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Techniques and Procedures for Verifying Nuclear Weapons Elimination

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CONTENTS

I. Introduction.

Methods for monitoring the destruction of strategic and shorter range missiles and strategic bombers are well-established and have been used to verify destruction of heavy missile launchers (silos and submarine launch tubes) and heavy bombers under the SALT and START treaties, and intermediate-range missiles under the INF Treaty.

Dual-purpose delivery systems for nuclear weapons, such as artillery and tactical aircraft, present special problems because the delivery vehicles are not usually designated for destruction. To detect and verify compliance with constraints placed on these systems requires an ability to monitor remote nuclear training, operational deployments, and storage and transport of warheads, or an ability to inspect for the presence of special nuclear launch and release equipment on nuclear-capable aircraft.

Methods for verifying the dismantlement of nuclear warheads have been worked out on a general level,[1] but no comprehensive verification regime is in place even on a bilateral basis. U.S./Russian cooperation in this area to date has been limited to demonstration of a few techniques for monitoring the storage of plutonium pits and other fissile material components removed from warheads.

The verification of declared fissile material stocks that are not in warhead component form is performed routinely by the International Atomic Energy Agency (IAEA), and the practical strengths and limitations of these methods are well understood by most technical experts, although not, it seems, by some political authorities.

While further verification technology improvements are always welcome -- and, it would appear, required if the closed nuclear fuel cycle is not to undermine prospects for a nuclear weapon free world -- they are not critical to the success of arrangements to verify the elimination of existing nuclear weapon stockpiles. What is most lacking today is U.S.-Russian agreement on the specific technologies and procedures to be employed to verify specific activities and facilities. What is most needed is a bilateral or multilateral program of technical cooperation to conduct laboratory and field demonstrations of plausible alternative approaches to the principle verification tasks involved in the reduction and eventual elimination of nuclear weapons.

Below we review monitoring technologies and verification procedures that are readily available for such field demonstrations and operational use in a full-fledged verification system.

II. [Inter]National Technical Means.

Before surveying cooperative verification measures, our major topic of interest, it is sufficient to note that a global monitoring regime for nuclear weapons elimination would reasonably be expected to benefit from a wide variety of remote monitoring technologies and national systems for collecting and collating human intelligence -- now called "National Technical Means". To a greater or lesser degree, all these systems are likely to have some capability for detecting the presence or absence of nuclear weapon-related activities. Such systems include:

- **multispectral imaging reconnaissance satellites** -- these systems use different parts of the electromagnetic spectrum (visible, infrared, ultraviolet, radar) depending on the specific "signatures" of the activity being monitored. For example, monitoring for signs of a clandestine plutonium production reactor might involve looking at infrared images for unexplained thermal discharges into lakes and rivers;

- **electronic reconnaissance satellites** -- these systems for gathering electronic intelligence (ELINT) are variously configured to detect and record the variety of signals -- including test telemetry -- emitted by military systems (SIGINT) and the communications of their operators and command authorities (COMINT);

- **ocean reconnaissance satellites** -- a special form of electronic intelligence satellite, these systems fly in a formation that locates ships by detecting radar and communications signals from more than one receiving point and "triangulating" the source;

- **missile warning satellites** -- primarily designed to provide early warning of ICBM or SLBM launches by infrared detection of their rocket plumes, these satellites also provide surveillance of missile test launches and are reported to carry visible light detectors and radiation sensors for detecting nuclear explosions;

- **GPS/IONDS satellites** -- a suite of ultra-violet and x-ray sensors called the Integrated Operational Nuclear Detection System (IONDS), carried on a number of Global

Positioning System (GPS) Satellites, provides a capability using time of flight measurements, to precisely locate nuclear explosions in the atmosphere and near space;

- **Aircraft** -- a variety of high-altitude reconnaissance platforms -- both manned aircraft and Remotely Piloted Vehicles (RPV's) have been developed to peer into and overfly foreign territory using side-looking radars, cameras, and a wide variety of ELINT receivers;

- **Ships** -- Los Angeles-class nuclear attack submarines, specially configured for SIGINT and COMINT missions, clandestinely eavesdrop along the coastlines of the world's nation states. Intelligence gathering surface ships overtly perform a similar mission;

