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CUTTING OFF NUCLEAR WEAPONS PRODUCTION AT THE SOURCE

The superpowers have together produced for use in nuclear weapons more than one thousand tonnes (one *million* kilograms) of highly-enriched uranium and plutonium—and they still don't seem to have enough. (Remember that the Nagasaki bomb contained only six kilograms of plutonium and the invention of thermonuclear weapons made it possible to trigger much larger explosions with only a few kilograms of fissile material.)

Soviet Stockpile Growing

As far as we can tell, the Soviet stockpile of weapon-plutonium is continuing to grow rapidly. In the US, the Department of Energy has undertaken new initiatives to increase our production greatly. These activities are making it easier for the superpowers to expand their nuclear arsenals by adding new generations of such nuclear-weapon delivery vehicles as cruise missiles and small, mobile ballistic missiles that are difficult to count, and hence to control verifiably in SALT-type treaties. (A cut-off would not stop these programs entirely however since fissile material can be recycled from old weapons and from existing fissile material stockpiles.)

Civilian stockpiles of separated plutonium are also growing. France and Britain are building large reprocessing facilities to recover plutonium from the "spent" nuclear power reactor fuel of nonnuclear weapon states as well as from their own spent fuel, and other countries in Western Europe and Japan are also planning to build commercial-scale reprocessing facilities. If current reprocessing plans are realized, the civilian stockpile of separated plutonium will grow by another 300-350 tonnes through the year 2000. What will become of all this plutonium?

In the absence of the large-scale introduction of plutonium breeder reactors which would have used this plutonium as startup fuel, some Western European nations and Japan are beginning to recycle their separated plutonium as a fuel in current-generation power reactors. If these activities mature, they will eventually spread to developing countries. In any case, the widespread use of plutonium as a commercial nuclear fuel will increase the danger of nuclear terrorism throughout the world and make it easier for nonnuclear weapon states suddenly to "go nuclear."

Accordingly, we advocate:

(1) An agreement between the superpowers to cut off further production of fissile material for nuclear weapons, and

(2) A US foreign policy that encourages the deferral of

EDITORIAL COMMENT

It is often argued that "production" of nuclear weapons systems cannot be verified and, in particular, that there is so much fissionable material already produced that control over the production of fissionable material is impossible.

FAS does not share this view. In the first place, America knows a great deal more than many realize about where and how the Soviet Union produces its weapon systems as a result of intensive surveillance of this problem over four decades.

As a consequence of this, and of modern technology, "production" controls have already been established in a signed Treaty. The SALT II Treaty contained a provision precluding the production of the SS-16 missile; this provision is based on the confidence of the U.S. intelligence community that it can tell whether the factory producing this missile is "turned on" or off.

The accompanying seminal article by Barbara Levi and Frank von Hippel of the Center for Energy and Environmental Studies of Princeton University relies on similar surveillance techniques. It is proposing to "turn off" an enormous complex with many observable parts that produces fissionable material for military purposes.

As recently as 1969, an American administration was willing to take the approach advocated herein with on-site inspections only at acknowledged (peaceful) nuclear facilities and national technical means controlling the rest. And, more recently, in 1982, the Soviet Union has expressed interest in this approach. We want this issue reopened.

This article is obviously only a beginning to much larger studies, partly on what can be verified—which requires classified studies to be most precise—but also on the short- and medium-term effect on weapons production here, and in the Soviet Union, of cutoffs in fissionable material.

We urge Congress to mandate a study pursuing this entire subject. If the arms race is ever to be ended, fissionable material for military uses has to be stopped sometime. And stopping it earlier, by itself or in conjunction with other measures, such as warhead fabrication and missile production, has much to be said for it. We plan to return to this subject as more analysis becomes available.

Finally, in the second half of the newsletter, David Albright of FAS and of Princeton University Center and Harold Feiveson at Princeton provide a detailed and important case for avoiding reprocessing and the recycling of plutonium particularly in light water reactors.

—JJS

the separation of plutonium from "spent" nuclear fuel.

The Fissile Production Cutoff

The Soviet Union seems finally to be interested in fissionable material cutoffs earlier proposed by the U.S. In 1982, Andrei Gromyko announced that "cessation of production of fissionable materials for manufacturing various types of nuclear weapons" could be one of the initial stages of disarmament, and he even said, "The Soviet Union is agreeable to placing under the control of the International Atomic Energy Agency a part of its peaceful nuclear installations—atomic power plants and research reactors."

Unfortunately, it is difficult to tell how far the Soviets are willing to go because the US has not pursued discussions with them on this issue. Congress should not approve the investments that are being requested to refurbish and expand the Department of Energy's production facilities in the absence of a good-faith effort at negotiating a cutoff agreement.

The Reprocessing Deferral

Nuclear fuel cycles involving nuclear fuel reprocessing and plutonium recycle will for the foreseeable future have no clear economic advantage over the currently dominant, more proliferation-resistant, "once-through" fuel cycle. Commercial reprocessing continues in other countries largely due to prior commitments, hopes that it will contribute to energy independence, and confusion over the best solution to the radioactive waste problem.

Unfortunately, despite the fact that plutonium recycle is no longer even economically attractive, the Reagan Administration looks with favor on civilian reprocessing and plutonium recycle in "safe" countries such as those in Western Europe and Japan. We believe that such a policy is short-sighted. While we cannot compel our allies to follow our lead, we should do everything we can to encourage them to do so.

Congress could help provide such encouragement by continuing its support of the Department of Energy's program to demonstrate that improvements in the "once-through" fuel cycle can save about as much uranium as plutonium recycle. Since 1981, the Reagan Administration has each year tried to phase out this highly cost-effective program. The Administration should implement existing legislation to offer technical and financial assistance to nations devising plans for spent fuel storage and disposal.

Finally, we see a potential political synergism between the fissile production cutoff and reprocessing deferral proposals. The prospect of restraint by the superpowers could significantly strengthen groups within the non-weapons states and in France and Britain willing to consider the deferral of commercial reprocessing. Similarly, a fissile cutoff would be easier to defend politically in the US (and perhaps the Soviet Union) if it were paralleled by a strengthening of the nonproliferation regime.

The articles that make up the body of this issue summarize the analytical basis for these important initiatives to curb the production of nuclear weapons "at the source."

(Joint Statement of the four authors)

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A CUTOFF IN THE PRODUCTION OF FISSILE MATERIAL FOR NUCLEAR WEAPONS

Barbara Levi and Frank von Hippel

No nuclear weapon can be made without the use of at least a few kilograms of fissile material. A cutoff of the production of fissile material for nuclear weapons would therefore place an ultimate limit on the numbers of warheads in the nuclear arsenals. Since the two superpowers have between them already more than a thousand tonnes of fissile material in their weapons stockpiles, a production cutoff at this time may seem relatively meaningless. Nevertheless, the superpowers continue to produce fissile material for nuclear weapons. A cutoff would therefore require a reduction in their plans and would set the stage for verifiable stockpile reductions. And if the production cutoff could be extended to China, France, and Great Britain, it would sharply limit the planned growth of their nuclear arsenals as well.

