are available on CD-ROM from the IAEA. See also Nakleh, C. W. *et al*., 'Noble-gas atmospheric monitoring for international safeguards at reprocessing facilities', *Science & Global Security*, vol. 6, no. 3 (1997), pp. 357–379; and Kalinowski, M. B. *et al*., *Rückschließbarkeit auf Plutoniumabtrennungen durch Auswertung von Messungen des atmospärischen Krypton-85 in Wochenproben bei verschiedenen Abständen von der Wiederaufarbeitungsanlage Karlsruhe* [Identification of plutonium separation by analysis of measurements of atmospheric Krypton-85 in weekly samples obtained from the Karlsruhe Processing Plant], (Interdisziplinäre Arbeitsgruppe Naturwissenschaft, Technik und Sicherheit (IANUS): Darmstadt, Mar. 1998). A range of US R&D programmes are designed to improve the techniques; in 1996 they received $194.4 million in funding. See Panofsky (note 28).

methods of verification include the application of seals, temperature and other signal measurements and analysis of environmental samples. Analysis of plutonium samples collected at reprocessing plants provides an unambiguous indicator of the age of the sample.

Satellite imagery is a special verification tool.[31] Since 1999, a new generation of commercial satellites has been launched with 1-metre spatial resolution at visible wavelengths. This allows any construction and visible changes at nuclear sites to be monitored. For example, at an undeclared nuclear facility or a closed facility which had restarted operations, high-resolution imagery would show security installations such as fences and guards, thermal signatures from the use of energy, traffic and movements into and from storage sites, and power lines associated with the electricity generated by reactors. Images acquired over a long period of time could be used to assess the status of the facility.

Operating reactors and several kinds of uranium enrichment facilities produce energy and therefore need cooling. For the former, air, steam or water is used, and for the latter, sea, lake or river water is often used for cooling. When a facility is operating, the higher temperatures of the streams leaving it can be monitored with thermal infrared detectors. The US Landsat satellite sensor is capable of detecting temperature differences as small as 0.25° C. This allows conclusions to be drawn about the operational status of reactors and other production facilities.

Environmental monitoring is an effective tool for clarifying suspicions. Instruments have been developed to identify extremely small traces of materials.[32] Uranium and plutonium isotopes can be detected in quantities smaller than a nanogram. The isotopic composition of environmental traces can be analysed to reveal production histories, as can traces in the vicinity of a plant. Noble gases and particulate matter are released into the atmosphere while a plant is in operation. Sampling them is not particularly difficult; it would be sufficient to wipe a surface or collect traces in the vicinity of plants.

Wide-area environmental monitoring to detect undeclared facilities is much more problematic. Some materials can be carried long distances. Monitoring rivers is fairly easy, but monitoring atmospheric distribution would require many stations, since weather conditions affect the results. Many of these methods are currently being implemented or explored by the IAEA as part of its Strengthened Safeguards System. In the course of nuclear disarmament, it might become necessary to implement similar verification in the NWS as well. It is likely that the FMCT will be the first nuclear disarmament treaty to make use of such processes.

[31] Zhang, H. and von Hippel, F., 'Using commercial imaging satellites to detect the operation of plutonium-production reactors and gaseous-diffusion plants' *Science & Global Security*, vol. 8, no. 3 (2000), p. 261; and Jasani, B. *et al.*, 'Space-based monitoring of proliferation of weapons of mass destruction', *Proceedings of the ESARDA–INMM Workshop on Science and Modern Technology for Safeguards,* EUR 17264EN (European SAfeguards Research and Development Association (ESARDA), EU Joint Research Centre and Institute for Nuclear Materials Management (INMM): Ispra, 1996), p. 275.

[32] US Congress, Office of Technology Assessment (note 30).

Detection of undeclared materials

If comprehensive nuclear disarmament becomes a reality, verification will have to move beyond the approaches described in sections III and IV of this chapter. The possession and production of nuclear material outside international controls would then be banned. Verification must be able to detect, with sufficiently high probability, any illegal use and production of fissile materials. It must also be able to track and identify any undeclared material. This type of international verification is currently applied by the IAEA in the NNWS parties to the NPT. When the current NWS no longer possess nuclear weapons, the task will be much more difficult because of their long and complicated production histories and the decades in which there were no international controls.