- **Ground-Based Monitoring Posts** -- Around the world, the U.S. intelligence community, and presumably other intelligence services, maintain a network of electronic listening posts for both signals and communications intelligence. For example, when the former USSR shot down a Korean Airliner (KAL-007) that strayed into its airspace over Sakhalin island, the whole sequence of communications involved in the shoot-down was recorded by a secret U.S. Army listening post on the northern Japanese island of Hokkaido;

- **Environmental/Effluent Monitoring** -- Clandestinely or cooperatively emplaced air, water, and soil sampling equipment can detect characteristic radionuclide and chemical emissions from a broad array of nuclear and other industrial activities;

- **Underwater Acoustic Surveillance** -- Seabed and mobile acoustic sensors are used to keep tabs on nuclear submarines and to detect any nuclear tests in the oceans;

- **Human Intelligence** -- intelligence analysts also collect information from agents, defectors, emigres, defense attaches, businessmen, tourists, and from the painstaking collation and sifting of the published and recorded electronic media. A more generalized form of this type of intelligence, called "societal monitoring" by its proponents, and international mechanisms for receiving and evaluating it -- could play a critical role in the regime for verifying global elimination of nuclear weapons.

III. Declarations and Cooperative Verified Data Exchanges.

Elimination of unnecessary secrecy relating to past and present nuclear weapon stockpiles and fissile material production activities would greatly ease verification efforts. Bilateral or multilateral agreements could include the following measures:

-- a data exchange, including the total number of warheads of each type, and the total masses of plutonium and highly-enriched uranium metal within and outside of nuclear weapons;

-- an exchange of serial numbers and storage locations of warheads and bombs, which could be updated at six- or twelve-month intervals;

-- application by the owning party of tamper-resistant, laser-readable bar-codes and/or "intrinsic fingerprint" tags on all nuclear weapons (or on their containers sealed with tamper-indicating locks);

-- random on-site inspection of weapon storage sites to verify the disposition of warheads as set forth in the periodic exchanges of data; identification of all nuclear weapons or sealed weapon canisters entering a dismantlement facility or leaving a production facility by matching the serial number to a unique bar code and/or "fingerprint" tag;

-- international safeguards over fissile material permanently removed from weapons use, civil stocks, and plants capable of producing such material.

Nuclear stockpile data exchanges and cooperative inspections have the potential to:

-- reduce the uncertainties in estimates of nuclear weapons and weapon-usable materials;

-- assure the international community that significant quantities of these materials are not being diverted to unauthorized uses or secretly kept in reserve for future use in nuclear weapons;

-- provide a verified basis for confidently reducing stockpiles well below current levels;

-- provide a coherent record of nuclear weapons elimination that could be relied upon by countries with smaller or undeclared nuclear arsenals, such as China and Pakistan, in reaching a decision to join the nuclear arms reduction process;

-- provide independent evidence of whether weapons and weapons-usable fissile material have been diverted;

-- enable one to identify the source of stolen or diverted material recovered by law enforcement or customs personnel, by comparing the isotopic profile of the intercepted material with a comprehensive library of such data previously compiled for each distinctive batch of fissile material at storage and production sites;

-- assist in identifying improvements that are needed with respect to physical security and material accounting programs.

A. Model Data Exchange.

In 1994 the United States and Russia agreed to initiate an exchange of data related to warheads and weapons-usable fissile material. A draft proposal for the type of data that might be exchanged has been tabled, but not made public. This effort has been stalled for the past year due to the failure to conclude an Agreement for Cooperation between the United States and Russia that is legally required before the classified data can be swapped. This impasse could have been avoided had both sides simply declassified the data and made it public. The other declared nuclear weapon states could make similar public declarations regarding their nuclear weapon and fissile material inventories.

A initial data exchange could include the following or similar categories of data (shown in **Table 1**), on it could be updated on an annual or semi-annual basis :

(1) the numbers of nuclear stockpile weapons added, retired, dismantled, and remaining in service (if any) in each of the following categories:

- (i) total stockpiles;
- (ii) strategic ballistic missile warheads;
- (iii) strategic bomber weapons;
- (iv) non-strategic land-based missiles (incl. air defense), artillery, mines;
- (v) gravity bombs;
- (vi) ship-launched weapons/sea mines.

(2) the total masses of plutonium and highly-enriched uranium in:

- (i) the total nuclear weapons stockpile;

(ii) weapons on or available for strategic nuclear delivery vehicles;

(iii) all other nuclear stockpile weapons;

(iv) other stocks outside of but available for weapons;

(v) irrevocably transferred from weapons use to peaceful use;

(vi) recovered from spent fuel;

(vii) fresh (>20%) enriched uranium (unirradiated);

(viii) the combined total inventory of potentially weapons-usable fissile material.