A fissile cutoff would be complementary to other arms control measures. For example, the SALT I and II Treaties limited only strategic nuclear weapons. Warheads associated with less verifiable, shorter-range "delivery vehicles" were left completely uncontrolled. A fissile production cutoff would limit the total number of all types of nuclear warheads. It could also be a first step toward a broader "freeze" on the production of nuclear warheads.

A cutoff in the production of fissile materials for nuclear weapons by the superpowers would increase the legitimacy of the Non-Proliferation Treaty (NPT) because it would require the superpowers to accept the same safeguards on their own nuclear establishments that the non-weapon state signatories of the NPT have already accepted. Since 1985 is a year when the NPT signatories will meet to review the Treaty, it would also be a particularly appropriate year for the superpowers to begin their negotiation of a fissile production cutoff.

How Verifiable Would a Cutoff Have to Be?

Any arms control agreement must be "adequately verifiable." But what does this mean for a fissile production cutoff agreement? In principle, an arms control treaty should be acceptable if we can detect any violation large enough to affect our security early enough to take remedial measures. But, at the current levels of the fissile stockpiles, it is hard to imagine *any violation of a production cutoff by one of the superpowers that would threaten the security of the other. This means that no rational security consideration should prevent either superpower from cutting off its production of fissile materials for weapons unilaterally*—just as President Johnson cut off US production of highly-enriched uranium in 1964.

Nevertheless, the history of the nuclear arms race shows that neither side will show restraint indefinitely unless both sides are bound by an arms control agreement. For example, the Reagan Administration is currently planning to restart US production of highly-enriched uranium for nuclear weapons. Therefore, we have sought to design a fissile cutoff agreement under which clandestine production of weapon-grade fissile materials should be detected with high confidence before the stockpiles could grow by a significant amount—which we arbitrarily define to be ten percent. For specificity, below we discuss the detectability of production operations on a scale that would result in the clandestine growth of one of the existing stockpiles by one percent a year. The ten percent requirement would therefore correspond to the requirement that production operations on such a scale be detected within ten years.

Sizes of the Stockpiles

The detectability of a violation would depend upon its *absolute* magnitude. It is therefore necessary to have estimates of the sizes of the existing superpower stockpiles of weapon-grade fissile materials. Although neither the US nor Soviet Union has made public the size of its stockpiles, it is possible using public data to make reasonably accurate estimates of the sizes of the US stockpiles of both plutonium and weapon-grade uranium and of the Soviet stockpile of plutonium.

The US has produced no highly-enriched uranium for its nuclear weapon stockpile since 1964. This fact, in combination with the published record of the "separative work" done by the US uranium enrichment establishment (see Figure 1), make it possible to make an upper-bound estimate of the amount of the weapon-grade (93.5 percent) uranium produced for the US weapon stockpile as 775 metric tonnes. Corrections for the amounts of uranium enriched prior to 1964 for nuclear reactor fuel and for nuclear weapons tests reduce this estimate to 550-700 tonnes.

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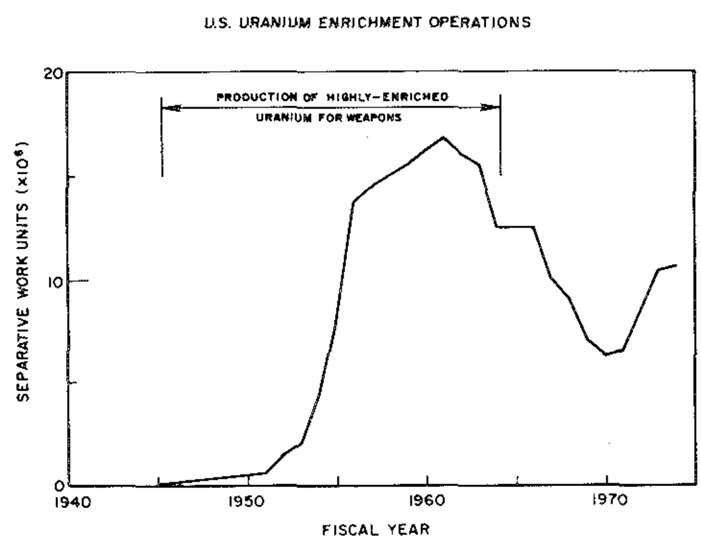

Figure 1: *History of US Uranium Enrichment Operations.* Prior to 1965, most US separative work went to the production of "weapon-grade" (93.5 percent U-235) uranium. Since about 1970, it has gone mostly to the production of low-enriched uranium fuel for nuclear power plants.

A first-order estimate of the US stockpile of weapon-grade plutonium may be obtained from the quantities of the 30-year half-life fission products, Sr-90 and Cs-137, in the high-level radioactive wastes at the US plutonium production complexes near Richland, Washington (the Hanford site) and near Aitken, South Carolina (the Savannah River site). After correcting for decay, we estimate that approximately 100 tonnes of U-235 were fissioned in the fuel reprocessed at the two sites. If we assume that a plutonium-production reactor produces about 0.9 atoms of weapon-grade plutonium for every atom of U-235 fissioned, then the US would have approximately 90 tonnes of weapon-grade plutonium in its stockpile.

We have made a number of small corrections to this estimate to allow for the fact that: some research reactor fuel has been reprocessed at the Savannah River and Hanford sites; some of the plutonium produced at Hanford was not weapon-grade; a small amount of Hanford fuel was reprocessed offsite at the short-lived commercial nuclear fuel reprocessing operation at West Valley, New York; the US obtained a small amount of weapon-grade plutonium from Britain in exchange for highly-enriched uranium and tritium; and that a small percentage of US weapon-plutonium must have been consumed in nuclear weapon tests. A further reduction by up to ten percent results when we use the estimate by Cochran and Hoenig of the amount of U-235 fission at the Savannah River site that was associated with tritium rather than plutonium production.

Taking into account all these estimates and their uncertainties, we arrived at the estimate that the US stockpile contains 75-95 tonnes of weapon-grade plutonium. The Department of Energy is currently adding to this stockpile at a rate of 1-2 tonnes per year (see Figure 2). It plans in

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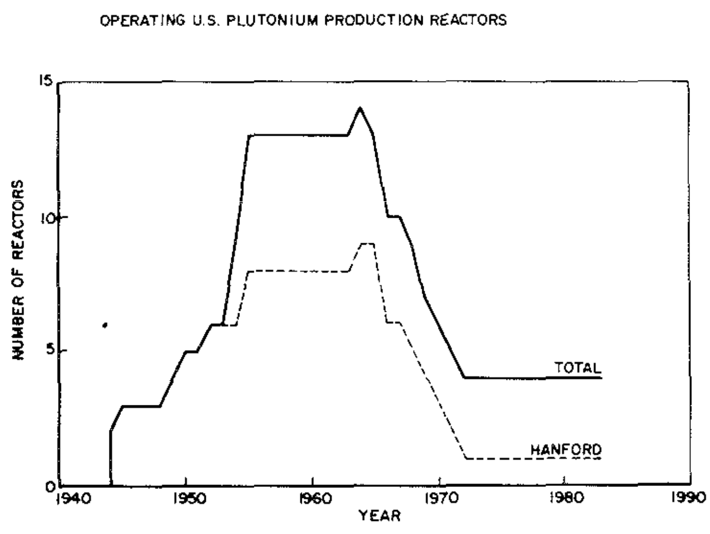

Figure 2: *Number of Operating US Plutonium Production Reactors.* When President Johnson ended US production of weapon-grade uranium, he also started shutting down production reactors. Since 1971, the Department of Energy (DOE) has had only four production reactors in operation: 3 at its Savannah River site and one at its Hanford site. The DOE is currently bringing a fourth Savannah River reactor out of retirement and is proposing the construction of a new production reactor in Idaho.

