FINAL REPORT
of the
US-RUSSIAN INDEPENDENT SCIENTIFIC COMMISSION
ON DISPOSITION OF EXCESS WEAPONS PLUTONIUM

June 1, 1997

Russian Participants	**U.S. Participants**
Evgeniy P. Velikhov, Co-Chair	John P. Holdren, Co-Chair
Aleksei A. Makarov	John F. Ahearne
Fedor M. Mitenkov	Richard L. Garwin
Nikolai N. Ponomarev-Stepnoi	Wolfgang K. H. Panofsky
Fedor G. Reshetnikov	John J. Taylor

Executive Secretaries

Dmitri F. Tsourikov	Matthew G. Bunn

FINAL REPORT
of the
US-RUSSIAN INDEPENDENT SCIENTIFIC COMMISSION
ON DISPOSITION OF EXCESS WEAPONS PLUTONIUM

Contents

Summary of Recommendations 1

A. Overall Approach
B. Storage, Protection, Control, and Accounting
C. Disposition of Excess Plutonium

Introduction 3

Background of the Recommendations 5

The Character of the Problem
Current Status of Management Efforts in the United States and Russia
Relation of the Materials-Security Problem and the Nuclear-Energy Problem

Recommendations 11

A. Overall Approach
B. Storage, Protection, Control, and Accounting
C. Disposition of Excess Plutonium

Annex: Planning, Managing, and Financing Disposition of Excess Weapons Plutonium 19

Introduction
Outline of a Notional Work Plan for Disposition of Excess Weapons Plutonium
Structures for Managing and Licensing Disposition of Excess Weapons Plutonium
Financing Disposition of Excess Weapons Plutonium

FINAL REPORT
of the
US-RUSSIAN INDEPENDENT SCIENTIFIC COMMISSION
ON DISPOSITION OF EXCESS WEAPONS PLUTONIUM

June 1, 1997

SUMMARY OF RECOMMENDATIONS

A. Overall Approach

A.1 The U.S. and Russian governments, with support and cooperation from the international community, should take additional steps — beyond those already underway — to more rapidly reduce the security risks posed by excess weapons plutonium.

A.2 Two approaches to reducing the weapons-usability of the excess plutonium to the spent-fuel standard — using the plutonium in mixed oxide (MOX) fuel for burning once-through in currently operating nuclear power reactors, and vitrifying the plutonium together with fission products in glass logs of the type planned for use in immobilizing high-level radioactive wastes from the defense-production complex — should both be brought to the point of operability at large-scale as rapidly as practicable in both countries.

A.3 The highest standards of materials protection, control, and accounting — as appropriate to the threat of theft or diversion — should be applied to excess weapons plutonium at all storage, processing, and transport steps until it reaches the spent-fuel standard. The same is true of HEU until it has been blended down to enrichment levels too low for use in nuclear explosives.

A.4 Increased transparency about the inventories of nuclear warheads and nuclear-explosive materials possessed by the United States and Russia, and about the steps being taken to reduce these inventories, should be pursued.

A.5 The U.S. and Russian programs of warhead dismantlement and management and disposition of the associated nuclear-explosive materials should continue to proceed in parallel, seeking to complete comparable steps in this process on comparable time scales, and to reach equivalent remaining quantities of plutonium and HEU in the two military stockpiles.

A.6 Increased funding should be provided on an urgent basis for analysis, development, testing, licensing, and deployment of the systems for management and disposition of weapons plutonium and HEU as described here.

B. Storage, Protection, Control, and Accounting

B.1 The U.S. and Russian governments should continue to cooperate in providing secure storage for fissile materials removed from nuclear weapons, and in improving security and accounting for all separated plutonium and HEU.

B.2 The United States and Russia should move quickly to implement and expand on the reciprocal information exchanges and mutual inspections related to nuclear stockpiles that have been agreed to in principle, to help ensure the transparency and irreversibility of nuclear arms reductions.

B.3 As the P-8 leaders agreed at the Moscow Nuclear Safety and Security Summit in April of 1996, excess plutonium and HEU should be placed under international safeguards as quickly as practicable.
B.4 Russia, like the United States, should begin declaring specific quantities of nuclear material to be excess to its military needs.

B.5 Both countries should seek to make additional tens of tons of material eligible for International Atomic Energy Agency (IAEA) safeguards during 1997.

C. Disposition of Excess Plutonium

C.1 The United States and Russia should move promptly to select, authorize, fund, and bring to the point of operability at the necessary scale the specific variants of both the MOX/current-reactor approach and the vitrification-with-wastes approach that will be used for disposition of excess weapons plutonium to the spent-fuel standard in each country.

C.2 The two governments should establish appropriate managerial structures — one in each country, as well as an international framework for managing joint activities — to be responsible to the Presidents for carrying out this work to specified endpoints on a specified timetable.

C.3 The United States and Russia should expedite and expand their technical cooperation focused on developing, testing, and demonstrating rapidly implementable and cost-effective means for converting pits to oxide suitable for MOX-fuel fabrication, and for processing other plutonium forms to prepare them for disposition.

C.4 The United States and Russia, along with other countries with relevant experience, should expand their technical cooperation related to analyzing, testing, licensing, and demonstrating the fabrication of MOX fuel made from weapons plutonium and the use of this fuel in currently operating reactors.

C.5 The United States, Russia, and the international community should begin now to address the largest obstacle to progress on plutonium disposition beyond interim storage, which is financing and constructing adequate capacity in the two countries for processing plutonium pits into plutonium oxide and for fabricating plutonium and uranium oxides into MOX fuel.

C.6 In order to facilitate rapid initiation of plutonium disposition in MOX fuel, contracts should be sought with existing European MOX fabrication plants to produce initial batches of weapon-plutonium MOX for U.S. and Russian reactors, while MOX fabrication facilities in the United States and Russia are being prepared.

C.7 Because of the urgency of proceeding with disposition to the spent-fuel standard, both the United States and Russia should begin their programs for this purpose using currently operating reactors.

C.8 Work should be continued to prepare for the possibility of weapon-plutonium/MOX use beyond the U.S. and Russian reactors now planned for the first phase of the reactor-disposition approach and/or beyond the partial MOX core loadings likely to be used initially in these reactors.

C.9 The United States and Russia, along with other countries with relevant experience, should expand their technical cooperation related to analyzing, testing, licensing, and demonstrating vitrification of plutonium with high-level radioactive wastes.

C.10 The nuclear-regulatory agencies in both countries should be directed — and funded — to develop the procedures to review and license promptly the MOX fuel fabrication plants, reactors using MOX fuels, and plutonium-with-waste vitrification plants needed to implement weapons-plutonium disposition.

C.11 The United States and Russia should move as quickly as practicable to end additional production of weapons plutonium, including providing the necessary financing to complete their cooperative project to convert the cores of the plutonium production reactors at Seversk (Tomsk-7) and Zeleznogorsk (Krasnoyarsk-26).

C.12 The United States and Russia should begin discussions with the goal of reaching a formal agreement governing plutonium disposition.

INTRODUCTION

Given the large-scale nuclear-arms reductions underway in the aftermath of the Cold War, the United States and Russia now face the unprecedented challenge of dismantling tens of thousands of surplus nuclear weapons and securely managing the hundreds of tonnes of fissile material — plutonium and highly enriched uranium (HEU) — that these weapons contained. Additional fissile material in storage for eventual use in weapons that now will not be built must also be managed under new conditions and against new threats, as must the plutonium and HEU in nuclear-research and nuclear-power establishments.

Fissile material is the key ingredient needed to build a nuclear weapon, and the knowledge of how to use either plutonium or HEU to build at least a crude (but still very powerful) nuclear bomb is widespread. Keeping these materials out of the hands of other nations and subnational groups is therefore an essential ingredient of nonproliferation and anti-terrorism policies. And creating confidence that these large stockpiles of excess fissile materials will not be re-used for weaponry by our two countries is critically important to enhance the prospects for agreement on deeper cuts in our nuclear arsenals, to help induce the other nuclear-weapon states to join the nuclear disarmament process, and to reinforce the global nonproliferation regime by indicating that the ongoing U.S. and Russian nuclear-disarmament process is genuine and not likely to be reversed.

The United States and Russia have been cooperating with each other and with other countries to address these issues. The US-Russian cooperation includes joint government-to-government activities established under the Nunn-Lugar program, lab-to-lab cooperation between the nuclear-weapons laboratories in the two countries, cooperation between the two nuclear regulatory agencies, and activities carried out through the International Science and Technology Center in Moscow. These activities are impressive, but they are not yet commensurate with the magnitude of the danger and the comprehensive approach required to address it. Much more needs to be done, and the need is urgent.

In April 1996, the Moscow Nuclear Safety and Security Summit focused new inter-national attention on the pressing international-security problem posed by the excess stocks of fissile material. The Presidents of the United States and Russia, together with the other leaders of the Group of Seven nations, expressed their determination:

- to ensure that "fissile material designated as no longer required for defense purposes will never again be used for nuclear-explosive purposes";
- "to identify appropriate strategies for the management of fissile material designated as no longer required for defense purposes";
- to ensure that these materials "are stored and handled under physical protection, accounting & control measures that meet the highest international standards and that ensure effective nonproliferation controls";
- to place these materials under International Atomic Energy Agency safeguards "as soon as it is practicable to do so," recognizing "the importance of ensuring transparency in the management" of these materials.
- "that effective management of this material will aim to reduce stocks of separated plutonium and highly-enriched uranium... as soon as practicable"; and
- that the result of disposition of these materials should be that they are "transformed into spent fuel or other forms equally unusable for nuclear weapons and disposed of safely and permanently."

The assembled leaders welcomed existing U.S.-Russian cooperation "to blend highly-enriched uranium (HEU) from dismantled nuclear weapons to low-enriched uranium (LEU) for peaceful non-explosive purposes." For the more difficult problem of excess plutonium, the leaders agreed that transformation into spent fuel or other forms equally unusable for nuclear weapons could be accomplished either by its "conversion into mixed-oxide fuel (MOX) for use in nuclear reactors" or by "vitrification or other methods of permanent disposal". They welcomed plans to conduct small-scale technology demonstrations related to these options, and called for an international experts' meeting to be held in Paris in late October of this year to examine the available options and identify possibilities for international cooperation in their implementation.

In this context, at the suggestion of Russian President Yeltsin, it was agreed in mid-1996 by Academician Yuri Ossipov, President of the Russian Academy of Sciences, and John H. Gibbons,

Assistant to the President of the United States for Science and Technology, to establish a bilateral commission of independent scientists to make recommendations to the U.S. and Russian Presidents concerning the management and disposition of excess weapons plutonium. This U.S.-Russian Independent Scientific Commission on Disposition of Excess Weapons Plutonium has been established at the initiative of the Russian Academy of Sciences (RAS) and the U.S. President's Committee of Advisers on Science and Technology (PCAST). The current document, produced after meetings of the Commission in Moscow in August, 1996 and in Washington DC in September 1996 and in February 1997, with intensive work on both sides in between, represents our final report. An earlier interim report was presented to the U.S. and Russian governments in September, 1996.

Our Commission has benefited from numerous prior and ongoing studies of the fissile-materials issue in our two countries and under international auspices, including for example the work of the Gore-Chernomyrdin Commission on this subject, the 1992-1995 study of "Management and Disposition of Excess Weapons Plutonium" by the Committee on International Security and Arms Control of the U.S. National Academy of Sciences, the 1995 PCAST review of cooperative programs to improve nuclear materials protection, control, and accounting (MPC&A), the 1995 report of the American Nuclear Society on "Protection and Management of Plutonium", and the continuing work of the Joint U.S.-Russian Plutonium Disposition Options Study. The recommendations we offer here integrate ideas developed in that other work with our own intensive joint reflection on what could and should be done now to address, more effectively and cooperatively, this compelling international-security problem.