(3) the current status, fissile material inventories, and output of all known facilities with the capacity for producing or processing significant quantities of fissile materials.

B. Confirmatory Inspections.

Once the parties have agreed upon the categories of data to be exchanged and periodically updated, a safeguards regime for the weapon states should be established to verify the data. Because much of the materials are in weapon or weapon-component form, it would be inadvisable to attempt to extend IAEA oversight to include comprehensive safeguards over the warhead dismantlement process. Some data can best be verified on a bilateral basis, some on a five-party multilateral basis, and some by extension of IAEA authority. There are a wide variety of technologies and procedures, discussed in Sections IV and V below, that are available for confirmatory inspections.

C. Nuclear Archaeology.

An important means of confirming inventories and insuring that declarations and exchanged data have not been falsified is to inspect historical documents pertaining to past nuclear weapons activities, especially the production and disposition of fissile materials, and make these documents available to the public, or at least to other governments.

1. **Inspection of Production Records.** As an example of what can be done, and should be done universally, the U.S. Department of Energy has declassified and made public ten of thousands of production records covering the entire operating history of the Hanford Reservation, one of the two principal sites where plutonium for U.S. weapons was produced. These records are being used to reconstruct the radioactive emissions from plutonium production and separation activities and off site radiation exposures. These records also can be used to confirm the plutonium production at the site.

2. **Access to Physical Evidence.** North Korea's claim that it has produced no plutonium provides a vivid example of the sorts of suspicions that can surround declarations, even when supplemented by inspections and records.[2]

(a) **Irradiation Histories of Reactor Components.** Measurement of the concentrations of long-lived radioactivity in permanent components of the cores of production reactor is a promising technique for estimating the neutron fluence in various parts of the reactor core, and these measurements, when coupled with a model of the core, can provide a basis for estimating how much plutonium might have been created in the reactor. While far from precise, these independent estimates might tend to substantiate, or raise doubts about, the authenticity of production records and official declarations of plutonium production.[3]

(b) **Enrichment Plant Records and Tails Assays.** Natural uranium contains three isotopes: U-238 (99.283%), U-235 (0.711%), and U-234 (0.0054%) and trace amounts of other uranium isotopes (U-232, U-233 and U-236) are a byproduct of reactor operation. The process of enriching uranium results in product and depleted tails streams having isotopic concentrations that differ from that of the feed material. Isotopic assays of tails, and also assays of uranium particulates retrieved through environmental monitoring in and around plant can be used to determine the enrichment level at which the plant operated.

From the mass and assay of the tails one can reconstruct the quantity of HEU produced and confirm production records, albeit with some uncertainty.[4]

IV. Warhead Verification Techniques.

A. Bar codes.

Commercially available bar code and bar code readers provide a simple, straightforward and inexpensive method for inventorying large numbers of warheads, warhead components, and component and fissile material containers. Hand-held laser-wand devices permit one to read the bar codes from a distance of a few meters and download the data into a laptop computer, allowing relatively non-intrusive data collection in the field.

B. Tags, Seals and Tamper Indicating Tape.

The IAEA has made extensive use of tamper indicating seals, for example, on storage containers and monitoring equipment. These and other commercially available tamper indicating seals can be used on warhead and fissile material containers, access ports to process lines and storage vaults, and surveillance equipment. Commercially available fiber optic seals and camera-verifier units provide greater flexibility and tamper resistance. The fiber optic cable of any length can be routed through and around the object to be sealed and then inserted in a plastic padlock unit, which locks and crimps the cable ends in a random manner creating a unique light pattern among one to two dozen individual fiber-optic strands. The seals and light images of the fiber ends can also be bar coded for easy identification and control.