An important parameter in the verification process would be the reconstruction of past production. It is possible to account for past production of fissile material by examining the physical evidence at reactors and enrichment facilities. Two technical methods of 'nuclear archaeology' have been described by Fetter.[33] The first technique uses the concentrations of long-lived radionuclides in permanent components of the reactor core to estimate the neutron flux in various regions of the reactor and thereby to verify declarations of plutonium production in that reactor. This method becomes complicated, however, when, instead of plutonium, tritium has been produced. An interpretation must therefore compare the results with the declarations and check for consistency. The second technique uses the ratio of uranium isotope concentrations in enrichment 'tails' to determine whether the uranium was used to produce LEU or HEU. These measurements must be compared to existing documentation and declarations. However, the tails must still be available for evaluation and the composition of the feed uranium must be known.

A prerequisite for nuclear archaeology techniques is complete openness regarding the production history of military fissile material. The task of verification then consists of confirming and re-recording measurement data with the aid of the documentation, in order to establish a book inventory that can be compared with the declarations. This procedure was followed in South Africa when its nuclear arsenal was dismantled. Furthermore, it is possible to draw conclusions regarding past production by using radiological measurements in nuclear plants that have been closed down or are still in operation. There will, however, be a higher rate of error in the determination of the initial stock than in anything in which the IAEA has previously been involved. For example, in the plutonium stockpile data published by the USA, there was a discrepancy of 2.8 tonnes between the measured and estimated stockpiles—an amount sufficient for the manufacture of about 1000 warheads.[34] This finding does not mean

[33] Fetter, S., 'Nuclear archaeology: verifying declarations of fissile-material production', *Science & Global Security*, vol. 3, nos 3–4 (1993), pp. 237–59.

[34] US Department of Energy (DOE), *Plutonium: The First 50 Years. United States Plutonium Production, Acquisition, and Utilization from 1944 through 1994*, DOE/DP-0137, Feb. 1996, URL <http://www.etde.org/html/osti/opennet/document/pu50yrs/pu50y.html>; and Albright, Berkhout and Walker (note 2).

that the 2.8 tonnes had been hidden or otherwise diverted; the discrepancy could be explained by the fact that there were insufficient documentation and inaccurate measurements in the past. Errors in future figures emanating from other NWS are likely to be even higher. In the Soviet Union, for example, material accounting was based solely on documentation, not on measurements.[35] In the NNWS ,whose nuclear industry was subjected to international surveillance at an early stage, there are also measuring inaccuracies, although on a much smaller scale, and it is assumed that their declarations are correct.

Measurements on materials and plants should also be carried out. It must be accepted that there will always be discrepancies and inaccuracies. However, with enhanced transparency, the use of diverse sources of information and the possibility of challenge inspections, it is highly probable that undeclared material storage sites will be detected sooner or later. This would have the effect of deterring deception.

Societal verification

The large discrepancies that are likely to be revealed through verification procedures do not necessarily indicate deception. They need not even give rise to suspicion as long as there is confidence in societal verification, which can be added to the classic technical instruments of verification. In contrast to traditional verification concepts, societal verification relies on the participation of the entire population of a state and is not confined to highly specialized, technically well-equipped teams of experts. In principle, citizens are encouraged to report to a competent international authority any information on treaty violations or attempted treaty violations. This would be not only the right but also the duty of every citizen and would therefore have to be incorporated into state legislation. The reporting of information must, therefore, not be treated as a punishable offence, either as treason or any other crime, in the states concerned. This concept of involving the whole population is also known as 'Citizens' Reporting'.[36] In practice, informants will often be individuals who come to learn of secret projects because of their training as specialists, engineers or scientists. They must be allowed to disclose their information without incurring the risk of reprisal.

However, confidence in societal verification will be highly dependent on how democratic a state is. Mechanisms could be set up for offering protection to informants, ranging from the provision of legal support in conflicts over industrial law to the creation of an international relief fund, or even relocating and hiding informants. The former approach is more relevant for democratic states, the latter in states where basic human rights are not guaranteed.

[35] Roumyantsev, A. N., 'Establishing a SSAC [State System for Accounting and Control] in Russia: structural, organizational, budgetary and political problems', Paper presented at the Conference on Fissile Material Security in the CIS, Deutsche Gesellschaft für Auswärtige Politik, Bonn, 7–8 Apr. 1997.

[36] Rotblat, J., 'Societal verification', eds J. Rotblat, J. Steinberger and B. Udgaonkar, *A Nuclear-Weapon-Free World: Desirable? Feasible?* (Westview Press: Boulder, Colo., 1993), pp. 103–18.

