Dispositioning military plutonium to promote nuclear non-proliferation

Robert Sancton

Security and Armed Conflict, Pax Christi International, Rue du Vieux Marché aux Grains, 21, B1000 Brussels, Belgium; rsancton@hotmail.com

Given that all chemical varieties of plutonium can be used in nuclear weapons, sophisticated measures are required to disposition it so that its potential to contribute to horizontal and vertical nuclear proliferation is minimised. This article argues that the present options for dispositioning military plutonium are not acceptable, and, as a result, this plutonium should be placed in international storage until an acceptable method is found. First, a brief description of plutonium and its use is given. A discussion follows on non-proliferation and feasibility criteria by which the policy options to disposition military plutonium should be assessed. Then several policy options are outlined and assessed against the specified criteria. Finally, the concept of international plutonium storage is described.

Nuclear proliferation includes both horizontal and vertical proliferation activities. Horizontal proliferation occurs when states and non-state actors acquire or develop nuclear weapons for the first time, and vertical proliferation occurs when nuclear weapon states [34] quantitatively expand or qualitatively improve their nuclear arsenals [3].

Nuclear proliferation is a threat to global security because as the number of nuclear weapons in existence grows so does the likelihood that they will be intentionally or accidentally used to seriously imperil human existence. This effect is magnified because instances of proliferation increase the likelihood of further proliferation. The appearance of a new nuclear weapon state can motivate a regional adversary to undertake further proliferation in response, as in the case of Pakistan following India's lead in the late 1960s [19]. Vertical proliferation also increases the likelihood of further proliferation if it is interpreted by state and non-state observers as evidence that existing nuclear-weapon states are not sincerely committed to fulfilling their legally-mandated disarmament commitments [6].

Military plutonium [35] is central to the problem of nuclear proliferation because the theft of such material is a possible pathway for horizontal proliferation. Furthermore, plutonium

ISYP Journal on Science and World Affairs, Vol. 1, No. 2, 2005 103-112

would likely be used in vertical proliferation because it is an essential component in most contemporary nuclear weapon designs.

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 the proliferation risks related to military plutonium. Nuclear bombers were dismantled and missile components were crushed [36]; however, the plutonium from nuclear warheads was left intact [11].

Initiatives to restrict exports do not address these aforementioned proliferation risks. Ad hoc groups of states rather than the United Nations have implemented export controls, though these initiatives have not been effective [15]. In any case, because export controls are focused on stopping actors from acquiring either nuclear weapons or the capability to develop them, this approach does not address vertical proliferation.

Even the Nuclear Non-proliferation Treaty (NPT), the key component of the international nuclear non-proliferation regime, does not fully address these proliferation risks. The NPT attempts to ensure that declared non-nuclear-weapon states are not developing nuclear weapons; however, it does not require the protection of military plutonium from unwanted access [9]. While there is a requirement for declared nuclear-weapon states to pursue disarmament [37], and thus curb their vertical proliferation ambitions, it has not been fully honoured.

Unlike uranium, plutonium cannot be 'blended down' into a form that is not suitable for nuclear weapons [6,38]. This technical fact necessitates the development of sophisticated measures to disposition the plutonium or change it in some way to minimise its capacity to be used in proliferation. 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 proposed methods transform plutonium in accelerators, launch it into the sun, or subject it to underground nuclear explosions.

This article argues that the present options to disposition military plutonium do not satisfy necessary non-proliferation 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. 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-origin plutonium [39]; however, since nuclear proliferation is a matter of concern for the entire international community, this article addresses the dispositioning of military plutonium in general without restricting its focus to the policies of any specific country or countries.

Background information on plutonium

Since the technical aspects of plutonium and its use in nuclear weapons have been adequately introduced elsewhere [40], the present discussion focuses on a few key points that are directly relevant to the following sections. Weapons-grade plutonium refers to a sample of plutonium that is ideally suited for nuclear weapons. As previously mentioned, all forms of plutonium can be used in nuclear weapons; however, the development of weapons with non-weapons-grade plutonium requires greater ingenuity to overcome losses in efficiency [3].