C. Intrinsic Surface Fingerprints.

Argonne National Laboratory has developed an inexpensive method of taking a unique "fingerprint" of a metal surface. The surface is scraped to bare metal, for example with emery paper and marked with a fiducial and bar code. A strip of plastic a few centimeters long is wet with acetone to soften its surface. The plastic is hand pressed against the metal surface and after the acetone dries in about 15-20 seconds, the plastic strip with its unique three dimensional fingerprint is removed and bar coded. Several prints can be taken in sequence and shared among the parties. The finger prints can be examined under a scanning microscope--an electron microscope of high resolution is desired--and the image compared to previous fingerprints. The surface provides a three dimensional image that is impossible to replicate with another surface, thus providing confirmation whether the surface (and therefore the warhead or container) is the same as that previous examined.[5]

D. Weights, Dimensions and Assays.

Measurement of the mass, dimensions and chemical composition of warhead components in theory provides a means of uniquely identifying nuclear warhead and warhead components. These data in most instances are considered sensitive nuclear weapon design information and are classified by the weapon states. Some data may be exchanged on a limited basis. The challenge is to identify classes of data or measurement procedures that can provide unique fingerprints of warhead types without revealing sensitive design information. The technology for doing so is available or readily adaptable, but the specific procedures have not been agreed upon by governments. Differences in political and professional opinion persist as to what warhead design information should be made public, exchanged on a classified basis, or remain tightly restricted, and these differences will encumber any effort to reach agreement on data exchanges and verification techniques.

1. Radiation Detection and Fingerprints. There are a wide variety of commercially available instruments designed to detect the presence of radiation or radioactive materials--portable survey meters, fixed air samplers, and laboratory instruments. They are typically designed to detect either x-, beta- and gamma-rays on the one hand, or neutrons on the other with varying efficiency, price, portability and ease of use. The simplest, cheapest and most portable of these are the single-channel hand-held radiation (x-, beta- and gamma-ray) survey meters. "Single channel" refers to the fact that these instruments are not capable of distinguishing differences in the energy of the radiation detected, and therefore cannot identify which radioisotopes are the sources of the radiation.

All nuclear warheads contain a variety of radioisotopes of either enriched uranium, plutonium or both. The most prevalent uranium isotopes are U-235 and U-238, and the most prevalent plutonium isotopes are Pu-239, Pu-240, Pu-241, and Pu-238. As they undergo radioactive decay each of these (and other radioactive) isotopes emits a characteristic set of x- and gamma-rays. Each set of emissions differs with respect to the number and frequency of individual emissions and the intensity, i.e., the energy of the emitted ray (or particle). Some isotopes, e.g., Pu-240 also emit neutrons spontaneously.

The simplest possible "fingerprint" for a warhead is the weight and isotopic composition of the enriched uranium and plutonium that it contains. A "fingerprint " of a radioactive material can be obtained using a multi-channel radiation spectrometer--an energy resolving detector coupled to a multi-channel analyzer that records the number of radiation counts, or "hits," as a function of the energy of the x- or gamma-ray. The recorded data--the number counts as a function of energy is called a gamma-ray spectra. The final sorting out and identification of the gamma-ray energies and the identification of the isotopes is usually performed in the lab using computers and commercially available software and isotope gamma-ray libraries. The gamma-ray fingerprint of a Soviet cruise-missile warhead is shown in Figure 1.[6]

The ability to distinguish isotopes using multi-channel detector/analyzers is a function of the energy resolution of the detector and the number of channels of the analyzer. Detectors with the highest resolution require liquid nitrogen cooling which encumbers field measurements.

From a practical standpoint, the range of a gamma-ray spectrometer for detecting warheads is only a few meters, and even at close range this method can be defeated by moderate shielding with dense materials, such as lead.[7] They are most useful for laboratory analysis of smears, air filters and other collected samples and as portal monitors. Because uranium-235 emits predominantly low-energy gammas that are difficult to detect above background radiation, enriched uranium is more difficult to detect than plutonium. Helicopter mounted neutron detectors can detect nuclear warheads at a distance of about 70 to 100 meters provided the warheads have plutonium components (containing Pu-240) and provided no extraordinary means have been taken to shield the warheads with thick neutron absorbing materials.

The overriding constraint on the use of high resolution gamma-ray spectrometers for fingerprinting is the recognition that warhead design details can be derived from the revealed spectra using warhead design codes. There are a variety of approaches that can be used to preserve the security of the design information while still reaping the advantages of the multi-channel detector/analyzer approach. First, one can use a lower resolution detector or an analyzer with fewer channels. For example, one can use a high resolution detector, but design the analyzer to detect only one or two of the discrete energy lines from the decay of Pu-239. Alternatively, one can retain the full high resolution of the detector/analyzer and compare using an agreed upon computer algorithm, the gamma-ray spectra against a statistical sample of measurements of similar warheads, without revealing any of the spectra to the inspecting party. Here, the radiation spectra of the warhead would only be revealed to the computer and these data subsequently would be erased.

