How can military plutonium be dispositioned? A discussion and evaluation of some policy options

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Introduction

Military plutonium, both inside and outside of nuclear arsenals, represents three threats to global security: vertical proliferation, if its owners use it to create new nuclear weapons, horizontal proliferation, if states or non-state actors steal it and use it to build their own weapons of mass destruction and loss of confidence in arms control initiatives, if non-nuclear-weapon states view its continued existence as an indication that nuclear-weapon states are not genuinely committed to disarmament agreements (Barnaby, 2003, pg. 7 and Bernstein, 1997).

Arms control initiatives since the end of the Cold War, such as the Strategic Arms Reduction Treaty, have led to reductions in nuclear arsenals but have failed to address these proliferation threats. Nuclear bombers were dismantled and missile components were crushed [1]; however, the plutonium from nuclear warheads was left intact (Bunn, Wier, and Holdren, 2003, pg.195).

Unlike highly enriched uranium, weapons-grade plutonium cannot be chemically "blended down" into a form that is not suitable for nuclear weapons because almost all chemical varieties of plutonium can be used in nuclear weapons (Bernstein, 1997). This technical fact necessitates the development of sophisticated measures to disposition the plutonium or permanently remove its capacity to be used to threaten global security as discussed above. One method immobilises plutonium and radioactive waste in large containers that are buried in underground repositories. Another method burns a mixture of uranium and plutonium in contemporary nuclear power plants. Other methods chemically transform weapons-grade plutonium in accelerators, launch it into the sun and subject it to underground nuclear explosions.

This paper argues that the present options for dispositioning military plutonium do not satisfy necessary security and feasibility criteria, and, as a result, the international storage of this plutonium should be implemented until an acceptable method is found.

This argument is developed in the following sections of this paper. The first section presents a brief description of plutonium and its use, the second section discusses the criteria by which disposition options must be assessed, the third section outlines several approaches and assesses them against the specified criteria and the fourth section describes the concept of international plutonium storage.

Much of the discussion about plutonium disposition in academic, government and scientific circles is framed by the activities of Russia and the United States, such as their September 2000 commitment to dispose of 34 metric tons of weapons-grade plutonium [2]; however, since plutonium disposition is a matter of concern for the entire international community, this paper addresses the issue in general without restricting its focus to the policies of any specific state or states.

Background Information about Plutonium

Since the technical aspects of plutonium and its use in nuclear weapons have been adequately introduced elsewhere [3], the present discussion focuses on a few key points that are directly relevant to the following sections. The term "weapons-grade" refers to a sample of plutonium that has a chemical composition that is ideally suited for nuclear weapons. As previously mentioned, almost all chemical forms of plutonium can be used in nuclear weapons; however, non-weapons-grade plutonium weapons require greater technical ingenuity (Barnaby, 2003, pg. 20).

In a nuclear weapon, a massive amount of energy is produced from the fission, or splitting, of either uranium or plutonium nuclei in a chain reaction. The energy produced in a nuclear reactor is the result of a fission chain reaction under controlled conditions. In a nuclear reactor that uses uranium fuel, plutonium is an expected by-product and is therefore present in its spent fuel (Barnaby, 2003, pg. 17-21). Other by-products of nuclear reactions, known as high level waste, are radioactive enough to be extremely harmful to human health. These radioactive elements are believed to protect spent fuel from unwanted access (Bernstein, 1997).

In this paper, the plutonium in question is weapons-grade except in the case of plutonium in spent fuel or unless otherwise noted. Most plutonium from dismantled nuclear warheads is not under the supervision of the International Atomic Energy Agency (IAEA) (Bengelsdorf and McGoldrick, 2002, pg. 34). In 1999, the Institute for Science and International Security estimated the total amount of plutonium in military stockpiles around the world to be 250 metric tons (Albright and Barbour, 1999). Approximately eight kilograms of plutonium is all the plutonium that is required to build a "Nagasaki-type bomb" (Macfarlane et al., 2001, pg. 53).

Criteria for the Assessment of Plutonium Disposition Policy Options

The plutonium disposition methods will be assessed against the security and feasibility criteria discussed in this section. These criteria are based on the fundamental assumptions that plutonium is a threat to global security and dispositioning plutonium "is a long-term issue on which urgent action is needed" (Bunn, Wier, and Holdren, 2003, pg. 195).

