

Spreading the Bomb without Quite Breaking the Rules (1976)

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The basic problem in limiting the spread of nuclear weapons is that in the next 10 years or so many countries, including many agreeing not to make bombs, can come within hours of a bomb without plainly violating their agreement—without “diverting” special nuclear material and, therefore, without any possibility of being curbed by “safeguards” designed to verify whether material has or has not been diverted.

This development would lower the political and economic price of nuclear weapons and at the same time greatly increase the incentives to acquire them. The legal acquisition of concentrated fissile material by regional powers will increase the desire of regional adversaries to do the same. Such a development is encouraged by the incoherence and carelessness of the policies of the United States and other nuclear exporters which allow material easily turned into bombs by government nuclear laboratories to be used or produced during the course of civilian research or the generation of electricity.

The problem in the present export rules can be made vivid by a comparison. Under these rules a non-weapon state can come closer to exploding a plutonium weapon today without violating an agreement not to make a bomb than the United States was in the spring of 1947, when the world considered us not only a nuclear power but *the* nuclear power. The plutonium bombs of the time were primitive in design and crated in knockdown form. The very bulky high explosives had to be glued together piece by piece with slow-drying adhesives to form an implosion system. The fusing and wiring circuits were much more primitive than those commercially available today, and even a skilled team would have required several days to put a weapon together. In the spring of 1947, moreover, we had no skilled teams. Yet some believe our nuclear force to have been the main obstacle to an adversary reaching the English Channel, and others believe it to have been the backup for “atomic diplomacy.” It should make suppliers thoughtful that their nuclear exports might bring a non-weapon state closer to exploding a plutonium bomb today than the United States was in 1947.

The Incoherence of Current U.S. Policies

From the outset of the nuclear age it has been clear that designing a bomb and getting the nonnuclear components are much easier than getting fissile material in high enough concentration for an explosive. Research on bomb design and testing of nonnuclear bomb components are not prevented by agreements on nuclear cooperation, and can proceed in parallel with the accumulation of fissile material. Fissile uranium (in particular, uranium-235) or fissile plutonium (especially plutonium-239) concentrated enough to need no isotope separation¹ and only a modest amount of chemical separation are then the main hard steps on the way to a nuclear bomb.

The fresh fuel used in the present generation of power reactors is either natural uranium, which is almost all uranium-238 with less than 1 percent of the fissile isotope uranium-235, or low enriched uranium with only 3 percent to 4 percent of uranium-235. Such fresh fuel with less than 20 percent of uranium-235 cannot be used in an explosive without isotopic separation. But the irradiated or "spent" uranium fuel contains, along with other by-products, significant quantities of plutonium which result from the absorption of neutrons by the uranium-238. The plutonium so generated along with electricity has upward of 70 percent of the fissile isotopes of plutonium and requires no isotopic, but only chemical separation to be used in an explosive. Some "critical experiments" use large amounts of plutonium and uranium in metal form needing little further change.

To avoid putting fissile, that is, readily fissionable, material into the hands of non-weapon states, we deny licenses on facilities for isotope separation which could produce highly enriched uranium. So also on reprocessing plants for chemically separating plutonium. In the nuclear suppliers group, according to news accounts, we argue in principle against any other country making such exports even under International Atomic Energy Agency (IAEA) "safeguards." While we so far haven't won on the general principle, we have successfully opposed French sales of reprocessing plants to Taiwan and South Korea. And though not successful in our opposition, we say we objected to the German sale of enrichment and reprocessing plants to Brazil as well as to the French sale of a reprocessing plant to Pakistan. We used to refuse to license the export of uranium enriched to more than 20

percent in uranium-235, whatever the inspection arrangements. All of this recognizes, sometimes explicitly, that safeguards imply timely warning and that material that is weeks, days, or hours from incorporation in a bomb therefore cannot be effectively safeguarded.

On the other hand, we have for some time exported to non-weapon states, for use in research, both separated plutonium and highly enriched uranium, which bring them closer to the bomb than do the facilities for separating such material. For example, from mid-1968 to spring 1976, we exported 697 kilograms of highly enriched uranium and 104 kilograms of separated plutonium to Japan and 2,710 kilograms of highly enriched uranium and 349 kilograms of separated plutonium to the Federal Republic of Germany.

And we continue to offer nuclear assistance to countries that plan to acquire fissile material, and even to a country like India which has already detonated a nuclear explosive in defiance of explicit Canadian and U.S. statements over the past decade that no nuclear explosive is exclusively peaceful within the meaning of their agreements on nuclear cooperation. We say that that is what our agreements have always meant (and it is indeed their commonsense implication),² and we try to make this obvious meaning explicit in new agreements. Nonetheless, for old agreements we content ourselves with statements of U.S. unilateral understandings on this subject, and continue nuclear exports to countries that have refused to endorse our unilateral interpretation.³

The State Department assures the Congress that such unilateral understanding is binding enough, but after the Indians made a nuclear explosive using Canadian and U.S. peaceful assistance, we denied that the Indians had violated anything but the Canadian unilateral understanding and went through extraordinary contortions to hide the fact that they had used U.S. heavy water. We raised no objections when the French sold a reprocessing plant to Japan. Indeed, in 1972, before that sale, we had authorized U.S. companies to sell a reprocessing plant to Japan under stricter safeguards than the Japanese were willing to accept, but apparently no stricter than those they actually accepted later for the French sale.

Our policies at that time did not recognize, as they do now, that the sale of reprocessing plants is mistaken even if safeguarded. The South Koreans observe that we treat Japan differently from them

when it comes to reprocessing. The French comment sardonically that we make a great fuss about the sale of a reprocessing plant to Pakistan, even though our representative to the IAEA approved the Agreement between Pakistan, France, and the IAEA on the transfer and safeguarding of that plant. And apparently not all American officials, and evidently not the most important ones, opposed the West German sale to Brazil in tones audible at the highest level of the German government. Chancellor Schmidt told the press in June 1975 that he regretted criticism by U.S. journalists and politicians but that “he knew of no criticism by the U.S. government.”

We get then the worst of both worlds: In the end we refused to supply reprocessing or enrichment facilities to the Brazilians, knowing that though nominally civilian, such facilities could bring Brazil close to a bomb. But because we never formulated a coherent policy explaining that, it was easy for the Federal Republic to tell itself that we were simply sore losers in a business deal and that clinching the deal by giving the Brazilians a “sweetener” in the form of the principal ingredient of a nuclear explosive was perfectly all right.

Our agreements on nuclear cooperation abound in clauses that presume that the importing country will separate and recycle plutonium and that stocks of plutonium may in principle be effectively safeguarded. Moreover, we have talked of separating and recycling plutonium as if they were essential to the future of nuclear power both here and abroad, and have allowed the myth to persist that power-reactor plutonium cannot be used as an explosive. We have recently made the recycling of plutonium a “key initiative” in our energy conservation program. The Nuclear Regulatory Commission (NRC) has only recently shown signs of considering the international consequences of recycling to be a factor in the U.S. decision to license it domestically. As for uranium, sometime in the 1960s our attention wandered and we began to ship highly enriched uranium to non-weapon countries. We appear to have shipped some five tons overseas – perhaps 300 bombs worth of readily fissionable material. Our confusion has been durable and bipartisan.

How We Got Into This Fix

The extensive fundamental overlap of the paths to nuclear explosives and to civilian uses of nuclear energy has been recognized since the mid-1940s.⁴ The “heart of the problem” of

international control, according to Robert Oppenheimer, was “the close technical parallelism and interrelation of the peaceful and the military applications of atomic energy.” We have almost from the start said that the military and civilian atoms were substantially identical yet, paradoxically, that we wanted to stop one and to promote the other. The paradox was present in the Truman-Atlee-King Declaration of October 1945, and we made our most valiant effort to reconcile these opposing aims in the Acheson-Lilienthal Report and the Baruch Plan of 1946.

The Acheson-Lilienthal Report tried to resolve the dilemma by proposing to “denature” plutonium: that is, to spoil it as an explosive. This was to be accomplished by leaving the fuel to be irradiated in the reactors long enough so that the fissile isotope, plutonium-239, generated in the uranium fuel rods, would in turn generate a large portion of higher isotopes of plutonium and, in particular, a large fraction of plutonium-240, which had serious drawbacks from the standpoint of the art of weapons design of the time. The idea had been advanced in March 1945, by Leo Szilard, quite tentatively. (The troubles with plutonium-240 had been discovered only in the summer of 1944.) The Franck Report proposed denaturing less cautiously in June 1945.