a. Active Radiation Detection. The above radiation detection techniques are called "passive detectors," in that they rely solely on the radiation spontaneously emitted by the source and background materials. "Active detectors," which represent a separate category of radiation detectors, rely on an external source of radiation to illuminate the object of interest. Radiation from the external source, for example, can be shined through the object to create an image or pattern detectable on the opposite side. The most common example of this technique is the x-ray machine. Another type of radiation, neutrons, can be used to mildly activate isotopes in the object of interest, and these activation products can be detected by radiation detectors of the type used to detect passive radiation. Examples of this technique are detectors for finding high explosives hidden in airplane luggage. This technique is useful to detect the presence, and to some level of specificity, the composition of chemical high explosive materials used in warheads.

E. Portal Perimeter Monitors.

Any, or a combination of techniques described above can be used to monitor the portals of warhead and weapon delivery vehicle assembly and disassembly plants and fissile material production and use facilities. High-energy radiography, for example, was used under the INF treaty to verify than none of the missiles shipped in canisters out of the Soviet Votkinsk plant were of the same dimensions as those used in the banned SS-20 missile.

V. IAEA Safeguards.

IAEA safeguards serve as a pillar of the international nonproliferation regime. Their effectiveness is critical to preventing the spread of nuclear weapons. Despite continuing efforts to upgrade them, IAEA safeguards still suffer serious weaknesses, primarily with regard to their inability to assure timely detection of the diversion of weapon-usable quantities of fissile material from bulk handling facilities, e.g., reprocessing plants and plutonium fuel fabrication plants and the ability of the IAEA to detect clandestine activities as occurred in Iraq. Member states--in particular, the weapon states-- have also failed to provide adequate funding for IAEA activities.

A. Commercial Nuclear Facilities.

1. Programme "93+2." Primarily in response to the Iraqi experience the IAEA, since December 1993, has had underway a major effort to develop and implement improved safeguards measures. Iraq is a member of the NPT and its declared nuclear facilities are subject to IAEA safeguards. Nevertheless, in violation of its NPT commitment Iraqi had a parallel clandestine nuclear weapon development program and diverted safeguarded reactor fuel shortly before the program was halted as a consequence of the Gulf War. The new measures relate to three main areas of reform: 1) strengthening the access to information, 2) increased physical access to sites, and 3) administrative streamlining. The IAEA is seeking to achieve greater transparency, through declarations, and increased monitoring capabilities. Increased physical access includes unrestricted access to nuclear and nuclear-related sites, access beyond these sites (arranged case-by-case to follow up on information or to implement technical measures. Some of the Programme 93.2 revisions are already being implemented, and others require renegotiation of IAEA safeguards agreements.

2. Environmental Monitoring. Radioactivity measurements of air, water, vegetation, surface (smear), and production samples have been used to monitor fissile material production and environmental releases from production activities, beginning as early as 1945 during the Manhattan Project. The technology and techniques have been refined to the point where they provide extraordinary sensitivity. The sensitivity essentially is now limited only by that imposed by limitations on access to the sampling areas.

VI. Monitoring Requirements for Specific Facilities.

To insure that weapon-usable fissile material is not produced or diverted for weapon use, multilateral weapon-state monitoring or IAEA safeguards will have to be applied to the following civil and military nuclear fuel cycle activities: uranium enrichment plants, nuclear reactors, fuel conversion and fabrication plants, reprocessing plants, mixed-oxide (MOX) fuel fabrication plants, fissile material storage, spent fuel storage, and disposal sites. In addition, during transition to a NWFW multilateral monitoring should be applied to warhead assembly/disassembly plants and warhead and fissile material component storage sites. Technologies and problems associated with monitoring or safeguarding each or these activities are discussed below.

A. Enrichment Facilities.

The accompanying Canberra Commission issue paper, "Technical Realities Confronting Transition to a Nuclear Weapon-Free World," discusses technical issues associated with safeguarding enrichment plants. The IAEA and the European Atomic Energy Community (EURATOM) currently have responsibility for safeguarding enrichment plants, other than those in Russia and the United States. Using assay techniques currently employed by the IAEA, it is possible to determine the enrichment level at which the plant is operating, or has operated in the past. From the mass and assay of the tails one can reconstruct the quantity of HEU produced and confirm production records, albeit with some uncertainty. These measurements also can be made from environmental samples in the vicinity of a plant to detect possible unauthorized operations. The challenge to safeguarding enrichment plants is to (a) detect clandestine plants for HEU production, (b) detect the diversion of HEU from declared plants designed to produce HEU, (c) detect diversion of low-enriched uranium (LEU) for subsequent enrichment to HEU at a clandestine plant, and (d) detect the conversion of a plant from LEU to HEU production. Detecting diversions of LEU or HEU from safeguarded enrichment plants through periodic inventories is exceedingly difficult, if not impossible, because uncertainties in measurements of the uranium inventories and throughputs give rise to large inventory differences.

