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Safeguarding the Ingredients For Making Nuclear Weapons

With thousands of bombs being disassembled, the U.S. and Russia must tighten controls to prevent theft of fissionable materials.

In the current state of the world, nuclear weapons are destined to play a decreasing role. The nuclear arms reduction agreements between the United States and the former Soviet Union, followed by declarations from the presidents of the United States and Russia, will reduce the deployed nuclear weapons of these two nations by close to a factor of five in the first decade of the next century. Moreover, the Nuclear Non-Proliferation Treaty, the subject of a critical extension review in 1995, obligates the nuclear weapons states "to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament."

With the end of the Cold War, concerns about the proliferation of nuclear arms have come to seem far more important than preventing or preparing for direct nuclear conflict. Controlling proliferation will necessitate dealing with technical, institutional, and political difficulties. The dominant technical difficulty is limiting access to fissionable material —the plutonium or highly enriched uranium (HEU) that can be used to make a nuclear weapon. Well over 20 percent of HEU is in the form of the fissionable isotope uranium 235. Natural uranium contains only 0.7 percent uranium 235; the balance is uranium 238. Plutonium does not occur in nature; it is produced inside a nuclear reactor, through neutron capture by uranium 238, followed by beta decay.

Keeping fissionable material from finding its way out of nations that possess nuclear weapons and into nations that do not will not by itself prevent proliferation, of course. Given a strong will and adequate resources, determined countries can generally find ways to produce fissionable materials on their own, as Iraq has recently demonstrated. Ultimately, we can keep nuclear weapons from multiplying only if we can persuade nations that their national security is better served without these

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weapons. A two-pronged approach—technical and political—is essential.

The rest of the world is concerned, and rightfully so, that states that do not now possess nuclear weapons can still acquire fissionable material, either indigenously or by transfer. The strong suspicion that North Korea has accumulated several kilograms of plutonium has generated widespread alarm. For planning purposes, we can assume that four kilograms are, on average, sufficient to make one weapon; specific amounts depend on weapons design. Yet the arms control measures agreed to by the United States and Russia are expected to generate more than 100 metric tons of excess plutonium. The risk that some of this immense stockpile might escape from tight control is a much greater concern than the small amount North Korea is surmised to have produced.

The risk of theft or diversion is particularly strong in Russia. The breakup of the Soviet Union has left weapons containing fissionable materials in the hands of four states: Russia, Kazakhstan, Belarus, and Ukraine. Although commitments to consolidate these weapons into Russia were agreed upon in the Lisbon protocol in 1992, at this writing it is not certain when—or even whether—this move will actually be completed. Ukraine in particular is creating difficulties. Nor do we have reliable information about how security will be imposed after nuclear warheads arrive in Russia or where they will be dismantled and the fissionable material stored.

Proper safeguards must include precise accounting and direct barriers against diversion. In the Soviet Union, accounting was relatively weak, but security measures around storage sites were strong. But now, the demoralization of some elements of the Russian military establishment as well as the pressure on individuals to supplement their incomes may encourage illicit sales of fissionable materials. Three thefts of HEU have been reported by Russian authorities, although in each case the culprits were caught. No diversions of plutonium have been confirmed, but there have been increasing numbers of false alarms.

Calculating the risks

Plutonium and HEU pose different kinds of risks and opportunities for control. HEU is produced by "enriching" natural uranium via a number of alternative technologies, all of which are sophisticated and expensive. HEU from nuclear weapons can be "blended down" with other kinds of uranium so that it cannot be used for nuclear weapons unless re-enriched using the complex technical processes. In contrast, weapons-grade plutonium cannot be blended down with other plutonium isotopes because all available plutonium isotopes are fissionable and in principle can be used to make nuclear weapons. Plutonium can be alloyed with other substances, but reclaiming it from such an alloy is relatively easy with purely chemical methods that require much less effort than isotope enrichment.

