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Destroy "Completely" or Store "Forever"

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## **Weapons and Commercial Plutonium Ultimate Disposition Choices--- Destroy "Completely" or Store "Forever"\***

Charles D. Bowman

### **Abstract**

All of the options under consideration for weapons and commercial plutonium disposition ultimately boil down to the choices of either "complete" destruction or storage "forever." None of the reactor-based plutonium burning systems demonstrated over the past 50 years of reactor development consume this material completely. Ultimately considerable unburned plutonium must be stored "forever" from those systems. Plutonium is considered to be dangerous both as a weapons material and as a health hazard. While properly stored plutonium might never make its way back by natural phenomena into the environment as a health hazard, stored plutonium is always accessible to recovery for malevolent purposes. It must be guarded wherever in the world it is stored for as long as it continues to exist. Complete destruction of the plutonium eliminates this material as a concern of future generations. Los Alamos National Laboratory accelerator-driven technology promises to allow safe and complete destruction of this material. Furthermore it appears that in the process of destruction the neutron rich features of the weapons plutonium provides benefits to society that place a value on weapons plutonium exceeding that of highly enriched uranium. A realistic time scale for development and deployment of burial technology either with or without partial burning in reactors is expected to be comparable with or to exceed the time for development and deployment of the accelerator-driven destruction method under study at Los Alamos.

### **I. Introduction**

The reduction of nuclear weapons stockpiles now underway in the U. S. and Russia has driven recent concern about the future disposition of weapons plutonium (W-Pu) and also plutonium in the spent fuel from commercial nuclear power production (C-Pu). In the course of dealing with the nuclear explosion hazard of W-Pu, it has become clear that C-Pu also can be used in nuclear weapons. The amounts of these materials are shown in Fig. 1. The U. S. and Russia each have produced about 100 tons of W-Pu. This amount is dwarfed by the 930 tonnes already produced in the world's commercial nuclear power program which is growing at the rate of about 50-75 tons annually<sup>1</sup>. Scientists participating in the recent NAS study<sup>2</sup> of plutonium disposition report that nuclear weapons with yields in the 1-2 kiloton range can be made with a modest amount of this material. If we were to take the amount required for such nuclear weapon construction to be 20 kilograms, the plutonium presently accumulated from commercial nuclear power production is sufficient for the construction of 1/2 million of these devices.

Nevertheless the greatest immediate concern is naturally directed to W-Pu. Completing with high priority the contemplated phase of weapons dismantlement, storage, and accounting probably can be readily agreed upon by all parties. However the initiative to move as quickly as possible after modification such as partial burn-up as MOX fuel solely to geologic storage, which appears to be presently dominant in U. S. policy development, is a path with substantial risk. An argument given for geologic storage is that international conditions demand that a quickly implemented means of getting this material into temporarily safe and inaccessible storage should dominate our policy<sup>2</sup>. This policy assumes that if the immediately expedient means of disposition turns out to be undesirable, the material can be recovered and disposed of by other means.

This approach reminds one of the somewhat similar situation of thirty years ago when overriding international concerns demanded weapons material production without accompanying consideration of long-term environmental impacts. This led to situations such as the Hanford tank field, or large scale contamination of Russian production sites which could be dealt with by future generations if necessary. We clearly underestimated how difficult the required corrective measures would be for this temporary solution. The concern about Russian W-Pu, particularly in view of the political and economic uncertainty there, is driving us to consider only underground storage as a serious technology for our generation. If this doesn't work out, the problem can be solved by future generations. Admittedly this comparison does not do justice to the deliberate pace and detailed studies which have already gone into the geologic storage option. However such studies will always have a highly uncertain component in them. The primary focus only on W-Pu disposition options that ultimately require geologic storage should be a matter of concern. For example, in case recovery is necessary, have the safety issues and costs been carefully enough evaluated?

Storage "forever" carries with it the obligation of vigilance "forever." "Complete" destruction of the plutonium would solve the problem completely and forever. Technology which promises to allow the nearly complete destruction (reduction by a factor of 1000 or better) of both W-Pu or C-Pu is under development<sup>3</sup> at the Los Alamos National Laboratory. The technology is based on the merger of high power accelerator technology with reactor technology, both developed over the past fifty years. The transmutation technology allows a departure from the continuous chain reaction, which characterizes all reactor types, to a decaying chain which can absolutely eliminate the possibility of a runaway chain reaction. In addition the accelerator supplements the neutrons, which in a reactor are available only from fission, to enable operating characteristics and performance which are impossible to achieve with reactor technology. Because reactor and accelerator technology are both mature having been invented at about the same time and pursued aggressively ever since, the successful merging of these should not be a daunting and therefore distant prospect. The Los Alamos technology for destruction of material of potential use for nuclear weapons is aimed at the following three objectives:

- \* The destruction of the plutonium and the higher actinide and long-lived fission product from commercial nuclear waste such that engineered storage is practical for the waste remnant.
- \* The production of nuclear energy from thorium so as to eliminate the production of nearly all of the plutonium and other higher actinides, to destroy the small amount of actinide produced, and to destroy the long-lived fission product as well so that there is no long-term high-level waste stream requiring geologic storage.
- \* The use of the excess neutrons from fission of W-Pu and HEU in both of the above systems to improve their neutronic performance and to thereby create a large positive value for these materials which will assure a strong economic drive behind their destruction and careful guarding until their destruction is completed.