HISTORY OF THE FISSILE CUTOFF PROPOSAL

Discussion of an end to the unsafeguarded production of fissile materials dates back virtually to the beginning of the nuclear weapons era.

- **In 1946, the US put before the United Nations the "Baruch Plan" which would have put under international control all "dangerous" parts of the nuclear fuel cycle such as uranium enrichment and fuel reprocessing plants. This proposal bogged down in a debate between the US and Soviet Union over whether the US would give up its possession of its nuclear weapons before or after the international safeguards regime had been established.**
- **In 1956, President Eisenhower proposed a bilateral cutoff in the production of fissile materials for nuclear weapons as a separate arms control measure. The Soviet Union responded that the stringent inspection regime that was proposed to verify the cutoff would be merely a cover for US spying and that, in any case, a production cutoff would only be of interest in association with measures to reduce existing stockpiles. A recently declassified US estimate suggests that the Soviet weapons stockpile was only about one tenth as large as that of the US at the time.**
- **In 1964, President Johnson became convinced that US production of fissile materials for nuclear weapons vastly exceeded requirements. He stopped production of highly-enriched uranium for nuclear weapons completely and began large cutbacks in US production of plutonium for weapons.**
- **In 1969, at the very beginning of the Nixon Administration, the US made its verification requirements for a fissile production cutoff consistent with those that had been incorporated into the NPT. We abandoned our demand for on-site inspections at locations other than acknowledged nuclear facilities and expressed our willingness to have the International Atomic Energy Agency (IAEA) take over the safeguards task at such facilities. Verification that there would be no clandestine activities was apparently to be left to "national technical means."**
- **In 1982, the Soviet Union for the first time expressed interest in a separate agreement to cut off the production of fissile materials for nuclear weapons. In his 1982 speech to the Second Special Session on Disarmament at the UN, Gromyko expressed Soviet interest in a fissile cutoff agreement as a first step toward a freeze. Since that time, the Soviet Union has negotiated a safeguards agreement with the IAEA covering a limited number of Soviet nuclear reactors. This will be the first time that the Soviet Union will have accepted on-site inspection by any outside organization.**
- **The Reagan Administration has not taken a public position on the fissile production cutoff proposal *per se* but has rejected the whole idea of a nuclear weapons freeze under current conditions.**

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addition to upgrade a significant fraction of its stockpile of the 17 tonnes of non-weapon-grade* plutonium from its breeder reactor R&D program for transfer to its weapons program.

An upper bound on the amount of plutonium produced by the Soviet Union can be estimated from the cumulative amount of Krypton-85 released to the atmosphere from the Soviet Union. Kr-85, a chemically unreactive fission product with a half-life of 10.8 years, is released into the atmosphere when nuclear fuel is reprocessed. The cumulative releases from all sources may be estimated from historical measurements of the concentration of Kr-85 in the atmosphere by correcting for the amount that decayed between release and the times of measurement. Subtraction of the estimated releases from US and West European reprocessing plants and from nuclear weapons testing then leaves a residual of 30-55 percent of the Kr-85 releases unaccounted for as of the end of 1980 (see figure 3). This Kr-85 we attribute primarily to Soviet nuclear fuel reprocessing operations. We estimate the corresponding US contribution as 32-41 percent. This comparison suggests that the Soviet stockpile of weapon-grade plutonium is roughly comparable to that of the US.

On-Site Safeguards

Even after the shutdown of the facilities that have been dedicated to the production of fissile materials for nuclear weapons, both superpowers would still have operating in their civilian nuclear sectors facilities with capabilities for producing large quantities of fissile material for weapons. Nuclear power plants in operation and under construction in both the US and USSR will require tens of tonnes of U-235 in their fresh fuel, and will discharge on the order of ten tonnes of plutonium in their spent fuel, each year. The uranium enrichment plants that produce the low-enriched uranium for the power plants could be used to produce highly-enriched uranium for nuclear weapons and the plutonium in the spent fuel is potentially weapon-usable. Under a fissile cutoff agreement, therefore, there would have to be arrangements for on-site inspection to ensure that civilian facilities were not being used to produce significant quantities of fissile materials for nuclear weapons.

Fortunately appropriate safeguard arrangements and technologies have already been developed under the auspices of the International Atomic Energy Agency which has established a system of surveillance, seals and inspections to ensure that civilian nuclear facilities in over 60 nonnuclear weapons states are not misused for military purposes. Although there continue to be legitimate doubts as to whether these arrangements could under all circumstances provide timely warning of the diversion of enough fissile material to make a single nuclear weapon, there can be little doubt that diversions from civilian nuclear facilities in the superpowers would be detected long before they were large enough to increase their stockpiles of weapon-grade fissile materials by anywhere near ten percent.

Neither side should have reason to fear on-site inspection as a cover for intelligence activity: the safeguards would be applied only to a specific class of facilities where there would be no secret activities as long as the two parties observed the cutoff agreement. The Soviet Union has announced its willingness in principle to accept such inspections and has already negotiated safeguard arrangements with the IAEA for a few of its nuclear facilities.

In addition to civilian nuclear power and research facilities, which have their analogues in nonnuclear weapon states, there are two other types of nuclear ac-
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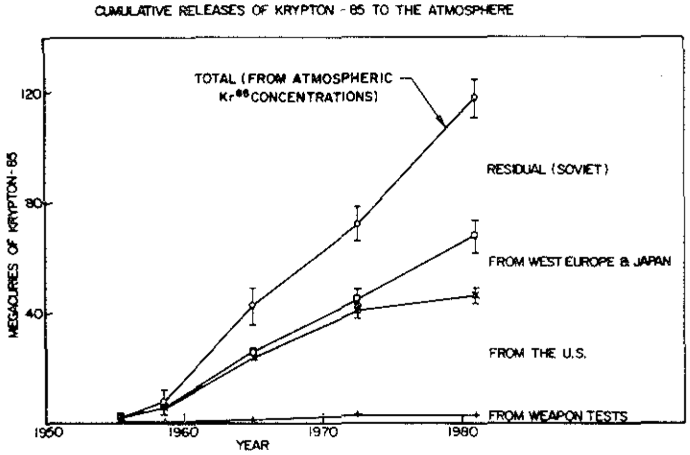

Figure 3: *Cumulative Releases of Krypton-85 to the Atmosphere.* The top curve shows the cumulative releases of Kr-85 to the atmosphere, estimated from the historical record of the atmospheric concentration of Kr-85. The bottom three curves show our estimates of the cumulative releases from nuclear weapons tests, and from nuclear fuel reprocessing in the US and in Western Europe and Japan. The residual, mostly due to sources in the USSR, is comparable to the US contribution.

