Control and Disposition of Nuclear-weapons Materials

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As several other speakers have noted, it now appears likely that the nuclear arsenals of the United States and Russia will be reduced by about a factor of ten in the next decade or two. The dismantlement of these vast arsenals will make available nearly 1,000 tonnes of highly enriched uranium (HEU) and 200 tonnes of weapon-grade plutonium. Dealing with this surplus creates problems as well as opportunities, but the problems are much less intractable than those we had to worry about earlier.

Uranium

Dealing with the HEU is relatively simple. Most of the HEU should be mixed with depleted uranium to yield low-enriched uranium (LEU) to fuel commercial nuclear reactors. A small fraction of the HEU may be reserved to fuel reactors that require HEU, such as certain research, test, and naval reactors, but every effort should be made to minimize such uses to diminish the potential for the theft or diversion of weapon-grade material. At current prices for natural uranium and separative work, 1 kilogram of HEU is worth $10,000 to $15,000 when mixed with natural uranium to yield LEU. The HEU in the nuclear arsenal is therefore worth $10 to 15 billion, substantially less than the $50 to 60 billion given by previous speakers. If the HEU released from weapons is sold over a period of 20 years, these sales would constitute only about 15 percent of the current market for LEU.

Tom Neff of MIT has proposed an excellent way to maximize the benefits from military HEU. Russia needs foreign currency, but selling large quantities of LEU would cause an already weak market to collapse. The United States could, however, sign a long-term contract to buy Russian LEU (or HEU) as it is produced from dismantled warheads. This would give Russia incentive to dismantle its warheads as quickly as possible, and the flow of HEU would give the United States assurance that the warheads were being dismantled irreversibly. The United States could then use this LEU, together with LEU made with HEU from its own dismantled warheads, to fulfill its contracts to supply reactors with fuel, thus allowing it to shut down its uranium enrichment facilities. Last year the United States lost $400 million in uranium enrichment services because of the low market price of LEU and because U.S. technology is outdated and inefficient. U.S. and Russian HEU would allow the United States to close its facilities while matching its current sales of LEU for about ten years. During this time, it could use the revenue (and the money saved by eliminating its losses) to modernize. The United States could stabilize the uranium market at current (low) prices, while allowing Russia to earn hard currency by continuing and expanding its uranium enrichment services.

In any case, uranium must be stored for a decade or more. I believe that this is best accomplished by mixing the HEU with natural or depleted uranium immediately to produce LEU (less than 20 percent uranium-235). While this material cannot be used in a bomb, it should be secure and safeguarded by the IAEA because most of the enrichment work that is required to turn natural uranium into HEU has already been done. It makes no sense to store the material as HEU to start up breeder reactors, because breeders will not be economical for many decades, unless there is very rapid growth in the use of nuclear energy. It makes much more sense to burn the HEU as LEU now. If the use of nuclear energy does greatly expand, breeders could be started using plutonium separated from the spent fuel of the many light-water reactors (LWRs) that would then be operating.

Plutonium

The case of plutonium is much more difficult, and it is here that I disagree with many of the earlier presentations. The assumption has been that plutonium, like HEU, has value as nuclear fuel, and that it should also be "disposed" of by burning it in reactors: as mixed-oxide (MOX) fuel in LWRs, in breeder reactors, or in specially designed fast reactors. But plutonium currently has no economic value. There is already a glut of plutonium from past (uneconomical) reprocessing, and warhead dismantlement will only deepen the glut.

MOX. At current prices for natural uranium ($20/kg) and separative work ($70/SWU), LEU costs about $750/kg--half the estimated cost of new MOX ($1300 to 1600/kg), even assuming that the plutonium is free. At these prices, it would cost roughly $5 billion to dispose of 200 tonnes of plutonium ($2 to 10 billion using a reasonable range of future LEU and MOX prices). Moreover, burning MOX in LWRs does not eliminate the plutonium, since about 300 kg of plutonium are produced for each tonne of plutonium loaded in the reactor. The plutonium in the spent fuel is, however, less desirable for use in nuclear weapons, having a much larger fraction of plutonium-240 than weapon-grade plutonium. I should emphasize, however, that it is perfectly possible to build a bomb using reactor-grade plutonium.

Another objection to MOX is based on nonproliferation concerns, and it is for this reason that the United States canceled reprocessing of spent fuel in the late 1970s. The disposal of weapon-grade plutonium as MOX would involve hundreds of shipments of fuel, and the diversion or theft of just one fresh MOX fuel assembly would make enough plutonium available to build several bombs. Fortunately, the United States has no plans to use the plutonium recovered from dismantled warheads as reactor fuel.