B. Reactors.

There are a variety of techniques that are currently in use for monitoring reactor operations: a) space based thermal imagining, b) surveillance cameras, c) coolant water temperature monitors, d) temperature monitors in and around the core, e) neutron flux monitors in and around the core, f) physically counting fuel assemblies or fuel and target elements. The challenge here is to be able to insure that no unsafeguarded fissile material production occurs at existing dual-purpose production reactors that are still in use for electricity production, or at tritium or other special isotope production reactors. No new technology is required. There may be difficulty in reaching agreement with regard to which technologies and procedures should be used.

C. Reprocessing Plants.

The IAEA and EURATOM currently have responsibility for safeguarding several large commercial nuclear fuel reprocessing plants. As noted elsewhere IAEA and EURATOM safeguards are inadequate to provide timely warning of the loss or diversion of weapon-usable quantities of fissile material at large bulk-handling facilities--reprocessing and MOX fabricating plants. The international community has resolved this predicament by accepting the technology and then establishing safeguards standards on the basis of what can be accomplished with existing commercial technology, rather than first establishing adequate safeguard standards, and than asking which commercial technologies can meet them. Older military chemical separation plants, particularly those in Russia and the United States, which were not designed with IAEA safeguards in mind, cannot meet even the IAEA's current standards.

If highly enriched uranium is recovered from fresh or spent highly enriched research reactor fuel, as Iraq intended to do, then only a few tens of kilograms of fuel must be processed to obtain a first weapon. At the other extreme, if recovery of weapon-grade plutonium from spent natural uranium fuel is desired, then depending on the fuel burnup about 2 to 10 tonnes of fuel must be processed for each kilogram of plutonium to be recovered. In either case, for a first weapon, the chemical separation can be conducted in a small clandestine facility over a period of months. The monitoring challenge is to detect the facility. As in the case of North Korea, a suspect site would have to be detected by other means before inplant and environmental monitoring could be used to confirm the existence of suspected activities.

D. Fuel Conversion and Fabrication Plants.

The IAEA and EURATOM currently apply safeguards to these facilities. As with other large bulk handling facilities, these plants are characterized by inherent uncertainties in detecting diversion in light of the large inventory differences associated with handling enriched uranium and plutonium in bulk form, i.e, in solutions, powder, and pellet form. To date, research and development of so-called "near-real time accounting" (NRTA) and other advanced safeguards approaches have not resolved these uncertainties in a manner that would permit commercially viable operation of these facilities with an acceptable degree of risk.

The risks are lessened if the use of HEU and separated plutonium as fuels are prohibited. With respect to naval fuel, this could be accomplished by requiring prefabrication of HEU cores covering the projected life of existing naval vessels and requiring that all new nuclear-powered vessels operate with naval reactors fueled with uranium enriched to <20% U-235. Recent studies indicate that the penalty in term of additional displacement (or lost internal space for other systems would be on the order of 10-15%).

E. Excess Fissile Material Storage.

No new technology is required to monitor the storage of fissile materials that are not in weapon component forms. The challenge here is to resolve how to monitor plutonium pits and other fissile material components of warheads without revealing sensitive design details. The procedures for doing this have been discussed above in connection with monitoring the warheads themselves. The United States and Russia are currently attempting to work out arrangements by which they bilaterally IAEA can safeguard fissile material that has been declared in excess of weapon requirements.

F. Spent Fuel.

Spent fuel storage in non-weapon states is currently safeguarded by the IAEA. Most spent fuel is in the form of heavy discrete, easily countable, fuel assemblies. The fuel of some older production reactors, like those still operating at Tomsk-7 and Krasnoyarsk-26 in Siberia, is in the form of individual fuel elements weighing only a few kg each. For these reactors verifying the disposition of few thousand such elements discharged monthly is extremely difficult at best.