Our accelerator-driven technology is expected to accomplish these objectives without the requirement of geologic storage facilities for the systems' waste streams, with transparently safe technology, with greatly increased non-proliferation features, with a closed fuel cycle, and without the complex infrastructure of the current nuclear power production system. The parameter space of combined reactor and accelerator technology has been carefully examined over the past three years at Los Alamos. We have selected the proton linac accelerator technology, which has been demonstrated at Los Alamos over the

past 20 years at LAMPF, and the molten salt liquid fuel reactor technology developed at Oak Ridge National Laboratory and demonstrated in the Molten Salt Reactor Experiment<sup>4</sup> which operated at ORNL for four years. Our program plan is to construct a subcritical molten salt liquid fuel reactor-like facility at Los Alamos driven by LAMPF to demonstrate the successful integration of these two technologies. The existing LAMPF accelerator could drive the system at a fission power level up to 30 MWt in a system which could be brought on line at full power in about four years<sup>1</sup>. The demonstrated performance and tests possible with this facility should allow the construction of an industrial-scale module operating at about 500 MWt about 8-10 years from now. It will be shown below that the time scale for development, deployment, and for complete destruction of W-Pu and C-Pu is comparable with that for completion of any geologic storage approach for this material.

## II. The Los Alamos Transmutation System

The Los Alamos transmutation system<sup>3</sup> is directed toward the ultimate objectives of (1) production of unlimited power from thorium in a subcritical system without a long-term high-level waste stream and (2) the destruction of both the higher actinide and fission product components in commercial spent fuel so that engineered storage for the remnant waste is acceptable. Reprocessing is not required for either case. It is not required for the thorium system because only <sup>232</sup>Th and a small amount of <sup>238</sup>U are fed to the system. For the spent fuel problem the plutonium is never separated from the other higher actinides or the fission product; material useful for weapons is never produced. Neither of the above objectives can be achieved with any type of reactor because of the insufficient number of excess neutrons available in reactors for the transmutation process. The accelerator supplements the neutron economy so that the waste destruction objectives can be realized. In addition the system can operate effectively as a subcritical system so that an easily controlled decaying chain reaction is practical as opposed to the continuous chain of reactors, which is much more difficult to control.

### Technology Description

The system for destruction of commercial waste is shown in Fig. 2. A proton accelerator provides beam to a target for neutron production. The target is surrounded by a blanket containing fissile and fertile material where fission power is generated using a decaying (subcritical) chain reaction and where the long-lived fission product and higher actinide components of the commercial nuclear waste are transmuted. The material to be fissioned is in the form of a fluoride salt which is dissolved in a molten salt carrier consisting of a nearly eutectic mixture of <sup>7</sup>LiF and BeF<sub>2</sub>. The heat from the fission is deposited in the molten salt which flows through an internal heat exchanger to deliver heat to a secondary coolant loop. This secondary loop carries the heat to a steam generator for electric power production. About 20 % of this electric power must be used to power the accelerator. The remainder can be fed to the grid to be sold to consumers. Owing to the high operating temperature of the salt, the system has a high efficiency of about 44 % for converting heat to electric power. A slip-stream for the salt allows the salt to be continuously cleansed of fission product and for continuous feeding of the material to be transmuted. Commercial spent fuel is prepared for transmutation by first a chlorination process<sup>5</sup> which removes the zirconium cladding by converting it to volatile ZrCl<sub>4</sub>. The volatilization removes the fuel containment and releases the fuel and fission product as oxide rubble. This material is then fluorinated<sup>5</sup> so that everything remaining is converted to fluoride. The main constituent at this point is uranium which is released as volatile UF<sub>6</sub> leaving all of the other material in the form of fluoride salt. This actinide and fission product salt remnant from the spent fuel assemblies is dissolved in the carrier salt and fed into the transmuter through a low flow-rate slip stream (about 10 kg/day for a 3000MWt

system.) It is important to note that plutonium is never separated from other higher actinides or fission products, so that it never is in a form suitable for use in weapons.

The slip stream into which the waste is fed also passes through an on-line processing system which separates the salt into a waste stream of fission products nearly free of actinide and another which is returned to the transmuter containing actinide and some fission product. Therefore actinide and fission product are fed into the system; all actinide is fissioned in the system; but no actinide is removed. The fission product exit stream is divided into long-lived and short-lived components. Key long-lived constituents with half lives greater than 30 years are separated and fed back into the system in the form of solid fuel assemblies where they are transmuted by neutron capture to stable or short lived species. Other innocuous species may be encapsulated for disposal. As shown in Fig. 2, the short-lived waste from the system after a suitable cooling period may go to near-surface storage meeting low level waste criteria; the nuclei  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  can go to engineered storage. Engineered storage implies containers which are capable of confining the waste over the several hundred year period required for the waste to decay to innocuous levels. Since no dangerous long-term high-level waste leaves this system, there should be no requirement for geologic storage of such wastes. The near-surface and engineered storage might be located on the same site as the transmuter. There are no plutonium or other higher actinide in the waste except for very small remnants ( $<1/1000$ ) because they all are burned internally.

### Cost Issues

The cost for accelerator-driven transmutation has not been carefully evaluated, but it appears that the costs for this process could be acceptable. Certainly the accelerator, the front-end partitioning, the back-end fission product removal, and engineered storage add to the costs for production of power by conventional reactors. However, the overall electrical efficiency of the system is at least as good as that of conventional reactors even taking into account the power consumed by the accelerator. Furthermore the net total annual production of power for the grid could be significantly higher than for a reactor because there is no down-time requirement for refueling with a continuously fueled system. Also there are no costs for fuel, control rods, fuel fabrication, fuel reprocessing, refabrication or geologic waste storage. It would be helpful if the costs could be reduced still further by the reduction of the accelerator size. This is where W-Pu and HEU can play a high-value role.