*Any mixture of plutonium isotopes can be used to make a nuclear explosive but, for a number of reasons, weapons designers find most convenient mixtures with a low admixture of the higher plutonium isotopes. The US nuclear weapons establishment defines plutonium containing less than 7 percent Pu-240 as "weapon-grade." The Department of Energy has two approaches to the problem of upgrading non-weapon-grade plutonium to weapon-grade: (1) laser isotope separation, and (2) diluting the Pu-240 in non-weapon-grade plutonium by mixing it with "super-grade" plutonium containing 3 percent Pu-240.

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tivities peculiar to nuclear weapon states not associated with the production of fissile materials for nuclear weapons. One is the production of highly-enriched uranium fuel for naval power reactors and the other is the production of tritium for nuclear weapons.

The US currently produces each year approximately 4 tonnes of highly-enriched (97.3 percent U-235) uranium for naval reactor fuel. The total shaft horsepower of Soviet nuclear ships is approximately the same as that for the US ships, and the Soviet ships are at sea a much smaller percentage of the time, so that it is unlikely that their U-235 requirements are any higher.

These annual demands for highly-enriched uranium are only about one percent of the amount that we estimate is already in the US nuclear weapons stockpile. One might therefore propose as a modest disarmament measure that the superpowers fuel their naval reactors from their weapons stockpiles for at least a decade or two.

If it were impossible to negotiate such an arrangement, however, it should still be feasible to work out an arrangement whereby the production of highly-enriched uranium for naval reactors could continue without the associated activities providing a convenient cover for the diversion of significant amounts of fresh highly-enriched uranium to the nuclear weapons stockpiles. For example:

- The two superpowers could agree to a common limit on their annual production of highly-enriched uranium for naval reactors—say five tonnes a year;
- This production could take place at a safeguarded enrichment facility; and

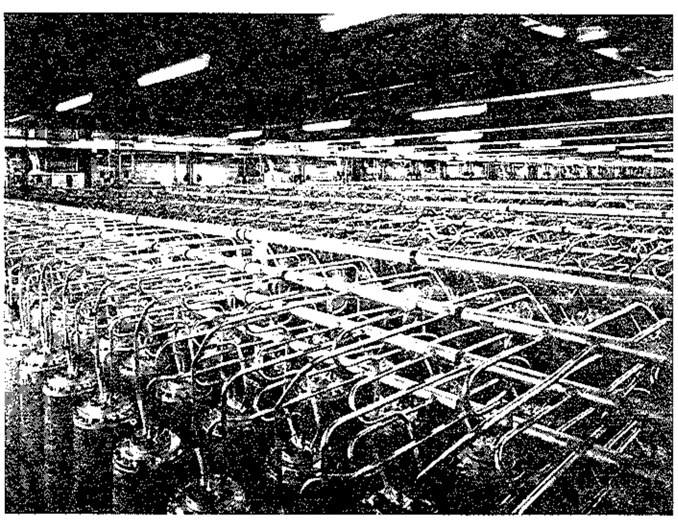

Figure 4: *Centrifuge "Cascade" in the Urenco Enrichment Plant at Almelo, the Netherlands.* A plant containing about 100,000 centrifuges such as those shown here would have to operate undetected for 10 years to produce the equivalent of 10 percent of the weapon-grade uranium in the US stockpile.

- The safeguards agency could ensure against the long-term accumulation of a significant fraction of this material in a nuclear weapons stockpile by requiring that within a few years an equivalent amount of irradiated highly-enriched uranium would have to be returned to a safeguarded facility.

Tritium is produced for nuclear weapons primarily by neutron bombardment of the lithium-6 isotope in production reactors. It is used to generate neutrons on nuclear weapons through the fusion reaction:

deuterium plus tritium ⟶ helium-4 plus neutron

The neutrons are used for a number of purposes: to initiate the fission chain reaction in fission explosives; to "boost" the percentage of fissile material fissioned later during the chain reaction and to produce most of the neutrons released by the "neutron bomb."

Even a "freeze" on the superpower nuclear arsenals would not end the requirement for producing tritium for weapons because tritium has a 12-year half-life and therefore must be periodically replenished. US tritium is currently produced along with plutonium by the three operating production reactors at Savannah River. One production reactor could maintain the US stockpile of weapon-tritium. It is likely that this is true also for the Soviet stockpile. These reactors could be put under safeguards to ensure that they were not being used to produce plutonium for weapons.

Detectability of Secret Production Facilities

On-site safeguards could protect against the diversion of fissile material only from acknowledged production facilities that were opened up to inspection. What about the possibility that one of the superpowers might set up a secret fissile material production complex? Could such a complex be detected by "national technical means?"

Above, we have defined the smallest "significant" violation of a fissile cutoff agreement as one in which one of the superpowers would add to one of its existing stockpiles at a rate of one percent per year for ten years. For the US, this would correspond to the production of about one tonne of plutonium or 6 tonnes of highly-enriched uranium each year. Although the quantities of material being produced are not large, the same cannot be said for the scale of effort required.

The creation of one tonne of weapon-grade plutonium a year would require a production reactor capacity equivalent to about two Savannah River production reactors. The associated chemical reprocessing facility would have to process on the order of 1000 tonnes of irradiated uranium per year in order to separate the plutonium from the associated highly-radioactive fission products. The costs involved in constructing such facilities would be billions of dollars. The production of 6-7 tonnes of weapon-grade uranium per year would require a similarly costly uranium enrichment facility. Thousands of people would be involved in construction projects of this magnitude. It would be virtually impossible to ensure that one of them would not reveal the nature of the facility in, for example, an intercepted microwave telephone

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transmission.

If the identity of the clandestine facilities were successfully hidden during the construction phase, it would be difficult to conceal the telltale signs of their operation. They would, for example, have to be supplied with large quantities of uranium feed—equivalent to about a thousand tonnes of natural uranium a year for either the threshold violation of the cutoff on plutonium or the highly-enriched uranium production. This is enough natural uranium to fuel one-quarter of the total Soviet nuclear power capacity in operation today (or about 10 percent of US capacity). Such a large flow of uranium from the civilian fuel cycle would be very difficult to conceal—as would a large-scale clandestine uranium-mining operation.

