# **STRENGTHENING NATIONAL AND INTERNATIONAL PLUTONIUM MANAGEMENT APPROACHES**

Miles A. Pomper

James Martin Center for Nonproliferation Studies

Washington DC, USA

John Carlson

Vienna Center for Disarmament and Non-Proliferation

Vienna, Austria

Email: john.carlson.safeguards@gmail.com

Leonard Spector

James Martin Center for Nonproliferation Studies

Washington DC, USA

Mycle Schneider

Independent energy consultant

Paris, France

Professor Tatsujiro Suzuki

Research Center for Nuclear Weapons Abolition (RECNA)

Nagasaki University, Japan.

**Abstract**

The paper discusses nuclear security risks relating to reprocessing and use of plutonium in civilian nuclear programs. These risks are usually considered in terms of state-level proliferation. Unirradiated plutonium, however, also presents risks in terms of nuclear security. While the greatest concern here is the possible use of plutonium by non-state actors (terrorists) for a nuclear explosive device, this is by no means the only risk. Terrorists could also use plutonium in a radiation dispersal device. Further, the prolonged storage of spent fuel in ponds awaiting reprocessing presents greater risk of sabotage compared with spent fuel in dry storage. In contrast to actions taken to reduce proliferation and terrorism risks from highly enriched uranium, minimizing the risks from separation and use of plutonium has been given far less attention. Global stocks of unirradiated civilian plutonium have continued to grow and, indeed, substantially exceed military stocks. Nuclear security is not limited to physical protection but must also include measures to avoid or minimize risk. Effective physical protection, through rigorous standards, overseen by strong regulators and appropriate peer review, is essential at all stages in the storage, handling, transport and use of plutonium. In addition, risk mitigation requires halting and reversing the growth in plutonium stocks. The historic rationales for reprocessing no longer apply. States operating or considering reprocessing programs should be prepared to thoroughly review the technical and economic rationales for these programs, with special attention to the security aspects, and to forswear the pursuit of plutonium-based fuels unless and until there is some unforeseen circumstance where the use of such fuels makes economic and technical sense. The paper suggests a number of specific measures, including the establishment of a multilateral forum to consider these matters.

## INTRODUCTION

The paper discusses nuclear security risks relating to unirradiated plutonium in civilian nuclear programs, that is, plutonium that has been chemically separated from fission products and uranium in spent nuclear reactor fuel by reprocessing but has not been reintroduced into a nuclear reactor and subjected to further irradiation.

Risks involved with reprocessing and use of plutonium in civilian nuclear programs are usually thought of in terms of proliferation, namely, the possible use of such plutonium by states to produce nuclear weapons. In addition to proliferation risks, however, unirradiated plutonium also presents risks in terms of nuclear security, relating to possible actions by non-state actors (terrorists).

Plutonium is described as a *direct use material*, that is, nuclear material that can be used for the manufacture of nuclear explosive devices without transmutation or further enrichment. Unirradiated plutonium is especially attractive for terrorist purposes as, by definition, it has been separated from highly radioactive fission products. Accordingly, for nuclear security purposes the International Atomic Energy Agency (IAEA) has placed unirradiated plutonium in the highest risk category (Category I) [1].

While from the nuclear security perspective the greatest concern is the possibility that unirradiated plutonium could be seized or otherwise acquired by terrorists and used to produce a nuclear explosive device, this is by no means the only risk. Terrorists could also use plutonium in a radiation dispersal device, by which conventional explosives are used to spread radioactive contamination. A radiation dispersal device would be relatively easy to make compared with a nuclear explosive device. The consequences might not be as severe as a nuclear explosion but could nonetheless include major political and economic impact. Because even a trace amount of plutonium could cause cancer if inhaled, contamination from the detonation of such a device might take years to clean up to levels acceptable to the public.