Because of concern about the security implications of the surplus plutonium, the National Security Council asked the Committee on International Security and Arms Control of the National Academy of Sciences (NAS) to carry out a yearlong study to formulate recommendations for the management and disposition of these materials. Excess weapons plutonium is part of the physical heritage of the Cold War, along with challenges such as getting rid of hundreds of tons of chemical weapons and enormous quantities of bullets and other conventional munitions. But the plutonium problem is different. Nuclear weapons not only possess enormous destructive power, but plutonium itself is highly toxic and a hazard to the environment. Moreover, questions about how to handle weapons-grade plutonium are bound up with our continuing quandary over how to manage the much larger quantities of reactor-grade plutonium generated by the civilian nuclear fuel cycle.

Although all isotopes of plutonium are fissionable and in principle can be used to make nuclear weapons, the dominant isotope, plutonium 239, is most suitable. When plutonium is produced in a nuclear reactor, plutonium 239 is formed, with the other isotopes initially growing at a slower rate. Thus, if plutonium is separated from a reactor's fuel rods early in the radiation cycle, this material is predominantly plutonium 239 or what is known as weapons-grade plutonium (W-Pu). If fuel rods are irradiated for a much longer time in order to extract most of the energy value from the fuel, then the separable plutonium also contains much larger admixtures of other plutonium isotopes, in particular plutonium 240 and plutonium 241 as well as some plutonium 238. This material is called reactor-grade plutonium (R-Pu).

These additional isotopes complicate the task of the weapons designer. Plutonium 240 has a high spontaneous fission rate, plutonium 241 decays into highly radioactive Americium, and plutonium 238 has a short half-life and thus produces substantial quantities of heat. Despite these complications, reactor-grade plutonium can be fashioned into nuclear weapons with an assured yield of a few kilotons; elaborate designs make even larger yields attainable. Historically, all the countries that have acquired nuclear weapons have done so by developing dedicated facilities for producing fissionable materials, rather than by diverting reactor-grade plutonium from nuclear power stations. But there is no reason why reactor-grade plutonium could not be used for weapons in the future.

Both the U.S. and Russia should disclose total amounts, categories, and locations of their plutonium stockpiles.

Almost 1,000 tons of R-Pu has accumulated since the beginning of the nuclear age. Most of it is in the form of spent fuel (R-Pu and a mixture of highly radioactive fission products and other substances). Such fuel rods are, for the time being, "self-protected," in that they are extremely radioactive, which makes it unlikely that they will be stolen or otherwise diverted. But about 70 tons of R-Pu has been separated or "reprocessed" from spent fuel rods. This material constitutes a proliferation hazard not unlike the excess W-Pu.

Policies and practices for handling spent fuel differ among the various states of the world. Mindful of the nuclear weapons proliferation risk generated by the separated R-Pu, the United States decided during the Carter administration not to reprocess spent fuel but instead to bury it intact in geologic repositories. When and how this strategy will be carried out remains uncertain, however. The chosen burial site for these materials is Yucca Mountain in Nevada, but the site will not be ready to receive these so-called high-level wastes until the first quarter of the next century. Other countries, notably Japan and some European states, have opted for the closed nuclear fuel cycle, in which plutonium is reprocessed from spent fuel and then reintroduced into reactors. These countries accept the increased risk of proliferation inherent in commercial plutonium traffic in exchange for wringing more fuel value out of a given weight of uranium.

At the time these countries made the decision to reprocess plutonium, the future of nuclear power looked very different from the way it does today. Supplies of uranium ore were expected to be much smaller and the demand for nuclear electricity much larger than either has proved to be. As a result, most of the world's reprocessed plutonium exists because of decisions and commitments made some time ago on the basis of assumptions about the economics of nuclear power that are no longer valid. Whether and to what extent reprocessing will continue in the future depends on economic and political factors that cannot now be foreseen. Decisions about what to do with W-Pu must be independent of that evolution. But the plans and policies for W-Pu must take into account these vast quantities of R-Pu.

Short-term imperatives

The management and disposition of W-Pu falls into a number of sequential phases. Possible theft or diversion of excess W-Pu is a clear and present danger. Therefore, the countries concerned, in particular Russia, should take immediate steps to tighten controls. Following those initial steps, the material will have to be transferred into intermediate storage. This interim solution is necessary because, for technical and institutional reasons, none of the more permanent solutions for disposition can be expected to make a dent in W-Pu stockpiles for at least a decade, and probably longer. Yet, precisely because disposition cannot be initiated for such a long time, it is urgent that choices be made very soon among the various avenues toward such disposition.