In a nuclear weapon, a massive amount of energy is produced in an extremely short period of time from the fission of either uranium or plutonium nuclei in an uncontrolled and rapidly multiplying chain reaction. The energy produced in a nuclear power reactor is the result of a fission chain reaction under precisely controlled conditions that prevent rapid multiplication. In a nuclear reactor that uses uranium fuel, plutonium is an expected by-product and is therefore present in its spent fuel [3]. Other by-products of nuclear reactions are highly radioactive fission products that are extremely harmful to human health and are believed to protect spent fuel from unwanted access [6].

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 [1]. Approximately eight kilograms of plutonium is all the plutonium that is required to build a 'Nagasaki-type bomb' [23].

Criteria for the assessment of plutonium disposition policy options

The plutonium disposition methods will be assessed against the non-proliferation and feasibility criteria discussed in this section. These criteria are based on the fundamental assumptions that military plutonium is a threat to global security, as discussed in the introduction, and dispositioning military plutonium 'is a long-term issue on which urgent action is needed' [11].

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 create non-proliferation barriers by preventing the reuse of the plutonium for weapons purposes by its owner and preventing its theft by terrorists and other actors. These barriers should be political and technical [8]. Technical barriers include 'physical, chemical, and radiological barriers to recovery of the plutonium' [6]. That is, the effort needed to obtain the plutonium after it has been dispositioned must be prohibitive. The non-proliferation measures must remain intact for at least several centuries. The implementation of the disposition method, including processing and transportation, must not introduce significant proliferation risks [11]. Some countries, 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 reactors [16; p. 8, cited in 6]. In this article, the spent fuel standard will be used to establish a minimum threshold, but it will not be narrowly applied to reject disposition methods that make military plutonium more difficult to access than the plutonium in spent reactor fuel [6].

The feasibility criteria for plutonium disposition involve timing, and technical and political requirements. The disposition method must be able to be implemented with reasonable start and completion times [33]. 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' [11]. In addition, the implementation of the disposition method must not contravene any international treaties.

Do nothing option – national storage

Before assessing the plutonium disposition options, it is necessary to examine the path of not taking any action to demonstrate that an active approach is required. In the do nothing option, military plutonium is simply left in assembled nuclear weapons or in stockpiles under its owners' control. This approach obviously meets feasibility criteria; however, it raises horizontal and vertical proliferation concerns.

While it is true that military plutonium inside assembled nuclear weapons is often protected by physical access barriers such as sophisticated locking mechanisms and military personnel, the risk of horizontal proliferation due to weaknesses in physical protection of military facilities has been identified in some states. While the problems in Russia and the states of the former Soviet Union have been well publicised [41], security concerns have also been raised about other countries with nuclear weapons including the United States [7].

The risk of horizontal proliferation also arises from present or potential political instability in some nuclear-weapon states, including states with weak civilian control over military plutonium and related decision-making [42]. Similarly, the facilities that contain military plutonium in states that are involved in regional and internal conflicts, including India, Israel and Pakistan, are potentially at risk of accidental or intentional attack.

Considering that in the do nothing option the military plutonium remains under national control and presently most military plutonium is not under the supervision of the International Atomic Energy Agency (IAEA) [4], the risk of vertical proliferation is also present. Furthermore, the absence of vertical proliferation activities does not guarantee that they will not be undertaken in the future, especially in cases in which nuclear weapons have a central position in national security doctrines.

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 highly radioactive waste. Another approach is to combine the plutonium and waste and then vitrify the mix [5]. The former approach is 'technically simple and quicker to implement' than the latter [6]. After the plutonium is immobilised, the end product is buried in an underground geological repository [8].

The barriers against proliferation provided by plutonium immobilisation include the high radioactivity of the material and the difficulty of accessing the underground repository [6]. Limiting the amount of plutonium in each container to ensure that it is less than in spent nuclear fuel is ostensibly a disincentive to theft [8].

Recognising that the plutonium is not actually destroyed in the vitrification process [6] and 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' [26]. While presently there are no industrial techniques to reprocess vitrified plutonium [12], the non-proliferation criteria remain unsatisfied, however, if it is assumed that such techniques will eventually be invented.