In what follows, we first provide a more extended description of the technical and political issues that form the background for our recommendations. Then we present the recommendations in a format that provides a few sentences of explanation and justification for each one.

BACKGROUND FOR THE RECOMMENDATIONS

The Character of the Problem

Dismantlement of nuclear weapons rendered surplus by the end of the Cold War and by associated arms-control agreements and initiatives has been proceeding at rates of 1500-2000 nuclear weapons per year in each of our two countries for the past several years. These dismantlement activities reflect a welcome reduction in the danger of large-scale nuclear war that loomed over civilization for most of the second half of the 20th century. We assume, in this report, that the United States and Russia will continue on their agreed path of nuclear arms reductions, that both countries will continue to pursue their agreed goal of making these reductions irreversible, and that neither nation will take steps that could contribute to a reversal of these reductions (such as abrogating or undermining the Anti-Ballistic Missile Treaty). Should the current arms reductions be stopped or reversed, the amount of fissile material considered excess to military needs might be substantially reduced.

Dismantlement of surplus nuclear weapons creates not only new security benefits, but also a new set of security challenges: how to manage, protect, and ultimately utilize or otherwise dispose of the nuclear-explosive materials removed from the weapons, in ways that minimize the chance

that these materials will ever be re-used for nuclear weaponry by the original possessor nations, by other nations, or by subnational groups.

The nuclear-explosive materials emerging from the weapon-dismantlement process comprise both plutonium and highly enriched uranium (HEU). The United States has determined that over 50 metric tonnes of the plutonium in its stockpile is excess to military needs, along with 175 tonnes of HEU. The corresponding quantities in Russia are likely to be the same or larger, given the larger Russian stockpiles of these materials. Modest quantities of either material by itself — in the range of 4 to 6 kilograms of plutonium or 15 to 20 kilograms of HEU — would suffice to make a "simple" fission bomb (or, in the hands of sophisticated bomb builders, a more advanced and powerful one).

Although the quantities of excess HEU are larger than those of plutonium, and although the HEU would be somewhat easier for inexperienced bomb-makers to use in simple nuclear weapons, the disposition problem for plutonium is ultimately a more difficult one than that for HEU. This is because HEU can easily be blended with the nonexplosive uranium isotope U-238 to make low-enriched uranium (LEU) that can be used economically as fuel in the most widely employed types of nuclear power reactors, and because reversing this process to recover weapon-usable HEU from the LEU fuel requires sophisticated and costly uranium-enrichment technology possessed by relatively few countries.

While plutonium can also be blended with U-238 to make fuel usable in ordinary power reactors, this process is so costly that the resulting mixed-oxide (MOX) fuel is not economically competitive with LEU fuel, at present, for use in most currently operating reactors, even if the plutonium itself is "free". And the process is also much easier to reverse (to recover weapon-usable plutonium from MOX), requiring only chemical separation techniques, compared to the isotopic separation (enrichment) technology required to reverse the HEU-to-LEU transformation. Because nearly all mixtures of isotopes of plutonium can be used to fabricate nuclear explosives (except nearly pure Pu-238, which exists in only modest quantities), weapon plutonium cannot be "denatured" isotopically in a manner analogous to blending HEU with U-238.

Whether plutonium or HEU, however, the nuclear-explosive materials removed from surplus nuclear weapons are alike in posing requirements for a combination of security and transparency throughout four stages of the management process: (1) de-mounting, transporting, and dismantling the weapons; (2) interim storage of the nuclear-explosive materials extracted during dismantlement; (3) processing and/or utilization of these materials in ways that reduce the potential for their re-use in weapons; and (4) long-term disposition and protection of all the potentially weapon-usable residuals from whatever processing and utilization has taken place.

Current Status of Management Efforts in the United States and Russia

Since the time, at the beginning of the 1990s, when the full dimensions of the problem of managing the nuclear-explosive materials from surplus nuclear weapons began to be widely recognized, the problem has been extensively studied in both countries (and elsewhere); it has been discussed in detail by our Presidents and other heads of state in bilateral and multilateral summits, and in the Gore-Chernomyrdin meetings; and various programs for dealing with it — including joint programs — have been initiated. The progress resulting from these studies, top-level discussions, and programs has been substantial, but much more needs urgently to be done. In what

follows, we review the current status of management efforts in relation to each of the four stages of management defined above.

STAGE 1. Substantial rates of de-mounting, transporting, and dismantling surplus nuclear weapons are underway. US-Russian cooperation under the Nunn-Lugar framework has significantly improved the security of nuclear weapons in transport, and cooperation to improve the accounting systems and physical protection measures for nuclear warheads prior to dismantlement is now underway. There is as yet no direct cooperation in relation to the dismantlement of nuclear warheads themselves. While the U.S. and Russian Presidents and other officials have agreed in principle to carry out mutual exchanges of information on weapons stockpiles and fissile material inventories, and reciprocal inspections of certain types of facilities, none of these transparency measures have yet been implemented.

STAGE 2. With respect to interim storage of the nuclear-explosive materials, the United States has adequate secure capacity for plutonium at its Pantex facility near Amarillo, Texas, and for HEU at its Y-12 facility at Oak Ridge, Tennessee, but is also considering building new, modern facilities for this purpose. The need for additional storage capacity on the Russian side will be met in substantial part by a new facility now under construction at the Mayak site, funded jointly with Nunn-Lugar funds from the United States and Minatom funds in Russia. After substantial initial delays, cooperation on this facility is moving forward, though construction remains behind schedule and the facility is unlikely to open in 1998 as originally projected.

Beyond the Mayak project, wide-ranging cooperative programs are underway — involving the US Department of Energy and the Russian Ministry of Atomic Energy (Minatom), the US Nuclear Regulatory Commission and the Russian Gosatomnadzor (GAN), and direct lab-to-lab cooperation between nuclear laboratories and facilities on both sides — to improve material protection, control, and accounting (MPC&A) at facilities, across Russia, holding plutonium or HEU. These programs address not only the plutonium and HEU removed from surplus nuclear weapons but also the inventories of these materials in civilian and military research facilities, nuclear-fuel production facilities, and naval-reactor fuel-storage sites. US support for this MPC&A work has increased from only a few million dollars two years ago to about $85 million in Fiscal Year 1996; further expansion is warranted to cover all the relevant facilities and to increase the pace of improvements.

STAGE 3. With respect to processing and/or utilization of the surplus nuclear materials in ways that reduce the potential for their re-use in weapons, actual progress in implementation has been made only in the case of HEU (which as noted above is an easier case than plutonium). The HEU Purchase Agreement concluded in February 1993, under which the United States will purchase 500 tons of Russian HEU in blended-down form over 20 years and market this material as nuclear-reactor fuel, is now being implemented, after initial delays: 6 tons of HEU was blended down and shipped to the United States in 1995, and the corresponding figure in 1996 will be 12 tons. The United States also plans to blend down most of its own surplus-weapons HEU for eventual sale as reactor fuel (with the remainder to be blended and disposed of as waste). Transparency arrangements for the blending-down operations were agreed just before the April 1996 P-8 nuclear summit and full implementation of these measures is expected to begin shortly. The pace of US purchases of Russian HEU could and should be increased, and the pace of blending-down operations on both sides could and should be accelerated — under fully implemented

transparency measures — perhaps going even beyond the pace of the sales themselves.

The more difficult problem of how best to process and/or utilize surplus weapons plutonium in order to reduce the potential for its re-use in weapons has been studied extensively in the United States and Russia, and jointly, but no decision has been made yet in either country on how to proceed. More specifically:

- A major study conducted by the US National Academy of Sciences (NAS) for the US government between 1992 and 1995 concluded that an appropriate goal for this stage of plutonium disposition is to convert it to forms no easier to use for nuclear weaponry than is the plutonium in spent fuel from contemporary nuclear-power reactors.[1] The NAS study concluded that the two fastest and cheapest options for achieving this "spent-fuel standard" are: (a) fabrication of the weapons plutonium into MOX fuel and use of this fuel in a "once-through" fuel cycle in power reactors of currently operating types; and (b) immobilization of the plutonium together with intensely radioactive fission products in massive glass logs of the type already planned for use in the United States for immobilization of military high-level radioactive wastes. The NAS study also concluded that security considerations dictate moving toward implementation of one or both of these approaches as rapidly as possible, in both the United States and Russia, as opposed to prolonging the period of interim storage.

- The US Department of Energy (DOE) has undertaken a major program (costing nearly $100 million in the current budget year) of analyses and experiments to study the advantages and disadvantages of the various options for disposition of excess US weapons plutonium. This effort, which was substantially shaped by the recommendations of the NAS study, is generating three major reports — a Technical Summary Report, a Programmatic Environmental Impact Statement, and a Nonproliferation and Arms Control Impact Assessment — all due to be released later this year in connection with a schedule in which a "preferred alternative" is to be announced in November and a formal "record of decision" generated in December. DOE is examining the reactor and immobilization options highlighted in the NAS study, as well as a third option also identified as a possibility in the NAS study, burial in deep boreholes.

- Russia's program of research and analysis to support a decision (and its implementation) on plutonium disposition beyond interim storage is currently receiving less funding than the U.S. program. It includes: analysis and tests relating to weapon-plutonium/MOX use in existing VVER-1000 light-water reactors and the existing BN-600 fast-neutron reactor; plans to construct larger BN-800 fast-neutron reactors (for which, however, sufficient funding is not yet available); and studies of high-temperature gas reactor systems. In

[1] This "spent-fuel standard" has now been accepted as a reasonable yardstick in a wide variety of other studies of plutonium disposition, in the United States and elsewhere. It refers to the combination of barriers, against re-use of the contained plutonium, that characterizes typical spent fuel from currently operating commercial reactors — the mass and bulk of the fuel elements, their radiation field, the low concentration of the contained plutonium and the difficulty of separating it chemically from the materials with which it is intermixed, and the deviation of the plutonium's isotopic composition from the ideal for weapons use. Achieving the spent-fuel standard means that the material's characteristics pose difficulties for theft and weapons use of the plutonium that are comparable to those associated with typical spent fuel — which itself varies with reactor type and the specific fuel's history inside and outside the reactor — not that the material needs to be identical, in each category of barrier, to a particular type of spent fuel.

addition, Russia has joint studies underway with France and Germany on MOX use in light-water and fast-neutron reactors, a joint study with Canada on the use of Russian weapon plutonium in CANDU reactors, a joint study with the U.S. firm General Atomics on the use of high-temperature gas reactors, and a joint US-Russian government-to-government cooperative study analyzing the technical characteristics of a wide variety of reactor, immobilization, and geologic-disposal options (without, however, drawing conclusions as to which option is best, or making recommendations).

In addition to these national and bilateral projects, the April 1996 P-8 nuclear summit called for an assessment of options for the disposition of excess weapons plutonium — and recommendations concerning practical next steps — by an international experts meeting in late October 1996. Follow-up meetings in 1997 are likely. The findings of this Independent Bilateral Commission will provide an important input to that experts' meeting, and the work that will follow it.