The safeguard challenge associated with monitoring typical power reactor spent fuel is the scale of the problem and the lack of sites for permanent geologic disposal, thereby extending the time over which safeguards must be monitored. The current world inventory of commercial spent fuel is about 90,000 t and this is increasing at a rate of about 7000 t annually. Most spent fuel is highly radioactive. The dose rate at a meter distant from a typical power reactor fuel element after 20 years cooling is on the order of 1000 rem per hour. However, after most of the short-lived fission products have decayed -- in 300 years the amount of cesium-137 has been reduced by a factor of 1000 -- the radiation no longer represents an effective barrier. The barrier is diminished much sooner in the case of some smaller research and test reactor fuel elements, and for spent fuel exposed to only small fuel "burnup."

Spent fuel assemblies must be safeguarded at least until their consolidation and disposal in a permanent underground repository, which would then be monitored to guard against any efforts at retrieval. Given the level of international cooperation that would necessarily predominate during and after the transition to a nuclear-weapons-free world, it would not be unrealistic to envision that centralized international arrangements for spent fuel management and disposal might be made a part of the international control arrangements.

To avoid the long-term "plutonium mine" problem posed by geologic disposal of spent fuel, some experts advocate the development of fuel cycle option that requires spent-fuel processing and burning much of the recovered plutonium in reactors, and transmuting the remainder in accelerators to non-weapon-usable and relatively short-lived fission products. This option is likely to prove unattractive for a variety of reasons: (a) one would have to reprocess all of a given nation's spent fuel, including potentially huge backlogs, in order to achieve the desired goal; (b) reprocessing and fabricating the MOX fuel cannot be safeguarded today with sufficiently high confidence to satisfy the requirements of a nuclear-weapons-free-world; (c) multiple recycling is required and the process will take hundreds of years, (d) reprocessing and the first recycle is likely to remain uneconomical, and the economic outlook becomes progressively worse with each subsequent recycle; and (e) the technical feasibility of the various transmutation schemes have not been demonstrated.

G. Weapon assembly/disassembly plants.

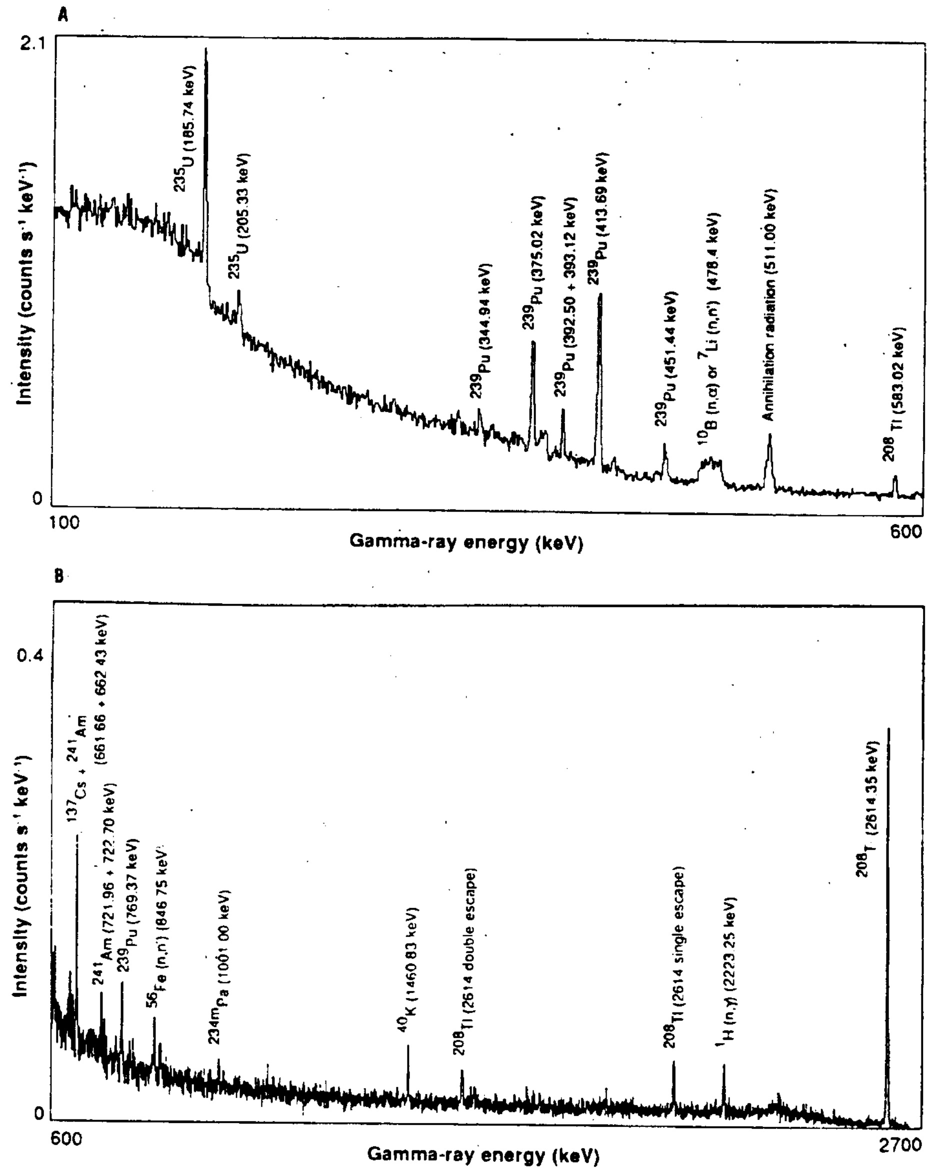
Effective monitoring of nuclear weapon assembly/disassembly plants is feasible using portal/perimeter monitoring radiation detectors and other surveillance equipment. The problems associated with the protection of sensitive design information are manageable, although disagreements could arise over the specific procedures and technologies to be employed. The difficulties associated with portal/perimeter monitoring of these plants, and fissile material component storage facilities, can be greatly reduced if the weapon states are prepared to reveal, at least to one another, the mass of individual components.