The immobilisation approach also fails to satisfy feasibility criteria. No single uncontroversial burial site has been identified anywhere in the world [24]. 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 [8]. Furthermore, those states, including Russia, that consider plutonium to be a desirable commercial energy source will likely reject immobilisation [12].

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 reactors. 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 fission products [6]. The reprocessing of spent MOX fuel is presently not being considered, so it will most likely become radioactive waste [5].

The non-governmental organisation Greenpeace has criticised the MOX fuel approach for creating 'more plutonium than existed in the original MOX fuel' [18]. 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 [20]. It is a fair criticism, however, that a process designed to treat plutonium in one form actually creates new plutonium in another form.

The MOX fuel disposition approach creates non-proliferation barriers to protect the end product of the dispositioning process. The remaining plutonium is protected by the radiation emitted by the fission products. Since MOX spent fuel will likely be disposed of in underground repositories, given that this is the expected disposal method for non-MOX spent fuel [8], 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 [26].

The fabrication and transportation steps required by the implementation of the MOX fuel disposition approach might make the plutonium vulnerable to theft. The radiological barrier to deter unwanted access only exists after the irradiation process, and would therefore not be present during the fabrication and transportation steps. In addition, only a basic level of scientific knowledge is required to extract the plutonium from un-irradiated MOX fuel. According to Frank Barnaby, the scientific knowledge needed 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' [cited in 27]. Some states may not have MOX fuel fabrication facilities or enough nuclear power reactors 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 [11]. To address the shortfall in nuclear reactors, one possibility is to burn MOX fuel made from Russian military plutonium in nuclear power stations in Canada. While this proposal would not violate the NPT if the material that is transferred to Canada is placed under IAEA safeguards [44], the transportation of MOX fuel between states introduces proliferation risks [2].

Although MOX fuel fabrication plants already exists in Belgium, France and the United Kingdom [23], 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' [32], and, as mentioned previously, Russia does not have enough reactors available. In any case, the MOX fuel option cannot disposition all forms of military 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' [6].

Plutonium disposition – other options

Another approach is plutonium disposition by accelerator transmutation. In accelerator transmutation, plutonium atoms are destroyed by nuclear fission [8]. Unlike in a nuclear weapon, the fission reactions in an accelerator are precisely controlled to prevent 'the possibility for a runaway chain reaction' [26].

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 [26]; however, others suggest that 'significant residues of…[the initial plutonium] would remain' [8]. 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 [8]. It is also not practical. The time needed for the research effort associated with accelerator transmutation is prohibitive [26].

Another disposition approach involves launching plutonium into the sun. The suitably packaged plutonium is 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' [26].

Solar disposal reduces proliferation risks to nil because all of the plutonium would be removed from earth and ostensibly destroyed in the sun. However, if the delivery vehicle accidentally returned to earth, there may be opportunities for theft if would-be proliferators could find and access the point of impact. Currently, dispositioning of plutonium by solar disposal is highly infeasible because it 'would require many decades of development' [29,26].

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 plutonium may be vulnerable to theft if there is a delay between burial and detonation and the explosions could be used as an excuse to research new weapons technology. This proposal is impractical because a large number of detonations would be required [8]. Also, the Comprehensive Nuclear-Test-Ban Treaty prohibits even peaceful nuclear explosions [45].

International plutonium storage

The previous section showed that the currently proposed options for dispositioning plutonium have shortcomings when assessed against necessary non-proliferation and feasibility criteria. Therefore, international storage of military plutonium should be pursued until an acceptable plutonium disposition approach 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' [46]. 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 [4]. 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 [4].

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 [13]. 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.)' [25].

Both models include political barriers to unwanted access. The centralised storage provided by the plutonium prison model represents a greater barrier to vertical proliferation. The author of this article 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' [5], 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 [4]. 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' [47].

Based on this discussion, the optimal design of an international plutonium storage programme 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 programme.