The operation of the clandestine facilities would also produce characteristic emanations. For example, the production of one tonne of weapon-grade plutonium per year would be associated with a release of fission heat at an average rate of 3 million kilowatts. This is equal to the waste heat from a large electrical power plant or a US city of 300,000. It would be very difficult to conceal from satellite telescopes able to detect radiation in the thermal infrared region. An unidentified, isolated heat source of this order of magnitude would be a clear signal that closer scrutiny was required. An attempt to "bury" the signal in the background heat generated by another large industrial facility or city would increase the likelihood of the population of that industry or city becoming aware of the nature of the clandestine facility. Of course, a number of smaller and more easily concealable clandestine production reactors could be built, but the advantage derived by the increased concealability of the individual facilities would be at least partially offset by the larger number which would be subject to detection. The detection of only one facility would "blow the cover" on an entire clandestine production program.

What if one of the superpowers were to detect the telltale signs of a clandestine production operation on the territory of the other? How could the suspicions thus raised be either confirmed or laid to rest? This is a generic problem. It would apply equally well, for example, to suspicious seismic events detected under the comprehensive nuclear test ban treaty on which negotiations were quite advanced at the time when the negotiations ceased in 1980. The obvious approach to resolution would be first to request an explanation of the suspicious indications and then, if one's suspicions were not assuaged, to request an on-site inspection at their location. Refusal of access without adequate justification would bring into question the continued viability of the cutoff agreement—much as the inadequate Soviet explanations of the outbreak of pulmonary anthrax at Sverdlovsk in 1979 have weakened the vitality of the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological Weapons.

GAINS FROM A SUPERPOWER FISSILE PRODUCTION CUTOFF

A treaty requiring the superpowers to stop producing fissile materials for nuclear weapons is one of the very few verifiable measures that could constrain the nuclear arms race across a broad front.

- **By limiting the availability of fissile material, it would impose an overall constraint on the multiplication of small, difficult-to-count, nuclear-armed delivery vehicles, such as cruise missiles.**
- **By preventing the production of replacement material, it would provide a basis for verifiable stockpile reductions through the transfer of fissile materials from weapons to non-weapons uses.**
- **By imposing on U.S. and Soviet nuclear facilities the same international safeguards already accepted by the nonnuclear-weapon-state signatories to the Non-Proliferation Treaty (NPT), it would strengthen the legitimacy of the NPT—due for review this fall.**
- **By gaining Soviet acceptance of on-site safeguards, it would lower the threshold for the inclusion of such safeguards in future superpower arms control agreements.**

For the United States, a cutoff agreement would also have the advantage that it would put under international safeguards the increasingly large number of Soviet graphite-moderated nuclear power reactors. These reactors are of concern because, unlike U.S. light-water-moderated power reactors, they can be refueled without being shut down and therefore could easily be used to produce large quantities of weapon-grade plutonium as well as power.

The Next Step: Reductions

One of the justifications for a cutoff in the production of fissile material for nuclear weapons is that such a production cutoff is a prerequisite to verifiable reductions in the existing stockpiles. The current ability of the superpowers to estimate each other's stockpiles of weapon-grade fissile materials should make it possible for them to negotiate at least 50% reductions in these stockpiles. Indeed, in 1963 the US proposed to accompany a fissile production cutoff with reductions—suggesting that the US would be willing to transfer to non-weapons uses 60 tonnes of weapon-grade uranium if the Soviet Union would similarly transfer 40 tonnes.

Highly-enriched uranium could easily be diluted down to low-enrichment levels for use as fuel in nuclear power reactors. Similarly, plutonium mined from the stockpiles could be fissioned in specially-safeguarded power reactors.

(The details of the analysis summarized here are available in the report by the authors, *Controlling the Source: Verification of a Cutoff in the Production of Plutonium and Highly-Enriched Uranium for Nuclear Weapons* [Princeton University, Center for Energy and Environmental Studies Report #167, revised December 1984.])

THE DEFERRAL OF REPROCESSING

David Albright and Harold Feiveson

Through 1984, over 250 metric tons of plutonium had been discharged from civilian nuclear power reactors in non-communist countries, comparable to the amounts thought to be contained in the weapons arsenals of the nuclear superpowers. By the end of the century, the plutonium generated in the civilian sector will exceed 1500 metric tons. A nuclear weapon requires less than 8 kilograms of typical reactor-grade plutonium.

These vast quantities of fissile material, which will inescapably be generated over the next two decades, pose a severe and immediate challenge. Whatever the long-term future of nuclear power, the international community must ensure that the material is not diverted to weapons use by current or emerging nuclear weapon states or by subnational, terrorist organizations.

Unfortunately, the isotopic composition of the reactor plutonium is no safeguard against such diversion, as has sometimes been thought. While plutonium from commercial power reactors is less desirable for use in an explosive device than the type produced in dedicated military reactors and may have less predictability of yield, nuclear weapons designers have repeatedly stated that commercial, reactor-grade, plutonium could be used directly in nuclear explosives.

The problem of safeguarding civilian-reactor plutonium has, so far, lacked urgency. This is principally because, ever since their introduction, nuclear power reactors have relied virtually exclusively upon once-through fuel cycles in which there is no recycling of weapons-usable material. As a result, most of the plutonium which has been produced remains locked in the spent reactor fuel in storage pools at the various individual reactor sites. Although nearly one-fifth of the plutonium contained in the spent fuel—or approximately 50 tons—has already been separated, most of this plutonium was separated from fuel irradiated in gas-graphite reactors in France and the United Kingdom. So far, only a small portion of the plutonium from light water reactor (LWR) spent fuel, which contains the vast bulk of plutonium now in the spent fuel, has been separated. Virtually all commercial reprocessing of spent fuel has been limited to two countries, France and the United Kingdom, and most of this material remains in the custody of these two nuclear weapon states.

Pressure for Change

Unfortunately, there are several trends which are eroding this present, relatively safe, situation:

EXPANSION OF LWR FUEL REPROCESSING IN FRANCE AND UK: The reprocessing services offered by France and the United Kingdom have proved a magnet of foreign LWR spent fuel. In the mid-1970's, France began to contract with foreign utilities to reprocess spent LWR fuel at the facility at La Hague. Thereafter, under arrangements in which foreign utilities have agreed to pay for the investment and a substantial part of the operation, the French have undertaken to construct substantial new reprocessing capacity, to be completed by about 1990. The United Kingdom too is now constructing a large LWR fuel reprocessing complex in a similar manner. Together, the two countries have now contracted to reprocess about 12,000 metric tons of foreign spent LWR fuel, mostly from West Germany and Japan. Given a contained plutonium fraction in the LWR spent fuel of about 1 percent, this fuel would yield about 120 metric tons of plutonium. In addition, France now has decided to reprocess all its considerable quantities of domestic spent light water reactor fuel. By the year 2000, despite constraints on reprocessing capacity, this could involve the separation of over 75 metric tons of plutonium. Figure 1 shows the growth in the amount of LWR fuel reprocessing capacity in Europe and Japan expected through the end of this century.