Further, the processing chain for separating plutonium presents risks of sabotage aimed at spreading radioactive contamination. This risk applies not only to the unirradiated plutonium product, but to reprocessing operations and radioactive waste handling and storage. In addition, states with reprocessing programs maintain their spent fuel in ponds for extended periods pending reprocessing rather than transferring it to dry cask storage and then permanent disposal. Keeping spent fuel in spent fuel ponds for extended periods, especially if dense packing is employed, presents a nuclear security risk. An attack leading to loss of coolant could result in a spent fuel fire and dramatic radiological consequences [2].

The absence to date of terrorist attacks involving plutonium certainly does not mean the risks are negligible. Risk reduction measures must be given high priority. Obviously, such measures must include rigorous protection of unirradiated plutonium in its various forms (bulk material, fuel assemblies, and so on). An essential aspect of risk reduction must also include, where possible, measures to avoid the risk arising in the first place – in other words, a major step towards containing and reducing the risks arising from plutonium separation would be the cessation of reprocessing. Current risks should not be added to through continuation and expansion of programs involving reprocessing and use of plutonium fuels.

## Civilian stocks of UNIRRADIATED plutonium CONTINUE TO increasE

In contrast to the other *direct use material*, highly enriched uranium (HEU), minimizing the risks from separation and use of plutonium has been given far less attention [3]. There has been concerted international action to cease production of HEU, reduce stocks of this material, and as far as possible eliminate it from civilian use. Similar efforts have yet to be made for plutonium. In those states that proceeded with civilian reprocessing programs, aggregate stocks of unirradiated civilian plutonium have continued to grow. Primarily this is due to a supply/demand imbalance – the rate of plutonium separation has substantially exceeded the rate of consumption of plutonium in new fuel. Contributing factors include the continuation of historic reprocessing contracts, postponement or cancellation of plutonium-fuel programs, and also transfers of excess plutonium from military programs. Compared with global military plutonium stocks, as of the end of 2018 estimated at around 220 tonnes [4], global stocks of unirradiated plutonium in civilian programs are substantially greater, around 349 tonnes (see Table 1).

Multiple approaches to limiting the separation of civil plutonium have been implemented, and still others have been given serious study, but stocks have increased regardless, and options for working down these stocks appear to be diminishing. Meanwhile, concern has deepened over the possible theft or diversion of this material, which, as noted, could bring weapon-sufficient quantities of plutonium into the hands of violent extremists.

There are several factors contributing to the relative lack of attention to addressing plutonium minimization and management. To begin with, HEU has been considered at far greater risk of theft and use by terrorists because, once obtained, HEU might be readily fabricated into a nuclear explosive device using a “gun-type” design. Building a plutonium-based device, on the other hand, would require the use of a more complex implosion design. This is considered substantially more challenging for terrorists to master, but cannot be excluded, particularly if a terrorist group receives expert assistance (see below). It should be kept in mind that terrorists do not need to produce a device as complicated and reliable as a military-deployed nuclear weapon: a crude device that achieves even a “fizzle” yield would have global political impact.

From the perspective of state-level proliferation, another explanation for the lack of progress in plutonium minimization may be that few states currently have civilian reprocessing programs, and most of these states already have nuclear weapons. The states currently with active civilian reprocessing programs are, in order of capacity, France, Russia, India, and China. The United Kingdom had a substantial reprocessing capacity, second only to France, but this program was closed in 2018. However, the United Kingdom still has the world’s largest civilian stocks of unirradiated plutonium. Japan is continuing construction of a reprocessing plant that would give it a capacity second only to France. Japan is the only one of these states that does not have nuclear weapons, but its strong commitment to remaining without such arms has reduced concerns that it might misuse its plutonium stocks. Thus reprocessing is not generally seen as a pressing proliferation issue (though the longer-term proliferation implications need to be considered).