The primary role of the accelerator is to supplement the neutrons from fission so that the transmutation becomes practical. However, W-Pu and HEU also are very effective sources of neutrons, which is partly why they are especially effective nuclear weapons materials. By feeding either of these materials into the system, the size of the accelerator can be significantly reduced. Accelerator current can be reduced in proportion to the amount of weapons material added and fissioned. This situation has been analyzed and it is found<sup>6</sup> that the value of the weapons material in terms of the reduction in accelerator size is about \$0.25 million per kilogram, which is about ten times the value of HEU if diluted for LWR fuel<sup>2</sup>. The W-Pu has a value about 20% greater than that for HEU because of its more favorable neutronic properties. Of course the accelerator-driven system would not pay a cost this high for W-Pu since it could just as cheaply derive the neutrons from the accelerator at a purchase price of \$0.25 million per kilogram. However at the present price of these materials, using them would have a substantial beneficial impact on the cost of waste transmutation.

It has been argued that this pricing approach for HEU and W-Pu is not valid because the costs are derived for a commercial waste transmutation system which is

uneconomic anyway. We believe that even without the use of the weapons materials that the cost of the electricity production would not be not more than about 20 % higher than for conventional production. The consumer's bill therefore would be about 10-15 % higher than for present electric power. The burning of weapons material in these systems would reduce the accelerator current by a factor of two to three with a significant reduction in costs. If our estimates of the costs are approximately correct, the price which could be paid for weapons material should be substantially larger than the present value of about \$25,000/kilogram.

Another argument which might be made against high W-Pu value is that with the enormous amount of these weapons materials, one small-demand high-value use would still not significantly influence the value of the large inventory of these materials. However there is hardly enough of this material in the U. S. and Russia to use for the destruction of all of the spent fuel which has accumulated in the world. The demand of this technology for W-Pu and HEU would therefore set the price of HEU at a significantly higher value than can now be paid for HEU diluted to the LEU  $^{235}\text{U}$  enrichment level.

A further argument against high W-Pu value is that the cost is not set by demand but by the cost of continued HEU production which is about \$25,000 per kilogram. Enrichment facilities could meet demand no matter how large. Therefore the price of these materials never will rise above \$25,000/kilogram. This is only true if the world's enrichment facilities are allowed to continue production of HEU instead of LEU. In fact if the move toward major reductions in stockpiles is real, it is inconsistent with that objective to allow continued production of HEU anywhere in the world. It is hard to predict how high the value of HEU and W-Pu might rise under the following conditions: (1) a use enabling elimination of the world-wide commercial plutonium inventory, (2) a use delivering electric power from waste destruction at competitive prices, (3) a use that required all of the W-Pu and HEU, and (4) curtailment of further production of these neutron-rich materials.

But there is another use for this material as well in the similar system mentioned in the introduction which is designed for power production from thorium<sup>3,7</sup> with concurrent transmutation of all actinide and long-lived fission product. The economic situation for the thorium systems, which is technically easier and more nearly capable of generating electric power at competitive costs than the commercial waste burner described above, can be further enhanced with the burning of W-Pu and HEU. These weapons materials also can be used to great advantage in start-up of these systems which initially are otherwise fueled only with  $^{232}\text{Th}$ .

Therefore the need (1) to destroy commercial plutonium and (2) to provide society with a safe, economical, and nearly waste-free energy source could drive the pricing of W-Pu and HEU. The reservation of these materials for beneficial high-value use within the lifetime of most of our population should be considered. *We maintain that there is no other means of destroying commercial plutonium and the other dangerous species from reactor spent fuel than with supplemental neutrons provided either by the accelerator or by these weapons materials.*

#### Comparison with Alternatives

The only other option for W-Pu is burial "forever" even though the material may be fussed with before it is buried. This fussing might take the form of vitrification of the W-Pu, or vitrifying it with high-level radioactive defense waste, or burning it as MOX. Each of these must be followed by geologic confinement. If any of these options were adopted, the governments owning this material would have to pay considerably for these procedures

and would still be faced with "everlasting" concern and liability for the safety of this buried material. If the near-term and relatively inexpensive transmutation studies advocated at Los Alamos confirmed the viability of the proposed transmutation technology, the owner governments would have as an option the possibility for sale of their plutonium at high value for use in the elimination of spent fuel plutonium (no other material can perform this function). Along the way a technology almost certainly would have been demonstrated which generates "unlimited" nuclear energy without the production of material which can be used in nuclear weapons and without a waste stream which must be stored "forever."