SPREAD OF REPROCESSING: Japan and Germany already have small reprocessing facilities and are planning to build commercial-scale units. Italy has a small pilot facility and Belgium is considering restarting its small commercial plant. India has two pilot reprocessing facilities and plans to build another one. Argentina, Brazil, and evidently Pakistan are also building rudimentary reprocessing capabilities. In addition, these countries and others, some of which are not now party to any nuclear supplier agreements, will eventually gain the sophistication and capability to export reprocessing technologies. Argentina has already considered such a possibility.

THE AVAILABILITY OF PLUTONIUM: It is now expected that another 300 to 350 metric tons of plutonium will be separated from commercial reprocessing plants in this century. Countries which have already committed substantial amounts of spent fuel for reprocessing must now decide how to dispose of the large quantities of separated plutonium which will be produced. These countries include Belgium, France, The Federal Republic of Germany, Italy, Japan, The Netherlands, Switzerland, and the United Kingdom.

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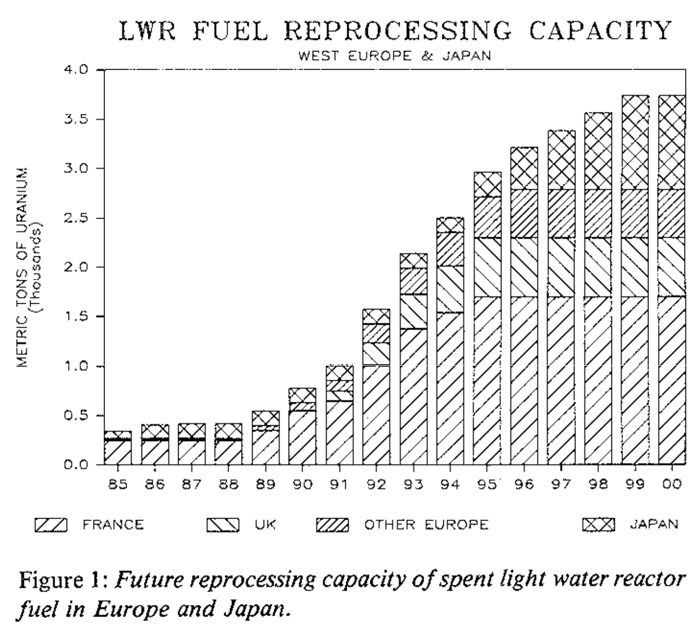

Figure 1: *Future reprocessing capacity of spent light water reactor fuel in Europe and Japan.*

The Pressures to Recycle

THE PLUTONIUM OVERHANG: Initially, the nuclear industries in Europe and in Japan imagined that the plutonium would be predominantly used for breeder research and development, and for the initial loadings of commercial breeder reactors. It is now clear that only a small fraction of the plutonium could be used in this way. Currently, there is one full-size commercial breeder reactor, Superphenix, that has been built, although it is not scheduled to operate until late 1986. In addition, there are a few smaller prototype and demonstration reactors which have been built or are under construction. During the rest of this century only one or two additional large breeder reactors are expected to be built.

Even were all the plutonium for these reactors to be supplied externally (with no recycle of breeder-produced plutonium), the total demand for plutonium for breeder reactors through the end of the century would be no more than 100 metric tons. An additional 10 metric tons might be required for the Japanese advanced heavy water reactors, although these reactors could use slightly-enriched uranium fuel as well as plutonium. Under current plans for world reprocessing, this gives a cumulative excess of available plutonium over that needed for breeders and the Japanese heavy water reactors (the plutonium overhang) of roughly 200 metric tons through 2000. Figure 2 shows that the annual excess or overhang at the end of this century will exceed 20 metric tons of plutonium per year.

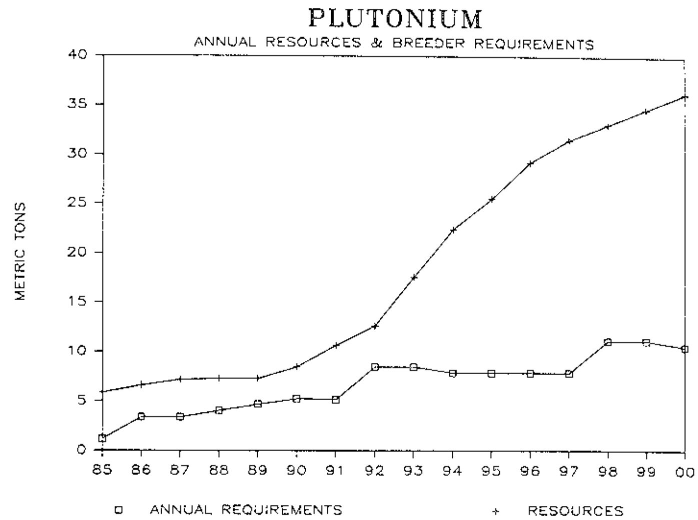

Figure 2: *The amount of plutonium that is expected to be recovered each year from spent fuel discharged from light water reactors and gas graphite reactors far exceeds the amount required for breeder reactors.*

PLUTONIUM RECYCLE IN EUROPE AND JAPAN: With the plutonium demand for breeders so low, several utilities in Europe and Japan have indicated the intention to recycle plutonium in conventional (thermal) light water reactors. In such a fuel cycle, the plutonium contained in the spent fuel is recovered after reprocessing, it is mixed with natural uranium to form mixed-oxide (MOX) fuel, and the MOX fuel is then recycled as fresh fuel into the reactor. The uranium recovered in the reprocessing would be recycled as well. Since the light water reactors are not breeders, a continuous supply of enriched uranium fuel would be required. But the simultaneous recycle of plutonium and uranium in a light water reactor could reduce uranium requirements by 20 to 30 percent.

The recent movement toward thermal recycle is striking. Belgium and West Germany had been interested in thermal recycle for many years, and both countries operate pilot fuel fabrication facilities which can manufacture either MOX or breeder fuel. These plants are now being expanded to handle about 2 metric tons of plutonium annually. Switzerland has already announced plans to recycle plutonium into LWRs. And France has just announced that it is considering doing the same. France and Belgium have established a joint marketing venture to sell MOX fuel to other countries, using existing fuel fabrication facilities. France is also considering building an additional, large MOX fuel fabrication facility. It is expected to make a decision about the new plant this year. Japan has recycled plutonium into its prototype advanced heavy water reactor for several years and is planning to build a demonstration reactor of the same type. It has underway a research and development program aimed at commercializing LWR MOX fuel use in the late 1990's. Finally, in response to all this interest, the United Kingdom is also considering thermal recycle. Current plans call for the reprocessing of the MOX fuel along with the normal uranium LWR spent fuel.

MOTIVES FOR RECYCLE: The reasons for this surge of interest in recycling is probably related to the excess plutonium supply. Although it is often claimed in the nuclear circles of Europe and Japan that it would be imprudent for energy-poor countries not to use the energy available in the plutonium, in fact, plutonium recycle could have only marginal impact on uranium demand and national energy security. If done on a sufficiently wide (and practically achievable) scale, it could reduce world uranium demand, which is already quite low relative to previous projections, by perhaps 15 percent over the next two or three decades. Such savings are comparable to those which can be achieved either through increased uranium burnup efficiency in the reactor or through reductions in the U-235 fraction left in the tails at uranium enrichment plants.