STAGE 4. Once the plutonium disposition campaign has transformed the excess weapons plutonium into forms that are no easier to use in nuclear weapons than plutonium in spent fuel, the weapons-plutonium disposition campaign itself can be said to be complete. The urgent and unique security problem posed by vast stockpiles of excess weapons plutonium will then have been reduced to one part of the broader, longer-term problem of management of spent fuel and other nuclear wastes. The forms resulting from plutonium disposition will be suitable for safe and secure storage for decades, while approaches for their final fate are being prepared. Nevertheless, in the long run, whatever plutonium remains in spent fuel or in immobilized waste forms will need to find final resting places with appropriate levels of protection against intruders, of isolation from the biosphere, and of monitoring to verify that the protection and isolation are being maintained. This fourth and last stage of the management process might involve direct disposal of spent fuel and immobilized waste forms in geologic repositories, or it might involve additional treatment (with or without reprocessing, in advanced reactors or accelerator-driven subcritical reactors, or otherwise) to fission more of the plutonium or to increase the durability of its packaging, before it is emplaced in its final resting place. In this fourth stage the residuals from the utilization or other disposition of military plutonium will represent only a fraction of a larger quantity of similar residuals from civilian nuclear-energy activities (as discussed below) and from the management of other military radioactive wastes. Extensive studies of the options for ultimate disposal of these similar waste-forms are underway in Russia, the United States, and elsewhere; and, while the addition of the residuals from disposition of military plutonium adds a few complications to these studies, there is much less urgency about making the final decisions than there is about the three prior stages of nuclear-explosive materials management.

Relation of the Materials-Security Problem and the Nuclear-Energy Problem

The issues of nuclear-materials protection and of civilian nuclear-energy generation are interconnected in a variety of ways, most obviously in that military plutonium and HEU are potential civilian nuclear fuels and plutonium and HEU from civilian nuclear-energy activities are potential bomb materials. More quantitatively and specifically:

- Nuclear-energy generation has already produced more than 1,000 tons of "reactor-grade" plutonium (which despite this terminology could be used for the production of either crude

or sophisticated nuclear weapons), and an additional 70 tons are produced each year. Hence, the question of how to protect surplus military plutonium must be seen in the context of a considerably larger and still growing quantity of civilian plutonium.

- The roughly 100 tonnes of military plutonium expected to be surplus by 2003 does not represent a very large energy resource compared to other sources of nuclear fuel. (This amount of plutonium corresponds to fuel for about 100 reactor-years of operation with current technologies.) Thus, from the global point of view, considerations of conserving energy resources should not play a very large role in deciding how best to reduce the security risks that the military plutonium poses.

- The part of the civilian plutonium that has been separated from fission products in order to make the plutonium recyclable as reactor fuel (amounting to over 150 tonnes today) is not much more difficult to use in nuclear explosives than is separated military plutonium and so requires a comparable degree of protection. The United States and Russia should cooperate with each other and with other countries to ensure that stockpiles of separated civilian plutonium and HEU worldwide are publicly declared to enhance transparency, placed under international safeguards, and handled with stringent standards of material, protection, control, and accounting — to be developed — as appropriate to the threat of theft or diversion. The disposition of accumulated stockpiles of separated reactor plutonium is also an important issue that eventually must be addressed.

- The larger quantity of civilian plutonium that remains embedded along with fission products in spent reactor fuel poses smaller security risks, and reducing the risks of surplus military plutonium to this "spent-fuel standard" is a suitable interim goal for disposition of this material. One obvious way to achieve this goal is to put the military plutonium into reactors in fresh fuel, so that after burnup of part of the plutonium in power generation the rest emerges in spent fuel resembling that from other civilian nuclear-energy generation.

- In the long run, the security risks from spent fuel will increase as the fission-product radioactivity decays and the technical sophistication needed to separate out the plutonium spreads. It may then be decided to protect spent fuel (including the spent fuel from reactor disposition of military plutonium) to a greater degree than has been thought necessary up until now, to accelerate the process of placing it in geologic repositories, or to burn up more of the contained plutonium using advanced reactors or accelerator-driven systems.

- If nuclear energy is to make a large contribution to world electricity generation over the long run, it will be necessary either to tap the vast but dilute uranium resources in seawater or to recycle large quantities of bomb-usable plutonium "bred" from uranium-238 (or, equivalently, bomb-usable uranium-233 "bred" from thorium). Recycling plutonium or uranium-233 on such a large scale without creating significant security risks is likely to require MPC&A measures at least as challenging to implement as those being contemplated currently for military plutonium, or to require the use of proliferation-resistant advanced reactor and fuel-cycle technologies that are not yet fully developed.

Notwithstanding these linkages, it is not appropriate to entangle the short-term decisions needed to minimize the immediate security hazards of surplus military plutonium with longer-term

decisions about the optimum technologies for meeting future nuclear energy needs. There is much uncertainty and controversy about how much energy will be required from nuclear sources in the future and about which nuclear-energy technologies will prove most attractive for meeting the nuclear-energy needs that materialize. These uncertainties and controversies may take decades to resolve. To delay decisions about the disposition of surplus military plutonium until the shape of the nuclear-energy future is clarified is to countenance unacceptable prolongation of the higher security risks of interim storage of this material (as compared with the improved protection against theft and diversion, and the positive "signal" for arms-control and nonproliferation, that would result from processing it as quickly as practicable into spent fuel or waste-bearing glass logs).

This is not to say that the future of nuclear energy should be ignored. Because it is possible that our countries and the world will need a significant long-term contribution from this energy source, prudence dictates vigorous research programs to explore a range of improved reactor and fuel-cycle options from which to select if their characteristics prove attractive in comparison to those of nonnuclear alternatives (which also need to be thoroughly explored). The United States and Russia, working with other countries, should expand their research on long-term nuclear-energy options — such as advanced light-water reactors, high-temperature gas reactors, and new fast-reactor types — as part of overall energy-research portfolios that also include expanded research on nonnuclear energy options. The research on advanced nuclear energy systems should incorporate, as a specific goal, minimizing the risk of theft of nuclear materials and other proliferation hazards.

When and if new advanced-reactor systems are constructed, on their merits as energy options it may prove desirable to employ them in the disposition of any surplus military plutonium that remains at the time, or in further reducing the risks from spent fuel or other waste forms containing both civilian and previously dispositioned military plutonium. But disposition, to the spent-fuel standard, of the surplus military plutonium that exists today should proceed in the meantime, using the existing reactor technologies and immobilization technologies that can most quickly, safely, and inexpensively be adapted to this task.

RECOMMENDATIONS

A. Overall Approach

A.1 THE U.S. AND RUSSIAN GOVERNMENTS, WITH SUPPORT AND COOPERATION FROM THE INTERNATIONAL COMMUNITY, SHOULD TAKE ADDITIONAL STEPS — BEYOND THOSE ALREADY UNDERWAY — TO MORE RAPIDLY REDUCE THE SECURITY RISKS POSED BY EXCESS WEAPONS PLUTONIUM. This would include acceleration of work to provide secure, monitored storage for this material, in parallel with an accelerated program to proceed with its transformation into forms no easier to use for nuclear weapons than is the plutonium in typical spent fuel from commercial reactors (the "spent fuel standard"). Speed in proceeding with these efforts is critical both for minimizing vulnerability of the material to theft and for signaling promptly the seriousness of U.S. and Russian commitments to remove the plutonium permanently from weapons use.

A.2 TWO APPROACHES TO REDUCING THE WEAPONS-USABILITY OF THE EXCESS PLUTONIUM TO THE SPENT-FUEL STANDARD — USING THE PLUTONIUM IN MIXED-

OXIDE (MOX) FUEL FOR BURNING ONCE-THROUGH IN CURRENTLY OPERATING NUCLEAR POWER REACTORS, AND VITRIFYING THE PLUTONIUM TOGETHER WITH FISSION PRODUCTS IN GLASS LOGS OF THE TYPE PLANNED FOR USE IN IMMOBILIZING HIGH-LEVEL RADIOACTIVE WASTES FROM THE DEFENSE-PRODUCTION COMPLEX — SHOULD BOTH BE BROUGHT TO THE POINT OF OPERABILITY AT LARGE-SCALE AS RAPIDLY AS PRACTICABLE IN BOTH COUNTRIES. These are the surest, least costly, and potentially fastest ways to achieve the spent-fuel standard for the quantities of weapons plutonium likely to be deemed excess to military needs in our two countries. Reactors suitable for using MOX fuel exist in both countries — the VVER-1000 light-water reactors and the BN-600 fast reactor in Russia and various light-water reactor types in the United States — of which several in each country would need to be used if the plutonium in these quantities is to be brought to the spent-fuel standard by the year 2020. Both countries also have well developed programs for immobilization of radioactive wastes in glass. The two approaches should be pursued in parallel to provide insurance against encountering unforeseen obstacles to the large-scale utilization of either one and because the vitrification process is likely to prove useful for disposal of certain plutonium forms that would be difficult to use in MOX fuel.

A.3 THE HIGHEST STANDARDS OF MATERIALS PROTECTION, CONTROL, AND ACCOUNTING — AS APPROPRIATE TO THE THREAT OF THEFT OR DIVERSION — SHOULD BE APPLIED TO EXCESS WEAPONS PLUTONIUM AT ALL STORAGE, PROCESSING, AND TRANSPORT STEPS UNTIL IT REACHES THE SPENT-FUEL STANDARD. THE SAME IS TRUE OF HEU UNTIL IT HAS BEEN BLENDED DOWN TO ENRICHMENT LEVELS TOO LOW FOR USE IN NUCLEAR EXPLOSIVES. Ongoing US-Russian cooperative programs to improve MPC&A need to be expanded and accelerated in order to reach these standards in a timely way.

A.4 INCREASED TRANSPARENCY ABOUT THE INVENTORIES OF NUCLEAR WARHEADS AND NUCLEAR-EXPLOSIVE MATERIALS POSSESSED BY THE UNITED STATES AND RUSSIA, AND ABOUT THE STEPS BEING TAKEN TO REDUCE THESE INVENTORIES, SHOULD BE PURSUED. It would build confidence in our two countries and around the world that our ongoing arms-reduction processes are significant and unlikely to be reversed, improve the prospects for deeper cuts in our two nuclear arsenals and for participation of the other nuclear-weapon states in the arms-reduction process, and enhance our capacity to play leadership roles in global nonproliferation efforts. We assume that a regime of increased transparency about these matters would include periodic declarations of the quantities (increasing over time) of weapons and nuclear-explosive materials deemed excess to military needs, along with increasing bilateral and multilateral monitoring of warhead dismantlement and subsequent nuclear-materials management and disposition steps. Achieving these aims will require dealing creatively and constructively with the inherent tensions between the need for openness and the need to protect weapon-related secrets that could help proliferators.

A.5 THE U.S. AND RUSSIAN PROGRAMS OF WARHEAD DISMANTLEMENT AND MANAGEMENT AND DISPOSITION OF THE ASSOCIATED NUCLEAR-EXPLOSIVE MATERIALS SHOULD CONTINUE TO PROCEED IN PARALLEL, SEEKING TO COMPLETE COMPARABLE STEPS IN THIS PROCESS ON COMPARABLE TIME SCALES, AND TO REACH EQUIVALENT REMAINING QUANTITIES OF PLUTONIUM AND HEU IN THE TWO MILITARY STOCKPILES. For reasons of symmetry and mutual confidence, it is

important that neither the United States nor Russia leave its excess plutonium in storage in forms that could be readily returned to weapons while the other moves forward in transforming its excess plutonium into spent fuel or other forms equally unusable in nuclear weapons. And, ultimately, just as the START treaties called for reductions to equal levels of deployed strategic nuclear weapons, the goal of plutonium disposition should be to reduce in parallel to roughly equivalent remaining quantities of plutonium and HEU in military stockpiles.

A.6 INCREASED FUNDING SHOULD BE PROVIDED ON AN URGENT BASIS FOR ANALYSIS, DEVELOPMENT, TESTING, AND DEPLOYMENT OF THE SYSTEMS FOR MANAGEMENT AND DISPOSITION OF WEAPONS PLUTONIUM AND HEU AS DESCRIBED HERE. Provision of such funding should be considered a highly cost-effective investment in national and international security. The problem of funding is particularly acute in Russia, where badly needed activities are being delayed by lack of money. We believe that the weight of the combined leadership of the two Presidents in calling attention to the need and the opportunity to address this problem as a matter of national priorities can be decisive in generating the needed funding.