The focus on proliferation, however, overlooks nuclear security risks. The existence of civilian plutonium stocks poses an ongoing risk – one that can never be fully eliminated – that plutonium will be seized, stolen or otherwise acquired and used by terrorists. This risk is not confined to the states operating reprocessing programs but applies wherever plutonium is being handled, transported or used. For example, reactors in Belgium, Germany, the Netherlands and Switzerland have been licensed to use MOX (mixed oxides of plutonium and uranium) fuel, and MOX fuel was fabricated in Belgium in the past.

TABLE 1. GLOBAL STOCKS OF UNIRRADIATED PLUTONIUM IN CIVILIAN PROGRAMS (TONNES), END 2018 (a)

|  |  |  |  |
| --- | --- | --- | --- |
|  | A. Holdings in-country | B. Holdings in other states  (included in C for the holding state) | C. Holdings for other states  (included in A) |
| France | 83.2 |  | 15.5 |
| India | 6.9 (b) |  |  |
| Japan | 9.0 | 36.7 |  |
| Russia | 61.3 (c) |  |  |
| United Kingdom | 138.9 |  | 23.1 |
| United States | 49.3 (d) |  |  |
| Others |  | 1.9 (e) |  |
| Totals (rounded) | 348.6 | 38.6 | 38.6 |

Notes: (a) Based on INFCIRC/549 reports for 2018, except for India which does not participate in the INFCIRC/549 arrangements.

(b) Comprises 0.4 tonnes under safeguards and a *strategic reserve* of around 6.5 tonnes of unsafeguarded reactor-grade plutonium from power reactors which could be used for civilian or military purposes (SIPRI Yearbook 2019, Table 6.12).

(c) In addition, Russia has announced that around 40 tonnes of plutonium will be released from its military program.

(d) Plutonium declared excess to national security needs.

(e) Estimate based on figures in column C less plutonium held for Japan (shown in column B).

As regards the capabilities of terrorist groups to produce a nuclear explosive device, Matthew Bunn for one has repeatedly raised concerns about the possibility of terrorists receiving expert assistance [5]. The increase in the number of states with nuclear weapon programs (whether or not successful) has broadened the range of individuals with specialised expertise who conceivably might be prepared to help terrorists.

Considering that the principal barrier to terrorists producing a nuclear explosive device is the difficulty of acquiring fissile material, it is hardly reassuring that civilian plutonium stocks continue to grow and are approaching twice the size of military stocks. The quantity of plutonium required to make an improvised nuclear explosive device, say, 10 kilograms, is a tiny fraction of the 349 tonnes in civilian programs. After successful efforts in recent years to reduce global civilian HEU stocks, today the hundreds of tonnes of civil plutonium represent by far the greatest stock of civilian nuclear weapon-usable material remaining at risk.

## STRENGTHENING MANAGEMENT APPROACHES TO ADDRESS RISKS FROM UNIRRADIATED PLUTONIUM

There is a need not only to address specific security measures for unirradiated plutonium, but to complement these with institutional and political measures, as well as technical measures, to mitigate risks from this material.

Effective physical protection of unirradiated plutonium is absolutely essential. This requires rigorous application of standards, overseen by a strong regulator and an appropriate peer review process. Unirradiated plutonium exists in a number of forms, processes and locations – rigorous standards must be applied at all stages in plutonium storage, handling, transport and use. The adequacy of security for plutonium should be regularly reviewed and appropriate mechanisms, such as various IAEA nuclear security missions, used to provide related assurances. Currently available measures are largely voluntary and have only been undertaken at the initiative of host states. The IAEA and nuclear suppliers should be more active in pressing plutonium holders to undertake such reviews and implement appropriate improvements accordingly.

At the political level, permanent disposition of unirradiated civilian plutonium should be acknowledged as a problem common to all states possessing significant quantities of this material. It is also an important issue for the international community generally – a major terrorist incident involving plutonium would have global impact politically and economically. A multilateral forum should be established to promote international collaboration on plutonium management issues, including the development of strategies for the permanent disposition of civil plutonium [6]. Multilateral collaboration would enable efficient sharing of costs, resources, knowledge and experience, and would also enhance international transparency and confidence [7].