Advocates of burial-as-soon-as-possible would not need to be greatly concerned about the safe storage of this material after the transmutation technology has been demonstrated. For any dangerous material with worthless or negative value, carefully managed storage is an onerous responsibility which must be promoted by moral appeals, inspections, international pressure, etc. If the material, owing to advanced technology, takes on a large positive value, no such external motivation factors are required. We willingly protect our precious things and insure them as well. If these applications ultimately were to set a price of \$100,000 per kilogram, the value of the world's 200 tons of W-Pu and 2000 tons of HEU would total about \$220 billion. The management of plutonium is therefore simplified mainly to monitoring transfers of material. *The most effective near term program to assure the safe management and accounting of W-Pu (and an accurate and complete inventory) could be the early confirmation of the new technology upon which the expected high positive value of the material is based. As owners of this material, it is in the best interest of both the U.S. and Russia to cooperate in the research to turn this sow's ear into a silk purse at the earliest possible date.*

### **III. Mythology Disparaging Plutonium Disposition by Destruction**

Even within the short period since significant weapons stockpile reductions have become a realistic possibility, mythology already has been established which inhibits decision-making on the destruction option for plutonium disposition. We address several of these myths below.

#### **Reprocessing is essential for destroying commercial plutonium.**

The real issue here is whether the processing results in the extraction of pure plutonium from spent fuel which could be directly used as weapons material. For plutonium recycle in the MOX context and for burning in fast reactors, pure plutonium must be extracted. For the transmutation system under development at Los Alamos, pure plutonium is not required. The first step in preparing spent fuel for transmutation is the removal of the zirconium cladding probably by chlorination. The next step is fluorination of all of the remaining oxide rubble to fluoride with the concurrent removal of the volatile UF<sub>6</sub>. The remaining material including the plutonium, other higher actinide and fission products is fed into the transmuter without further separation. Weapons material is therefore never produced.

#### **The value of W-Pu always is negative**

Part of the argument advanced by those who wish to rush to disposal is that the material will always have a negative value so that there is no need to hold this material for future substantial beneficial use. They use the argument that the only value is in the 200 MeV of energy released per fission. This position does not take into account the value of W-Pu which derives from its neutron-rich feature, which as described above is part of the reason it is good weapons material.

#### **U.S plutonium burning policy can be defined irrespective of Russian plans.**

The U.S can proceed promptly with a plutonium disposition policy such as near term burial but such a policy will be stopped cold if the Russians proceed differently at a

slower pace. Who believes that the U. S. Congress will allow plutonium to be nearly irretrievably buried if the Russians hold on to the material for maximum societal benefit? The disposition of plutonium must be pursued in lock step with Russia. Russia appears to call the shots in this regard. Therefore U.S. plans should be strongly influenced by the Russian position on plutonium disposition. If Russia believes that this material has high value and the U. S. has no convincing basis for proving otherwise, the U.S. policy should be to pursue a disposition policy which allows this possibly high value to be confirmed and then extracted in the plutonium destruction process. It would be foolish for the U. S. simply to declare the material to be less than useless and to pursue an immediate burial program which will be aborted as soon as the U. S. attempts to put the first plutonium into the ground.

**The value of weapons plutonium is not a factor in establishing protection policy.**

We already have made the point above that protecting negative value material is a burden; high positive-value material has much better incentives for protection without persuasion, force, or regulation. The development of the near-term high positive value uses for W-Pu advocated here could have more impact on safe storage than any measures enforced by international agreements or by international oversight agencies.

**Destruction of plutonium takes much longer than burial**

It is readily apparent that geologic storage of plutonium is not the near-term prospect it was thought to be. To even the casual observer the time until emplacement in geologic storage has grown over the years. Parker, a long term leader in repository storage studies, presented<sup>8</sup> the curve in Fig. 3 showing the growth in time to the beginning of waste emplacement in the U.S. starting around 1970. The message is clear. Even the Swedish program, which is considered by many to be the most advanced in the world, will not move to emplacement until at least 20 years hence. (Swedish law now requires the consideration of alternatives to permanent storage of commercial spent fuel.) This is plenty of time to develop and deploy new technology which is enhanced by burning W-Pu and perhaps HEU. The time scale for development and deployment of the new commercial waste transmutation technology advanced by Los Alamos and presented to the JASONs in January 1994 is compared in Fig. 4 with the time for completing the emplacement of waste in a geologic repository. The claims that storage is significantly faster or costs less than destruction are speculation.

**Even with transmutation of W-Pu and C-Pu, geologic storage of the transmuted material still is required in the end.**

We should not forget that the purpose of geologic storage is to provide containment by geologic means for material which cannot be confined by man-made (engineered) barriers that maintain their integrity for 1000 years or less. If by transmutation the amounts of the long-lived actinides and fission product constituents in nuclear waste can be reduced sufficiently that they meet existing EPA and NRC requirements for near-surface storage and the shorter lived material can be confined by engineered barriers, what purpose does geologic storage serve? The Los Alamos Transmutation Technology Project does not advocate the abandonment of geologic storage since technical failure of transmutation cannot be ruled out, but it does insist that transmutation has very substantial potential to provide an alternative that eliminates concern for plutonium forever.

**Accelerator-driven systems might be safer but they are prohibitively expensive.**

Obviously the capital cost of the accelerator, its operation and maintenance costs, the power, and on-line processing are factors which would increase the cost of an



accelerator-driven system over a reactor. However other features of the Los Alamos system such as the low vapor pressure liquid fuel move the cost in the other direction. The liquid fuel allows a high thermal-to-electric efficiency of up to perhaps 44 %, increasing the power output and the income from power sales. This is enhanced still further by the continuous refueling possible with the liquid fuel which eliminates the need for a refueling shut down. There is no fuel cost for the system nor any fabrication or refabrication cost. The enhanced safety of the system eliminates much of the need for expensive back-up safety and control systems such as control rods.