B. Storage, Protection, Control, and Accounting

B.1 THE U.S. AND RUSSIAN GOVERNMENTS SHOULD CONTINUE TO COOPERATE IN PROVIDING SECURE STORAGE FOR FISSILE MATERIALS REMOVED FROM NUCLEAR WEAPONS, AND IN IMPROVING SECURITY AND ACCOUNTING FOR ALL SEPARATED PLUTONIUM AND HEU. We recommend that sufficient funding should be provided to complete construction of the modern safe and secure storage facility at Mayak, with the goal of opening the facility in 1998 or 1999. In addition, we recommend expanding and accelerating the successful cooperation underway to modernize Russia's systems for security and accounting for plutonium and HEU. (We think the resources committed to this cooperative work should be increased by at least 50 percent above the 1996 levels.) In keeping with the program announced at the Moscow Nuclear Safety and Security Summit in April of 1996, moreover, we urge that cooperation be substantially expanded in the area of prevention of smuggling of nuclear materials, including joint work to ensure that relevant police, intelligence, customs, and border patrol forces are appropriately trained and equipped, and working together effectively.

B.2 THE UNITED STATES AND RUSSIA SHOULD MOVE QUICKLY TO IMPLEMENT AND EXPAND ON THE RECIPROCAL INFORMATION EXCHANGES AND MUTUAL INSPECTIONS RELATED TO NUCLEAR STOCKPILES THAT HAVE BEEN AGREED TO IN PRINCIPLE, TO HELP ENSURE THE TRANSPARENCY AND IRREVERSIBILITY OF NUCLEAR ARMS REDUCTIONS. We believe that the United States and Russia should work more expeditiously to implement the exchange of data on stockpiles of nuclear warheads and fissile materials agreed to by President Clinton and President Yeltsin in September 1994 during the first quarter of 1997, as well as to implement the broader transparency agenda agreed to by the two Presidents at their summit in May 1995. In this connection, discussions should be resumed toward early completion of an Agreement for Cooperation to provide the legal basis in both countries for exchange of those types of secret information needed to permit the bilateral measures agreed to. (In order to assuage concerns, an initial agreement on classified information might be limited to those specific types of information needed for monitoring plutonium and HEU from dismantled weapons.) The two sides should also accelerate their joint efforts to develop measures to verify the

dismantlement of nuclear weapons — and to confirm the inventories of plutonium and HEU removed from them — without compromising sensitive information or imposing undue intrusiveness or costs, with the goal of conducting initial demonstration experiments by mid-1997 and having a full bilateral regime in place during 1998.

B.3 AS THE P-8 LEADERS AGREED AT THE MOSCOW NUCLEAR SAFETY AND SECURITY SUMMIT IN APRIL OF 1996, EXCESS PLUTONIUM AND HEU SHOULD BE PLACED UNDER INTERNATIONAL SAFEGUARDS AS QUICKLY AS PRACTICABLE. For material now in unclassified forms, this process should be able to move forward rapidly in both countries. For plutonium and HEU in classified forms (such as components from dismantled warheads) the United States and Russia should work together with the IAEA to develop modified safeguards approaches that would permit credible international monitoring of these materials without revealing information that could contribute to proliferation. In particular, the Commission believes that declassification of the average amount of plutonium in a weapon component or "pit", and of the key features of the radiation signature from such components, would pose little or no threat to security while allowing the development of a credible safeguards regime in which the IAEA could certify to the world that specified quantities of excess plutonium were under its monitoring and were being used only for peaceful purposes. The two countries should seek to develop a credible monitoring approach for classified materials, acceptable to both of them and to the IAEA, by the end of 1997 and begin implementing it in 1998.

B.4 RUSSIA, LIKE THE UNITED STATES, SHOULD BEGIN DECLARING SPECIFIC QUANTITIES OF NUCLEAR MATERIAL TO BE EXCESS TO ITS MILITARY NEEDS. We hope that declarations of further material as excess will occur regularly in the future on both sides.

B.5 BOTH COUNTRIES SHOULD SEEK TO MAKE ADDITIONAL TENS OF TONS OF MATERIAL ELIGIBLE FOR INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA) SAFEGUARDS DURING 1997. We also believe that the United States and Russia should pursue new safeguards agreements with the IAEA that, compared to the current voluntary offer agreements, would make removal of the materials from safeguards more difficult. This and other steps recommended here toward increased international transparency would help assure the world community that the materials removed from excess nuclear weapons are not being re-used for military purposes and that any reversal of this arms-reduction process would be rapidly detected.

C. Disposition of Excess Plutonium

C.1 THE UNITED STATES AND RUSSIA SHOULD MOVE PROMPTLY TO SELECT, AUTHORIZE, FUND, AND BRING TO THE POINT OF OPERABILITY AT THE NECESSARY SCALE THE SPECIFIC VARIANTS OF BOTH THE MOX/CURRENT-REACTOR APPROACH AND THE VITRIFICATION-WITH-WASTES APPROACH THAT WILL BE USED FOR DISPOSITION OF EXCESS WEAPONS PLUTONIUM TO THE SPENT-FUEL STANDARD IN EACH COUNTRY. This will entail: (a) pushing to completion, by mid-1997, the ongoing processes for selecting, in each country, the least-delay, least-cost variants of the two approaches, consistent with effective nonproliferation controls and protection of environment, safety, and health; (b) cooperation of the executive and legislative branches of government in both countries to designate plutonium disposition to the spent-fuel standard as a top national-security priority, and to enact legislation authorizing and providing funding for the necessary activities; and

(c) establishing, within the independent nuclear-regulatory agencies in both countries, well funded divisions dedicated to the task of providing timely review and licensing of the needed facilities and operations to make and use MOX fuel and to vitrify plutonium with wastes. Of course, each country will decide for itself how its excess plutonium will finally be divided between the two disposition methods, based on the circumstances in that country. But there is good reason for both methods to be available to both countries: moving forward with the two approaches in parallel will offer greater confidence in the overall program, as each approach could provide a backup in the event of unexpected problems with the other; and the United States and Russia each have excess plutonium in some forms well suited to use as reactor fuel and in other forms better suited for vitrification.

C.2 THE TWO GOVERNMENTS SHOULD ESTABLISH APPROPRIATE MANAGERIAL STRUCTURES — ONE IN EACH COUNTRY, AS WELL AS AN INTERNATIONAL FRAMEWORK FOR MANAGING JOINT ACTIVITIES — TO BE RESPONSIBLE TO THE PRESIDENTS FOR CARRYING OUT THIS WORK TO SPECIFIED ENDPOINTS ON A SPECIFIED TIMETABLE. To leave this program at the mercy of the distractions and competing priorities within existing bureaucratic structures is to ensure that too little will be accomplished, too slowly.

C.3 THE UNITED STATES AND RUSSIA SHOULD EXPEDITE AND EXPAND THEIR TECHNICAL COOPERATION FOCUSED ON DEVELOPING, TESTING, AND DEMONSTRATING RAPIDLY IMPLEMENTABLE AND COST-EFFECTIVE MEANS FOR CONVERTING PITS TO OXIDE SUITABLE FOR MOX-FUEL FABRICATION, AND FOR PROCESSING OTHER PLUTONIUM FORMS TO PREPARE THEM FOR DISPOSITION. Neither the United States nor Russia has an industrial-scale facility for conversion of plutonium metal "pits" to other forms. This is an essential step for all the plutonium disposition options under consideration, and will also make it possible to place this material under the same type of IAEA safeguards as are applied in non-nuclear-weapons states. The two countries have a strong common interest in determining, and then deploying, the least-cost, least-delay technology for implementing this mission while ensuring nonproliferation and protection for the environment, safety, and health. Both countries have extensive relevant experience, and have recently begun exploring areas for potential cooperation in this high-priority task. This cooperation should be expedited, with the goal of rapidly carrying out prototype-scale demonstrations in both countries sufficient to provide the information needed for licensing and construction of full-scale capacity. Technologies for ensuring effective material control and accounting throughout this process are a particularly high priority for cooperation in this area.

C.4 THE UNITED STATES AND RUSSIA, ALONG WITH OTHER COUNTRIES WITH RELEVANT EXPERIENCE, SHOULD EXPAND THEIR TECHNICAL COOPERATION RELATED TO ANALYZING, TESTING, LICENSING, AND DEMONSTRATING THE FABRICATION OF MOX FUEL MADE FROM WEAPONS PLUTONIUM AND THE USE OF THIS FUEL IN CURRENTLY OPERATING REACTORS. MOX fuels have been fabricated and used at industrial scale in a number of European countries, but there has been no substantial experience anywhere with the fabrication and use of MOX made from weapons plutonium. Preparation for doing this will involve close collaboration among the fuel fabricators, the operators of the reactors and their safety specialists, and the regulators concerning the properties of the weapons-plutonium/MOX fuel and its behavior in the reactors. Issues that must be addressed include the effects of this fuel type on core physics and thermal hydraulics — and the behavior of

the fuel itself in terms of, e.g., fission-product retention and fuel-cladding interaction — under normal and accident conditions, in a all of the reactor types being considered for use in the disposition mission (i.e., VVER-1000 light-water reactors and the BN-600 fast reactor in Russia, various light-water reactor types in the United States). The results will determine, for each reactor type, the feasible combinations of weapons-plutonium percentage in MOX, fraction of MOX in the reactor core, and modifications to reactor hardware and software needed to maintain acceptable safety characteristics; and this will determine, in turn, how many reactors of what types can process how much weapons plutonium how quickly. The substantial analytical and experimental effort involved can and should be greatly facilitated — and accelerated — by international cooperation that includes sharing and comparison of computer codes, shared access to experimental facilities and to the results of tests in these, and so on.

C.5 THE UNITED STATES, RUSSIA, AND THE INTERNATIONAL COMMUNITY SHOULD BEGIN NOW TO ADDRESS THE LARGEST OBSTACLE TO PROGRESS ON PLUTONIUM DISPOSITION BEYOND INTERIM STORAGE, WHICH IS FINANCING AND CONSTRUCTING ADEQUATE CAPACITY IN THE TWO COUNTRIES FOR PROCESSING PLUTONIUM PITS INTO PLUTONIUM OXIDE AND FOR FABRICATING PLUTONIUM AND URANIUM OXIDES INTO MOX FUEL. Russia and the United States not only lack industrial-scale capacity for conversion of pits to oxide, as noted above; they also lack industrial-scale capacity for fabricating the plutonium oxide and uranium oxide into MOX fuel. Large investments will be needed to provide these facilities — in the range of 1 billion dollars — which Russia in particular will not be able to finance on its own. A plan should be developed and implemented for international cooperation in financing the needed facilities in Russia. (One option that should be explored is financing these facilities by borrowing against the revenues from future sales, in the world market, of blended-down Russian HEU beyond the 500 tons already agreed in the US-Russian "uranium deal"; this approach would require the Western countries to open their markets to the additional fuel from which the revenues would serve this purpose.) As soon as financing has been obtained, bids should be solicited for the construction of the needed MOX capacity in both countries.

C.6 IN ORDER TO FACILITATE RAPID INITIATION OF PLUTONIUM DISPOSITION IN MOX FUEL, CONTRACTS SHOULD BE SOUGHT WITH EXISTING EUROPEAN MOX FABRICATION PLANTS TO PRODUCE INITIAL BATCHES OF WEAPON-PLUTONIUM MOX FOR U.S. AND RUSSIAN REACTORS, WHILE MOX FABRICATION FACILITIES IN THE UNITED STATES AND RUSSIA ARE BEING PREPARED. This will require taking steps to ensure that the weapons plutonium is as well protected, controlled, and accounted for in the country or countries doing this fabrication, and in transport, as it would be under the criteria described here for MPC&A in the United States and Russia.