But what about economics? Consider first a comparison of the fuel cycle costs of recycle with those of a once-through fuel cycle under the assumption that reprocessing is not yet a sunk cost—that is, that the plutonium has not yet been separated. This comparison will be dominated by the tradeoff in plutonium recycle between the lower costs of uranium fuel on the one side and the extra costs of reprocessing and MOX fabrication on the other. Using price and fuel cycle flow assumptions adopted by analysts

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at Bechtel and the Electric Power Research Institute, we calculate in Figure 3 the uranium price at which the two fuel cycles cost the same, assuming that the plutonium in the recycle case is all internally generated. The critical price assumption is that reprocessing costs $800 per kg heavy metal (1984 dollars). This is approximately the price that the French and the British are reported to be charging.

It may be seen in figure 3 that the price of uranium would have to reach over $100 per lb. U308, or over three times current contract prices, for the once-through fuel cycle to cost as much as plutonium recycle. However, the more important finding is that the cost difference between the fuel cycles, even at very high uranium prices, represents a very small fraction of total power costs, which are relatively insensitive to the price of uranium, and hence to fuel cycle choice. This "indifference" is a robust result whereas the precise crossover point between the costs of a once-through cycle and a plutonium recycle system must be highly uncertain and dependent on detailed assumptions.

One factor, perhaps, whetting the interest of utilities in recycle is the cost of plutonium storage, the principal alternative to recycle *once the plutonium is separated.* In the above comparison, it was assumed that spent fuel storage cost about one-half mill per kilowatt-hour and that spent fuel and high-level waste disposal costs were approximately equal, about one mill per kilowatt-hour. If, however, the separated plutonium were indefinitely stored rather than recycled, there would have to be an additional charge for this. At present, France is reported to be charging $2-5/gm/year for plutonium stored longer than some initial period covered by the basic reprocessing contract. So eventually this plutonium will begin "burning a hole" in the pockets of the utilities if it is not otherwise used. These costs, while not high compared to other costs of financing and operating a large nuclear power plant, might nevertheless make recycle appear, in some circumstances, slightly more favorable than the alternative of storage. It is doubtful, however, that this advantage could ever be more than on the order of one mill per kilowatt-hour. Such a cost difference would represent about 10 percent of total fuel cycle costs and roughly 2 percent of total electricity-generation costs. It would be foolhardy for countries to allow such marginal economics to drive utilities to reprocessing and recycle. Even from a narrow economic perspective, there exist substantial uncertainties in the costs of recycle, whereas the costs of once-through fuel cycles are well established. Furthermore, the costs of the security systems which recycling will require are likely to be substantial.

In summary, there does not appear to be any large-scale demand for plutonium to be used for breeder research and development or any strong economic pressure for recycle in thermal reactors. The movement toward the commercial use of plutonium appears less driven by pressing factors of economics and resources than by haphazard, unplanned decisions, unconstrained by any clarity of international policy or objective. Above all, the move toward recycle appears to be a result rather than a cause of the commercial reprocessing which is now taking place and promises to take place in the future.

GENERATION COSTS OF NUCLEAR POWER

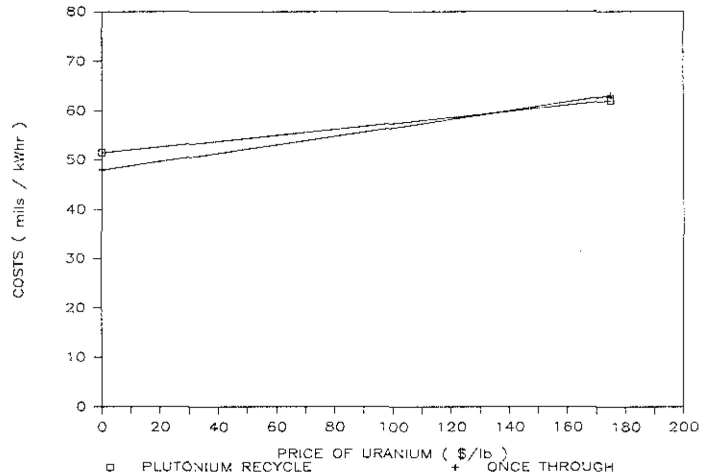

Figure 3: *A comparison of the fuel cycle costs of the once-through fuel cycle for light water reactors and the recycle of plutonium and uranium into light water reactors.*

Incentives to Reprocess

What then is driving the reprocessing? In France and the United Kingdom, the move to commercial reprocessing appears to have been provoked largely by domestic considerations. Historically, commercial reprocessing was an outgrowth of the weapons programs of the two countries. It harnessed the technical experience and infrastructure involved in the reprocessing of weapon-grade plutonium. It also appeared a necessary adjunct to the development and commercialization of breeder reactors to which France, at least, has been strongly committed. With the delay of the breeder dream, it was natural that the reprocessing companies in the two countries would look to foreign customers; and, as long as such customers are forthcoming and insensitive to price, the reprocessing of foreign fuel can be a profitable venture.

With respect to the motives of these customers, the picture is less clear. Some of the countries, certainly, were initially interested in breeder reactors and perhaps saw the foreign reprocessing as an interim solution until they developed their own reprocessing capabilities. Some may also have felt that reprocessing was a necessary step in rationalizing waste disposal. In Japan and in many countries in Europe there was intense pressure on the utilities to find some solution for the disposal of the spent fuel as a condition for the further development of nuclear power. Since there are not yet any agreed methods for such disposal, there has been great temptation for these utilities simply to ship the spent fuel out of the country, at least for some lengthy period. In the absence of any established market for the disposal of spent fuel, and with the US effectively

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barring the return of spent (US-supplied) fuel to this country, the clearest alternative open to utilities in Japan and Germany, Spain and elsewhere has been to send the spent fuel to France or to the United Kingdom for reprocessing and storage of the separated plutonium. It may be significant that, soon after the Swedish law requiring utilities to reprocess spent fuel was changed to allow for storage, the utilities evidently made plans to drop previously-concluded reprocessing contracts with France.

Defer Reprocessing and Recycle

Under such circumstances, it might be an opportune time for the US again to take the initiative in encouraging as wide a deferral of reprocessing and recycle as possible. It is true that similar US initiatives in the 1970's had at best mixed success and fostered considerable resentment abroad. But time has been kind to the US arguments. The case against rapid development of breeder reactors is no longer contested; and, while the Europeans and Japanese did not follow the US example in abstaining from reprocessing, the US position still appears strong both on economic and policy grounds. Despite the sunk costs in a complete reprocessing plant at Barnwell, South Carolina, the private sector in the US remains unwilling to undertake reprocessing as a commercial venture without substantial government subsidies, which the Reagan Administration has been unwilling to extend.