Other factors not yet fully understood which significantly increase the cost of reactors are dealt with directly by the Los Alamos system. It addresses the nuclear waste storage issue by destroying the long-lived components, it addresses the nuclear runaway issue with its subcriticality, and it addresses the afterheat issue by making the fuel and the coolant one and the same so that the fuel may either be drained away in a loss-of-coolant accident or more effectively removed by thermal convection of the dilute liquid fuel without the need to transfer the heat from fixed solid fuel to the coolant. An accurate assessment of the costs of the Los Alamos system cannot be done without detailed design work, but there is good reason to expect that costs will be about the same as reactors and therefore not a significant factor in the issue of deployment of the transmutation technology. Rather the matters of a viable solution to the nuclear waste problem and overall safety of nuclear energy generation ultimately will be the deciding factors.

#### **IV. Summary**

As a result of the present nuclear weapons stockpile reduction underway, pressures exist to drive a rapid decision on disposition of excess weapons material; it rivals concern about nuclear weapons themselves a decade ago. Policy is being pushed for the removal of this material from the environment with the greatest urgency. There really are only two choices for dealing with W-Pu once it has been placed in safe temporary storage and inventoried properly. The material must be placed deep underground "forever," or it must be destroyed completely by fission. A virtual "cottage industry" has arisen proposing means for preparing this material for permanent storage. Every waste storage or reactor design program is offering a proposal which eventually will lead to Pu storage deep underground. The urgent rush toward underground emplacement without due regard to consequences brings to mind the time of plutonium production when storage of production waste in tanks was deemed satisfactory enough for the moment; future generations could deal with the consequences. We of the transmutation project at Los Alamos believe that complete burn-up of plutonium can be done safely, economically and with significant societal benefits that only W-Pu and HEU can provide. These include the destruction of the long-lived species in commercial nuclear reactor spent fuel and the launching of "unlimited" energy production from thorium in a subcritical system without a long-term high-level waste stream. We believe that these new technologies can be developed and deployed on a time scale commensurate with that of any of the storage options. Plutonium destroyed is gone forever; plutonium stored requires vigilance "forever."

This new accelerator-driven transmutation technology must deal with the usual problems of development and deployments of advanced systems. Some of the issues that have come up in the general environment of plutonium disposition were discussed above. We restate them here in summary;

- \* Plutonium destruction does not require reprocessing; no weapons plutonium is ever produced in the Los Alamos transmutation process.
- \* The beneficial use that we propose for W-Pu should give it a positive value; plutonium is not useless, valueless nuclear material.

- \* Russia believes W-Pu has significant positive value in the foreseeable future and therefore is mainly interested in interim storage and development of these positive value uses. We promote the destruction of this material by helping in the development of technologies which place a high value on the material.
- \* Whatever the value perceived for W-Pu by the U. S., the different nuclear infrastructure situation in Russia compared to the U. S. means that Russia has valid reason for seeing the issue differently.
- \* While the disposition solution may be different in Russia from that chosen for the U.S., political realities require that the two nations proceed in lock step toward removing the material from the accessible environment.
- \* Development and deployment of means for destruction of plutonium can be achieved on about the same time scale as any safe underground storage system can be implemented.
- \* Partial burning of plutonium or any other means short of complete destruction requires geologic storage of some kind accompanied by vigilance "forever." In the case of plutonium storage, "out of sight" is not "out of mind."
- \* The cost of accelerator-driven systems may be competitive with that of existing fission reactors if all costs for the reactors such as waste disposition are included.

In conclusion, the only options open for W-Pu are either complete destruction which requires no storage, or deep underground storage possibly preceded by partial burning. The complete destruction probably can be done so that the Pu owner receives very substantial payment for the benefit to be gained from burning the W-Pu. The owner of the W-Pu will assuredly have to pay if the material is to be buried deep underground. The owner probably will never be rid of responsibility for the buried plutonium; if it is burned completely it is gone forever.

