FORUM ON PHYSICS & SOCIETY

of The American Physical Society
April 2006
Vol. 35, No. 2

ARTICLES (2)

Bombs, Reprocessing, and Reactor Grade Plutonium

Gerald E. Marsh and George S. Stanford

A recent, ill-conceived call to action from the Union of Concerned Scientists says this:

"In his State of the Union address, President Bush called for investment in 'clean, safe nuclear energy.' This seemingly harmless phrase, however, does not describe the controversial new program currently under consideration by the administration and some members of Congress. Under this new plan, the U.S. would 'reprocess,' or separate, weapons-usable plutonium from the spent nuclear fuel generated by U.S. power reactors.

"This proposal would make it easier for terrorists to acquire the material for making a nuclear bomb. It would require the construction and operation of an array of nuclear facilities that would handle enough plutonium annually to make thousands of nuclear weapons. It would also make disposing of nuclear waste more difficult, encourage other countries to reprocess, and cost a tremendous amount of money. Help us make this program politically 'radioactive:' please tell your representative and senators to keep nuclear material out of the hands of terrorists by rejecting all efforts to fund this dangerous plutonium reprocessing program."

The fundamental problem with that position is failure to accept the fact that *reactor fuel is going to be recycled*, whether we like it or not. Nuclear power is expanding rapidly world-wide. Its growth will be exponential for some time, and long-continued use of a fuel cycle that uses less than a hundredth of the energy in the mined uranium is out of the question. China, India, Japan, South Korea, and Russia are already among the nations that see the coming need to multiply their energy resources with fast-reactor technology and recycling. The development will be managed well, or it will be managed badly.

Our views [1,2,3] on nuclear power and reprocessing are well known to readers of *Physics and Society* and will not be rehashed here. Our thesis this time is that the growth of nuclear power *can*—and must—be managed well.

The outlook is not nearly as bleak as it seems to the UCS. The root of their concern, apparently, is the oft-quoted mantra, "all plutonium is weapons usable," an assertion that we will examine. We will also look at the claim that reprocessing "would . . . make disposing of nuclear waste more difficult, encourage other countries to reprocess, and cost a tremendous amount of money."

For starters, the UCS claim that "Under this new plan, the U.S. would 'reprocess,' or separate, weapons-usable plutonium from the spent nuclear fuel" is just plain wrong. The Global Nuclear Energy Partnership (GNEP) announced by the Administration in February of 2006 [4], specifically does *not* do that—the plutonium is always mixed with other elements that render it useless for weapons without further processing.

More generally, however, the widespread apprehension about the weapons potential of pure reactor-grade plutonium is overblown. That worry has three sources: an article by J. Carson Mark, with an appendix by Frank von Hippel and Edwin Lyman, on the probability of different yields [5]; the 1962 test of a nuclear device using reactor-grade plutonium, which successfully produced a nuclear yield; and the claim that weapons of modern design could use reactor-grade plutonium with no degradation in yield. We will consider each of these in turn.

Let's be clear that we *do* agree that reactor-grade plutonium needs to be safeguarded. We also agree that acquisition of reprocessing facilities gives a nation the potential to subvert them, in conjunction with specially operated reactors, to produce weapons-grade plutonium. That reality is why reactors need to be safeguarded, and, as we point out in Ref. 3, reprocessing should be done under the aegis of an international organization such as the International Atomic Energy Agency or the International Energy Agency. The GNEP is a step in the right direction, and we fully support it.

Carson Mark's Article

Carson Mark calculated the range of fizzle yields to be expected from a Trinity-style device made with reactor–grade material ("Trinity" was the first test of an implosion-driven plutonium warhead, at Alamagordo, New Mexico, in 1945). Figure 1 is reproduced from the appendix by von Hippel and Lyman.

For the reactor-grade plutonium curve, setting the spontaneous neutron emission rate at $20x10^5$ per second is equivalent to choosing the mass as 10 kg, since the spontaneous emission rate of reactor-grade plutonium is ~200 n/s/g. According to the curve, there will always be a yield ratio of at least 2.7%, and the probability of degradation to a yield ratio less than 0.1 is about 83%. This is why it is often said that likely fizzle yields range from 100 tons to a kiloton or so, for a Trinity type of device. This is also why reactor-grade plutonium must be safeguarded—it's *possible* get an explosion with the stuff. Fortunately, the technical hurdles are daunting.