C.7 BECAUSE OF THE URGENCY OF PROCEEDING WITH DISPOSITION TO THE SPENT-FUEL STANDARD, BOTH THE UNITED STATES AND RUSSIA SHOULD BEGIN THEIR PROGRAMS FOR THIS PURPOSE USING CURRENTLY OPERATING REACTORS. As already noted, both the United States and Russia have significant numbers of current-generation reactors in operation which could potentially use excess weapons plutonium as MOX fuel. Implementation of the MOX-reactor option for plutonium disposition can and should begin by using some of these existing reactors. (Waiting for new reactors to be built before beginning this mission would be a recipe for intolerable delay.) We recommend, in fact, that steps be taken now to select

— and to formalize arrangements with — the specific nuclear power stations in both countries where plutonium disposition using MOX fuel would begin.

C.8 WORK SHOULD BE CONTINUED TO PREPARE FOR THE POSSIBILITY OF WEAPON-PLUTONIUM/MOX USE BEYOND THE U.S. AND RUSSIAN REACTORS NOW PLANNED FOR THE FIRST PHASE OF THE REACTOR-DISPOSITION APPROACH AND/OR BEYOND THE PARTIAL MOX CORE LOADINGS LIKELY TO BE USED INITIALLY IN THESE REACTORS. We believe that partial-MOX cores in a number of U.S. light-water reactors, Russian VVER-1000 light-water reactors, and the Russian BN-600 fast reactor will prove to be the fastest route to startup of reactor-MOX disposition of weapons plutonium at significant scale, and that, depending on the number of reactors in each country actually prepared and licensed for this mission, this route may also suffice (given adequate MOX-fuel fabrication capacity) to process all of the weapons plutonium declared excess in the two countries within about two decades of beginning to load weapons-MOX into the reactors. As a backup in case unforeseen obstacles reduce the number of reactors in these categories that can be used — or in case additional weapons plutonium is declared excess or, for other reasons, there is need to speed up the rate at which plutonium is loaded into reactors — it would be desirable to be able to use additional reactors and/or higher core loadings of MOX for this purpose. Reactors that could be considered for backup or augmentation of the U.S. and Russian reactor-MOX disposition programs include Canada's heavy-water-moderated, channel-type (CANDU) reactors and the VVER-1000 light-water reactors in Ukraine. There are complications that would need to addressed in order to implement these options, but we believe studies of using them should be continued as insurance against shortfalls in plutonium-disposition capacity elsewhere. Finally, disposition capacity could be increased in any given number of reactors if the plutonium percentage in MOX fuel elements and/or the fraction of the cores devoted to MOX fuel were increased; the programs recommended above for analysis, testing, licensing, and demonstration of weapons-MOX/fuel fabrication and use in currently operating reactors should be extended to determine the feasibility of such increases in plutonium loadings.

C.9 THE UNITED STATES AND RUSSIA, ALONG WITH OTHER COUNTRIES WITH RELEVANT EXPERIENCE, SHOULD EXPAND THEIR TECHNICAL COOPERATION RELATED TO ANALYZING, TESTING, LICENSING, AND DEMONSTRATING VITRIFICATION OF PLUTONIUM WITH HIGH-LEVEL RADIOACTIVE WASTES. The high desirability of proceeding with both the vitrification and the reactor-MOX approaches to plutonium disposition in both countries was emphasized above. The United States, Russia, and several other countries have industrial-scale experience with vitrification of nuclear wastes, but there is as yet no large-scale experience with incorporating large quantities of plutonium in such vitrified wastes. Elements of an expanded and accelerated cooperative effort to analyze and demonstrate relevant technologies should include efforts to determine and certify a combination of glass composition, plutonium loading, and melter design adequate for the purpose (including considerations of avoiding accidental criticality in the melter or, subsequently, in a repository). At least one variant of this approach should be demonstrated at pilot-plant scale in each country as a step toward full-scale operation. In parallel with this analytical, experimental, and licensing effort, the U.S.-Russian cooperative project, just beginning, for clarifying the quantities and characteristics of those plutonium forms in each country that would be more suitable for vitrification than for MOX-fuel production should be expanded and completed.

C.10 THE NUCLEAR-REGULATORY AGENCIES IN BOTH COUNTRIES SHOULD BE DIRECTED — AND FUNDED — TO DEVELOP THE PROCEDURES TO REVIEW AND LICENSE PROMPTLY THE MOX-FUEL FABRICATION PLANTS, REACTORS USING MOX FUELS, AND PLUTONIUM-WITH-WASTE VITRIFICATION PLANTS NEEDED TO IMPLEMENT WEAPONS-PLUTONIUM DISPOSITION. Licensing requirements of the U.S. Nuclear Regulatory Commission and Gosatomnadzor in Russia have the potential to impose substantial delay in the disposition programs. The regulatory agencies will require safety analyses, detailed designs, and experimental data. Early and continuous interaction among regulators, other government agencies, research institutions, and operators of plutonium-disposition facilities will be necessary for the disposition programs to move forward without delay. The regulatory authorities must be adequately funded for these reviews and should be directed to give them high priority.

C.11 THE UNITED STATES AND RUSSIA SHOULD MOVE AS QUICKLY AS PRACTICABLE TO END ADDITIONAL PRODUCTION OF WEAPONS PLUTONIUM, INCLUDING PROVIDING THE NECESSARY FINANCING TO COMPLETE THEIR COOPERATIVE PROJECT TO CONVERT THE CORES OF THE PLUTONIUM PRODUCTION REACTORS AT SEVERSK (TOMSK-7) AND ZELEZNOGORSK (KRASNOYARSK-26). Inasmuch as the purpose of plutonium disposition is to reduce the stockpiles of weapons plutonium stored in forms readily accessible for use in nuclear weapons, ending the addition of new weapons plutonium to these stockpiles should also have very high priority. The United States and Russia have agreed that no newly produced plutonium or HEU will ever again be used in weapons, and have committed themselves, along with their P-8 partners, to "the immediate commencement and early conclusion of negotiations on a non-discriminatory and universally applicable convention banning the production of fissile material for nuclear weapons or other nuclear explosive devices." Weapons-grade plutonium continues to be produced, however, at the three remaining plutonium production reactors in Russia. These reactors continue to operate because they provide needed heat and power for nearby communities, and their spent fuel continues to be reprocessed to separate the plutonium because the spent fuel is not suitable for long-term storage. The United States and Russia are cooperating to design, license, and implement converted cores for these reactors, so that they would no longer produce weapons-grade plutonium. The United States and Russia should act to provide sufficient financing to complete the engineering design of the converted cores during 1997 and implement the conversion of these reactors by 1999. We welcome the decision of the U.S. Congress action to provide necessary funding for this work in fiscal 1997. Additional funding will be required in subsequent years. The existing technical teams implementing this work have been highly successful, and this existing framework for cooperation should be maintained.

C.12 THE UNITED STATES AND RUSSIA SHOULD BEGIN DISCUSSIONS WITH THE GOAL OF REACHING A FORMAL AGREEMENT GOVERNING PLUTONIUM DISPOSITION. A formal agreement setting out the quantities, schedules, and approaches involved in plutonium disposition could do a great deal to ensure that the United States and Russia proceed in parallel, that appropriate nonproliferation controls are maintained, and that sufficient priority is assigned to the plutonium-disposition mission. Such an agreement, particularly if combined with timely action to place the excess material under international safeguards, could do a great deal to increase the credibility of U.S. and Russian plans to irreversibly reduce their stocks of excess material in forms readily usable in weapons; this credibility benefit could be particularly important over the period of roughly a decade before industrial-scale disposition operations can probably begin. In addition, such an agreement may help ensure funding stability: legislatures in both countries are more likely to provide necessary funding if that funding is needed to fulfill an international commitment.

Annex: Planning, Managing, and Financing Disposition of Excess Weapons Plutonium

1.0 Introduction

The body of the report recommends that the United States and Russia should move forward with disposition of excess weapons plutonium to meet the spent fuel standard as quickly as practicable, and that two approaches to achieving that goal — using the plutonium in mixed oxide (MOX) fuel for burning in nuclear power reactors, and vitrifying the plutonium together with fission products in large glass logs — should both be brought into operation at large-scale as rapidly as practicable in both countries. Because of the urgency of proceeding, the reactor option should begin in both the United States and Russian with once-through use in currently operating reactors. (Of course, when and if new advanced-reactor systems are constructed, on their merits as energy options, it may prove desirable to employ them in the disposition of any surplus military plutonium that remains at the time, or in further reducing the risks from spent fuel or other waste forms containing both civilian plutonium and military plutonium whose disposition has already been accomplished.)

The United States has made a formal statement of its intention to pursue this dual-track approach to plutonium disposition, in the Record of Decision announced by the Department of Energy on January 14, 1997. We believe the Russian government should now make a corresponding formal statement of its intention to pursue this dual-track route. Indeed, we recommend that the United States and Russia agree on a joint document formally indicating their mutual intention to pursue this dual-track route at the fastest rate consistent with the availability of funds to do so.

This annex is intended to provide more detail on the steps we believe are necessary to implement this dual-track approach to plutonium disposition. The most essential measures to accomplish this objective are: to develop an effective work plan identifying the steps that need to be taken to accomplish the objective; to establish the necessary institutions to carry out the plan; and to provide the resources needed to get the job done. Individual sections of this annex expand on the report in each of these three areas. Each section includes a principal recommendation for action, which is then followed by supporting text.

First, we recommend the development and implementation of a work plan for bringing three key technologies to full-scale operation as quickly as practicable: disassembly of plutonium weapons components ("pits") and the conversion of these and other plutonium forms to oxide; fabrication of MOX fuel from this oxide and its irradiation in reactors; and immobilization of plutonium with fission products. For each of these three technologies, the steps that are required can be broken into three phases: (1) analyses, tests, studies of feasibility and cost, demonstrations, and other steps necessary to prepare for construction of major facilities (or modification of existing ones); (2) construction or modification of major facilities (the phase likely to involve the highest yearly expenses); and (3) operation of these facilities. The combination of the scale of the necessary facilities and the length of time they will need to operate will be determined by the total amount of excess plutonium requiring disposition (which we expect will be worked out in negotiations between the United States and Russia, as recommended in the body of the report), and the fraction of that total going to MOX or to immobilization (which the United States and Russian can each decide for themselves with respect to their own excess plutonium).

The next section of this annex describes the steps that need to be included in such a work plan in some detail. These steps are each associated with a notional time by which they might be accomplished, based largely on existing U.S. Department of Energy plans (with some interpolation based on our own judgment of what is technically feasible). These plans would result in bringing the necessary facilities into operation at times ranging from 2003 to 2007. It is our judgment that if adequate funding were provided, Russia could proceed even more rapidly than this, particularly in implementing the reactor option -- and that if plutonium disposition were genuinely made a matter of high national security priority, the United States might well be able to proceed somewhat faster as well. The period of operation of these facilities is left unspecified, since it depends on the capacity of the facilities and the amount of material requiring disposition. We recommend that however much plutonium is declared excess -- a figure we hope will grow over time as arms reductions proceed -- facilities and approaches be put in place that are capable of bringing this material to the spent fuel standard within two to three decades from now.