* 1. **Limit existing reprocessing programs and their risks**

*3.1.1 Political measures*

States with reprocessing programs should be encouraged to thoroughly review the technical and economic rationales for reprocessing, and the nuclear security aspects, and to forswear the pursuit of plutonium-based fuels unless and until there is some unforeseen circumstance where such fuels make economic and technical sense.

These states should take into account whether the benefits of reprocessing are sufficient to justify the risks from this activity. Regarding the claimed benefits, the historic rationales for reprocessing and use of plutonium fuels no longer apply. Plutonium fuels are not required to ensure the sustainability or reliability of nuclear energy. Uranium is abundant and low-cost; plutonium is more expensive than use of even very high-cost uranium (including extraction of uranium from seawater). Use of plutonium fuels has no convincing waste management advantage [8]. These facts are implicitly recognised in the termination of fast breeder reactor (FBR) programs in Japan and France. Japan announced the closure of the Monju FBR in 2016. Subsequently Japan joined the ASTRID demonstration FBR project in France. However, in August 2019 France’s CEA (Atomic and Alternative Energies Commission) announced the termination of the ASTRID project. The CEA said that in the current energy market the industrial development of fourth-generation reactors was not planned before the second half of this century.

With these decisions it is difficult to see how the continuation of reprocessing in these two states can be justified. Similar considerations should apply in the other states currently engaged in or considering reprocessing.

Japan should be encouraged to make its moratorium on reprocessing at Rokkasho permanent and to pursue dry cask storage as an alternative to reprocessing. A complication is that currently Japanese legislation does not allow for final disposal of spent fuel (or unirradiated plutonium): reprocessing is the only legal option for long-term management of spent fuel. Japan should be encouraged to change its laws to enable the most appropriate management strategy to be adopted.

Likewise, France should be encouraged to pursue dry cask storage as an alternative to reprocessing. French companies are among the world’s leading dry storage system providers and French builder-operator EDF will implement dry storage rather than reprocessing at the Hinkley Point C plant currently under construction in the United Kingdom. The November 2019 law on energy and climate does not mention spent fuel management. However, according to the draft Multi-Annual Energy Plan, spent fuel reprocessing and plutonium use “must be maintained”. At the same time, the official abandoning of the ASTRID project pushes the realization of a plutonium-fuelled FBR, if ever, into the second half of the century and likely would also require the construction of a new generation of reprocessing and MOX fuel fabrication facilities absent any economic justification. This should be the occasion for France to reconsider its spent fuel management and plutonium research and development policies altogether, abandon plutonium separation and use, and engage with the international community to develop conditioning and disposal options for its considerable unirradiated plutonium stocks. France should also reconsider its proposal to export a reprocessing plant to China [9].

*3.1.2 Technical measures*

As already noted, storage of spent fuel for extended periods in ponds awaiting reprocessing presents considerably greater risks of sabotage and outside terrorist or military attack, especially where high density storage is used, compared with expeditious transfer of spent fuel from ponds into dry storage. Termination of reprocessing programs would enable spent fuel to be held in safer conditions in dry storage casks.

* 1. **Limit the risk of existing civilian plutonium stocks**

*3.2.1 Political measures*

Options for multilateral management of plutonium stocks should be examined, including further consideration of international plutonium storage concepts.

*3.2.2 Technical measures*

The number of sites with unirradiated plutonium holdings and the number of transport movements of plutonium should be minimized, and regular reviews conducted of the security of such sites and transport arrangements.

Non-essential holdings of plutonium should be identified, and appropriate actions taken to deal with these, as has been done for HEU. Actions could include consolidating holdings (reducing the number of locations), and where possible, removal to the supplier state.

Where plutonium is held in the form of plutonium oxide, consideration should be given to converting it into less sensitive forms (such as MOX pellets and fuel assemblies) as early as practicable, in order to increase the time needed for any attempt at weaponization, provided this can be done without incurring additional security risks. Conversion to MOX could be extended to include plutonium insufficiently pure to be used in reactor fuel.