Discussion was necessarily muted and limited by the requirements of secrecy, by the bounds of the current state of the art, and by the limitations of current understanding of that state of the art. The initial report was predicated on the belief that denaturing would interpose the high barrier of isotopic separation between the use of plutonium for civil and military ends. This, given the elaborate mechanism of international control called for in the Acheson-Lilienthal Report, would assure some two to three years warning. The report itself exhibited some uncertainty and ambivalence⁵ about the hope for denaturing and the hope was almost immediately modified by a committee of distinguished Manhattan Project scientists to suggest that such plutonium could be used in a weapon, but would be very much less effective.⁶ Even the qualifications immediately introduced, we now know, were not strong enough. Yet the initial hope for denaturing has generated a long and inconsistent trail⁷ of statements which still have their effect in encouraging the belief that plutonium left in the reactor long enough to become contaminated with 20 to 30 percent of the plutonium-240 or plutonium-242 would be unusable or, at any rate, extremely ineffective when used in a nuclear explosive. Since power reactors operated “normally” were expected for reasons

of economics to achieve maximum "burnup" of fuel by leaving the fuel rods in the reactor long enough to so contaminate the rods, a kind of denaturing was hoped for as a result of standard procedures. However, this hope turned out to be a slender reed.

The Baruch Plan would have given sovereign states control only of "safe" civilian activities. They would have gotten all of their fissile material in denatured form, separated from spent fuel in plants owned by an international authority. That authority was to have a monopoly of all "dangerous" activities: that is, all those that could quickly be turned to the manufacture of explosives. The plan rejected as unworkable any reliance on inspection rather than on ownership and control of dangerous activities.

The Soviets turned down the Baruch Plan. Since then we have come to rely on exactly the scheme regarded as unworkable by the authors of the Acheson-Lilienthal Report and the Baruch Plan. We rely in essence only on accounting and inspection of dangerous activities in non-weapon states. We are encouraged to do so by remnants of the belief that plutonium from a power reactor is not very dangerous.

But why was it important that plutonium be made safe for civilian use? The short answer is that we were powerfully impelled after the horrors of Hiroshima to believe that nuclear energy had a constructive use in electric power as spectacular as its use in military destruction. And we believed, on the basis of our initial understanding of the scarcity of uranium, that plutonium was essential to the future of nuclear electric power. The known reserves of natural uranium in the late 1940s were a mere 2,000 short tons. Since natural uranium contains only a tiny fraction of the fissile isotope, uranium-235, converting the more abundant uranium-238, which is not itself fissile, into fissile plutonium seemed a logical way to extend the scarce supply of fissile material for electric power. (From the first, we had contemplated using plutonium not only in breeders, but also in present-day reactors.)

And the natural impulse to find civilian use for this enormous force led statesmen frequently to talk as if the civilian use were a substitute for the military one: The more we used atoms for peace, the less we would use them for war. We subsidized the spread of civilian nuclear technology not simply in the hope for spectacular economic benefits, but as if it were a decisive measure of nuclear disarmament. We dispersed "research" reactors in the Third World as a substitute for sending a symbolic "atomic peace

ship" around the world rather than as a matter of hard economics for development, and were embarrassed to find that we had made it a matter of international prestige to have a research reactor, even for countries that had no trained personnel to use it. We made concessionary loans for power reactors almost as tenuously based in economics, and we did this as if they were necessarily advancing the cause of peace.

Robert Oppenheimer was quite right in saying that, unlike the Acheson-Lilienthal Report or the Baruch Plan, the Atoms for Peace program had no "firm connection with atomic disarmament" and that its bearing on the prospect of nuclear war was "allusive and sentimental" rather than "substantive and functional." This symbolic use of atomic energy antedated the Atoms for Peace program and relates to our earliest habits of talking about promoting the peaceful uses of the atom as if they would automatically displace the military use.

However, it can be said of the pioneers of the nuclear age that though they sometimes talked as if there were a dichotomy, they also saw that the heart of the problem was a large overlap between civilian and military applications of nuclear energy, and they grasped very firmly the point that keeping the two sorts of activities separate means more than simply detecting a violation of an agreement. It means early detection of the approach by a government toward the making of a bomb in time for other governments to do something about it. This principle has been reaffirmed recently by the president, by the assistant administrator for national security of the Energy Research and Development Administration (ERDA), and by the inspector general of the IAEA. But, in practice, the point has a way of getting lost in the middle reaches of both national and international bureaucracies.

It was only to be expected that over two decades of Atoms for Peace programs would result in the formation of large groups of professionals in industry, in nuclear engineering departments of universities throughout the world, in governments, and in regional and international agencies. All of these groups have a strong interest in the "enlargement and acceleration" of the use of nuclear energy and a much milder concern with such long-term problems as the disposal of radioactive waste or the spread of nuclear explosives. They tend to identify any restraints to control the dangers of proliferation as simply — dread word — "antinuclear." The hostility has been worsened by some of the extremists of the environmentalist movement, who seem dedicated to stopping and

dismantling all civilian nuclear power rather than controlling its dangers and encouraging the development of safe forms of nuclear and nonnuclear energy. The nuclear energy faction inside large industrial corporations in turn feels embattled by any attempt at further restriction, precisely because reactor manufacture has so far involved great business losses in spite of subsidy. The nuclear debate degenerates into a dog fight between extremes, with the accusations by Squeaky Fromme and the Manson Family about a nuclear power conspiracy almost mirrored in the dark hints by the beleaguered industrial bureaucracy.

For example, delegates to a meeting in Vienna last spring of the International Union of Producers and Distributors of Electrical Energy suggested that the holdups in separating plutonium to "close" the fuel cycle are due to "subversive elements" at work among groups opposing nuclear development.⁸ At a conference in Düsseldorf earlier that week the chief executive of VEBA, a leading West German energy concern, indicated that the nuclear opposition was heavily backed with cash "from across the border."⁹ But from the standpoint of reactor manufacturers whose profits are all still in the future, less sales promotion and a more sober look at the social and even the entrepreneurial risks would be salutary for the industry itself. Treating as the enemy all doubters of nuclear market and cost-benefit studies encourages badly timed investments and the present industry troubles.

However we got into our present fix, we still have to ask what the fix portends for the future of proliferation, if we do nothing.

Is the Spread Likely?

Past predictions of immediate spread have, for the most part, been false alarms. So, immediately after the war, scientists who had figured in the Manhattan Project predicted that, unless there were very drastic international controls, bombs would spread rapidly. Harold Urey forecast a half dozen countries entering the nuclear club in as few as five years. Irving Langmuir predicted that Russia would get nuclear weapons very quickly, but would be beaten in the race by Canada and England. And the general public reflected this pessimism. Intelligence estimates in 1948 were more hopeful (excessively so in predicting when the Soviet Union would get the bomb), but official predictions have had their ups and downs.

A second flurry of alarm came in the late 1950s as the military

potential of the Atoms for Peace programs began to be visible. Officials predicted, for example, that not only Canada and Sweden would get nuclear weapons in the early 1960s but, unless there were a multilateral nuclear force, West Germany would too. Perhaps the best known study done then was by the American Academy of Arts and Sciences and the National Planning Association (NPA): it suggested that without international control there might be as many as 10 new nuclear powers in five years. This study was summed up somewhat incautiously by C.P. Snow's famous statement in 1960 that all physical scientists ". . . know that for a dozen or more states, it will only take perhaps six years, perhaps less" to acquire fission and fusion bombs. Nothing of the kind happened. By comparison with these early alarms, the actual increase in the number of countries testing nuclear explosives has been very slow. Three additional countries tested at intervals of eight, four, and 10 years in the 22 years following the British nuclear explosion.

There is a lesson to be drawn from a close examination of these past apocalyptic predictions. They assumed essentially that, in the absence of some quite extreme and politically implausible change in circumstance, countries that could get nuclear weapons would do so, and would do so more or less in the order of their technical and industrial competence. The incentives and drawbacks for proceeding with a nuclear weapons program were in all essentials neglected. However, political will is the key, rather than mere competence. The demand for weapons was softened by a system of working alliances and explicit or implicit guarantees that applied to most of the then likely prospects for an independent nuclear capability. The price and risks in undertaking a nuclear weapons program were also higher than most of the prophets had recognized. It is important today, as then, to look soberly at incentives and disincentives for the spread and how they might be affected. We should not easily assume inevitability.

Some students of proliferation, however, observe that three countries tested in the first decade, two in the second, one in the third, and are made excessively cheery by the diminishing sequence. But changes are taking place beneath the placid surface, which is presently undisturbed by new countries testing weapons. These changes are much less cheering. Under the present rules, civilian nuclear energy programs now under way assure that many new countries will have traveled a long distance down the path leading to a nuclear weapons capability. The distance

remaining will be shorter, less arduous, and much more rapidly covered. It need take only a smaller impulse to carry them the rest of the way. There is a kind of Damoclean overhang of countries increasingly near the edge of making bombs.