## V. Acknowledgments

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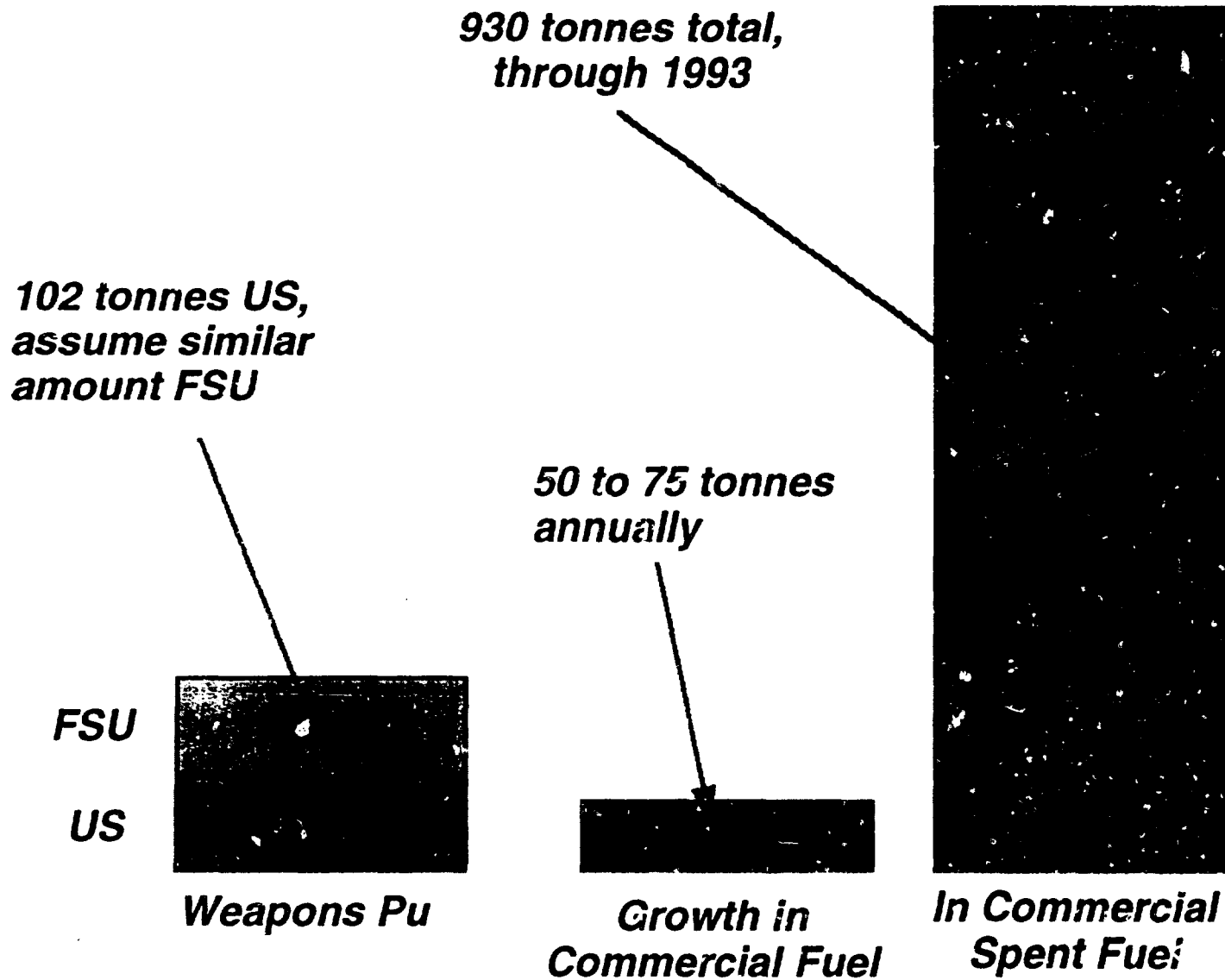
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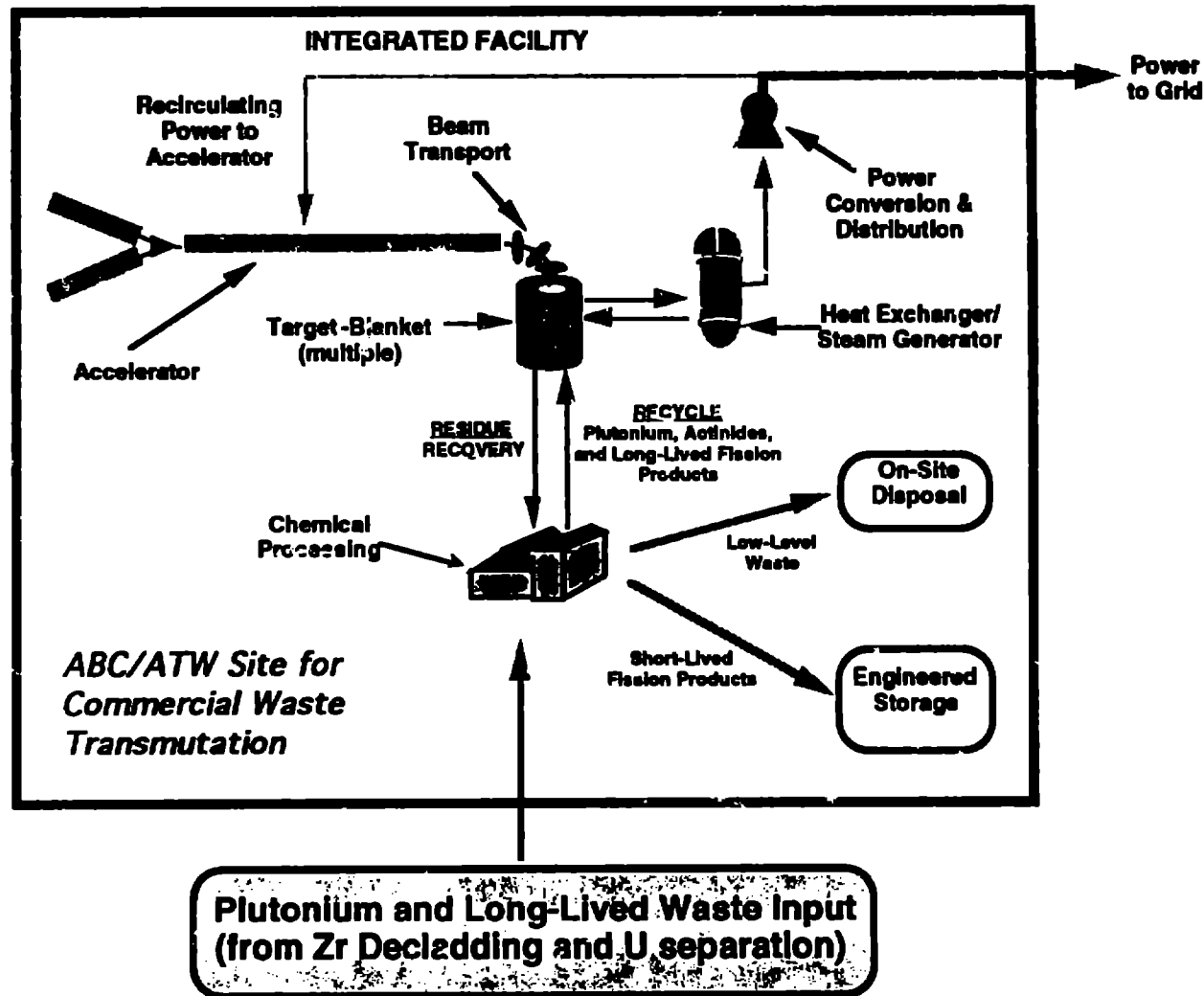
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**8. Figure presented by F. L. Parker in his talk, "Technical and Philosophical Issues of Nuclear Waste Disposal," in the plenary session of the meeting, "Safe Waste 93, An International Conference on the Safe Management and Disposal of Nuclear Waste," p. 43-54, Palais de Papes, Avignon, France (June 1993)**