All things considered, there is a good chance that fraud would be detected. If a party to a convention intends to cheat by withholding undeclared nuclear materials, extreme secrecy would have to be kept and maintenance staff would have to be carefully selected and controlled. Furthermore, indoctrination and intimidation, as well as the offering of rewards, would be needed to guarantee that employees and those who knew about the deception would not reveal the fraud. A 'technical myth' would have to be created to conceal the real nature of the activities. In this context it would have to be explained, for example, how the radioactivity in the samples came to be there. (The North Korean violation of the NPT was uncovered by inconsistencies between analysis results and North Korean explanations.) The deception would have to be coordinated between all participants, and personnel would have to be indoctrinated into believing as much of it as possible, although key employees would realize that they were violating national legislation.

If the international community became suspicious, a cheating state might refuse inspections, as occurred in both Iraq and North Korea, or it might use delaying tactics such as adjourned diplomatic negotiations in order to allow time for the removal of revealing clues, as occurred in Iraq. The more often observations of this kind are made, the stronger the suspicion becomes. This could then trigger additional, more intrusive verification methods, for example, interviews with staff at suspected plants and establishments.

V. Special issues

Sensitive information at nuclear weapon facilities and secret past activities

In former military facilities—reprocessing and enrichment plants or nuclear warhead maintenance and dismantlement facilities—verification could reveal sensitive information.

In some NWS, the isotopic composition of fissile materials is still regarded as highly classified information. Verification scenarios developed for the disposition of plutonium therefore include the use of blend stock in order to mask its isotopic composition. If the isotopic composition were to be revealed, an additional risk of proliferation danger would not be created because it is generally known that the NWS prefer a high plutonium-239 content for their weapon plutonium and a high uranium-235 content for their weapon uranium. There is room for speculation as to whether such secrecy is simply an unquestioned tradition or whether there would be surprising revelations, for instance, that the composition is of an embarrassingly poor quality or, on the other hand, that plutonium has been further enriched.[37]

It is possible that material pieces or tools that reveal the amounts used in nuclear weapon components could be found at production sites. This informa-

[37] In 1994 a smuggled sample of plutonium was intercepted in Tengen, Germany. It originated in Russia and apparently had been centrifuge-enriched with plutonium-239.

tion is regarded as being far too sensitive to be revealed. An urgent task at such a facility would therefore be the removal of such parts and tools as soon as possible in order to prepare it for the start of safeguards. This work is necessary in any event in order to minimize proliferation dangers.

Specially managed access arrangements to protect sensitive parts of a facility will still be necessary. This type of problem has been solved in France and the UK by the Euratom safeguards.[38] Euratom has verified activities at dual-use facilities as long as they were declared civilian. When the activities were declared to be military, Euratom ended its verification, as occurred at the Sellafield Nuclear Power Plant in the UK. At former military facilities that are now used for civilian production and at which sensitive information can still be found, verification and site inspections should be less intrusive and would need specially managed access provisions. As a consequence, material accountancy in the interior of such facilities might not be possible for a certain period. However, this period must be limited, declared and extended only as long as needed in order to remove the sensitive data. At former military facilities which are now closed and where there is still sensitive information, verification must use containment, surveillance and additional observation from the outside for a limited period. The question of how much managed access is possible in the event of strong suspicions remains to be investigated.

Facilities not designed for safeguards

Special technical verification problems are posed by facilities which were not designed to accommodate safeguards or equipped to facilitate sampling procedures. These facilities have not set up their measuring points with easy access, and it could be technically difficult to provide material balance areas. Records could have been kept very differently from the procedures used in the NNWS. In particular, facilities in the NWS did not need to make physical inventories for safeguards inspectors since those states were not required to accept international verification arrangements. It is much more difficult to install technical equipment in an existing facility than to prepare for installation when the facility is being designed and built.

Many problems need to be solved. Regulations should be implemented for technical, organizational and reporting requirements for material control and accountancy, measurement systems need to be set up and personnel should be trained.

[38] Chapter VII of the 1957 Euratom Treaty establishes safeguard agreements for EU member states. Euratom has an agreement with the IAEA for joint application of safeguards to verify that there is no diversion of nuclear materials to nuclear weapons or other nuclear explosives in any of the European Union's non-nuclear weapon states. See Goldblat, J., *Arms Control: The New Guide to Negotiations and Agreements* (SAGE: London, 2002), p. 328.