For obvious reasons, a disposition method that physically destroys the plutonium at hand is considered to be optimal. Failing complete physical destruction of the plutonium, the disposition method must possess barriers against the reuse of the plutonium for military purposes by its owner. The dispositioned plutonium must also be protected from theft by terrorists and other actors. These barriers should be political and technical (Brooks, Franke, and Hoenig, 1992, pg. 131). Technical barriers include "physical, chemical, and radiological barriers to recovery of the plutonium" (Bernstein, 1997). That is, the time to transform the end product of the dispositioning process to a nuclear weapon must be significant. Security measures must remain intact for at least several centuries. The implementation of the disposition method, including processing and transportation, must not introduce proliferation risks (Bunn, Wier, and Holdren, 2003, pg. 197). Some states, particularly the United States, have proposed the spent fuel standard as a guide by which the security of dispositioned plutonium should be assessed. This standard specifies that dispositioned plutonium should be as difficult to access as the plutonium in spent fuel from nuclear power stations (G7 Moscow Summit on Nuclear Security, 1996, pg. 8, cited in Bernstein, 1997). The adoption of the spent fuel standard is problematic because it means that certain disposition methods that make military plutonium more difficult to access than spent fuel plutonium are rejected (Bernstein, 1997) and it is meaningless for states that reprocess spent fuel to extract the plutonium that it contains (Makhijani and Makhijani, 1995). In this paper, the spent fuel standard will be used as a guide, but it will not be used to reject disposition options that outperform it.

The feasibility criteria involve both timing and technical requirements. The disposition method must be able to be implemented with reasonable start and completion times (US-Russian Independent Scientific Commission on Disposition of Excess Weapons Plutonium, 1996, pg. 1, cited in Bernstein, 1997). The process must not be excessively delayed by infrastructure or technology needs. For example, the approach must not rely on "the development, licensing, and construction of new types of reactors" (Bunn, Wier, and Holdren, 2003, pg. 199). In addition, the implementation of the disposition method must not contravene any international treaties.

Plutonium Disposition – Immobilisation

The immobilisation method involves creating radiological and physical barriers to protect the plutonium from unwanted access. In one approach, known as the "can-in-canister", an inner container of vitrified plutonium is placed within an outer container of radioactive high level waste. Another approach is to mix the plutonium and waste together and then vitrify the mix (Berkout, 1998, pg. 23). The former approach is "technically simple and quicker to implement" than the latter (Bernstein, 1997). After the plutonium is immobilised, the end product is buried in an underground geological repository (Brooks, Franke, and Hoenig, 1992, pg. 135).

Two security barriers provided by plutonium immobilisation include the high radioactivity dose and the difficulty of accessing the underground repository (Bernstein, 1997). In addition, a smaller amount of plutonium in each container than that in spent nuclear fuel is ostensibly a disincentive to theft (Brooks, Franke, and Hoenig, 1992, pg. 136). While presently there are no industrial techniques to reprocess vitrified plutonium (Buyers et al., 2000, pg. 17), the security criteria remain unsatisfied, however, if it is assumed that such techniques will eventually be invented. Recognising that the plutonium is not actually destroyed in the vitrification process (Bernstein, 1997) and that the radioactivity would decrease significantly in less than two centuries, the plutonium dispositioned in this way "would be a mineable source for nuclear weapons for future generations" (McCormick and Bullen, 1998, pg. 694).

The immobilisation approach also fails to satisfy feasibility criteria. To date, no single acceptable burial site has been identified anywhere in the world (Makhijani and Makhijani, 1995). In addition to the time required to identify an appropriate geological repository, time is also required to research the vitrification process. Although vitrification is a well-known industrial technology, the vitrification of plutonium requires further research (Brooks, Franke, and Hoenig, 1992, pg. 136). Furthermore, those states, including Russia, that consider plutonium to be a desirable commercial energy source will likely not support immobilisation (Buyers, Harvey, and Salvin, 2000, pg. 7).

Plutonium Disposition – MOX fuel

This option involves fabricating a nuclear fuel made from a mixture of plutonium and uranium oxides known as MOX, and irradiating it in nuclear power stations. The end product of this activity is similar to that of the irradiation of normal uranium fuel. The radioactivity of both kinds of spent fuel is generated by the highly radioactive by-products of fission reactions (Bernstein, 1997). The reprocessing of spent MOX fuel is presently not being considered, so it will most likely become radioactive waste (Berkout, 1998, pg. 23).

The non-governmental organisation Greenpeace has criticised the MOX fuel approach for creating "more plutonium than existed in the original MOX fuel" (Greenpeace, 2001). While the overall process does create plutonium as a by-product of the irradiation of the uranium component in the MOX fuel and the standard uranium fuel that would accompany the MOX fuel, it is not clear that there would necessarily be a net gain in plutonium because a portion of the initial plutonium is destroyed during irradiation (Holdren et al., 1994, pg. 155). It is a fair criticism, however, that a process designed to dispose of plutonium in one form actually creates new plutonium in another form.