Subnational Groups

The *possibility* of getting a yield does not mean a terrorist group could readily do so—they would have great difficulty even with weapons-grade plutonium. They would face two major hurdles: the heat generated by the material, and the difficulty of fabricating the high-explosive assembly.

As Mark noted in his article, heat is generated in the assumed type of device at a rate of about 100 watts—versus 8 watts in a modern fission weapon. This corresponds, he estimated, to an equilibrium temperature of 190^{o}C, well above what the high explosive can withstand. He then did some hand-waving, using the high thermal conductivity of aluminum, to argue that a "thermal bridge with a total cross-section at the surface of the core of only about one cm^2 could halve the temperature increase induced by reactor grade plutonium." Since high-explosive breakdown, as he notes, becomes significant beginning at 100^{o}C, more than one cm^2 would obviously be needed.

We intentionally use the term "hand-waving" because incorporating aluminum fins in the high explosive without interfering with the implosion process is non-trivial—well beyond the capabilities of a terrorist group. Even making an implosive assembly with no thermal intrusions is no simple task. After all, a significant part of the Manhattan Project was devoted to designing and fabricating the high-explosive lens assembly. Terrorist "explosive experts" can use semtex and other explosives to make bombs, but that does not mean they would have anywhere near the expertise to duplicate the Manhattan Project's result in their proverbial basement, let alone incorporate non-perturbing thermal bridges.

Melting reactor-grade plutonium to make cores, casting the high explosive in the required shape, and dealing with the heat generated in an assembled explosive device—all are simply beyond any reasonable estimate of what a terrorist group could do.