For convenience, distinguish three conditions in which plutonium might be found in the course of generating nuclear electric power. The first is the accumulation of plutonium in irradiated or "spent" uranium fuel which is now a normal by-product of any operation of our current reactors. The second condition, much closer to being usable in a nuclear weapon, would be that of plutonium in fresh mixed plutonium and uranium oxide fuel rods. Even if a country did not separate plutonium or manufacture such mixed oxide fuel rods itself, it could have plutonium in this second form in reloads of mixed oxide fuel at the input end of reactors. Plutonium in the third condition would be found already separated in the form of plutonium dioxide or plutonium nitrate. In this form, it could be found at the output end of a separation plant, or at the input end and in stocks-in-process in facilities that manufacture mixed plutonium and uranium fuel rods. Plutonium in these three conditions comes successively closer to a nuclear explosive. The last two conditions need occur only if plutonium recycling becomes general.

At present, our agreements on cooperation in general leave title to the spent fuel and all its products in the importing country. For governments accumulating the spent fuel, the barrier to obtaining a high enough concentration of fissile plutonium will be the need to separate the plutonium chemically. This is a less formidable obstacle than isotopic separation, the facility for which costs billions of dollars using present techniques and would take years to construct. Nonetheless, chemical separation is substantial barrier and perhaps the most important one remaining, if nuclear suppliers do not secure the return of spent fuel. Getting spent fuel is a considerable stride along the road to nuclear weapons, compared to the position of the weapon states which started from scratch. But spent fuel still needs to be reprocessed, and that involves delay and then remote manipulation of extremely toxic, radioactive substances, facilities with six or seven feet of shielding, lead glass windows, etc. Tons of spent fuel must be handled to produce kilograms of plutonium.

At the other extreme is the plutonium that would be stored at the output or "back" end of reprocessing plants and at the input or "front" end of plants fabricating plutonium or "mixed oxide" fuel. Such plutonium in the form of plutonium dioxide

or plutonium nitrate could be converted to plutonium metal using generally known methods and without remote handling equipment or extensive shielding and the like, but only a glove box. It should take no more than a week in a facility covering 3,600 square feet and costing about \$1,400,000.

Plutonium would also be found, if it is recycled, in fresh unirradiated fuel rods at the input end of the reactor. Extracting plutonium from such mixed oxide fuel would be very much easier than taking it out of the irradiated spent uranium fuel. Plutonium is more concentrated in the mixed oxide fuel rods (4.5 percent compared to .7 percent). Unlike irradiated fuel, it is not highly radioactive and would require no delay, no "hot cells" with heavy shielding, no remote manipulation, and no removal of fission products. A facility for separating 5 kilograms per day and converting it to plutonium nitrate might exist in a 1,400 square foot laboratory and might cost \$235,000. This is trivial by comparison with the cost of a facility for deriving comparable quantities of plutonium nitrate from the spent uranium fuel. The latter might cost from \$75 million to \$100 million. The difference is important, because today many proposals would ban separating plutonium in non-weapon states, but not recycling it in mixed plutonium and uranium fuel. So, for example, early drafts of U.S. agreements of cooperation with Egypt and Israel.

We can measure the advance toward the ability to manufacture nuclear explosives implicit in recent civilian nuclear electric programs, as of 1975, by showing first the number of countries, including the present weapon states, that would have enough separable but possibly unseparated plutonium for a few bombs between now and 1985. Second, the large number of countries with various quantities of plutonium in fresh reloads of unirradiated plutonium fuel if plutonium recycling should become general, and even if these countries do not themselves separate plutonium or manufacture plutonium fuel rods. Third, the number of countries that have planned to have a capability to separate that much plutonium by 1985. The results of these three sets of calculations are displayed respectively in Figure 1, Table 1, and Figure 2.

Figure 1
The overhang of countries with enough separable plutonium for primitive or small military forces

Vertical scale: number of countries

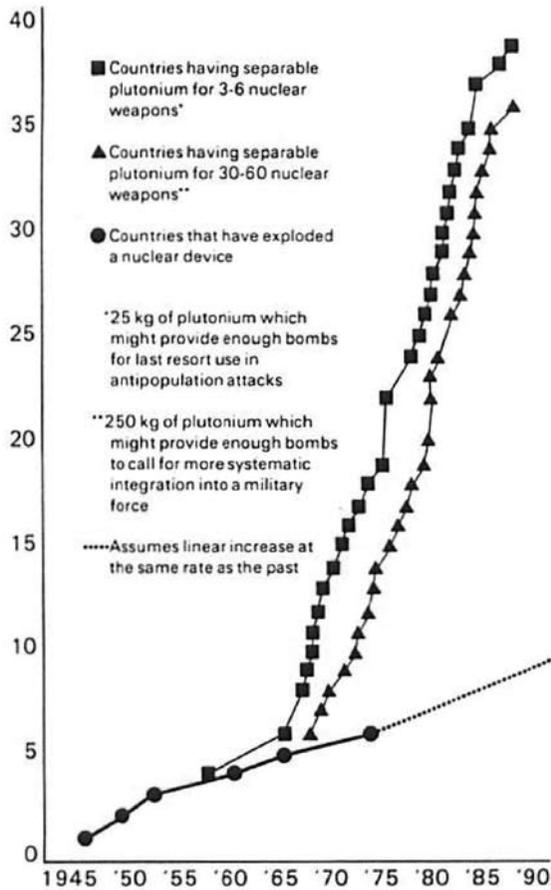


Figure 1.

Table 1
Plutonium Available
from Reloads of Mixed Plutonium
and Uranium Oxide (MOX) Fuel
in the Early 1990s*

	kg of Pu ^a (Plutonium)	Number of Bombs' Worth ^b
Austria	400	46
Belgium	2,800	325
Brazil	500	58
West Germany	11,700	1,357
India ^c	360	42
Iran	3,200	371
Italy	2,100	244
Japan	9,000	1,044
South Korea	900	104
Mexico	800	93
Netherlands	400	46
Philippines	1,000	116
Spain	5,600	650
Sweden	4,800	557
Switzerland	3,200	371
Taiwan	3,200	371
Yugoslavia	500	58
Egypt	700	81

* Using only indigenously produced plutonium and assuming that one reload is always kept at each reactor. Any country without its own MOX fuel fabrication facilities could justify stocking one reload. A single MOX reload might contain 350-900 kg of plutonium (40 to 104 bombs worth). Countries that fabricate MOX fuel would have still more plutonium available in process.

^a Assuming 580 kg per 1,000 megawatt boiling water reactor reload and 770 kg per 1,000 megawatt pressurized water reactor reload, linear scaling for other reactor sizes. See U.S. Atomic Energy Commission, Generic Environmental Statement Mixed Oxide Fuel (GESMO), Vol. III, August 1974, p. IV C-65.

^b 8.62 kg Pu per bomb assuming 5kg fissile Pu/bomb and assuming MOX Pu is 58 per cent fissile Pu.

^c The figures for India are the result of direct calculation.

Table 1.

Figure 2
Countries planning to have plants for separating plutonium or enriching uranium in quantities enough for several bombs

Vertical scale: number of countries

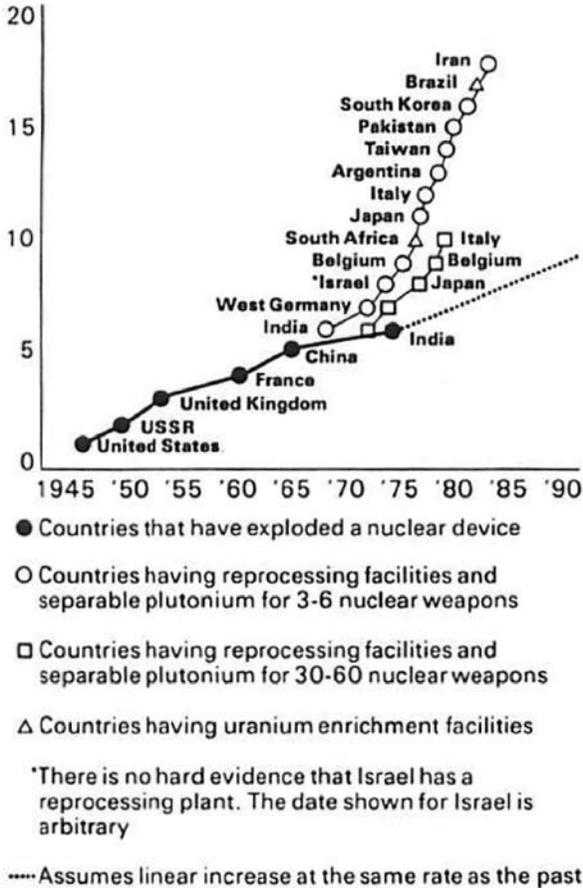


Figure 2.