The first step—that is, improved management and safeguards for the excess W-Pu—requires that the nations concerned operate with much less secrecy. Until very recently, even the total quantities of W-Pu in the United States and Russia were secret. The U.S. government has now released that information. Russia has not yet done so, partially due to inertia and the inability of various Russian ministers to reconcile their interests. Also, the Ministry of Atomic Energy tends to play its cards close to the chest, with a view toward trading the information for commercial gain. Our range of uncertainty about Russian stockpiles is equivalent to thousands of nuclear weapons. Both the United States and Russia should disclose total amounts, categories, and locations of their plutonium stockpiles.

In parallel with these declarations, the two countries should cooperate to improve accounting and inventory practices for nuclear materials in Russia and generally increase the openness of the nuclear weapons complexes of the two sides. Declarations of the kind envisaged here cannot be verified with as much confidence as we have been led to expect from earlier arms control agreements. But a number of cooperative measures can make it unlikely that, practically speaking, such declarations would be far off the mark. For example, if the operating records of facilities that produce fissionable materials, such as enrichment plants and production reactors, are made available and if these plants are open to reciprocal inspections, then falsified declarations are likely to lead to inconsistencies. Such a regimen would greatly reduce the world's ignorance about total plutonium inventories and about what is being done to keep them safe and secure.

There are strong reasons to advocate such a new system. First, with the acceptance of democratic principles by Russia, openness rather than secrecy should be the norm. Second, without more specific knowledge of fission-materials inventories, it is difficult to foresee cuts in deployed nuclear weapons beyond those now envisaged in START II. Third, prospects for achieving compliance with nonproliferation measures would surely be enhanced if the very large stockpiles of the nuclear superpowers were known and accounted for.

One element of increased openness would be mutual inspections of the dismantling of nuclear weapons. Interestingly enough, the Ukrainians, under an agreement with the Russians, are inspecting the dismantling of weapons that have been moved from Ukraine to Russia. It appears entirely feasible technically to carry out this sort of inspection without compromising information on the design of nuclear weapons. The preferred mechanism is perimeter portal monitoring (PPM), in which the disassembly facility is fenced and the incoming and outgoing materials are inspected with mutually agreeable technical devices. These devices can determine that the incoming object is indeed a weapon and measure the amount of fissionable material in the outgoing substances. PPM has been an important tool for verifying the successful Intermediate Nuclear Forces Treaty in Europe. Destruction of certain intermediate-range missiles is being verified in both Russia and the United States using an analogous procedure.

At present, nuclear weapons are being dismantled in the United States at a rate of roughly 1,800 per year. Similar rates are believed to prevail in Russia. The Russians claim that their rate is limited by the lack of storage facilities for the W-Pu-containing "pits" withdrawn from nuclear weapons. In the United States these pits are stored at the Pantex assembly and disassembly plant near Amarillo, Texas. Although storage capacity could be expanded at Pantex, there is considerable local opposition to storing more than an already agreed-upon number of pits, and the secretary of energy appears to support such a limit. Local opposition has also scuttled a Russian plan to build a storage facility near Tomsk. The Russians are now discussing the use of multiple sites, each of which would store only locally generated materials. Such an arrangement would be difficult to reconcile with the need for increased and long-lasting security.

Spending money on a new U.S. storage facility may not be justifiable, largely because other military and nonmilitary facilities exist that could handle the job. The United States should, however, supply assistance with constructing such a facility or facilities in Russia, provided that they contain all the surplus Russian W-Pu and that transparent accounting and safeguarding practices are in place. Such intermediate storage facilities would provide a place to keep surplus W-Pu under safeguards—initially bilateral and eventually multilateral—in order to guarantee that these materials can be withdrawn only for peaceful purposes, in line with existing practices of the International Atomic Energy Agency. The amount of material designated for such storage by each country should be as large as possible.

One issue is the form in which the W-Pu should be stored in international facilities. It would be most expedient to continue to store the material as pits.