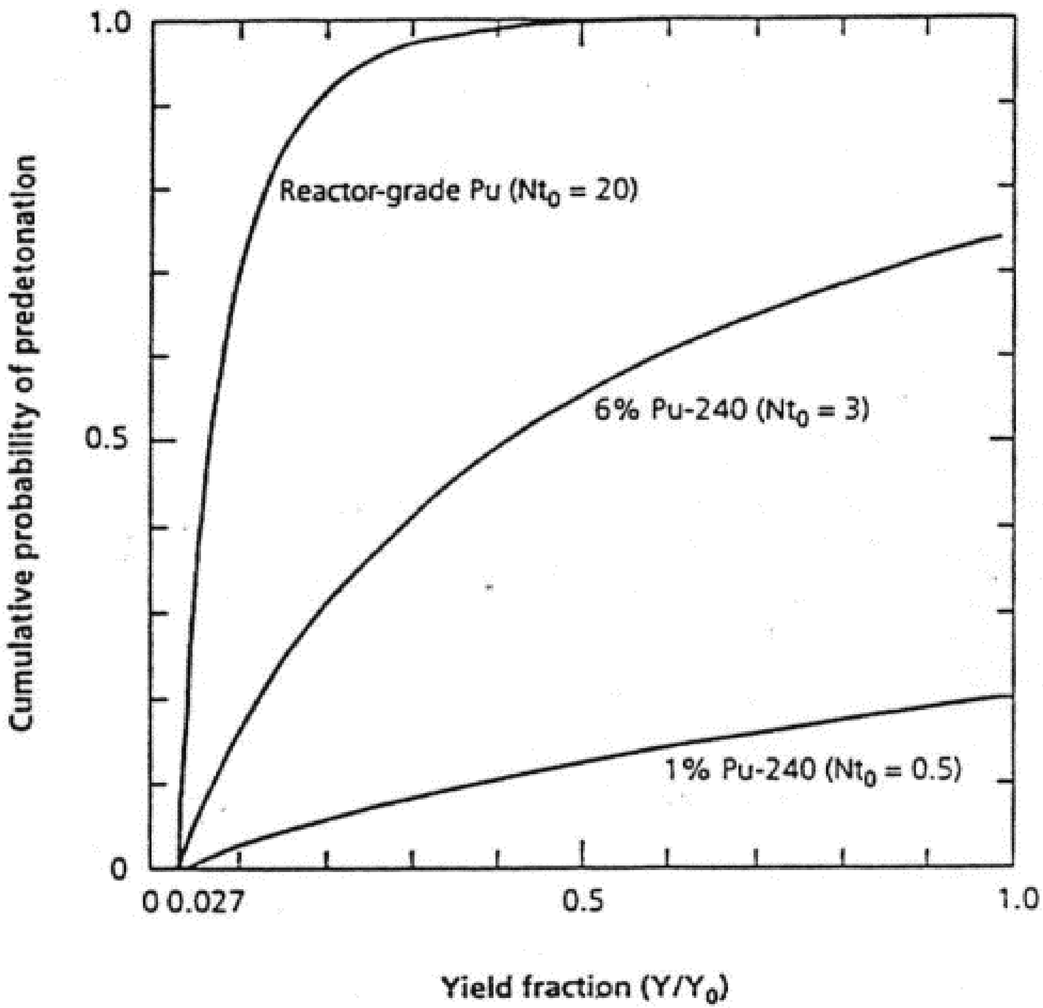

Fig. 1. Y is the yield as reduced by predetonation, Y_0 is the design yield, N is the number of spontaneous neutrons per second (here specified to be 0.5, 3, and 20×10^5), and t_0 is the time interval during which the imploding assembly is supercritical (here about 10^{-5} sec). (From Ref. 5.)

Gun-Type Devices and Reactor-Grade Plutonium

It has been suggested that terrorists might use reactor-grade plutonium in a gun-type device, since they would not care if the yield is degraded by pre-initiation, provided they could get even a few tons of TNT equivalent.

In the Manhattan Project, the original plan for plutonium was to use a gun-driven assembly. That effort, code named "Thin Man," was under Robert Oppenheimer's direct supervision. Work on it continued until Emilio Segre's experiments on the spontaneous fissioning of plutonium proved that it could not be used to bring together reliably even high-quality plutonium. Oppenheimer then decided to abandon Thin Man. Work on the gun continued, however, focused on uranium, with the code name changed to "Little Boy." Little Boy was developed with few major complications. It used a special gun that could withstand high breech pressures. The bomb weighed some 9000 pounds.

We suggest that the scenario where terrorists would even attempt to build a Little Boy type of device lacks credibility.

The 1962 Test

The Department of Energy has released the following information about the 1962 test:

* "A successful test was conducted in 1962, which used reactor-grade plutonium in the nuclear explosive in place of weapon-grade plutonium."

* "The yield was less than 20 kilotons."

There are very good reasons why the details of the test have not been made public. It was not a simple test, and the details of the design rightly remain classified. The test did give a single data point for the reduction in yield due to pre-initiation—undoubtedly it was consistent with the curves given above—but it finessed the heat-generation problem.

Thus, while the 1962 test arguably confirmed what was already known—that a yield can be obtained—it cannot be used as evidence that reactor-grade plutonium is an acceptable material for building nuclear weapons, nor can one conclude from it that terrorists could successfully detonate even a crude device based on that material.

Designs using Reactor-Grade Plutonium with No Yield Reduction

Probably all sides of this debate will agree that only a modern design could even conceptually use reactor grade plutonium without a severe degradation in yield. "Conceptually," because such a scheme has never been tested in the United States—nor elsewhere, to our knowledge.

While modern designs may deal with the problem of pre-initiation, the heat problem is not totally eliminated and would still be of concern. The development of modern, efficient fission weapons required an extensive testing program, and any nation making such an effort will not waste its time and money on reactor-grade plutonium. It is far simpler to produce weapons-grade plutonium, as other nations, such as India, have done.

The discussion above is restricted to the problems of pre-initiation and heat generation. There are other problems with bomb design and construction that are outside the scope of this article.

Reprocessing

Reactors based on a thermal neutron spectrum (virtually all of today's power reactors) cannot extract even one percent of the energy in the original ore. The increasing rate at which new reactors are being planned and built around the world will sooner or later put a strain on the supply of low-cost uranium. But efficient recycling with fast-spectrum reactors can get essentially all the energy from the mined uranium, rendering the cost of uranium ore irrelevant to the cost of power. Already at least six countries are planning to implement such a technology (China, India, France, Japan, Russia, and South Korea).