The first thing to be said about the numbers in these charts is that they are very large ones. Chemical separation of plutonium and the enrichment of uranium are civilian activities which have long been regarded as “normal,” if not yet operational, parts of the nuclear electric fuel cycle. They may sometimes and in some

places be discouraged by various ad hoc national policies, but they have not been subject to a clear-cut international or universal national prohibition by supplier countries. The problem of inhibiting or reducing the size of this burgeoning capacity is not merely then a matter of an improved watch, to see that a clearly agreed prohibited line is not crossed. Among other things it would involve defining and moving such a clearly agreed boundary to preclude activities which cannot provide adequate warning. And for whatever dangerous activities remain on the permissible side of the agreed boundary, we need to elaborate a consistent national policy to discourage them and encourage other safer alternatives.

The second thing to be said is that this large growth is not inevitable. It presumes the carrying through of plans, negotiations, and constructions not yet firmly committed; some, like the Korean and Taiwan separation plants, have had setbacks. The growth, moreover, is open to further influence, a subject for the elaboration of policy of supplier as well as recipient governments. But American influence on the policies of various importing and exporting countries is limited by the confusion and arbitrariness of our policy on access to fissile material. Figures 1 and 2 and Table 1 are not unconditional forecasts, but indications of what may happen if conditions are not altered.

The gist of these figures is that, under the present rules of the game, any of a very large number of countries may take these further long strides toward the production of nuclear weapons in the next 10 years or so without violating the rules—at least no vigorously formulated, agreed-on rules.

These paths toward producing weapons are in addition to paths which exploit the weakness of sanctions against breaking the Treaty on Non-Proliferation of Nuclear Weapons (NPT) or bilateral rules, and in addition to paths open to those governments which have not ratified the NPT. Extending the NPT to more countries or increasing the efficiency of “safeguards” or physical security measures would not, therefore, block these paths. The recent interest in measures against “diversion,” while useful in itself, distracts attention from the steady spread of production capacities within the rules.

Some part of the stocks of fissile material might always be diverted within the limits of error of material unaccounted for by any inspection system. In the future, when these stocks are very large, diverting even a small percentage would yield sizable

absolute amounts. This tends therefore to be the focus of most attention. Yet it is much less important than the possibility of piling up significant stocks of fissile material legally, without diversion, for use later in explosives.

I have distinguished for convenience four kinds of nuclear explosive capacity. The first is the sort of capacity which has been much in the public eye in the last year or two, due especially to the efforts of Dr. Theodore Taylor to make clear its dangers. It would consist in the manufacture of a crude device derived from stolen fissile material, perhaps not using plutonium metal, but plutonium dioxide powder, yielding as little as 10 or 100 tons of energy, and designed for terrorist use by some nongovernmental group, or possibly even a single individual. It might use poorly separated material and be dangerous not merely if exploded in anger, but to store and handle.

The second capacity would rely on a few explosives, perhaps implosion weapons in the kiloton or greater range. They might be used by governments as a desperate last resort threat against populations (or transferred by some governments to terrorists). The third capacity I have taken arbitrarily as consisting in perhaps 50 such devices, enough to call for plans to incorporate them into a military force. The fourth would be much more sophisticated. It is the kind that an industrial power like Japan might contemplate, if it made the decision to become a military nuclear power in the 1980s or 1990s. It would require very sophisticated fission and fusion weapons with predictable yields and with more advanced and protected delivery capabilities.

This article focuses especially on the second sort of capability. It imposes no stringent requirements for delivery. (These requirements are very stringent for a middle power to get a serious and responsible force in the 1980s.) I do not, however, mean to imply that the capacity to produce a few bombs for use as a last resort will actually realize the hopes some government might place in it. It is likely to be extremely inflexible, vulnerable, and available only for suicidal use. Nonetheless, some governments might take this route.

However, the nuclear energy bureaucracy, and statesmen informed by it, have been cheerfully arguing that the recycling of plutonium will not make the spread of weapons more likely. Their arguments are residues of the initial faith in denaturing. They are saying that power reactor plutonium would be contaminated in normal reactor operations and abnormal operations would be

quickly detected and punished; that power reactor plutonium cannot be used as an explosive; or if so used, it would be ineffective, with generally low yields and highly variable ones; that only sophisticated nuclear weapon countries like the United States and the Soviet Union, with many years in the business, could so derive weapons that have any genuine military use; and finally, with a touching bathos, that power reactor plutonium is anyway less than optimal for weapons.

It is surprising that the faith in denaturing of plutonium, however plausible initially, could have survived for more than three decades. Since this belief explicitly or implicitly rationalizes so much carelessness, it is important, before putting it to rest, to offer some current examples. "Both Framatome and French officials," according to *Nucleonics Week*, June 3, 1976, "deny the [South African] deal is conducive to weapons building. 'The worst way to make a bomb is to buy an LWR (light water reactor) for 5 billion francs,' commented Leny. Abourdarham [also of Framatome] added, 'To get clean Pu-239 from our type of reactor, you'd have to lower the burnup rate and discharge the reactor not once a year but about twice a month.' The higher the burnup the more contaminated the spent fuel is with Pu-240." The new French foreign minister, while ambassador to the United Nations, told the Security Council flatly that plutonium so derived "could not be used for military purposes."¹⁰ In Germany, officials of Kraftwerk Union have suggested that weapons-grade plutonium must be 98 percent pure plutonium-239, and that anything less could be used not in a military weapon, but only in "terrorist explosive devices" of low and uncertain yield, which in any case would be extremely hard for terrorists to make.¹¹ The Swedish government committee on radioactive wastes (the Aka Committee) reports that "The plutonium . . . produced in Swedish power reactors contains as much as 25 percent to 30 percent of plutonium-240 [and] . . . can only be utilized in weak and probably unreliable nuclear charges of highly questionable military value."¹²

In the United States, the president of the Atomic Industrial Forum says that if nuclear reactors are "run on an economic fuel cycle—that is, long irradiation times—the plutonium produced is readily used only for making explosive devices which are hardly military weapons."¹³ He goes on to suggest that only very sophisticated weapons countries like the United States and the Soviet Union are able to overcome the difficulty by special design. The Forum's Committee on Nuclear Export Policy concludes that

we should promote peaceful nuclear electric power only to the extent consistent with the goal of eliminating proliferation, but they do not think that should impose much constraint, since, “. . . power reactors are not a practical or economic vehicle for producing weapons-grade plutonium. The processing of fuel from a power reactor at low irradiation levels would be costly and revealing of intentions, thus jeopardizing the supply of new fuel. On the other hand, the use of reactor-grade plutonium of high irradiation levels for weapons purposes presents formidable technical challenges.”¹⁴

And finally American government officials in agencies granting loans and subsidies to countries like India which have or propose to get reprocessing plants take comfort from the fact that, “While the plutonium produced by these reactors could be used in an inefficient and unsophisticated explosive program, it is not optimum material for explosive uses because of the high percentage content of the nonfissionable plutonium isotope plutonium-240.”¹⁵

But all of this is quite misleading. For one thing, a non-weapon country can operate a power reactor so as to produce significant quantities of rather pure plutonium-239 without violating any agreements or incurring substantial extra expense. This would involve departing from theoretical “norms” for reactor operation, but a look at the actual operating record of reactors in less developed countries suggests how theoretical these norms are. Even in America in the early 1970s, leaking fuel rods caused Commonwealth Edison to discharge the initial core of its Dresden-2 reactor early, with nearly 100 bombs-worth of 89 to 95 percent pure fissile plutonium.¹⁶ (In India, as of September 1975, 97 percent of the fuel discharged from its Tarapur reactors had leaked.) Countries like Pakistan and India, with smaller electric grids and poorer maintenance, have operated much less and much more irregularly than the steady 80 percent of the time originally hoped for; and have irradiated their fuel and contaminated the plutonium in it less. Since it is neither illegal nor uncommon to operate reactors uneconomically, governments may derive quite pure plutonium-239 with no violation nor much visibility.

What is more, there is plainly a considerable latitude in the degree of purity actually required for explosives. The discussion in the European nuclear industry frequently assumes that “weapons-grade” plutonium must be 98 percent pure plutonium-239.¹⁷ In this country, however, under present classification guidance,

the fact that plutonium containing up to and including 8 percent plutonium-240 is used in weapons is unclassified as is the fact that more than 8 percent plutonium-240 (reactor-grade) *can* be used to make nuclear weapons.

Most significantly, 20 years of Atoms for Peace programs have dispersed well-equipped and well-staffed nuclear laboratories among nonnuclear weapons states throughout the world. (For example, by 1974 the United States alone had trained 1,100 Indian nuclear physicists and engineers. The Shah of Iran plans to have 10,000 trained.) Many of these laboratories would be quite capable of designing and constructing an implosion device and of studying its behavior by nonnuclear firings. It is true that if they were to use power reactor plutonium with 20 to 30 percent of the higher isotopes, they would be likely to obtain a lower expected yield and a greater variation in possible yields than if they should use more nearly pure plutonium-239. (Of course a nonnuclear component could fail, but this has nothing to do with the grade of plutonium used.) However, they could build a device which, even at its lowest yield level, would produce a very formidable explosion. This may be seen from the record (now public) of the characteristics of the Nagasaki plutonium bomb.