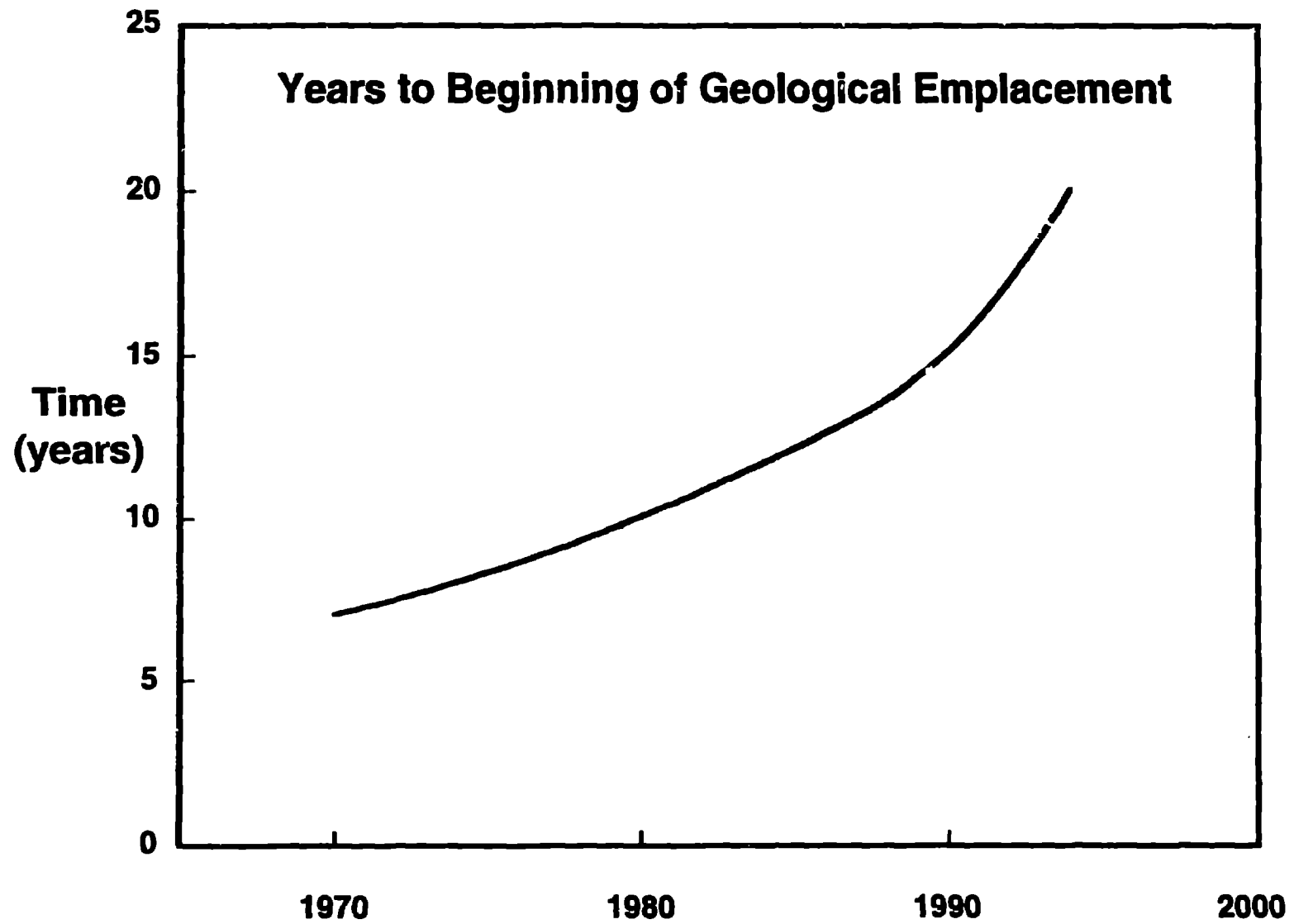
**9. J. Swahn, "Direct Disposal Options for Separated Plutonium," Presented at the workshop, "Managing the Plutonium Surplus: Applications and Options," at the The Royal Institute of International Affairs, London, chaired by M. Grubb and R. Garwin (January 1994)**