Conclusion

Dispositioning military plutonium is necessary to address the proliferation 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 reactors. Other approaches include: altering its physical properties in an accelerator, launching it into the sun, and subjecting it to underground nuclear explosions. All of these approaches fail to satisfy necessary non-proliferation and feasibility criteria. This article recommends that international plutonium storage should be implemented until such time as a satisfactory disposition method is found.

Notes

1. David Albright and Lauren Barbour, Plutonium watch: separated inventories of civil plutonium continue to grow, 1999. (http://www.isis-online.org/publications/puwatch/putext.html).
2. Dave Andrews, The problem of civil plutonium stockpiles, in: Basic Reports: Newsletter on International Security Policy, 2003, pp. 4-5.
3. Frank Barnaby, The FMCT handbook: a guide to a fissile material cut-off treaty. Oxford Research Group (2003). (http://www.oxfordresearchgroup.org.uk/publications/books/fmcthandbook.htm).
4. Harold D. Bengelsdorf and Fred McGoldrick, International custody of excess plutonium, Bulletin of the Atomic Scientists 58 (2002) 31-35.
5. Frans Berkhout, Commercial prospects for plutonium, in: Oxford Research Group, Managing plutonium in Britain: current options, Current Decisions Report Number 21, Oxford Research Group, 1998, pp. 21-31.
6. Adam Bernstein, Russia: introduction to plutonium disposition, 1997. (http://nti.org/db/nisprofs/russia/fissmat/plutdisp/dispovr.htm).
7. Danielle Brian, Lynn Eisenman and Peter D. H. Stockton, The weapons complex: who's guarding the store?, Bulletin of the Atomic Scientists 58 (2002) 48-55. (http://www.thebulletin.org/article.php?art_ofn=jf02brian).
8. Alexandra Brooks, Bernd Franke and Milton Hoenig, Plutonium: deadly gold of the nuclear age, International Physicians Press, 1992.
9. Matthew Bunn, Securing nuclear warheads and materials: global nuclear security standards, 2003. (http://www.nti.org/e_research/cnwm/securing/standards.asp?print=true).
10. Matthew Bunn and George Bunn, Reducing the threat of nuclear theft and sabotage, IAEA-SM-367/4/08, International Atomic Energy Agency, 2001. (http://www.iaea.org/NewsCenter/Features/Nuclear_Terrorism/bunn02.pdf).
11. Matthew Bunn, Anthony Wier and John P. Holdren, Controlling nuclear warheads and materials: a report card and action plan, Harvard University, 2003. (http://www.nti.org/e_research/cnwm/cnwm.pdf).
12. William J. L. Buyers, John Harvey and Alan J. Salvin, The disposition of weapons-grade Plutonium as MOX fuel in Canadian reactors, Canadian Association of Physicists, 2000.
13. Brian G. Chow, Richard H. Speier and Gregory S. Jones, A concept for strategic material accelerated removal talks (SMART). RAND (1996).
14. Department of Foreign Affairs and International Trade, Australia. The report of the Canberra Commission on the Elimination of Nuclear Weapons, 1996. http://www.dfat.gov.au/cc/CCREPORT.PDF.