The Fat Man and the Little Boy

The first American implosion design, "Fat Man," was used in the Trinity test and the Nagasaki bomb. It had a finite probability of predetonating even though it used an extremely high percentage of plutonium-239. Plutonium-239 itself emits neutrons spontaneously, though five orders of magnitude less so than an equal quantity of plutonium-240. More important, though the Trinity and Nagasaki devices used exceptionally pure plutonium-239, they had a significant fraction of plutonium-240. They had a definite chance, then, of detonating prematurely, that is, between the time the rapidly assembling fissile material first became critical and the time that it might have arrived at the desired degree of supercriticality; and the less supercritical, the lower the yield.

In a memorandum to General Farrell and Captain Parsons immediately after the Trinity test, and before the use of Fat Man at Nagasaki, Oppenheimer wrote, "As a result of the Trinity shot we are led to expect a very similar performance from the first Little Boy (the gun-assembled uranium weapon used at Hiroshima) and

the first plutonium Fat Man. The energy release of both of these units should be in the range of 12,000 to 20,000 tons and the blast should be equivalent to that from 8,000 to 15,000 tons of TNT. The possibilities of a less than optimal performance of the Little Boy are quite small and should be ignored. The possibility that the first combat plutonium Fat Man will give a less than optimal performance is about 12 percent. There is about a 6 percent chance that the energy release will be under 5,000 tons, and about a 2 percent chance that it will be under 1,000 tons. *It should not be much less than 1,000 tons unless there is an actual malfunctioning of some of the components. . . .*" (italics added)¹⁸

Indeed General Groves, like Oppenheimer writing between the Trinity test and the actual use of the implosion weapon at Nagasaki, anticipated an increase in the fraction of plutonium-240 in later weapons. He wrote, "There is a definite possibility, 12 percent rising to 20 percent as we increase our rate of production at the Hanford Engineer Works, with the type of weapons tested that the blast will be smaller due to detonation in advance of the optimum time. *But in any event, the explosion should be on the order of thousands of tons.* The difficulty arises from an undesirable isotope which is created in greater quantity as the production rate increases" (italics added).¹⁹

The essential point to be made is that even if a device like our first plutonium weapon were detonated as prematurely as possible—at a time when the fissile material was least supercritical—its would still be in the kiloton range. Apart from a modest degradation in the quality of the fissile material employed, and hence in the size of the expected yield, all that a higher fraction of plutonium-240 in such a first implosion device could do is increase the probability of obtaining a yield smaller than the optimal, but still as large or larger than that already enormously destructive minimum.

The lowest yield of such a weapon can by no stretch of the imagination be called "weak." Moreover, by comparison with the average or even the maximum yield possible in that implosion design (or by any standard), it would by no means be contemptible. In fact, only 7 months before Trinity, the first implosion weapons were expected to yield much *less* than one kiloton.²⁰ A reduced yield would not mean a proportionate reduction in damage. The area destroyed by blast overpressure diminishes as the two-thirds power of the reduction in yield, and the reduction in prompt radiation—which is the dominant effect on population of a low-

yield weapon—is even smaller. (If the expected yield were eight kilotons, and the less probable but actual yield were “merely” one kiloton, the blast area would be reduced not by seven-eighths, but only by three-fourths and the region in which persons in residential buildings would receive a lethal dose of prompt radiation would only be halved.) The lethal area would still be nearly a square mile.

Variability in yield would be a drawback for an advanced industrial country preparing the sort of force I have referred to as of interest to an industrial power like Japan in the 1980s or 1990s. Such a power might want a theater weapon that minimized collateral damage if only for the protection of its own troops. However, for a last resort weapon used against a distant population, it is important only that the blast effect of the yield be formidable; and if in fact more destructive energy is released than anticipated, this would only reinforce the destruction intended.

Finally, the variations in damage due to differences in the purity of the plutonium are likely to be much less than the variation in damage due to the differing operational circumstances in the use of the weapon. The Nagasaki plutonium implosion bomb had an estimated yield of 21 kilotons. The Hiroshima uranium gun weapon is now estimated to have released 14 kilotons. Yet, due to differences in terrain, weather, accuracy of delivery, and the distribution of population, the Hiroshima bomb killed twice as many people as the Nagasaki weapon.

As for the argument that military men would never use a device whose result was not precisely predictable, this is not very persuasive. If so, military men would hardly ever enter battle. The uncertainties of surviving ground attack, of penetrating air defense, and of delivering weapons on target are cumulatively larger than the uncertainties in the yield of a bomb made with power-reactor plutonium. Plans for delivering the first nuclear weapons were going forward before any test, and during a period when the Manhattan Project scientists had highly varied estimates of their yield.

In sum, no one should believe that power-reactor plutonium can be used only in a feeble device too unreliable to be considered a military weapon, or that recycling plutonium is therefore safe.

Recently, as some of the examples I have cited suggest, the bureaucracy has taken a slightly different tack: power-reactor plutonium can be used as an explosive, it is admitted, but would-be nuclear countries won't use it that way. They can get better

plutonium more cheaply and easily by buying reactors specifically for the purpose of producing plutonium and not for generating electricity. However, if one already has paid for an electric power reactor, the relevant economic figure is not the total, but the marginal, or extra, cost to get bomb material, given the fact that one has paid anyway for the reactor. In fact, if recycling is accepted as essential for the fuel cycle, the cost of separation plants would be charged to the generation of electricity and would involve no incremental cost for getting separated plutonium for weapons. Getting impure plutonium in this way would be nearly costless. Getting a significant quantity of rather pure plutonium would involve some fuel and operating costs, but these would be small by comparison with the expense of a program to produce and separate plutonium exclusively for weapons.

The more important costs are political for any program designed overtly to get plutonium for a weapon. That could be why the Pakistanis, the Koreans, the Taiwanese, and others deny that they are doing any such thing. It would hurt them militarily, economically, and politically. They can more easily get the financial and technical assistance and trading relations necessary for a power reactor. The political costs would be high for the exporting country too.

Finally, what the bureaucracy seems to miss altogether is that a non-weapon state under the present rules can proceed down the path toward making a weapon without deciding to do so in advance. It doesn't have to start out as a "would-be nuclear country." It can change its mind or it can make up its mind later. It doesn't have to get a production reactor.

Of course a production reactor might be disguised as a vague sort of "research" reactor, though this is likely to yield smaller quantities of plutonium. In fact, the rules governing research reactors and "critical experiments" have been even more careless and need tightening even more than those governing power reactors. But this second line of argument is hardly a cheery confirmation that the rules make the spread unlikely. It has the opposite sense. It has led industry representatives to suggest that the spread is inevitable "sooner or later" and we will just have to live with it.²¹

Would the Spread to More Countries be Bad?

As we and other supplier countries continue to subsidize the export of materials, equipment, and information needed for making nuclear explosives, the bureaucrats in industry and government associated with these programs tend more and more to tell themselves and everyone else that the spread of nuclear explosives may not be so bad after all: governments that get nuclear weapons will themselves behave more cautiously; their nuclear weapons will inspire caution in their neighbors; this in turn might free the United States from the burden of defending some troublesome allies.

However, the spread of nuclear weapons to many countries will disperse not only instruments of deterrence and prudent behavior, but also means of coercion and reckless or deliberate devastating attack. Not all threats of nuclear aggression will be neatly offset and canceled by convincing promises of nuclear response. The risks will rise very high. In unstable parts of the world, the disasters possible in short conflicts will increase enormously. In the Middle East, for example, before outside powers could stop the conflict, as a result of an exchange involving a few bombs the Arabs might suffer several million and the Israelis a million dead in contrast with the thousands killed in the October war. In a conventional war, it takes a very long time or huge resources to kill the number of people that would be destroyed by a few nuclear weapons in a matter of hours. The spread of nuclear weapons will reduce our ability to control events. It will have a dissolvent effect on alliances, expose our own forces overseas to huge new risks, and ultimately impose large costs in shaping our own offense and defense to protect the continental United States against small terror attacks by national, as well as subnational groups. Even distant small powers using freighters and short-range missiles, such as the Soviet SCUD, will be within system range of the United States.

Even if such a development were, as it is claimed, inevitable “sooner or later,” later would be better than sooner, and less better than more.

What Can We Do to Limit or Slow the Spread?

The characteristic view in the bureaucracy is that we have no leverage. We can't prevent foreign suppliers from selling nor

importers from buying nuclear technology on terms even less constraining than ours. It's unfair then to burden our nuclear exporters. Besides, we can retain our influence on non-weapon states only by continuing to supply them with nuclear services, equipment, and materials without interruption.