The MOX fuel disposition approach creates security barriers to protect the end product of the dispositioning process. The remaining plutonium is protected by the radiation emitted by the fission by-products. Since MOX spent fuel is expected to be disposed of in underground repositories, given that this is the expected disposal method for non-MOX spent fuel (Brooks, Franke, and Hoenig, 1992, pg. 135), the handling and recovery difficulties associated with these locations offer some protection against theft. However, as with immobilised plutonium, the underground repositories of MOX spent fuel represent a source of plutonium that could be mined in the future (McCormick and Bullen, 1998, pg. 695-696).

The fabrication and transportation activities required by the implementation of the MOX fuel disposition approach might make the plutonium vulnerable to theft. It is important to note that the radiological barrier to deter handling only exists after the irradiation process. Only a basic level of scientific knowledge is required to separate the plutonium from un-irradiated MOX fuel. According to Frank Barnaby, the scientific knowledge required is more basic "than that required for the illegal manufacture of designer drugs, or that employed by the Aum Shinrikyo cult in 1995 to prepare sarin nerve gas for release into the Tokyo subway" (Millar, 2001). Some states may not have MOX fuel fabrication facilities or enough nuclear power plants to process weapons plutonium in a reasonable period of time. Because it does not have enough suitable nuclear reactors, Russia may need to ship plutonium to other states to be irradiated (Bunn, Wier and Holdren, 2003, pg. 198). The transportation of MOX fuel between states introduces proliferation risks (Barnaby, cited in: Andrews, 2003, pg. 4). One proposal is to burn MOX fuel made from Russian plutonium in a nuclear power station in Canada. In addition to the vulnerability described above, this proposal may violate the Non-Proliferation Treaty because it involves the transportation of special fissionable material to a non-nuclear-weapon state [4].

Although MOX fuel fabrication plants already exists in Belgium, France and the United Kingdom (Macfarlane et al., 2001, pg. 53), the dispositioning of plutonium as MOX fuel does not satisfy the feasibility criteria. With regard to infrastructure requirements, "neither Russia nor the United States has industrial-scale MOX fuel production facilities" (Sokova, 2002), and, as mentioned previously, Russia does not have enough reactors available. In any case, the MOX fuel option cannot disposition all forms of weapons-grade plutonium, so it is not a complete solution. For example, the United States estimates "that as much as one third of its own plutonium surplus stockpile will be too impure to fabricate into MOX fuel" (Bernstein, 1997).

Plutonium Disposition – Other Options

Another approach is plutonium disposition by accelerator transmutation. In accelerator transmutation, plutonium atoms are destroyed by nuclear fission in a large scientific apparatus called an accelerator (Brooks, Franke, and Hoenig, 1992, pg. 135). Unlike in a nuclear weapon, the fission reactions in an accelerator are controlled to prevent "the possibility for a runaway chain reaction" (McCormick and Bullen, 1998, pg. 699).

It is not clear how much of the original plutonium would be destroyed in the transmutation process. James M. McCormick and Daniel B. Bullen posit that a large amount would be destroyed (1998, pg. 699); however, others suggest that "significant residues of…[the initial plutonium] would remain" (Brooks, Franke, and Hoenig, 1992, pg. 135). In any case, not all of the original plutonium is destroyed in the transmutation process.

Plutonium disposition by accelerator transmutation does not mitigate against proliferation risks. The required processing of the plutonium introduces the opportunity for theft (Brooks, Franke, and Hoenig, 1992, pg. 135). It is also not practical. The time needed for the research effort associated with accelerator transmutation is prohibitive (McCormick and Bullen, 1998, pg. 699).

Another disposition approach involves launching plutonium into the sun. The suitably packaged plutonium could be launched "into earth's orbit. Then, by decelerating the payload to counter the spacecraft's orbital velocity around the sun, the waste eventually would drop into the sun" (McCormick and Bullen, 1998, pg. 700).

Solar disposal reduces proliferation risks to nil because all of the plutonium would be removed from earth and ostensibly destroyed in the sun. However, in catastrophes such a launch pad accident or a return of the delivery vehicle to earth, the author of this paper believes that there may be opportunities for theft. Currently, dispositioning of plutonium by solar disposal is highly infeasible because it "would require many decades of development" (North, 1997, pg. 52, cited in: McCormick and Bullen, 1998, pg. 700).