15. Mohamed ElBaradei, Nuclear weapons and the search for security, 54th Pugwash Conference on Science and World Affairs, 2004. (http://www.iaea.org/NewsCenter/Statements/2004/ebsp2004n010.html).
16. G7 Moscow Summit on Nuclear Security, Background document on nuclear safety and security, 1996.
17. Global Security, 'A. Q. Khan', 2003. (http://www.globalsecurity.org/wmd/world/pakistan/khan.htm).
18. Greenpeace, Greenpeace briefing: the disarmament myth of plutonium fuel production, 2001. (http://archive.greenpeace.org/~nuclear/ waste/plutodisposition.pdf).
19. Peter Grier,. A big test of nuclear deterrence, 2002. (http://www.csmonitor.com/2002/0104/p1s2-wosc.html).
20. John P. Holdren, John F. Ahearne, Robert J. Budnitz, Richard L. Garwin, Michael M. May, Thomas H. Pigford and John J. Taylor, Management and disposition of excess weapons plutonium, National Academy Press, 1994.
21. Pervez Hoodbhoy, Pakistan: inside the nuclear closet, 3 March 2004. (http://www.opendemocracy.net/debates/article-2-95-1767.jsp).
22. Edwin S. Lyman, A perspective on the proliferation risks of plutonium mines, 14 December 1994. (http://www.nci.org/s/sp121495.htm).
23. Allison Macfarlane, Frank von Hippel, Jungmin Kang and Robert Nelson, Plutonium disposal, the third way, Bulletin of the Atomic Scientists 57 (2001) 53-57. (http://www.thebulletin.org/article.php?art_ofn=mj01macfarlane).
24. Arjun Makhijani and Annie Makhijani, Fissile materials in a glass, darkly: technical and policy aspects of the disposition of plutonium and highly enriched uranium, Institute for Energy and Environmental Research, 1995. (http://www.ieer.org/pubs/fissmats.html).
25. Jessica Mathews, Putting plutonium in prison, The Washington Post, 4 February 1997, p. A15. (http://www.fas.org/news/usa/1997/02/msg00043e.htm).
26. James M. McCormick and Daniel B. Bullen, Disposing of the world's excess plutonium, Policy Studies Journal 26 (1998) 682-702.
27. Stuart Millar, Scientist says BNFL plant is terrorist risk, The Guardian, 31 May 2001. (http://www.guardian.co.uk/uk_news/story/0,3604,499014,00.html).
28. New Scientist, Plutonium for sale: with nuclear smuggling on the increase, how long before a terrorist builds a bomb?, 26 May 2001. (http://www.newscientist.com/article.ns?id=mg17022921.100).
29. D. W. North, Unresolved problems of radioactive waste: motivation for a new paradigm, Physics Today 50 (1997) 48-54.
30. John Russell and Helen Hughes, A guide to verification: for arms control and disarmament, Verification Research, Training and Information Centre and United Nations Association of Great Britain and Northern Ireland, 2002. (http://www.vertic.org/assets/verification_pamphlet.pdf).
31. Henry Sokolski, Breeding nukes: why is the US government risking the spread of plutonium around the world?, The Weekly Standard 8 (2002).
32. Elena Sokova, Plutonium disposition, 2002. (http://nti.org/e_research/e3_11a.html).
33. US-Russian Independent Scientific Commission on Disposition of Excess Weapons Plutonium. Interim report, 1996.
34. Vertical proliferation is only used here to describe the actions of states because vertical proliferation by non-state actors, although logically possible if non-state actors undertake horizontal proliferation,

is not considered to be a serious possibility at this time. In this article, nuclear-weapon states include both declared and de facto nuclear powers.

35. Military plutonium is defined as the plutonium that exists in the military complex of a declared or de facto nuclear-weapon state. Military plutonium includes weapons-grade and non-weapons-grade material in assembled nuclear weapons and stockpiles. In this article, plutonium refers to military plutonium except in general scientific discussions or where otherwise noted.
36. 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.
37. See the Treaty on the Non-Proliferation of Nuclear Weapons, 1968, Article VI.
38. Technical constraints would likely limit the efficiency of nuclear weapons made from some forms of plutonium. See the section entitled 'Background Information about Plutonium'.
39. 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 Co-operation, 2000.
40. See, for example, [3; pp. 19-21, 44-45].
41. See, for example, [10; p. 3].
42. It is likely that the Pakistani nuclear scientist Abdul Qadeer Khan operated his proliferation network with the support of actors within his country's security sector [21,17].
43. Proliferators with adequate resources would likely find it easier to produce new plutonium than retrieve immobilised plutonium from a geological repository [22; p. 9].
44. See the Treaty on the Non-Proliferation of Nuclear Weapons, 1968, Article III.
45. See the Comprehensive Nuclear-Test-Ban Treaty, 1996, Article I. As of February 2005, this treaty has been signed and ratified by several states but it has not entered into force.
46. See the Statute of the International Atomic Energy Agency, 1956, Article XII, A.5. [cited in 4; p. 32].
47. See the Antarctic Treaty, 1959, Article V.