There is an obvious muddle in the bureaucracy's view that we can't influence events on the one hand, but on the other hand that we do have an important influence that we can retain only by continuing to export and – to make the muddle muddier – by continuing to export to buyers, no matter what their behavior, no matter what moves they make toward nuclear explosives. For the bureaucracy, in short, we can retain our leverage only if we never use it. A lever is a form of abstract art rather than a tool giving us a mechanical advantage.

All this is plainly disingenuous: We've talked of the inevitable while actively promoting nuclear energy in non-weapon states in forms that permit access to readily fissionable material, subsidizing the financing of these sales, giving away research reactors with highly enriched uranium cores, assisting "critical experiments" that involve hundreds of kilograms of separated plutonium and highly enriched uranium, urging that non-weapon states recycle plutonium, training engineers from non-weapon states in how to separate plutonium, arguing for domestic recycling as an essential to the future of all nuclear electric power, and in general setting an example to non-weapon states that suggests that the stocking of fissile material is both necessary and safe.

The State Department argues that we must supply nuclear services, equipment, and material "reliably" – by which it means that we should supply them steadily and indiscriminately to importers who do and to those who do not live up to an obligation to avoid getting explosives, or materials quickly convertible to nuclear explosives. Such "reliable" supply, it claims, will enable us to influence the importers. Exactly the opposite of the truth. Importers will be influenced to stay away from stocks of explosive material only if it costs them something not to do so, and only if our threats or sanctions are taken seriously. The Indian use of Canadian and American help for "peaceful uses only" in order to make nuclear explosives illustrates the point marvelously. The Indians guessed right in not taking the constraint seriously. Their explosion inspired only ingenious apologies for them in our State Department.

One token of our lack of seriousness is the piecemeal way we decide on licensing exports without considering the cumulative effect of our own and other suppliers' individual decisions in enabling an importing country to get explosive material. For example, we limit the amount of highly enriched uranium in the core of an individual research reactor we have given away, but place no constraint on the total amount of highly enriched uranium the importing country might gather from several sources. In this and other ways, we set a confused and incoherent example for other suppliers.

But other supplying countries have an interest in avoiding the spread of weapons to more states. The French government doesn't like the prospect of Spanish nuclear weapons, and neither the Germans nor the French could afford explicitly to use bombs as sweeteners for reactor sales, even if they wanted to. The French and Germans point out correctly that they now impose more stringent safeguards on exports than the IAEA requires, but they do not recognize, nor do we point out, that safeguards cannot be effectively applied to fissile material only a few hours away from a bomb; that is, such "safeguards" cannot give timely warning.

The principal precondition for us to influence other suppliers as well as importers is a clear, consistent policy: a set of signals which are green on some activities, red on others. We now flash red, yellow and green on practically everything.

But there are clear signals we can send and effective levers we can press. On the political and military side, we can help countries defend themselves against nonnuclear attack without resort to nuclear weapons. Our military sales program should be designed to discourage a nuclear defense and to make nonnuclear defenses more effective. And our alliance policy can strengthen guarantees against nuclear adversaries. For example, we can supply the South Koreans with improved short-range surface-to-air missiles and short-range precision guided nonnuclear weapons, and discourage their attempts to convert Nike Hercules into 200-mile surface-to-surface rockets which would be effective only with nuclear warheads and only against population targets.

On the economic side, we can design our export and export financing policy to affect an importing country's energy program considered as a whole, not piecemeal, by encouraging the use of nonnuclear energy and of comparatively safe forms of nuclear energy and by discouraging or penalizing the dangerous forms of nuclear energy that permit access to fissile stocks.

The effectiveness of the levers at our disposal can be illustrated by the extreme sensitivity of various programs in the non-weapon states of the Third World (where the impending spread is now most threatening) to simple alterations in the terms of financing. Korea, for example, has drastically cut back its nuclear program in response to a slight hardening in Canadian and American financial terms. And the effectiveness of our political and military levers is illustrated by the cancellation of the Korean reprocessing plant.

In sum, statements that we have no leverage mean that we don't want to press the levers we have, that we are not serious about proliferation. We don't think about the international consequences of digging ourselves deeper into a commitment to recycle plutonium, for example, by bailing out Allied General from its costly investment in reprocessing at Barnwell. We prefer to hang on to some quite inessential outworn conceptions of the nuclear fuel cycle and we are moving toward competing with the French and the Germans by giving away para-bomb capabilities.

Other governments have reason to doubt our claim that we unequivocally oppose proliferation. But actions against proliferation do cost something. It is only fair to ask whether they are worth the cost.

Will Slowing the Spread Cost More than It Is Worth?

Slowing the spread means reducing the demand for nuclear weapons by intelligent policies of alliance and of military sales and assistance. It means reducing the supply of nuclear weapons materials by sensible nuclear energy policy for our domestic as well as our foreign sales. On the supply side in particular, restrictions are often thought of as depriving us and other suppliers of enormous market benefits and imposing energy shortages on all of us, including the Third World countries now in the market for nuclear energy that is at least overtly civilian.

Nuclear energy has an important role to play, but its positive contributions will not make the difference between heaven and hell on earth. Its benefits have been puffed up from the start in ways that have greatly distorted its performance and made national energy programs follow something much less than the best path and timing for introducing nuclear energy into the total energy mix. A more sober program would benefit the security interests of the United States and ultimately the economic interests

of the industry. Without the extensive conversion of uranium-238 into plutonium and the separation of plutonium from spent fuel, we can have enough coal and enough of the fissile isotope uranium-235 at reasonable prices to last us well into the second quarter of the twenty-first century. By then we should be able to make an intelligent transition to the use of abundant or renewable resources: a safe and economic breeder; or a safe form of fusion; or solar energy, whether in the form of solar electric power, biomass, or some other. We have time.

The contrary claim that we need immediately to add to the reserves of uranium-235 by the extensive use of separated plutonium in the current generation of light water reactors, and that we should now contract into the early use of the plutonium breeder, is based on bad economics. It ignores the way an increase in market prices generates a larger supply of specific scarce resources (by making them worth finding and exploiting), or a supply of substitutes, and at the same time reduces the demand.

In fact, the nuclear industry has suffered chronically from premature commitments based on exaggeration of energy demand, the demand for electric power, in particular the demand for nuclear electric power, and the derived demand for uranium and for enrichment services. This exaggeration applies to overseas as well as to domestic demand. And the impression of crisis has been encouraged further by understatements of the supply that might be made available at various prices and by the discouragement of supply that has followed from the wild swings in demand when excessive hopes have been deflated. In 1975, the AEC predicted 450 GWe²² of nuclear capacity operating in the United States in 1985. In 1970, it predicted 300 GWe by that date. Today, on the basis of actual construction and orders, the Federal Energy Administration (FEA) expects 145 GWe or less. Given varied technical assumptions appropriate for the dates when the forecasts were made,²³ these predictions imply a cumulative need respectively for about one million, 500,000, or 220,000 tons of fresh uranium yellow cake if there is no recycling. The 80,000 tons that would be needed annually by the year 1985, if the AEC's 1970 nuclear power forecasts were right and we did not recycle, far exceeds the supply of low cost uranium that might be available at that time. The 33,000 tons that would be needed to fulfill the more sober FEA schedule during the year 1985 is quite in line with what is in prospect. ERDA has estimated that a rate of 33,000 tons can be available in the early 1980s at the low forward cost of \$15 per pound.²⁴

Much the same can be said about inflated forecasts of the need for uranium enrichment services; and about the longer term forecasts until the end of the century for both uranium and enrichment. European, Japanese, and Third World nuclear power forecasts have been similarly inflated. In 1957, Euratom forecast about 15 GWe of nuclear power in 1967 and about 50 GWe in 1975. In actuality there was 1.6 GWe in 1967 and at the end of 1976 there will be only about 12.2 GWe.²⁵ The Japanese in 1970 expected 60 GWe by 1985. They have officially cut this to 49 GWe and some Japanese experts expect it to be as low as 30 GWe.

The nuclear bureaucracy believes that overstating demand is much less harmful than understanding it.²⁶ This is not so. The exaggeration has severely damaged both national policy and the profitability of industry. Exaggerated uranium demand biases decisions toward plutonium recycling in the current reactors as well as in breeders. The inflated domestic demand for enrichment led us in 1974 to ban any new enrichment commitments to foreigners. This led to the present scramble overseas to get enrichment capabilities independent of the United States with an obvious resulting loss of U.S. control. Inflated market expectations have also cost the industry money. Chronic premature commitment has meant, in the United States, a loss to General Electric of \$500 million to \$600 million on 13 turnkey contracts; a loss of \$.5 to \$2 billion by Westinghouse depending on how it settles the legal claims of public utilities on its forward sale of uranium that it used to sweeten its reactor sales. Royal Dutch Shell and Gulf Oil, the two owners of General Atomic, have lost over one billion dollars on the latter's high temperature gas-cooled reactor.