Another disposition approach is underground nuclear detonation. This involves subjecting buried plutonium to a nuclear explosion. Plutonium dispositioned in this way introduces proliferation risks because the explosions could be used as an excuse to research new weapons technology and the plutonium may be vulnerable to theft if there is a delay between burial and detonation. This proposal is impractical because a large number of detonations would be required (Brooks, Franke, and Hoenig, 1992, pg. 138). Also, the Comprehensive Nuclear-Test-Ban Treaty prohibits even peaceful nuclear explosions [5].

International Plutonium Storage

The previous section showed that the currently proposed options for dispositioning plutonium have shortcomings when assessed against necessary security and feasibility criteria. Therefore, the international storage of plutonium should be pursued until an acceptable plutonium disposition option can be implemented.

There are numerous models for international plutonium storage. They differ in their conceptualisations of where the plutonium is stored and how easily it can be accessed. The international custody model and the plutonium prison model are discussed below.

In the international custody model, plutonium is placed in the custody of the IAEA which already has the mandate in its statute "to require deposit with the Agency of any excess of any fissionable materials recovered or produced as a byproduct over what is needed" and return deposited plutonium to the owner "provided that the material is used for peaceful purposes under continuing IAEA safeguards" [6]. Deposited plutonium would continue to be legally owned by the state and would not be moved outside of its territory. By assuming custody of the plutonium, the IAEA would verify that domestic security meets international standards and block access to the plutonium except by legitimate requests for withdrawals (Bengelsdorf and McGoldrick, 2002, pg. 33). The withdrawal of plutonium is envisaged to be "a routine matter based on the provision of a certificate of use" in the spirit of the widely adopted International Plutonium Guidelines (Bengelsdorf and McGoldrick, 2002, pg. 35).

In the plutonium prison model, military plutonium is moved to a single global repository and, unlike the international custody model, withdrawal of plutonium would be infrequent and difficult (Chow, Speier, and Jones, 1996, pg. 7-8). The repository would be protected by an international military presence and "engineered features that would make it easy to move the material in quickly but hard to take out (collapsing tunnels, dismantled railroad tracks, etc.)" (Mathews, 1997, pg. A15).

Both models include political barriers to inappropriate access. The centralised storage provided by the plutonium prison model represents a greater barrier to vertical proliferation. The author of this paper believes that the military presence and physical protection afforded by the plutonium prison model give greater protection against external theft than the security measures in the international custody model. However, the transportation of plutonium to the global repository, although presumably under heavy guard, represents a proliferation risk.

Noting that "national sovereignty has remained a basic principle in the management of plutonium" (Berkout, 1998, pg. 30), local storage in owner states is probably more politically acceptable than centralised international storage; however, the Japanese policy of not keeping any excess plutonium in Japan demonstrates that the international storage of plutonium, albeit when national ownership is maintained, is possible (Bengelsdorf and McGoldrick, 2002, pg. 32). One practical problem with finding a location for the plutonium prison is that treaties defining nuclear free zones may prohibit the selection of certain locations. The Antarctic Treaty, for example, specifically forbids the "disposal there of radioactive waste material" [7].

Based on this discussion, the optimal design of an international plutonium storage program appears to be a hybrid of the best features of the two models. The hybrid model would store plutonium in each owner state under the international custody of the IAEA supported by an international military presence. The plutonium would remain in custody until the termination of the program.

Conclusion

Dispositioning military plutonium is necessary to address the global security risks associated with its existence. Various methods have been proposed. One approach involves immobilising it in glass and burying it in underground repositories. Another approach involves making it into a nuclear fuel and burning it in nuclear power plants. Other approaches include: altering its chemical composition in an accelerator, launching it into the sun, and subjecting it to underground nuclear explosions. All of these approaches fail to satisfy necessary security and feasibility criteria. This paper recommends that international plutonium storage should be implemented until such time as a satisfactory disposition method is found.

Endnotes

1. See the Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Reduction and Limitation of Strategic Offensive Arms, 1991, Protocol on Procedures Governing Conversion or Elimination.
2. See the Agreement Between the Government of the United States of America and the Government of the Russian Federation Concerning the Management and Disposition of Plutonium Designated As No Longer Required for Defense Purposes and Related Cooperation, 2000.
3. See, for example, Barnaby, 2003, pg. 19-21 and 44-45.
4. See the Treaty on the Non-Proliferation of Nuclear Weapons, 1968.
5. See the Comprehensive Nuclear-Test-Ban Treaty, 1996, Article I.
6. See the Statute of the International Atomic Energy Agency, 1956, Article XII, A.5. Cited in: Bengelsdorf and McGoldrick, 2002, pg. 32.
7. See the Antarctic Treaty, 1959, Article V.

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