Nuclear fuel is going to be recycled more and more, and it behooves us to accept the inevitable and strive to ensure that it is done in the best way possible. Fortunately, the UCS is simply wrong in claiming that reprocessing would "make disposing of nuclear waste more difficult, encourage other countries to reprocess, and cost a tremendous amount of money."

Rather, waste management is made very much easier. The decree that Yucca Mountain must isolate the waste for more than 10,000 years is due primarily to the presence of long-lived transuranic elements. Appropriate reprocessing will allow those troublemakers to be consumed in fast reactors, leaving only the real waste—the fission products—to be disposed of, and their radioactive toxicity fall below that of the original uranium ore after less than 500 years. Effective waste management becomes a slam dunk.

Encourage other countries? The lesson of the last thirty years is that what the United States does with its spent fuel is irrelevant to other countries' decisions to reprocess. If the United States does not recycle its used fuel, the unabated buildup of plutonium and waste will strangle nuclear power in this country, while the rest of the world forges ahead without U.S. input regarding either technology or policy.

Costs are addressed in reference 1. In a nutshell, while the technology has yet to be demonstrated on a production scale, there are no evident show-stoppers—there is no reason to suspect that the resulting power will not be competitive, even before factoring in the cost saving from avoiding the construction of more repositories like the one in Yucca Mountain.

Conclusions

Let's keep in mind that our best protection against international nuclear conflict lies in reducing the level of international tension, and that energy-related conflicts are a major cause of such tension. Only nuclear power has the potential to ensure that the nations of the world have sufficient indigenous energy without intolerable environmental consequences.

The terrorist threat from reactor-grade plutonium has been greatly exaggerated by the argument that what is *theoretically possible* to do *can* be done by subnational groups.

The notion that the potential for proliferation will increase if spent fuel is reprocessed to close the fuel cycle and allow a rational waste disposal policy is simply incorrect.

The points we want to make are two: First, while it is not utterly impossible for terrorists to make a nuclear explosion, appropriate safeguards, combined with major technical problems and other, easier ways for terrorists to do damage, can make the probability low. Second, since recycling is not going to go away, the choice is simple: manage it poorly, or manage it carefully and safely.

Wishing it away is not an option. The Union of Concerned Scientist's call to action is ill-founded, and could harm the chances for this country to formulate a coherent and realistic energy policy. If the UCS were to use its influence to promote a safe and realistic international control of the nuclear fuel cycle, it would be part of the solution instead of part of the problem.

References

[1] William H. Hannum, Gerald E. Marsh, and George S. Stanford, "Smarter Use of Nuclear Waste", *Scientific American* (December 2005), p. 84.

[2] William H. Hannum, Gerald E. Marsh, and George S. Stanford, "Purex and Pyro are Not the Same", *Physics and Society* (July 2004), p. 8.

[3] Gerald E. Marsh, and George S. Stanford, "Nuclear Power and Proliferation", *Physics and Society* (January 2006), p. 7.

[4] http://energy.gov/news/3161.htm

[5.] J. Carson Mark, "Explosive Properties of Reactor-Grade Plutonium," *Science & Global Security* **4**, 111 (1993).

Gerald E. Marsh is a physicist, retired from Argonne National Laboratory, who has worked and published widely in the areas of science, nuclear power, and foreign affairs. He was a consultant to the Department of Defense on strategic nuclear technology and policy in the Reagan, Bush, and Clinton administrations, and served with the U.S. START delegation in Geneva. He is a Fellow of the American Physical Society. His most recent book is: "The Phantom Defense: America's Pursuit of the Star Wars Illusion" (Praeger Press).

George S. Stanford is a physicist, retired from Argonne National Laboratory. B.Sc. with Honours, Acadia University; M.A.,Wesleyan University; Ph.D. in experimental nuclear physics, Yale University. He is a member, American Nuclear Society, and a past member of the American Physical Society. He has served on the National Council of the Federation of American Scientists. Co-author: Born Secret: The H-Bomb, the Progressive Case, and National Security (Pergamon, 1981), and Nuclear Shadowboxing: Contemporary Threats from Cold-War Weaponry (Fidlar Doubleday, 2004). His technical publications have pertained mainly to experiments in nuclear physics, reactor physics, and fast-reactor safety.