It is hard to disentangle losses on commercial nuclear sales in company statements that, in general, merge those losses with profits on fossil fuel plants, military nuclear sales, or other industrial products. But it appears that Babcock and Wilcox, and Combustion Engineering, the other two major U.S. reactor manufacturers, have suffered respectively a cumulative loss on nuclear sales of about \$100 million and \$150 million; for 1976 each will have an estimated \$10 million pre-tax loss. General Electric's pre-tax loss on nuclear sales in 1976 will be about \$40 million. AEG Telefunken, part owner of Kraftwerk Union, lost DM 685 million (\$274 million) on nuclear sales in 1974, and expected losses in "three figure millions" marks in 1975.²⁷ It is harder to determine Framatome's losses. As for reprocessing of light water reactor fuel, though very little has been performed, the

losses have been impressive. General Electric's Morris, Illinois, plant which cost \$64 million had to be abandoned without ever going into operation.²⁸ The Allied General Nuclear Services plant at Barnwell, owned by Allied Chemical, Royal Dutch Shell, and Gulf Oil, originally estimated to cost about \$50 million actually has cost \$250 million so far, and may take about a billion dollars in total to complete in accordance with current requirements. Getty's Nuclear Fuel Service plant in West Valley, New York, shut down for modification after about \$30 million in gross sales. It might require some hundreds of millions just to dispose of the radioactive waste from its previous work. Getty wants to cancel some \$180 million in reprocessing contracts it has accepted, since it estimates it will take \$600 million to fulfill the contracts within regulatory requirements. The government-owned plant in Windscale, England, had troubles with the head end. The Eurochemic plant in Belgium has been shut down, and Europeans now judge that the recycling of plutonium will exceed the cost of getting fresh uranium fuel and that if reprocessing should be necessary for waste disposal, it will require subsidies from public utilities.²⁹

In general it is plain that for the nuclear industry as a whole, profitability is still a vision of the future. Immense losses could be avoided by greater realism.

The collapse of expectations in domestic markets unfortunately has led to an aggressive campaign to sell to the less-developed countries (LDCs), where, in general, nuclear power is least economic: Nuclear electricity is highly capital intensive, efficient only in very large sizes and requires continuing highly sophisticated maintenance. The LDC reactor market, which the industrial powers might fight to share, is quite small, and the market for reprocessing plants is even smaller—1 percent or 2 percent of the reactor market. The heavily subsidized initial sales have been made on terms which worsen the problem of proliferation without any realistic prospect that the ambitious LDC long-term nuclear programs will be fulfilled. Yet in the past the French have talked of sales to the Third World of plutonium breeders which are more damaging and even less plausible for LDCs than the present generation of reactors which [the breeders] will exceed in capital costs, diseconomies of small scale, and sophistication.

The most urgent issue, if we are to restrict access to fissile material, is the use of plutonium as a fuel in current reactors. This has been argued for on grounds that it would (1) save a

lot of money, (2) save much scarce uranium, (3) be essential for permanent disposal of radioactive wastes, and (4) be required now in order to get the plutonium breeder on present schedules. None of this is true. On the first point, the estimates of costs for separating plutonium and making it into fuel rods have multiplied tenfold in 10 years and are still highly uncertain and in controversy. On Vince Taylor's calculations, they exceed the estimated costs of fresh uranium fuel rods. Most important, even if plutonium separation were costless, it could make only a 1 percent or 2 percent difference in the delivered kilowatt hour cost of nuclear electricity.

As for point two, the conservation argument should be related to the economics: We are not impelled to extract plutonium from spent uranium fuel any more than we are presently moved to extract the enormous quantities of uranium from sea water. It depends on the costs. Fissile material is present in spent fuel in more concentrated form than in ore, but, by comparison with uranium ore, it is enormously radioactive. There are cheaper ways of getting uranium, by mining and even by a change in U.S. enrichment policy. (In unpublished work, Vince Taylor of PAN Heuristics has shown that the apparent uranium shortage of the 1980s has been effectively created not only by inflated projections of nuclear power and the derived demand for uranium but also by U.S. policies that (1) envision adding substantially over the next 10 years to an already immense government stockpile – worth \$8 billion at current prices – of enriched and natural uranium, (2) leave an excessive amount of uranium-235 in the waste streams of the enrichment plants, thus inflating the amount of natural uranium that must be fed into the plants, and (3) force customers to stick to schedules for delivering uranium for enrichment which they contracted for before the recent substantial cutbacks in nuclear power programs both here and abroad.) But even if one were absurdly optimistic about the costs of using plutonium fuel for light water reactors, the private cost savings would be trivial. The political and social costs plainly dominate.

As for point three, plutonium separation would remove most of the longest-lived radioactive actinides, and so, it has been hoped, would economize in packaging and compacting wastes. However, spent uranium fuel can be stored without reprocessing and recent study indicates that the process of separation will contaminate much of the equipment, filters, solvents, etc. used and that the total volume and heat content of the waste so created and

of the spent plutonium fuel which will require remote handling and geologic isolation will exceed those of the unprocessed spent fuel.

On point four, the present schedule calls for ERDA recommendations on a commercial breeder in 1986. If the decision is positive, it is hoped that the first commercial breeder will start operating in the mid-1990s. We can, therefore, defer the decision on plutonium separation for at least five years.³⁰ In fact, the spent fuel would cool enough in that period to make separation easier and the savings would nearly pay for the storage costs. This fourth argument is, however, revealing. It is motivated in good part by a desire to force a positive decision on a commercial plutonium breeder — another case of premature commitment. The domestic U.S. decision on plutonium separation has obvious international implications and it is these that will impose the largest political and social costs.

Policies

The last year has seen a salutary ferment about changing policy so as to discourage nuclear proliferation. Proposals range from David Lilienthal's recommendation at one end, to stop all nuclear exports, through the bureaucracy's at the other, which suggests that we continue pretty much as we are. Rather than engage in a detailed analysis of this wide range of proposals, I will set down summarily a program indicated by my argument so far.

On the Demand Side

Slowing the spread of nuclear weapons means reducing the demand for them as well as restricting the supply of nuclear weapons material. Political and military policy on alliances, on nuclear guarantees, and on non-nuclear military sales and assistance should be directed to help in non-nuclear defense against non-nuclear threats and to provide nuclear guarantees against threats of nuclear coercion or attack. I have illustrated the sort of thing needed in my earlier remarks about South Korea. But such a policy has to be shaped country-by-country and does not lend itself to easy summary.

On the Supply Side

1. Deny access to readily fissionable material. We need to state as a general guide for U.S. domestic as well as export policy that it is our plain purpose to deny access by individual terrorists, either here or abroad, and to deny access by governments of non-weapon states to nuclear materials that can be readily converted to explosive use. This principle should be the basis for our negotiations in the suppliers group where we will then be able to say we not only advocate it but illustrate it. The general principle has implications spelled out in many more detailed policy suggestions.

2. Delay for at least 5 or 10 years any decision to separate plutonium in the United States.

3. Press actively for fuel cycle designs which would eliminate access to highly enriched uranium or chemically separated plutonium in power reactors and research reactors. Up to now, this has not been part of any design criterion.

4. Continue to deny export licenses for isotope enrichment facilities and plutonium separation plants.

5. Provide to any non-weapon state low-enriched uranium services at nondiscriminatory prices provided that the importer agrees (a) not to acquire further enrichment facilities or plutonium separation facilities, (b) to place all its nuclear facilities under IAEA safeguards, (c) not to acquire nuclear explosives, and (d) not to acquire fissile material quickly convertible to explosive use. We should make new commitments for the sale of nuclear technology only under these conditions. Though we have no shortage of enrichment capacity, it may be prudent to expand our enrichment capacity because it is critical for exercising control, and for assuring supplies of low-enriched uranium to importers who live up to their agreements. We should alter our perverse enrichment policy which has done much to create the appearance of a shortage of uranium and of enrichment. We should first start to reduce our \$8 billion stock of natural and low-enriched uranium; second, permit customers to cancel or defer dates for delivering uranium to be enriched; and third, start operating our enrichment plants, subject to capacity constraints, so as to minimize the amount of uranium needed to produce nuclear fuel for our customers.

6. Where we supply low-enriched uranium to non-weapon states, either lease it or otherwise arrange for its return. (The Soviet Union apparently does this.) Spent fuel so returned would make

up a small percentage of the enormous radioactive wastes from our military program and our own domestic power program.

7. In the future, when centrifuge or laser separation facilities might otherwise become widespread, consider transfers of enrichment technology to an international or multinational center that would provide only low-enriched uranium (and not plutonium fuel) services to non-weapon states. However, do not encourage plutonium separation in such centers with or without the fabrication of mixed plutonium and uranium oxide fuel. If such centers shipped out separated plutonium to non-weapon states, it would be immediately available for explosives. And plutonium is much more easily separated chemically from fresh unirradiated mixed oxide fuel than from spent fuel. Low-enriched uranium is not an explosive. Plutonium separated from reactor fuel is.