VI. Excessive secrecy

The establishment of warhead disassembly and fissile material disposition transparency is the most challenging part of nuclear disarmament since it directly affects the core of the nuclear complexes and their best-guarded secrets. Currently, there is no nuclear arms control treaty on verification or transparency in warhead disassembly, and there is no tradition for developing such measures. All efforts to introduce greater transparency in this domain have failed, for several reasons.[39]

First, the disclosure of the technical details of warhead design and construction poses proliferation dangers and could conflict with the commitments of the NWS under Article I of the NPT. Information that could accelerate a proliferator's secret nuclear weapon programme, such as the principles of warhead construction or materials manufacture, should not be revealed. However, some states classify information that is not proliferation-relevant or is already in the public domain, even on the Internet.

The second reason has to do with national security. Military planning relies on surprise and therefore on secrecy. In addition, there is often a desire not to reveal the level of technological development, the motive being to hide technological weaknesses or to protect technological superiority. These secrecy policies were part of the nuclear strategy practised during the cold war. Belief in the deterrent effect of nuclear weapons—and the quest for strategic advantage—depended on maintaining uncertainty about intentions and capabilities, even if a degree of transparency was sought through arms control measures where uncertainty threatened to seriously destabilize strategic relations.[40] This tradition also plays a role today.

The third factor that impedes transparency is the status that is traditionally associated with secrecy in the nuclear complexes of the NWS, usually linked to privileges. The disclosure of technical information is perceived as a surrender of status and often as defeat. Many of the best scientists have been attracted to the nuclear weapon programmes of the NWS and proliferator states. As these scientists have been withdrawn from the international community and been unable to publish their research results, they have become dependent on the appreciation of a closed community. However, because nuclear weapon scientists have an interest in being able to communicate with their peers in the wider scientific community, they might not wish to subject themselves to tight restrictions. Secrecy can be perceived as a status symbol not only by nuclear weapon scientists but also by other groups, such as politicians. The belief in a special status conferred by the possession of nuclear weapons often results in an uncritical assignment of status to aspects traditionally associated with nuclear weapons, one of which is secrecy. Conservative politicians who emphasize the

[39] Bunn (note 1), p. 47; and chapter 5 in this volume.

[40] Walker, W., 'Reflections on nuclear transparency and irreversibility: the re-regulation of partially disarmed states', Background paper for the Conference on the Fissile Material Cutoff, Schlangenbad, Germany, 25–27 July 1997.

need for national military strength often exaggerate 'national security' and overestimate the dangers of security leaks to foreign intelligence.[41]

Finally, a fourth reason for the lack of transparency is the lack of democracy. The less democratic a state is, the more it may tend to use secrecy as a convenient cover to avoid criticism. The critics may be citizens of the state or the international community. Secrecy can also serve to cover up mismanagement, corruption or even crime. Furthermore, it may be abused by certain constituencies to set agendas that serve their special interests, preserve autonomy in decision making, maximize their power through knowledge and avoid scrutiny by competitors or the public.[42] The more democratic a state is, the more legal limits are in place against such abuse of secrecy.

The creation of greater transparency therefore requires not only new verification technologies but also domestic policy reforms and international pressure. In the meantime, much work can be undertaken on the technical side.

VII. A universal verification regime for fissile materials?

Over the long term, it will be necessary to focus on fundamental safeguards reforms with the goal of achieving a universal system for both the NWS and the NNWS. However, there are many political and technical hurdles: paving the way for universal acceptance within the NWS and states outside the NPT is a political problem and is likely to be a long process. Implementing safeguards systems, including material accountancy, in these states is a technical issue and will require the investment of time and money.

A global system must be different from the existing system; it must be characterized by a new safeguards culture, based more on technical and political judgement than on the implementation of quantifiable measures. A safeguards reform leading towards that goal will have to address issues of finance, organization, decision making, effectiveness and concern about non-compliance as well as underlying principles such as standards for significant quantities. A global approach could lay the foundation for a nuclear weapon-free world.

[41] The 'Cox Report', which has been criticized for partisan bias and mistakes, examined allegations of Chinese espionage at a US nuclear weapon laboratory. US Congress, House of Representatives, Select Committee on US National Security and Military/Commercial Concerns with the People's Republic of China, *Final Report,* House Report 105-851 (US Government Printing Office: Washington, DC, 25 May 1999), URL <http://www.gpo.gov/congress/house/hr105851>. See also Garwin, R. L. and Panofsky, W. K. H., 'Nuclear secrets: rush to judgment against China', *International Herald Tribune*, 3 Aug. 1999: 'Each of us has a right to make up his or her own mind, but not to make up his or her own facts. Yet that seems to be happening on the nuclear threat from China'.

[42] Walker (note 40).