Second, we recommend the establishment of an international legal entity for financing and implementation of plutonium disposition, described in the following section of this annex. Plutonium disposition will be a big job, involving large facilities, coordination of contributions from several countries, many tens of tonnes of material, and hundreds of millions of dollars. Establishing an effective organization with the responsibility to carry out an agreed plan for doing the job on a specified timetable is fundamental to getting the job done. The United States and Russia should jointly work with their partners in the "P-8" (the Political Eight, consisting of the traditional Group of Seven countries and Russia) to prepare an agreement establishing such an international institution capable of carrying out the mission.

At the same time, we recommend that the United States and Russia also take other steps to improve the management and implementation of plutonium disposition, including establishing specialized offices within their nuclear regulatory agencies to expedite licensing of the activities needed for plutonium disposition, and beginning bilateral discussions of a formal plutonium disposition agreement. Such an agreement could be pursued in two stages: we recommend that the two governments begin now to prepare a joint document reflecting their agreement in principle to implement plutonium disposition as rapidly as practicable; to pursue the dual-track approach in both countries; to jointly work with their P-8 partners to establish appropriate financing and management mechanisms; to jointly accept a series of verification and nonproliferation measures that would apply to programs to carry out disposition of excess weapons plutonium their plutonium disposition activities; and to work toward a second, more formal agreement setting out the quantities, schedules, and approaches for disposition of excess weapons plutonium. Such a near-term bilateral statement would be extremely useful in convincing legislatures, publics, and international partners that the United States and Russia genuinely intend to move forward together in eliminating their stockpiles of excess weapons plutonium.

Third, we recommend that financing for cooperative activities related to plutonium disposition be immediately and substantially increased, and that work begin now on pulling together an international cooperative approach to financing plutonium disposition, particularly in Russia. This final section of the annex provides a rough description of the likely costs involved in plutonium disposition, and outlines some possibilities for financing them. The issue of financing of plutonium disposition in Russia is probably the single largest barrier to accomplishing the plutonium disposition mission: Russia does not currently have the financial resources to make the large investments needed entirely on its own, and the United States is not likely to move forward on a large scale with disposition of its excess weapons plutonium unless Russia is moving forward as well. The costs of plutonium disposition must be seen as a highly cost-effective investment in national and international security, small by comparison to the sums the states involved have routinely spent to provide for their military security.

The urgent steps to address the security risks posed by excess weapons plutonium outlined in the body of the report and specified in more detail in this annex can and should be agreed on and implemented even while differences remain about the longer-term issues of the future of nuclear energy and the nuclear fuel cycle; resolution of these important problems need not and should not be linked. Arrangements for international cooperation in carrying out this critical disarmament mission should be carefully designed so as not to force any of the parties to repudiate their views on the future of the fuel cycle: the mission of disposition of excess weapons plutonium can and should be implemented without the United States having to support steps that would contribute to additional reprocessing and recycling of plutonium, and without Russia or the other participating states having to agree to permanently foreclose reprocessing and recycle.

2.0: Outline of a Notional Work Plan for Disposition of Excess Weapons Plutonium

RECOMMENDATION: THE UNITED STATES AND RUSSIA, WORKING WITH OTHER INTERESTED COUNTRIES AS APPROPRIATE, SHOULD EACH DEVELOP AND APPROVE A WORKPLAN WITH SPECIFIC SCHEDULES AND PROJECTED BUDGETS, TO IMPLEMENT THE DUAL-TRACK APPROACH TO PLUTONIUM DISPOSITION, INCLUDING BRINGING THREE TECHNOLOGIES INTO OPERATION ON A LARGE SCALE AS RAPIDLY AS PRACTICABLE: PIT DISASSEMBLY AND PLUTONIUM CONVERSION; MOX FABRICATION AND USE IN REACTORS; AND IMMOBILIZATION OF PLUTONIUM WITH FISSION PRODUCTS.

2.1 Overview

The body of the report recommends that the United States and Russia should move promptly to select, authorize, fund, and bring into operation at the necessary scale the specific variants of both the mixed-oxide/current-reactor approach and the vitrification-with-wastes approach that will be used for disposition of excess weapons plutonium to the spent-fuel standard in each country.

To carry out this dual-track approach to reducing the weapons-accessibility of excess weapons plutonium, each of the three technologies mentioned in the recommendation -- pit disassembly and plutonium conversion; MOX fabrication and use in reactors; and immobilization of plutonium with fission products -- will have to be brought into operation at a large scale as quickly as practicable, in both he United States and Russia. This annex outlines, for each of these technologies in turn, the steps required to achieve this objective. Detailed plans along the lines of

the outline below should be adopted and carried out in both the United States and Russia, with the two countries working together and with other interested states as appropriate (and with substantial international contributions to financing the effort in Russia, as described in the last section of this Annex). For each of these technologies, regulatory authorities should participate from the earliest stages (consistent with the somewhat different regulatory procedures in each country), to ensure effective safety review and to expedite necessary permits and licenses for the various facilities and activities needed. For each of these technologies, specific material protection, control, and accounting (MPC&A) approaches should be developed to meet nonproliferation and arms reduction goals. As noted earlier, the following schedules are based on DOE estimates for the U.S. program; with adequate funding, several of the key steps could be accomplished still faster in Russia. Indeed, proposals exist to procure three MOX lead test assemblies for irradiation in currently operating Russian reactors by 1999-2000, and to have a pilot-scale MOX fabrication plant in operation by 2002-2003 (each of these dates being three to four years earlier than those shown below).

2.2 Pit Disassembly and Plutonium Conversion

Both the United States and Russia will need industrial-scale facilities which they do not currently have for conversion of plutonium metal "pits" to other forms, and for preparing other plutonium forms for disposition.

1997-1998: Analyses and tests (including both dry and aqueous processes) to choose the least-cost, least-delay technology that can accomplish pit conversion while providing effective material controls and protection for the environment, safety, and health. This would include analyses and tests to ensure that the technologies produce oxides equally suitable for MOX fabrication or immobilization, including analyses and tests of approaches to removing gallium from the weapons plutonium (and of the acceptability of any residual gallium levels), and analyses and tests of means to produce oxides with particle sizes and other characteristics suitable for MOX fabrication or immobilization.

1997-1999: Analyses and tests of material accounting and control technologies to provide effective monitoring of the pit conversion process.

1997-1999: Full-scale prototype demonstration of the selected pit conversion technologies. (Demonstration of an initial prototype using a dry process is planned at the Los Alamos National Laboratory in the United States in the winter of 1997-1998, with an upgraded version following in 1999; building a prototype system in Russia should be pursued vigorously with the goal of demonstrating a viable system in 1999. This will require the use of existing buildings with substantial plutonium-handling capabilities.)

1998-2001: Planning, design, and siting of industrial-scale facilities for pit conversion in the United States and Russia; acquisition of permits and licenses for construction as appropriate. (Such a facility might initially be built at pilot-scale, for example to support a pilot-scale MOX plant as proposed by Russia, France, and Germany; such pilot-scale facilities should be designed to allow for the possibility of expansion, if successful, to the full scale needed to accomplish the mission of disposition of excess weapons plutonium.)

1999-2003: Construction of pit conversion facilities (or modification of existing facilities for this

purpose), and pre-operational testing.

2004-: Operation of pit conversion facilities.

2.3 MOX Fabrication and Reactor Irradiation

To use excess weapons plutonium in reactors as rapidly as practicable, both industrial-scale capacity to fabricate plutonium oxide into MOX fuel and the ability to use this fuel in currently operating reactors on the necessary scale must be made available in parallel.

1997-1998: Fabrication and irradiation of small rods of MOX pellets (testing such matters as materials properties, pellet-clad interactions, and fission-product retention). (The United States has the necessary experimental-scale fabrication facilities at the Los Alamos National Laboratory, and has already fabricated small batches of MOX pellets made from plutonium from dismantled weapons, and plans to irradiate experimental MOX pellets in the Advanced Test Reactor in Idaho and at Canadian test facilities at Chalk River. Russia has very small-scale experimental fabrication facilities at the Bochvar Institute of Inorganic Materials, and larger-scale experimental facilities at the Mayak Production Association; small MOX assemblies have been tested in the BR-10, BOR-60, and BN-600 fast neutron reactors, and are now being irradiated in the MIR thermal test reactor at Dmitrovgrad. Future experiments with MOX made from plutonium from dismantled weapons should be conducted, with testing in the BN-600, MIR, and the Chalk River facilities.)

1997-1998: Updating and validation of computer codes for analyzing reactor behavior and safety using MOX fuel (examining, e.g., core physics and thermal hydraulics). This should include the provision to Russia and the U.S. of existing European data from critical assembly experiments and from operational use of MOX fuel (with appropriate provisions to protect the commercial interests of the current owners of this data), and including whatever additional experiments may be necessary. Benchmarking U.S., Russian, and European code calculations against experimental and operational data would contribute significantly to the validation and licensing process. (In the U.S. program, updated and validated codes are available, which have already been used to analyze the use of MOX in U.S. reactors, but additional recent operational data from Europe would be extremely helpful. In Russia, codes are available for modeling the performance of the BN-600 fast neutron reactor using a partial core of MOX fuel, and cooperation is underway with France and the United States using their codes as well. Codes for modeling MOX use in Russian light-water reactors (LWRs), however, have not yet been fully updated and validated. Existing European data may be sufficient for the validation of these codes; existing test facilities at Dmitrovgrad should be capable of carrying out any additional critical experiments that may be necessary.) Both relevant data and adequate resources should be provided to complete the task of updating and validating these codes -- essential for licensing the use of MOX in operating power reactors -- as rapidly as practicable.

1997-1999: Determination of the maximum loadings of plutonium (considering both percentage of plutonium in the MOX fuel and percentage of the reactor core loaded with MOX fuel) that can be safely used in currently operating reactors, and examination of

reactor modifications that might be able to improve safety and plutonium loading levels, using the updated and validated MOX codes developed in the previous step. (In the United States, it is believed that a substantial number of U.S. LWRs can safely use MOX in 100% of their reactor cores, and studies of fuel designs and possible reactor modifications are continuing. In Russia, it is believed that the BN-600 fast-neutron reactor could be readily converted to safely use a hybrid core in which roughly 25% of the core was MOX fuel, and production of new plutonium was minimized, but whether the reactor can be safely and rapidly converted to use 100% MOX fuel requires further study. Preliminary results suggest that Russian VVER-1000 reactors can safely use MOX in one-third of their reactor cores, and possibly substantially more with appropriate modifications to their control systems, but more reliable analyses require updated and validated MOX codes. Studies to date indicate that Canadian CANDU reactors can accommodate 100% cores of MOX fuel, but additional study is needed to determine whether the percentage of plutonium in the fuel can safely be increased to levels comparable to those achievable in light-water reactors.)

1998: Selection of the specific currently operating reactors to be used for irradiation of MOX fuel (including sufficient reactors to carry out disposition of the amount of excess plutonium expected to be used as MOX over two decades of operation), negotiation of agreements with the organizations operating those reactors, and selection of contractors for construction of a MOX fuel fabrication facility. Both reactors and fabrication contractors should be selected early, so that both reactor operators and fabricators can contribute to the development of fuel and reactor approaches from the earliest stages of the program. (In the United States, several tens of reactors have sufficient licensed lifetimes remaining to play a major role in the plutonium disposition mission without requiring license extensions, far more than needed for the plutonium disposition mission. Selection will be based on a variety of factors, including negotiations with individual utilities over irradiation fees. A contractor or contractors will be selected to build or modify a government-owned MOX fabrication facility on one of several existing Department of Energy sites. In Russia, the reactors chosen for the MOX mission could be the existing BN-600 fast-neutron reactor and most if not all of the seven existing VVER-1000 LWRs. As these reactors are not likely to be sufficient to carry out the mission within their licensed lifetimes using the partial MOX cores with which there is industrial experience, and financing for completing new reactors is currently uncertain, consideration should be given to increasing the fraction of these reactors' cores that can safely use MOX fuel (possibly up to 100%); extending their licensed lifetimes; using additional VVER-1000 reactors in countries with which Russia has fuel supply agreements (such as Ukraine); irradiation of some of the material in CANDU reactors in Canada; irradiation of some of the material in MOX-licensed LWRs in Europe; and immobilization of quantities of material that cannot readily be accommodated in available reactors.)