8. Deny further assistance for critical experiments in national laboratories of non-weapon states, since these experiments involve access to unirradiated or only lightly irradiated, readily fissionable material. Where warranted, provide for U.S. or possibly multinational or international facilities for the conduct of critical experiments by non-weapon states.

9. Deny licenses for the export to non-weapon states of research reactors with highly enriched uranium cores or significant plutonium output unless the total nuclear program for an importing country will not permit it to derive enough readily fissionable materials for weapons.

10. Change Export-Import Bank policy so that its loans and the private loans it guarantees will support rather than defeat the preceding recommendations.

11. Offer further financial and technical assistance to IAEA to improve safeguards, but alter trilateral agreements to permit and require IAEA to report on the location, size, and chemical and physical composition of all stocks of readily fissionable material monitored under these agreements. The improvements in IAEA inspection to detect violations will be useful if, and only if, export agreements are altered so that accumulating readily fissionable material becomes a violation, whether accounted for or not. Presently, IAEA centers its attention on the "limits of error in material unaccounted for" ("LEMUF" in the jargon) without reporting on the legal accumulation of explosive materials.

The best maxim to keep in mind is that of Florence Nightingale: "Whatever else hospitals do, they shouldn't spread disease." On these complex issues it has been all too easy to advance resounding

programs to slow the spread of weapons which actually speed it. That is how we got into the present fix. So Atoms for Peace, and so some of the incompatible clauses of the NPT. Using the eighteenth century language of natural law from our Declaration of Independence, the NPT asserts the “inalienable right” of all countries to peaceful nuclear energy—which includes, some exporters apparently feel, reprocessing. We have then the new natural right to Life, Liberty, and the Pursuit of Plutonium.

And now most recently each side in the last presidential campaign showed how the multinational form can distract from substance in slowing the spread. Each sometimes contemplated not only the return of spent uranium fuel but using multinational centers for making and distributing fresh mixed plutonium and uranium oxide fuels. Yet, plutonium for use in explosives is much more easily extracted from the fresh mixed oxides than from the spent uranium fuel. The word “multinational” tends to give many opponents of the spread a warm feeling all over, unless it is followed immediately by the word “corporation.” But this cure would simply spread the disease. Here it is essential to focus our aim precisely on the substance rather than the symbol. Multinational centers for the distribution of bomb material will not help.

ENDNOTES - Wohlstetter - Spreading the Bomb

1. Isotopes of the same heavy element, such as uranium-235 and uranium-238, undergo the same chemical reactions at almost the same reaction rates and therefore cannot be separated by any known conventional chemical means, but so far only by an expensive, difficult, and time-consuming physical process that exploits slight differences in atomic mass. The fissile isotopes are those that are readily fissionable by slow or thermal neutrons as well as fast neutrons.

2. U.S. Senate, Committee on Government Operations, Hearings on S. 1439. testimony by Robert J. McCloskey, Department of State, June 16, 1976, p. 811.

3. Indeed, we attached a “related note” to our agreement with Spain of March 20, 1974, which said, “It is understood that the material subject thereto will not be used for any nuclear explosive device, regardless of how the device itself is intended to be used. . . .” We signed the note, but Spain did not.

4. For a more extended analysis, see Chapter III of *Moving Toward Life in a Nuclear Armed Crowd?* a Pan Heuristics report to the Arms Control and Disarmament Agency. A revised edition will be published by the University of Chicago Press.

5. For example, it said "... the development of more ingenious methods ... which might make this material effectively usable is not only dubious, but is certainly not possible without a very major scientific and technical effort" (pp. 26-27), but also unequivocally that "the limit between what is safe and what is dangerous ... will not stay fixed" in "what is sure to be a rapidly changing technical situation" (p. 30). U.S. Department of State, Publication 2497, March 16, 1946.

6. The committee included Oppenheimer and C. A. Thomas, who among the authors of the Acheson-Lilienthal Report were the two qualified to speak on the subject. Its statement was issued on April 9, 1946.

7. The ambivalence and inconsistency were present at the start. Like Szilard, who had been cautious about denaturing a few months earlier, Glenn Seaborg, whose team had discovered plutonium in 1941, signed the final draft of the Franck Report which stated flatly that "denaturalization of pure fissionable isotopes ... [would] make them useless for military purposes." Yet Seaborg, commenting on early drafts, had written, "Can't denature 49 by dilution with stable isotopes." "Forty-nine" was the wartime code for the element 94, plutonium. The James Franck papers, University of Chicago Regenstein Library.

8. "Nuclear Experts Give Warning on Build-up of Untreated Waste Fuel," *The Times*, London, May 25, 1975.

9. Guy Hawtin, "East Bloc Aids Bonn Anti-Nuclear Groups," *Financial Times*, London, May 22, 1976.

10. Address by Louis de Guiringaud, June 19, 1976, New York: *Service de Presse et d'Information*, 1976, No. 76/95, p. 3. In September 1976 the French cabinet reconsidered such dangers, though not as a result of any clear message from the State Department. Michel Tatu, *Le Monde*, September 9, 1976.

11. Lecture entitled, "The Fuel Cycle and the Export Situation," by Dr. G. Hildebrand, to visiting embassy representatives at the Kraftwerk Union plant in Mülheim, West Germany, on April 30, 1976.

12. "Spent Nuclear Fuel and Radioactive Waste," Statens Offentlige Utredningar, Document No. 32, Stockholm: Libervorlag, 1976, p. 43.

13. Carl Walske, "Nuclear Energy Environment in the United States," a paper presented at a conference in Madrid, Spain, May 4, 1976.

14. The Atomic Industrial Forum's Committee on Nuclear Export Policy, *U.S. Nuclear Export Policy*, July 21, 1976, p. 3.

15. Letter to Congressman Findley from Denis M. Neill, Assistant Administrator for Legal Affairs, Agency for International Development, Department of State, August 18, 1975.

16. The spent fuel had 13 kg of plutonium that was 95 percent, 110 kg that was 93 percent, and 331 kg that was 89 percent purely fissile.

17. Hildebrand, *op. cit.*

18. Memorandum from Oppenheimer to Farrell and Parsons, 23 July 1945, Top Secret; Manhattan Engineering District Papers, Box 14, Folder 2, Record Group 77, Modern Military Records, National Archives, Washington, DC. Declassified in 1974.

19. Memorandum to the Chief of Staff by General Leslie Groves, 30 July 1945. *Ibid.*, Box 3, Folder 5B. Declassified in 1972.

20. See Richard G. Hewlett and Oscar F. Anderson, Jr., *The New World, 1939/1946, Volume I, A History of the United States Atomic Energy Commission*, University Park, PA: The Pennsylvania State University Press, 1962, p. 321.

21. See, e.g., Walske, *op. cit.*, and Hildebrand, *op. cit.*

22. "GWe" means gigawatts, that is, thousands of megawatts of electrical capacity.

23. Estimates of uranium requirements vary with precise assumptions as to the percentage of uranium-235 left in the tailings by the process of enrichment, the rate of growth in reactors, the capacity factor or percentage of time the reactors are generating electricity; and such technical characteristics of reactor operation as fuel enrichment levels, fuel burnup levels, and frequency of reloads. These earlier estimates assume 80 percent capacity factors. The 1976 forecast assumes a 70 percent capacity factor. I assume .2 percent tails assay throughout.

24. John Patterson, chief of the Supply Evaluation Branch, Division of Fuel Cycle Production, "Uranium Supply Developments," a paper presented at the Atomic Industrial Forum Fuel Cycle Conference, Phoenix, Arizona, March 22, 1976. More recently ERDA has estimated an "attainable" U.S. production capacity of 47,000 tons of yellow cake at the \$15 cost level by 1985 and 60,000 tons by about 1990. According to *Nucleonics Week*, September 23, 1976, ERDA summed up, "The information we have today indicates that there is a good possibility that uranium will be available at reasonable prices."

25. End 1976 estimates are taken from *Nuclear News*, "World List of Nuclear Power Plants," August 1976, pp. 66-79.

26. See U.S. Congress, Joint Committee on Economics, *Review and Update of Cost-Benefit Analysis for the Liquid Metal Fast Breeder Reactor*, May 27, 1976, Washington, DC: U.S. Government Printing Office, 1976, p. 18.

27. *Financial Times*, London, December 9, 1975. American loss estimates by R. Cornell of E. F. Hutton.

28. *Chemical Engineering*, January 6, 1975, p. 68.

29. *Nucleonics Week*, July 22, 1976, p. 8.

30. On ERDA's projections the plutonium then available from

light water reactor fuel will be over three times more than the amount needed by breeders at the end of the century. Moreover, even ERDA's low growth projections for the breeder presume an unrealistically early and rapid build-up of commercial breeders.