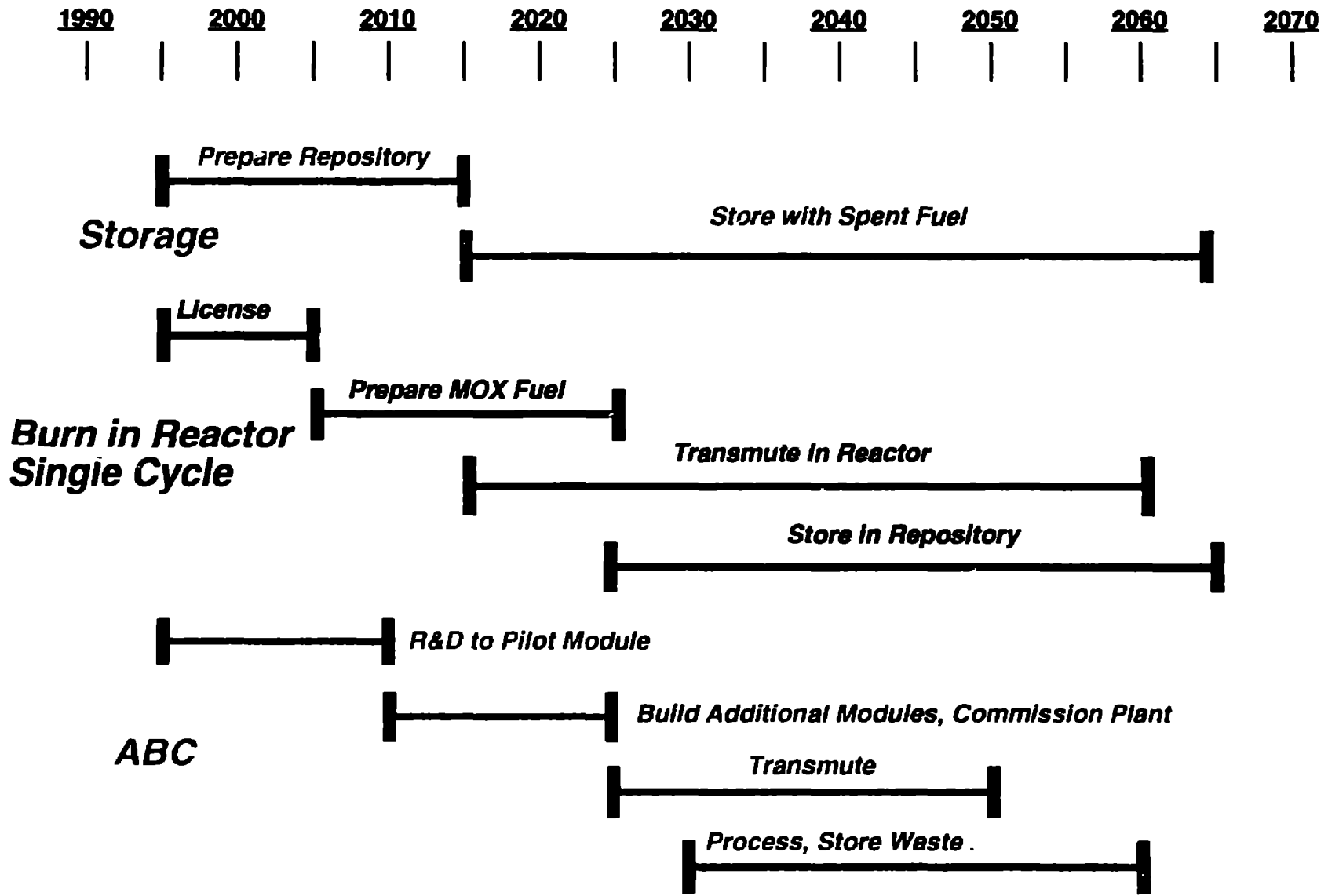
**Figure 1. Global plutonium inventories.** On the left side of the figure the amounts of W-Pu are shown as about 100 tonnes each of Former Soviet Union W-Pu and U. S. W-Pu. Very little W-Pu is expected to exist elsewhere. This W-Pu may be compared on the right with the total world inventory of plutonium of 930 tonnes originating from commercial nuclear power production. Of course this amount is growing and the rate of increase is shown in the center of the figure to be about 50-75 tonnes annually.



**Figure 2. An ABC-ATW System for Destruction of Pu, Actinides, and Fission Products in Commercial Waste.** A reactor-like sub-critical system with  $k_{eff} = 0.90$  to  $0.96$  is driven by an accelerator which produces neutrons sufficient to drive the system at a fission power level of 500 MW or more. The heat is converted with high thermal-to-electric efficiency to electric power of which about 20 % is used to power the accelerator. The remainder is sold to offset the capital and operating costs of the system. The system contains molten salt as a carrier of liquid fuel so that the system can be continuously fueled and the wastes removed. The plutonium, other higher actinide, and long-lived fission product can be destroyed with this system. A substantial reduction in the accelerator size requirement and improvement in cost effectiveness is possible if weapons plutonium or HEU is fissioned in the system. The "complete" burn-up of the long-lived components of the waste should allow the waste remnant to be stored in near-surface or engineered storage.



**Figure 3.** Illustration of the time until first emplacement of spent fuel in a geologic storage facility. The time to emplacement has continuously moved further into the future since serious consideration began around 1970. See reference 8.



**Figure 4. Timelines for Plutonium disposition.** Time lines for plutonium disposition are compared for the three case of storage2 after vitrification with defense waste, storage2 after once through thermal reactors as MOX fuel, and engineered storage of remnant waste after accelerator-driven transmutation.