A deferral of reprocessing would require that unreprocessed spent fuel be stored for some indefinite period—something which the US, Canada, and Sweden are now committed to doing with their own, domestically-produced fuel. These countries are also now committed to seeking ways to dispose permanently of the spent fuel without reprocessing, an approach to waste management which is no longer seen as intrinsically more difficult or expensive than disposal of separated high-level wastes.

How important would such a deferral be? From the point of view of physical security—protecting the fissile material from gangster and terrorist groups—it appears very important. Reprocessing and subsequent recycle would place into normal commerce substantial quantities of relatively uncontaminated material, which could be made into weapons in days or weeks. This is in sharp contrast to "once-through" fuel cycles, in which the uranium and plutonium in the spent fuel are not separated and in which weapons-usable material is never isolated. The demands which reprocessing and recycle would place on physical security systems would clearly be tremendous.

The impact of a reprocessing deferral on national proliferation is more disputable. Certainly, one should have no illusions that it would solve the problem of nuclear weapons proliferation. Unfortunately, the very existence of nuclear *power* programs facilitates the development, and construction, of nuclear weapons. To produce nuclear electricity required national cadres of nuclear scientists and technicians, a network of research facilities, research reactors, and laboratories. Also, while the plutonium in spent fuel is "protected" against diversion by the intense radioactivity of the nuclear fission products, and is thus much less at risk than separated plutonium, it is feasible for a country intent on acquiring nuclear weapons to build in a short period (less than a year) a crude reprocessing facility adequate to extract enough plutonium for a few nuclear weapons from spent fuel inventories at hand.

Furthermore, any country intent on acquiring nuclear weapons can do so via many routes other than the diversion of plutonium from civilian nuclear power programs. Although reactor-grade plutonium is usable in weapons, a weapons designer would much prefer plutonium produced directly in specially dedicated facilities. The use of dedicated facilities would also avoid the disruption of commercial power programs.

Nevertheless, there are strong reasons to fear an intensification of reprocessing. Although reprocessing activities are now concentrated mostly in countries which either already have nuclear weapons or have signed the Non-Proliferation Treaty and accepted international safeguards, it is clear that countries with less advanced nuclear programs would eventually want the same advanced nuclear technologies as those pursued by the most advanced industrialized countries. As these advanced programs of reprocessing and recycle evolved, there would inevitably be intense efforts by the less-developed countries to obtain such technologies for themselves, and aggressive efforts by the industrialized supplier countries to export the technologies. With this ill-starred convergence, a significant technical barrier to proliferation would be shattered in industrialized and developing countries alike. A large number of countries would gain access to enormous quantities of weapons-usable material and to reprocessing fabrication facilities able to produce such material relatively quickly. Warning times for the acquisition of nuclear weapons would be markedly reduced; and the task of international safeguards, made manageable now by the absence of sensitive facilities in most countries, would be vastly complicated.

Civilian nuclear power programs based on the utilization of separated plutonium or other nuclear weapons-usable material could present a relatively low-risk opportunity for nuclear weapons acquisition. Countries could proceed with little cost to a point but a step away from the acquisition of nuclear weapons without deciding or announcing in advance their intentions.

Advocates of recycle argue that once the plutonium is separated, its safest place is in a reactor, where it is inaccessible and will be partially consumed. This may be true, especially if the alternative is simply storing the separated plutonium in the countries of origin. The problem with recycle is partly that it would of necessity include several points of possible diversion—the reprocessing plant, the MOX fabrication facilities, the reactors using MOX fuel, and the manifold transit routes required; and it would require everywhere stringent systems of physical protection. Far more important, a movement to recycling on a large scale would be used to justify and lend economic credibility to reprocessing, credentials which it does not have.

GOLD MEDAL FOR HARDEST BARGAINER: U.S. OR U.S.S.R.?

Nothing is more firmly entrenched in the minds of American citizens than that the Russians are ferociously hard bargainers. By contrast, Americans deem themselves to be easy marks, softies, hopelessly addicted to compromise, and dangerously committed to reaching even bad agreements. It isn't true.

The reason is simple. America can ratify agreements only if two-thirds of the Senate will approve. And this requires, in particular, that the agreement receive the bipartisan support of two political parties in constant rivalry with one another—often to show which is toughest in dealing with Bolshevism.

What else can explain the fact that the last three treaties solemnly approved and signed by our Executive Branch have never been ratified? Among them, the SALT II Treaty was said by the Joint Chiefs of Staff to have only "nominal" effects on U.S. force planning. Nevertheless, a host of wholly political complaints killed the treaty even though this "something for nothing treaty" did provide limits on the Soviet program if not on ours.

As a result of this kind of experience, negotiators on both sides know that U.S. ratification of a treaty requires that it look really favorable to the American public and to Congress—and this obviously influences the shape of the negotiations in our favor.

In fact, in the last forty years the only two negotiations that produced important ratified treaties were both cases in which the United States sold the Soviet Union a dead horse.

It was only because the mothers were marching in the streets against strontium 90 in the milk that atmospheric testing was negotiated away in the Atmospheric Test Ban. And it was only because 50 Senate votes opposed building the anti-ballistic missile that America negotiated the ABM Treaty banning them. In both cases, it was highly uncertain that America could continue doing what was at issue anyway, even in the absence of a treaty. This was precisely why the treaties could be approved.

Where there is no similar public uprising, American Presidents simply do not have the political capital to secure the acceptance of even wholly fair treaties. They often need more.

American negotiating positions have, accordingly, verged increasingly on the bizarre. In the case of intermediate-range missiles, we offered to tear up plans to install Pershing and Cruise Missiles if the Soviet Union would dismantle missiles already in place. And even when the threat of that posture began to get results, Paul Nitze could not get the Administration to agree to substantial Soviet unilateral disarmament of SS-20s in return for our not building up to a missile equality in Europe that we had never had.

The Administration's present position has moved even further into super-hard bargaining. For example, the "moderates" in the Administration have been threatening to tear up an already signed and ratified ABM Treaty of indefinite duration if the Soviet Union does not make cuts in already deployed offensive weapons. In short, they want further Soviet concessions as a price for keeping to obligations we have already undertaken in an earlier deal. This position gives new meaning to the word Chutzpah.

And most of the Administration is taking a harder line. Their position is that the President's Star Wars brought the Soviets to the bargaining table but that it should be nonnegotiable. (This school wants to spend the talks patiently explaining to the backward Russians that their position on ABMs is wholly wrong, even though it happens to be precisely the one the U.S. spent ten years talking them into with a view to securing their reluctant signature on the present ABM Treaty.)

It is not only the Russians who have found us difficult. The British did also. During our negotiations with them in the 1920s over naval limits, at a most opportune time Lord Lee of Fareham, the First Lord of the British Admiralty, felt constrained not to propose the naval conference he wanted. Instead, he later explained, he made an address which was "intended as an invitation for an invitation because the invitation itself," he knew, had to come from America. "The American people," he felt, "would accept nothing that was not settled on American soil and at the suggestion of America."

—Jeremy J. Stone

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