A state, in particular France, that has large stores of MOX with impurities unlikely to be re-reprocessed within a calendar year, should consider placing MOX fuel pins or assemblies in dry casks with highly radioactive spent fuel assemblies for final disposal. This strategy would combine high-quality conditioning, security level and proliferation resistance. Pending the ultimate disposal of such material, this would provide increased protection against access by non-state actors.

Active strategies should be followed to run down plutonium stocks. If reprocessing cannot be terminated in the short term, the rate of plutonium separation should be kept well below the rate of consumption, to ensure that stocks are drawn down. There is a dilemma here – while plutonium use and disposition programs play a positive role in reducing the size of plutonium stockpiles, they also introduce new dangers through additional handling and transport of plutonium. There is a further dilemma – while transfer of excess military stocks of plutonium to civilian programs is important for disarmament, adding to civilian stocks adds to existing risks. Dilution, conditioning and direct disposal of plutonium in deep geological repositories should be rapidly developed as an alternative to the ongoing use of plutonium in fuels.

Dilution and direct disposal are particularly important strategies in states where MOX fuel is currently not being used, such as the United Kingdom and the United States. Given the poor economics and remaining security risks of MOX (plutonium can be chemically separated sufficiently easily that the IAEA considers MOX to be a “direct use material”) there is little reason today to initiate a plutonium fuel system. As the United States pursues its “dilute-and-dispose” option for the permanent disposal of excess military plutonium, it should be prepared to share dilution and conditioning technologies with other states and to include these states in unclassified aspects of ongoing US research and development activities.

* 1. **Discourage new reprocessing programs**

*3.3.1 Political measures*

Policymakers considering proposals for reprocessing and plutonium fuels should be encouraged to ensure that the economic and technical rationales, as well as nuclear security aspects, are analysed rigorously. This is particularly relevant in the case of China, which is currently considering the establishment of a large-scale reprocessing program [10].

Current restraints on transfers of reprocessing equipment and technology should be maintained. Additional commitments, like those in US nuclear cooperation agreements (such as the agreement with the United Arab Emirates), where the US partners have agreed to renounce reprocessing into the indefinite future, should be pursued.

Dry cask storage technology should be actively promoted as the fundamental principle of spent fuel management.

*3.3.2 Technical measures*

For the future, if use of plutonium fuels is warranted, this should not proceed unless technologies are developed that reduce the risk of subnational theft by ensuring plutonium remains difficult to access – for example, through techniques that avoid separation of pure plutonium and leave plutonium in a highly radioactive mix with other actinides and fission products. Security-by-design, safeguards-by-design and proliferation-resistance should be pursued as design objectives for new technologies.

## CONCLUSION

The existence of civilian unirradiated plutonium stocks poses an ongoing risk – one that can never be fully eliminated – that plutonium will be accessed, acquired and used by terrorists. This risk is not limited to states with plutonium in their fuel cycles. Because any major terrorist incident involving plutonium will have global repercussions (political, economic, loss of public confidence in nuclear energy), this risk is shared by – or imposed on – the international community as a whole. Accordingly, decisions on plutonium issues are not the exclusive concern of the state involved, the international community has a legitimate interest. A multilateral forum is needed to foster consultation and collaboration on plutonium management, including safety and security aspects, and to ensure the international interest is well represented.

Risk mitigation for plutonium requires not only application of rigorous safety and security standards, but also that the risks are contained, reduced and eliminated. This requires the current trend of increasing stocks of unirradiated plutonium to be reversed. Reprocessing should not continue unless it can be demonstrated that the overall benefits outweigh the risks. In foreseeable market conditions, it is difficult to see how reprocessing can be justified. Instead, dilution and disposal options should be considered for current plutonium stocks, and spent fuel held in ponds should be moved to dry storage without further delay.

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