1999: Confirmation of the MOX fuel designs and formulations and reactor control system approaches to be used.

1999-2002: Acquisition of licenses for irradiation of initial "lead use assemblies" in currently operating power reactors. Safety justifications would be based on analyses using the

MOX codes developed and validated in previous steps.

2003-2004: Procurement and initial irradiation of lead use assemblies in currently operating power reactors. (Neither the United States nor Russia has MOX fabrication facilities large enough to produce even a small number of LWR fuel assemblies. To accomplish this step while industrial-scale MOX facilities are being built, both countries should contract with European contractors to fabricate these initial assemblies in Europe -- though in Russia, a possible alternative is to invest funds in expanding the existing experimental-scale MOX facilities at Mayak to give them the capability to fabricate a small number of fuel assemblies. Fabrication in Europe would probably involve substantially lower costs than expanding the facilities at Mayak, but it would be essential to ensure that transportation and security issues (including Russian declassification of sufficient information to permit the shipment abroad of plutonium oxide powder made from dismantled weapons) were effectively addressed. For both countries, the entities that will eventually be fabricating MOX domestically, and the regulatory authorities, must participate in the process from the beginning, to ensure a smooth transition from foreign to domestic fabrication. The Russian program to produce 3 weapons-plutonium MOX fuel assemblies for irradiation in one of the Balakovo VVER-1000s should be given high priority, and earlier steps in the process should be geared toward contributing to completing that plan as rapidly as practicable.)

1998-2002: Planning, design, and siting of industrial-scale facilities in the United States and Russia for MOX fabrication; acquisition of permits and licenses for construction as appropriate. (Such a facility might initially be built at pilot-scale, as in the case of the plant proposed by Russia, France, and Germany; such pilot-scale facilities should be designed to allow for the possibility of expansion, if successful, to the full scale needed to accomplish the mission of disposition of excess weapons plutonium.)

2000-2003: Reactor modifications, as needed.

2002-2003: Acquisition of licenses for operational loadings of MOX fuel in currently operating power reactors, using data acquired in previous steps (including irradiation of lead use assemblies).

2002-2006: Construction of MOX fabrication facilities (or modification of existing facilities for this purpose), and pre-operational testing. (As noted earlier, completion of the initial module of a MOX fabrication facility may take longer in the United States, where it is planned to build a full-scale facility from the beginning and the process will face numerous legal and political challenges, than in Russia, where Russia, France, and Germany envision completing a pilot-scale facility by 2002. Even in the United States, however, reactors could potentially begin irradiating MOX with not only test assemblies but initial cores fabricated in existing European facilities, which could accelerate the beginning of the mission by 3-4 years.)

2007-: Operation of MOX fabrication facilities, irradiation of plutonium in currently operating reactors.

2.4 Immobilization

While the United States, Russia, and other countries have industrial-scale experience immobilizing high-level waste (HLW), there is no industrial-scale experience with incorporating significant amounts of plutonium in such immobilized waste. Both the United States and Russia need to carry out the necessary R&D, analyses, and tests to choose and qualify an approach to plutonium immobilization; determine how much plutonium to immobilize; and construct or modify the necessary industrial-scale facilities for plutonium immobilization.

1997-1998: Tests to demonstrate acceptability of material forms and compositions, plutonium loadings, and immobilization approaches (including safety, criticality, proliferation resistance, and repository performance). This will include experimental-scale tests of different waste form and melter designs and glass compositions.

1997-1998: Selection of an immobilization form.

1997-1998: Assessment of quantities and characteristics of impure plutonium stockpiles potentially more suitable for immobilization than for use in MOX fuel. (Such an assessment has already been done in the United States, though more detailed assessments are ongoing; similar assessments of impure plutonium forms and the hazards they may pose should be carried out at the major nuclear complex sites in Russia, in cooperation with the United States, including experts from similar U.S. sites. Russia may have less of these impure plutonium forms, because it has not shut down its major processing operations in the midst of processing substantial quantities of plutonium, as was done in the United States.)

1999: Prototype "hot tests" in the United States and Russia immobilizing plutonium in full-size glass logs with high-level wastes. (In the United States, such a "hot test" is planned for the "can-in-canister" immobilization approach, in which small cans of plutonium-bearing material would be arrayed within a large canister into which molten high-level waste glass would be poured. This appears likely to be selected as the preferred immobilization approach in the United States, as it makes it possible for the HLW glass production to simply be part of ongoing HLW immobilization in already-operating facilities, and for the plutonium immobilization to be done using small, critically-safe melters installed in existing glove-box lines. Similarly, Russia could carry out such immobilization at the Mayak site, using melters installed in existing glove-box facilities there and the operating high-level waste immobilization facility there. Alternatively, Russia could choose to pursue a homogeneous immobilization approach, in which plutonium and high-level wastes would both be immobilized together in the same material.)

1998-2002: Planning, design, and siting of industrial-scale facilities in the United States and Russia for plutonium immobilization; acquisition of permits and licenses for construction as appropriate. (Such facilities might initially be built at pilot-scale, in parallel to the pilot-scale MOX plant proposed by Russia, France, and Germany; such pilot-scale facilities should be designed to allow for the possibility of expansion, if successful, to the full scale needed to accomplish the mission of disposition of excess weapons plutonium.)

2000-2003: Construction of plutonium immobilization facilities (or modification of existing

facilities for this purpose), and pre-operational testing.

2004-: Operation of plutonium immobilization facilities.

3.0 Structures for Managing and Licensing Disposition of Excess Weapons Plutonium

RECOMMENDATION: THE UNITED STATES, RUSSIA, AND THEIR P-8 PARTNERS SHOULD, WITHOUT DELAY, ESTABLISH AN INTERNATIONAL ENTITY FOR FINANCING AND IMPLEMENTATION OF PLUTONIUM DISPOSITION, RESPONSIBLE TO THE LEADERS OF THE PARTICIPATING COUNTRIES FOR CARRYING OUT PLUTONIUM DISPOSITION TO SPECIFIED ENDPOINTS ON A SPECIFIED TIMETABLE. THE UNITED STATES AND RUSSIA SHOULD ALSO, WITHOUT DELAY, ESTABLISH: (1) SPECIAL-PURPOSE OFFICES IN THEIR NUCLEAR REGULATORY AGENCIES, DIRECTED AND FUNDED TO EXPEDITE REVIEW AND LICENSING OF NECESSARY PLUTONIUM DISPOSITION ACTIVITIES; AND (2) U.S.-RUSSIAN DISCUSSIONS DESIGNED TO LEAD TO A FORMAL U.S.-RUSSIAN AGREEMENT ON PLUTONIUM DISPOSITION.

3.1 An International Entity to Carry out the Mission

Disposition of excess weapons plutonium is a big job, involving many tens of tonnes of material, a wide range of activities and facilities, and hundreds of millions to as much as one to two billion dollars in investment spread out over many years. Hence, getting the job done requires a management structure with substantial resources and authority. Since accomplishing this mission in the near term will require international contributions (both financial and technical), an international body needs to be established quickly to coordinate this international effort. (Potential costs and possible financing arrangements are discussed in more detail in the next section of this annex.) It is not too soon to begin work now on establishing such an entity. Like the national management structures described above, this international structure should be given adequate authority and resources to accomplish the job assigned to it, and should have a sufficiently exclusive focus that it is not distracted by other priorities.

There have been a variety of large-scale international cooperative projects in the past involving significant investments and major technical components, from high-energy physics to nuclear power for the Korean peninsula to fusion energy to construction of an international space station. These past and present cooperative efforts can provide models for what works and what does not, which will be useful in designing an international entity to accomplish this mission.

We recommend that as rapidly as possible, an international agreement should be reached which establishes a legal international entity charged with carrying out international participation in the financing and implementation of plutonium disposition. The entity would be responsible for overseeing the required implementation operations, assessing progress toward the implementation goals, and ensuring that appropriate safety, nonproliferation, and verification standards and conditions are met. Such an entity should have:

- A board of directors (which might meet 2-4 times per year) consisting of individuals nominated by governments, with sufficient authority to represent their governments and make commitments on their behalf;
- Committees on both the technical aspects of the program and the financial and management aspects;
- A permanent full-time staff, as needed to accomplish the mission.

A broad range of more detailed issues of both principle and organization will have to be addressed in establishing such an entity, including (among others) definitions of responsibilities and authority, relationships to relevant national authorities, its tax status (the participating states will justifiably insist that the funds provided for the disarmament mission of plutonium disposition all be used for that purpose), and the ultimate ownership and management of whatever facilities are eventually built.

As described in the next section, international financing is much more urgently needed for disposition of excess plutonium in Russia than in the United States. Thus, this international entity will inevitably be intimately involved in implementation of disposition in Russia. For the sake of parallelism and the overall credibility of the program, while the United States is expected to finance and manage its own disposition program, the international entity should have a role in coordinating international technical contributions to that effort, and in ensuring that it proceeds in parallel to the Russian program, with reciprocal verification and nonproliferation arrangements.

The establishment of such an entity could be pursued in two stages. In stage 1, a first agreement (which could be reached as soon as the Denver P-8 summit this year) could include:

- agreement in principle on establishing an international entity for this purpose, with its specific charter to be worked out later;
- agreement in principle on the verification and nonproliferation conditions to be applied to facilities built by this international venture (described in the next section);
- agreement to undertake (and to finance) the analyses, tests, designs, cost estimates, and feasibility studies necessary over the next year or two to prepare for decisions on financing and construction of major facilities;
- agreement that once these preparatory efforts are complete, at a specified time a decision will be taken on going forward and financing the construction of the needed facilities.

The second agreement would be reached at the time designated in the first, and would cover financing, construction, and operation of the major facilities that will need to be built to implement the dual-track approach. This might require 1-2 years after the initial agreement to begin preparations and establish the international entity. But it is critical to begin as soon as possible, to plant a seed that will grow as time passes.

Even before such an authoritative international entity can be established, efforts should be made for improved coordination of the existing cooperative programs underway involving the United States, Russia, France, Germany, Canada, and several other countries, including ad hoc meetings of the technical experts involved in these efforts. This will make it possible to avoid duplication or contradiction in these programs, and to take opportunities for synergies. The Russian Ministry of Atomic Energy has proposed establishing an international coordinating group for this purpose; this proposal should be accepted, but broadened into the more authoritative international entity just described.

3.2 Special-Purpose Offices for Expedited Nuclear Regulatory Review

Licensing requirements of the U.S. Nuclear Regulatory Commission (NRC) and Gosatomnadzor (GAN) in Russia have the potential to impose substantial delay in plutonium disposition programs. These regulatory agencies will require safety analyses, detailed designs, and experimental data. Neither of these agencies currently has sufficient staff with all the appropriate expertise to expedite review of the necessary licenses: the NRC has not licensed large-scale plutonium facilities or the use of plutonium in reactors for two decades, and GAN remains an organization struggling to carry out a mission much larger than the resources it has been provided.

To ensure that review and licensing can be accomplished without undue delay, the United States and Russia should each direct -- and fund -- their nuclear regulatory agencies to establish special-purpose offices to develop the procedures to review and license promptly plutonium disposition construction and operations, giving these reviews high national security priority. These offices should be established as quickly as possible, as early and continuous interaction among regulators, other government agencies, research institutions, and operators of plutonium-disposition facilities is essential to avoid delay.