This would be environmentally benign since no plutonium handling is required and pits are known to be safe and stable. The disadvantage is that pits could be reconstituted into weapons more readily than if the plutonium was refabricated into other shapes or composition. On balance, it seems preferable to store the material as pits temporarily, pending agreement on eventual disposition. Once such a choice has been made, the plutonium can be processed into whatever form is required.

The U.S. must convince Russia to put as much as possible of its weapons-grade plutonium in internationally safeguarded storage.

Storage options

This leads me to the third phase of the process, which is final disposition. Here it is impossible to make a specific single recommendation. Instead, the NAS committee identified those options that should be kept open and those that are so unpromising that they should be pursued no further.

The world is not now ready—and may never be ready—to eliminate all its plutonium. R-Pu, despite its inherent risk of leading to nuclear weapons proliferation, may remain a world commodity in order to satisfy future demands for nuclear power. The United States has, at least for the time being, foregone the option of separating plutonium from spent fuel for reuse as an energy source. Whether other nations will adopt that caution in the future—or whether, conversely, the United States will resurrect the reprocessing option—cannot be foreseen today.

Therefore, it would be wasteful—and, in fact, counterproductive—to insist that disposition of W-Pu means complete elimination of the material from human access. If total elimination is to be the goal, it should be applied to all of the plutonium in the world, rather than only the excess plutonium from nuclear weapons. Both R-Pu and W-Pu can, after all, be made into nuclear weapons. For this reason, the most certain and expedient course is to dispose of W-Pu in a way that meets the “spent fuel” standard. In other words, processed W-Pu should be no more accessible for potential weapons use than the plutonium in spent nuclear fuel rods.

Two paths to this goal are open at present. One way is to fabricate the W-Pu Into a fuel suitable for one-time use in existing nuclear reactors. The other is to mix the W-Pu with high-level waste from nuclear reactors, thereby making it as radioactive—and inaccessible—as spent nuclear fuel rods.

The leading option for burning plutonium in existing power reactors is to convert it into plutonium oxide and then fabricate it into mixed oxide fuel (MOX), which contains perhaps 4 percent plutonium oxide, with the rest uranium oxide, MOX fabrication and use is practiced in Europe. With excess plutonium from nuclear weapons pleading for disposition, the MOX route is technically feasible in the United States and Russia, but the question of its institutional and political acceptability must be explored further.

Because of the U.S. decision not to recycle plutonium from spent fuel rods, no MOX fabrication facilities have been completed in the United States. There is an unfinished facility for fabricating MOX fuel on the Hanford Reservation in Washington; it could be completed more cheaply than building a facility from scratch. Several U.S. nuclear reactors are technically capable of fully substituting MOX cores for their current lightly enriched uranium (LEU) cores, which contain 3 to 4 percent of the isotope uranium 235. In addition, the Canadian CANDU reactors could be fueled with 100 percent MOX fuel elements. Almost all other U.S. reactors could burn a core containing one-third MOX, with the remainder consisting of the standard LEU elements. This would, of course, mean that a much larger number of reactors would be involved in the plutonium fuel cycle, a disadvan-tage in safeguarding the process against diversion.

The net result of burning MOX would be the generation of spent fuel rods containing a somewhat larger fraction of plutonium than is now the case in the conventional commercial fuel cycle. The total number of spent fuel rods that would eventually require geological disposition would not, however, differ significantly from the total if the same amount of nuclear electric power were to be generated without using MOX.

Disposing of W-Pu by "once-through" burn-up in existing nuclear reactors should not require the construction of new reactors or the development of new reactor types. There is a clear advantage in using the minimum number of existing reactors; if the use of a full MOX core is feasible, then two or three reactors could burn up the excess W-Pu in one or two decades. The fact that new reactors cannot be justified for the mission of burning W-Pu does not, of course, imply anything about whether new reactors should—or should not—be built or developed for the future of nuclear power.