VII. Conclusion.

For most on-site and portal/perimeter verification applications, commercially available technology exists and much of it is already in use by the IAEA, multilateral, and/or national physical security and material control and accounting programs. With respect to the verification of nuclear weapons elimination, the major problem has been obtaining formal governmental agreements, on a bilateral or multilateral basis, on what should be safeguarded, and then reaching agreement upon the use of specific procedures and technologies. Technical experts and political-military authorities within the weapon states are not of one view regarding which nuclear weapon and naval fuel design information can be revealed on a confidential bilateral, or multilateral basis, or made public. This is likely to complicate and drag out negotiations over the monitoring of intact retired weapons, weapon components, weapon assembly/disassembly facilities, and naval reactor fuel and fuel fabrication facilities.

The ultimate ease or difficulty in safeguarding nuclear-related facilities will depend to a significant degree on whether the continued use of HEU, particularly for naval reactor fuel, and separation of plutonium for commercial reactor fuel, is permitted or banned. If either of these activities is permitted, monitoring and safeguarding of nuclear fuel activities may never be accomplished with the high degree of confidence that national security authorities are likely to demand for the transition to a nuclear-weapons-free world.

Figure 1.
Gamma-Ray Spectra of a Soviet Cruise Missile Warhead: From A) 100-600 keV, and B) 600-2700 keV.[1]



[1] Steve Fetter, Thomas B. Cochran, Lee Grodzins, Harvey L. Lynch, and Martin S. Zucker, "Gamma-Ray Measurements of a Soviet Cruise-Missile Warhead," *Science*, May 18, 1990, Vol. 248, pp. 828-834.

Notes

1. See, for example, "Ending the Production of Fissile Material for Weapons [and] Verifying the Dismantlement of Nuclear Warheads, the Technical Basis for Action," Federation of American Scientists, June 1991.

2. Steve Fetter, "Nuclear Archaeology: Verifying Declarations of Fissile Material," *Science and Global Security*, Vol. 3, Nos. 3-4 (1993), pp. 237-259.

3. Ibid.

4. See, for example, Thomas B. Cochran, "Highly Enriched Uranium Production for South African Nuclear Weapons, *Science and Global Security*, Vol. 4 (1994), pp. 161-176.

5. "Report of the Third International Workshop on Verified Storage and Destruction of Nuclear Warheads, " held in Moscow and Kiev, December 16-20, 1991, Natural Resources Defense Council, Washington, D.C., January 1992, p.23-31.

6. Steve Fetter, Thomas B. Cochran, Lee Grodzins, Harvey L. Lynch, and Martin S. Zucker, "Gamma-Ray Measurements of a Soviet Cruise-Missile Warhead," *Science*, May 18, 1990, Vol. 248, pp. 828-834.

7. Gamma-ray telescopes have a longer range, but their size and need to count for an extended period of time while aimed at a fixed target severely limits their utility.