3.3 Pursuing a Formal Agreement on Plutonium Disposition

The United States and Russia should begin discussions with the goal of reaching a formal agreement governing plutonium disposition. As a first step, Russia should announce a specific date by which it will match the U.S. declarations of excess fissile material by making an initial declaration of the specific quantity of Russia's plutonium which is excess to its military needs. We hope that declarations of further material as excess will occur regularly in the future on both sides, in parallel, resulting in time in reductions to equivalent remaining quantities of plutonium and HEU in the two military stockpiles.

A formal agreement setting out the quantities, schedules, and approaches for plutonium disposition could help ensure that the U.S. and Russian disposition programs proceed in parallel, that appropriate nonproliferation controls are maintained, and that sufficient priority is assigned to the plutonium-disposition mission. Moreover, such an agreement could help provide the predictability and stability needed to implement plutonium disposition over the long run, and to give international partners the confidence needed to provide their financial, political, and technical support. Such an agreement, particularly if combined with timely action to place the excess material under international safeguards, could also greatly increase confidence that the United States and Russia actually will irreversibly reduce their stocks of excess material in forms readily usable in weapons; this credibility benefit could be particularly important over the period of roughly a decade before industrial-scale disposition operations can probably begin. In addition, such an agreement may help ensure funding stability: legislatures in both countries are more likely to provide necessary funding if that funding is needed to fulfill an international commitment. More broadly, an agreement to transform specified quantities of excess weapons plutonium into forms meeting the spent fuel standard could be a first step toward, and an inherent part of, a broader agreement to control and reduce stockpiles of nuclear warheads and the fissile materials needed to make them. Such controls could make a fundamental contribution to future agreements on deep, transparent, and irreversible reductions in nuclear arms.

Such an agreement could be pursued in two stages: we recommend that the two governments begin now to prepare a joint document reflecting their agreement in principle to implement plutonium disposition as rapidly as practicable; to pursue the dual-track approach in both countries; to jointly work with their P-8 partners to establish appropriate financing and management mechanisms; to jointly accept a series of verification and nonproliferation measures that would apply to programs to carry out disposition of excess weapons plutonium; and to work toward a second, more formal agreement setting out the quantities, schedules, and approaches involved in disposition of excess weapons plutonium. Such a near-term bilateral statement would be extremely useful in convincing legislatures, publics, and international partners that the United States and Russia genuinely intend to move forward together in eliminating their stockpiles of excess weapons plutonium.

The forum and approach for discussing and negotiating such an agreement should be carefully chosen. This forum, which will involve questions of foreign and national security policy, need not be the same as the management structure created to implement cooperative plutonium disposition activities, which is likely to focus on technical and program management issues -- though the trust and spirit of cooperation built up in carrying out joint technical activities are likely to be essential to success in reaching a formal agreement.

4.0 Financing Disposition of Excess Weapons Plutonium, Including International Cooperation

RECOMMENDATION: THE UNITED STATES, RUSSIA, AND OTHER INTERESTED STATES SHOULD: (A) IMMEDIATELY AND SUBSTANTIALLY INCREASE THE OVERALL LEVEL OF FUNDING BEING PROVIDED FOR NEEDED COOPERATIVE ANALYSES AND TESTS OF PLUTONIUM DISPOSITION TECHNOLOGIES; (B) DEVELOP, AGREE ON, AND IMPLEMENT, AS RAPIDLY AS PRACTICABLE, A PLAN FOR STABLE LONG-TERM INTERNATIONAL FINANCING OF CONSTRUCTION OF NECESSARY PLUTONIUM DISPOSITION FACILITIES IN RUSSIA; AND (C) AGREE ON CONDITIONS NECESSARY TO ENSURE INTERNATIONAL FINANCIAL SUPPORT, INCLUDING FOCUSING THESE FACILITIES ON THE DISARMAMENT MISSION OF EXCESS WEAPONS PLUTONIUM DISPOSITION, AND ENSURING INTERNATIONAL VERIFICATION AND EFFECTIVE NONPROLIFERATION CONTROLS.

4.1 Overview

All of the options for disposition of excess weapons plutonium to the spent fuel standard will cost money. Capital investments required will be in the range of hundreds of millions to one to two billion dollars. This cost must be seen as a highly cost-effective investment in national and international security, small by comparison to the amounts that the United States and Russia have traditionally spent to ensure their military security. Nevertheless, as noted in the body of the report, the difficulty of financing this cost (particularly in Russia) is likely to be the single largest obstacle to progress on plutonium disposition, and badly needed activities are already being delayed by lack of money. Provision of increased financing is required on an urgent basis. The Presidents of the United States and Russia should exercise their personal leadership in ensuring that the necessary financing is provided.

In the United States, the Department of Energy (DOE) has established a multi-year program plan, and estimated the funding required to implement it. These costs are included in projected budgets for future years, in the context of a seven-year balanced budget plan. (The approved budget for U.S. plutonium disposition activities for the current fiscal year is just over $100 million, and the request for the 1998 fiscal year is expected to be the same.) These projected budgets will, of course, require Congressional appropriations. Ensuring stable financing for the long-term investments required, given the U.S. budget system, is a major concern; serious consideration should be given to providing multi-year financing, similar to that provided, for example, for purchases of multi-billion-dollar aircraft carriers. Congressional approval of the necessary stable financing for disposition of U.S. excess plutonium is only likely to be forthcoming if disposition of Russian excess plutonium is proceeding on a parallel track -- which in turn depends on financing of disposition in Russia.

Russia currently faces an extremely difficult economic and budgetary situation, which has substantially delayed financing for even the most basic needs. Given the urgent national security imperative for plutonium disposition, financing should nevertheless be made available to carry out this mission. Realistically, however, near term success will require some form of international participation in the financing of disposition in Russia. High priority should therefore be placed on developing, negotiating, and implementing a plan for international cooperation in financing the needed facilities in Russia.

4.2 Immediate Increased Funding for Cooperative Analyses and Tests

For the first phase of the effort, the funds required for the needed analyses, tests, and design efforts that precede construction of major facilities are not large. The United States and Russia,

working with other countries with relevant experience and interests, should expedite and expand their technical cooperation to accomplish these immediate-term steps. As noted earlier, this includes cooperation to develop, test, demonstrate, and license: (a) rapidly implementable and cost-effective means for converting plutonium weapons components ("pits") to oxide, and for processing other plutonium forms to prepare them for disposition (including full-scale demonstrations of complete prototype systems for this purpose in each country); (b) fabrication of plutonium-uranium mixed oxide (MOX) fuel made from weapons plutonium and the use of this fuel in currently operating reactors (including carrying out whatever critical experiments may be necessary to validate computer codes for modeling the safety of MOX fuel use in currently operating reactors, and demonstrating fabrication and irradiation of MOX fuel made from weapons plutonium); and (c) immobilization of plutonium with high-level radioactive wastes (including "hot tests" in each country immobilizing plutonium in full-size glass logs with high-level wastes). (See the suggested work plan in Section 2.)

The countries that are cooperating with Russia to carry out this work, particularly the United States, should, on an urgent basis, substantially increase the funding they are making available for these projects. At the same time, Russia should increase its own funding of these activities, to further expedite the work, avoid undue dependence on foreign financing in these critical areas, and attract additional foreign investment in this effort.

4.3 Planning for International Financing of Plutonium Disposition Facilities

The second phase of the effort, involving construction or modification of major facilities, will require larger-scale financing, in the range of hundreds of millions to one to two billion dollars. The United States should agree to offer its political and financial support for the pilot MOX fabrication plant proposed by Russia, France, and Germany, with appropriate nonproliferation conditions and provisions for eventual expansion to the full scale needed to implement the plutonium disposition mission. The United States and Russia should jointly offer political and financial support for both this project and parallel projects in Russia related to facilities for converting weapons-component "pits" to oxide, and immobilizing plutonium. The United States and Russia should then begin working jointly with their partners in the "P-8" (the Political Eight, including the traditional Group of Seven countries and Russia) to gain their political and financial support for these projects, and to create mechanisms for international cooperation in their financing and management, which could be agreed to at this year's P-8 summit in Denver.

While detailed designs and cost estimates are still being prepared, initial estimates suggest that the cost of the pilot-scale MOX plant proposed by Russia, France, and Germany, capable of handling approximately 1.3 tonnes of plutonium per year, would be approximately $300 million (taking into account the use of some of the equipment from the never-opened Hanau MOX fabrication facility in Germany). Designing the facility with the capacity for later expansion to the full 5-7 tonne-per-year capacity likely to be needed would modestly increase costs, but would allow this substantial initial investment to serve as a major downpayment on the cost of a full-scale facility. The trilateral proposal also includes a pilot-scale pit conversion facility to provide the 1.3 tonnes of plutonium oxide per year used by the MOX plant, though Germany, as a non-nuclear-weapon state, would not be participate in the portion of the project that would process classified weapons components. This facility is expected to add perhaps 50 percent to the overall capital cost of the plan. As noted earlier, a pilot-scale immobilization facility should also be pursued in Russia. It is possible that this effort can rely primarily on existing glove-box lines and high-level waste immobilization operations at the Mayak site, reducing the magnitude of the initial cost. All told, the initial capital cost of these pilot scale facilities is likely to be just over half a billion dollars. An additional investment likely

amounting to several hundred million dollars would be needed later to expand these facilities to full-scale.

Financing the significant costs of these projects is the largest barrier to their implementation. Two basic approaches are being considered. One approach would be to rely on government contributions from the P-8 nations and possibly other interested states. If, for example, the P-8 were to simply divide the cost, this would amount to less than $80 million for each country. Another possibility which is being discussed is to finance these projects through a sort of barter arrangement: Russia would provide low-cost uranium and enrichment services to the Western firms involved in constructing the plants in payment for their services, and the Western governments would agree to allow these increments of uranium and enrichment into their markets (where entry of Russian uranium and enrichment exports is generally strictly limited). If this approach is pursued, Russia should agree to draw the uranium and enrichment from additional blending down of HEU from dismantled weapons, beyond the 500 tonnes Russia has agreed to blend down for sale to the United States. In that way, the project would result in reductions in stockpiles of both excess plutonium and excess HEU. Given the substantial recent recovery of the uranium market, and the continuing health of the enrichment market, the market should readily be able to accommodate the modest additional amounts of uranium and enrichment services originating from such an arrangement. Either of these approaches (of a combination of them) are potentially viable; the key is to reach agreement as quickly as practicable on an approach that will reliably provide the stable, long-term financing needed to implement disposition -- both initial pilot-scale facilities and later expansion to full scale.

4.4 Nonproliferation Conditions Necessary for International Financing

International participation in the financing of these efforts will inevitably involve international participation in their management and implementation as well, and in setting the terms and conditions under which they will proceed, including nonproliferation conditions. International financing -- and particularly U.S. financial support, which is likely to be crucial to the success of the overall project -- is only likely to be forthcoming if there is agreement that the projects will be focused on the disarmament mission of disposition of excess weapons plutonium as an overriding priority, and that this mission will be carried out with international verification and effective nonproliferation controls. Therefore, Russia and the United States should reaffirm their Moscow Nuclear Summit agreement that in each country, facilities for these purposes will have security and accounting measures meeting stringent international standards and ensuring effective nonproliferation controls, and will be placed under international safeguards as early in the process as practicable (in a manner that will protect key classified weapons information). In addition, the United States and Russia should agree that facilities to be built with U.S. support for the disarmament mission of disposition of excess weapons plutonium will be used only for that purpose, and that the spent MOX fuel that results will not be reprocessed, at least until the job of bringing all of the excess weapons plutonium to the spent fuel standard is complete. These conditions and verification arrangements should apply equally to facilities in Russia and in the United States, making them fully reciprocal.