Breeders and fast reactors. Plutonium can be used in breeder reactors, but few such reactors exist now or in the near future. Moreover, since breeder reactors produce as much plutonium as they consume, it is hard to understand how one could advocate using breeders to "dispose" of plutonium. One could, however, build special fast reactors without a breeding blanket that would consume plutonium without producing more of the same. While the consumption of plutonium in such reactors is higher than in LWRs, special fast reactors will be much more expensive than LWRs, large amounts of plutonium will be discharged in the spent fuel and require recycling, and the plutonium will remain of high quality for nuclear weapons.

Thus, the least-bad option for burning plutonium in reactors is as MOX in LWRs. If, after exploring alternative solutions for plutonium disposal, this option is chosen, the geographic distribution of MOX use should be as limited as possible. Today MOX is used in only one-third of the core, but if an LWR core is reconfigured it could operate with 100 percent MOX, consuming about 1 tonne of plutonium per reactor year. Thus, the 100 tonnes of plutonium in the Russian nuclear arsenal could supply a group of five specially configured reactors for twenty years. The spent fuel, which would contain reactor-grade plutonium, could then be put in geologic disposal.
What are the alternatives to burning plutonium in reactors?

Storage. One is simply to store the plutonium to start a future generation of breeder reactors. While this is not economical for HEU, there is no competing short-term use for plutonium. Preliminary estimates indicate that plutonium storage would cost about $1 per gram per year. Thus, storing 200 tonnes of plutonium might cost roughly $200 million/year, for a net present value of roughly $2 billion. As indicated above, this is likely to be less than the cost of burning the plutonium as MOX, and even less if breeder reactors are built in the not-too-distant future and the plutonium becomes valuable.

Several speakers have said that long-term storage is not safe or secure. The same speakers believe that MOX recycle *is* safe and secure. I find this hard to understand. There is almost no risk of theft from a heavily guarded facility, and little risk of surreptitious diversion. There is, of course, always the possibility that the United States will turn fascist in one hundred years and reclaim the material for weapons. If this is your worry, then the storage facility should be located in a neutral and stable country, like Switzerland (or the Vatican!). To my mind, the short-term risks that would be involved in a full-blown MOX reactor economy, in which the diversion or theft of just one fresh MOX fuel assembly out of thousands could support the construction of several bombs, is a far greater danger, and I believe that this is widely accepted in the United States.

Irretrievable disposal. A third option is to dispose of the plutonium in a practically irretrievable manner. My preferred solution is to mix U.S. weapon-grade plutonium with the high-level wastes (HLW) resulting from military reprocessing that are stored at Hanford and Savannah River. Current plans are to vitrify the HLW and to dispose of it in deep geologic storage. Russia has similar plans for its HLW. There appears to be no technical reason that plutonium cannot be mixed with HLW before vitrification. As you all know, the United States plans to dispose of spent fuel without reprocessing, so there are no psychological barriers to disposing of plutonium as waste, as there are in Europe. It should not be too difficult to design IAEA safeguards for the disposal process.

The United States plans to incorporate HLW into 25,000 tonnes of glass, at a rate of about 1,000 tonnes of glass per year, enough to dispose of 100 tonnes of plutonium in five years, if the glass contains 2 percent plutonium. The buried glassified waste would be highly inaccessible, dilute, and radioactive; this waste form appears to be even more proliferation resistant than buried spent fuel.
The cost of disposing plutonium in this way are much lower than burning or storage. A recent analysis by Pacific Northwest Laboratories estimates the total additional cost at $100 million to

convert 100 tonnes of plutonium metal to oxide and mix it with HLW--ten times cheaper than storage, and ten to fifty times cheaper than MOX.

Other disposal methods, such as nuclear explosions and space disposal, are more costly, offer few advantages, and have additional risks.

It is often said that Europeans object to disposal of plutonium because it, along with other actinides, represents most of the long-term hazard from spent fuel. But plutonium does not represent most of the *risk* posed by deep geological storage of spent fuel, because it is quite insoluble in water, while long-lived fission products such as technetium-99, iodine-129, and cesium-135 are very soluble. The only plausible way that wastes buried deep in the earth could come into contact with humans is through ground-water migration, but in this case the dose from long-lived fission products is likely to be much higher than the dose from plutonium. Thus, it is unclear whether reprocessing provides significant waste-disposal benefits. In any case, these benefits are certainly not great enough to outweigh the extra costs and proliferation risks.

Conclusion

In conclusion, HEU and weapon-grade plutonium from dismantled weapons should be placed under international safeguards as soon as possible. Most of the HEU should be diluted immediately to LEU and sold over an extended period as LEU fuel for LWRs. In addition, there are large potential advantages for both the United States and Russia if the United States contracts to buy Russian HEU (or LEU) as it becomes available from dismantled weapons.

The form in which plutonium should be stored deserves greater study. Since I believe that the best option for plutonium disposal is to mix it with HLW and bury it, short-term storage as pits is probably fine, although it would be better to convert it to oxide in anticipation of glassification. Disposal of plutonium in this way is the cheapest, fastest, safest, and most proliferation-resistant method, and is superior in every respect to burning the plutonium as MOX.