The second option for disposing of W-Pu to the spent fuel standard would involve adding plutonium to the process for converting high-level nuclear waste into glass logs. After some difficulties, this process is now well advanced. Limited experimentation and calculations have shown that several percent of plutonium by weight could be added to the logs without undue consequences. Still, outstanding questions remain about precisely how much plutonium could be safely loaded into logs and about how to introduce the plutonium into the melters that fuse the different materials together without creating any risk of an inadvertent chain reaction. Another potential risk is whether, over millennia of storage, leaching could remove boron from the borosilicate glass faster than leaching removes the plutonium itself. Boron inhibits nuclear chain reactions, so there is a remote possibility that differential leaching might be a problem.

These two competing candidates for disposing of W-Pu to the spent fuel standard should be pursued and investigated for the time being because they are the most favorable options for disposition. They face somewhat different obstacles. MOX burning is a fully established technology in Europe, but there are institutional and possibly political obstacles to introducing plutonium into existing American or Canadian reactors. Plutonium mixed with high-level wastes to form vitrified logs appears more straightforward from the regulatory point of view, but some technical problems remain.

Will Russia go along?

A major question is whether these preferred options for disposition are acceptable to Russia, where security problems surrounding W-Pu appear more serious. The Russians have a light-water reactor that, according to U.S. experts, can be adapted to burn a full fuel load of MOX and that can be operated safely by Western standards. But the Russians do not favor this route because they would rather keep the plutonium as fuel for future breeder reactors, which create new plutonium as they burn the old. Unfortunately, breeder-reactor development is not well advanced in Russia, and initial operation is probably decades away. Moreover, under present conditions in Russia, this solution would require extensive subsidy. The Russians are also unsympathetic to vitrification because they believe that W-Pu has value and that throwing it away along with high-level waste is the wrong thing to do.

The "value" of plutonium is a contentious issue, and much conflicting information has been published about it. The first problem is what the term means. If it refers to fuel value, then there is no question that W-Pu has an energy content that is comparable, on a weight-by-weight basis, to the value of uranium 235. But if the term means economic value, then W-Pu has to be compared with the conventional LEU fuel for nuclear reactors.

In making such a comparison, analysts must agree on what counts as part of the economic cost. For instance, it is reasonable to assume that if W-Pu is to be burned in a nuclear reactor, the government concerned has already written off the cost of producing it, and it will be available free. Therefore, in comparing the economics of burning MOX using W-Pu with all-LEU fuel, one might assume that the cost of MOX is based on free plutonium, but it includes the cost of producing plutonium oxide, fabricating MOX fuel, licensing and modifying the reactors to burn MOX, operating the reactors securely and safely using MOX, and, finally, disposing of the spent material. By comparison, the cost of using LEU would include mining of uranium and enriching the natural uranium to the required uranium 235 concentration, fabricating LEU fuel elements, burning the material in the reactor, and disposing of it. The cost of money to build the necessary capital facilities also has to be part of the equation. Given the length of the process required for licensing and constructing appropriate facilities, this is a major factor.

Using these comparisons, plutonium cannot now compete with LEU, which is abundant and cheap. This may change eventually, but it is extremely unlikely that plutonium will become competitive in less than half a century. Such a long delay would lead us to assign a negligible present value to the plutonium. Moreover, plutonium can be considered a renewable resource; if an economic need to generate it does develop decades from now, plutonium could then be bred from natural uranium and recovered by reprocessing.

The Russians' desire to preserve their present W-Pu inventories while waiting for a breeder economy cannot be justified economically, and the plan also constitutes a security risk because the material would have to be guarded for such a long period. Moreover, the idea that plutonium embedded in glass logs is plutonium thrown away is not a persuasive argument against the vitrification option, since what is being thrown away does not have economic value.

Persuading the Russians that these economic arguments are correct will require considerable diplomatic effort. The West may need to strengthen the persuasion with financial incentives, justified on the basis of security rather than economics. In particular, U.S.diplomacy should give high priority to motivating the Russians to declare the maximum amount of W-Pu as excess, to place that excess material in internationally safeguarded storage, and to agree on the most rapid feasible disposition option.

This is not a happy story. The large stockpiles of W-Pu are a grim legacy of the Cold War. They must be dealt with in a way that minimizes their risk to security, both national and international. I am deliberately using the word "minimize" rather than "eliminate." I know of no way to make that risk disappear.

Recommended reading

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