Why the US Should Not Reprocess Spent Nuclear Fuel

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Because the timetable for disposal of spent fuel set forth in the Nuclear Waste Policy Act of 1982 will not be met, there are renewed calls for reprocessing of the fuel. The potential advantages for the reprocessing of spent nuclear fuel over direct disposal are usually stated as lowering future fuel costs and making disposal of nuclear wastes easier. It is sometimes thought the only reason why we do not recycle plutonium is because of proliferation concerns. However, it is to be remembered that analyses of fuel cycle costs have consistently shown no economic advantage for the US to recycle plutonium from spent fuel and there is little reason to expect this to change in the next several decades. The alleged waste disposal advantages have similarly been found to be dubious despite technical advances. In fact, reprocessing has not been determined to significantly reduce long-term environmental or health risks after disposal. Although the original schedule for disposal cannot be met, there is still no reason to consider reprocessing a viable option.

I. Introduction

President Carter issued an order in 1977 suspending indefinitely commercial spent nuclear fuel reprocessing in the US because of growing nuclear weapons proliferation concerns. Economic reasons also pointed away from the reprocessing option at that time, and environmental benefits to reprocessing, if any, were seen by his administration to be small. Direct disposal of spent nuclear fuel in geological repositories became the US national policy when codified in the 1982 Nuclear Waste Policy Act. Although there have been amendments to the act, the original date of January 31, 1998 for acceptance of spent fuel by the US Department of Energy for disposal has never been changed. Because of very difficult political problems at all prospective nuclear waste repositories or storage sites since 1982, and significant technical and political problems at the Yucca Mountain site in Nevada since 1987, the DOE has not been able to accept spent fuel according to the schedule.

This failure of the federal government over the last 16 years combined with fears of energy shortages is taken by some to mean that reprocessing of spent fuel should once again be considered an option.[1] This paper shows that careful analysis will lead one to the conclusion that reprocessing the spent fuel would not help in nuclear waste disposal and would not improve the economics of nuclear power. Indeed many of the major reasons for President Carter's decision are as valid as before. Additionally, these facts cannot be expected to change any time soon.

II. Reprocessing and Recycling Costs and Benefits

In 1977 The Nuclear Energy Policy Study Group, which was initiated by McGeorge Bundy, President of the Ford Foundation (and former National Security Advisor to President Kennedy), released a study "Nuclear Power Issues and Choices," (the Ford/MITRE report).[2] President

[*] The views expressed in this paper are of the author only and do not represent the views of Los Alamos National Laboratory or the University of California. William C. Sailor has been a member of the ANS for 15 years.

Carter used the results of this study in forming his decisions regarding the reprocessing of spent fuel nationwide.

The Ford/MITRE Group concluded that despite its many problems, nuclear power in the form of the Light Water Reactor (LWR) would and should be a major source of electric power in the future. They concluded, however, that the breeder reactor would be too expensive to compete in the market and therefore stockpiling of plutonium for the breeder was unnecessary. Furthermore, there were no significant cost advantages in the waste disposal aspects of plutonium recycle versus the once-though fuel cycle. Under these circumstances, which have not changed, there was no economic incentive to reprocess spent fuel.

Estimates of the future availability and cost of uranium are central to any decisions on the economic viability of plutonium reprocessing and the need for and timing of breeder reactors. Until the cost of uranium ore rises significantly, it is cheaper to produce low-enriched uranium from new ore than to separate plutonium from previously irradiated fuel elements. If uranium followed the example of other minerals, the higher costs accompanying increased demand would generate much larger supplies than previously forecast as it was discovered that lower grade sources could be profitably exploited.

On the basis of more realistic estimates of uranium reserves and the capital costs involved in plutonium reprocessing, the study concluded "there is no compelling reason at this time to introduce plutonium or to anticipate its introduction in this century." Although the reprocessing policy was reversed under President Reagan, commercial reprocessing was never re-started in the United States because the federal government had become an unreliable partner in reprocessing and the profitability was in serious doubt. The US nuclear industry then, as now, is not interested in private financing of plutonium reprocessing. Consequently, the Barnwell (South Carolina) plutonium reprocessing facility, which which undertaken as a commercial venture and had been ordered mothballed by President Ford, was finally terminated in 1983.

Because of a great slowdown in new nuclear power plant construction activities during the 1980s, anticipated demand for uranium did not materialize. New uranium ores of higher quality were discovered. In two decades there have been no shortages of uranium and no increase in cost. In fact, there is such an over-supply of uranium that the cost today (about $10 per pound) in inflation-adjusted dollars is less than one tenth the cost at the time of Carter's decision. It is difficult to identify any other basic material whose real cost has declined so precipitously. At present many uranium mines have closed because they cannot compete at current prices and there is a worldwide excess capacity of enrichment facilities to produce low enriched uranium for standard light water reactors. In short, there is no market for plutonium fuel.

A review of economic analysis published in 1996 by the Electric Power Research Institute (EPRI) shows that the market price of uranium must increase by at least a factor of 5 over its current price before plutonium becomes competitive with uranium in LWR's.[3] The price requirement may be relaxed somewhat if reprocessed plutonium were to be used to fuel Liquid Metal Reactors (LMR's), in the unlikely event that a large number of LMRs are built.

In the plutonium scenario, the waste from the spent fuel processing facilities is packaged and, after interim storage, transported to high-level and low-level waste repositories. The bulk of the uranium recovered at the spent fuel processing facilities is stored and then reused as feed to MOX fuel fabrication facilities.

Costs (in the LWR case) include the capital and operating costs of the reprocessing facility (8.5

mills/KWh) and fuel fabrication facility (1.6 mills/KWh). Benefits include the savings from not purchasing uranium yellowcake (2.8 mills/KWh) and not having to enrich it (2.3 mills/KWh). They also claim that reprocessing wastes will be 2 mills/KWh less expensive to dispose of in a geological repository than spent fuel becuase of reduced repository heat loads.

In the analysis the 2.8 mills/KWh saved by not purchasing yellowcake is a linear function of the market price of uranium. The market price of $55 per pound U_3O_8 gives this result. Included in the analysis is the cost of starting-up the reprocessing facility, so that the $55 value is slightly higher than the break-even price. The cost of money to utilities is taken as 5%/year above inflation.

Based on the analysis it is concluded that the time for economically introducing reprocessing and recycle may (with about 50% likelihood) occur within 50 years. They do not recommend slowing the US spent fuel geological isolation program as a result of these findings because adequate spent fuel will be available above ground in the future regardless of whether Yucca Mountain has been opened.

It may be reasonable to accept their findings and advocate continuing with Yucca Mountain project on the basis of their analysis alone. However, they seem to have ignored the significant effect that increased uranium prices would have on uranium exploration. Because a factor of 5 in the price of uranium is a very significant increase, it stands to good reason that a significant amount of new exploration for uranium ores will be undertaken worldwide before the full factor of 5 is realized. Yet their analysis is based on currently-known and estimated reserves only.

Reserve and resource estimates for minerals have a long record of being understatements. Estimates of reserves typically originate with industry and reflect its view of what is marketable as well as of what it is prudent to characterize as reserves. These estimates are conditioned by the technology of exploration and recovery and by the extent of exploration. Behind it all this is some concept of the mineral's future significance and the future economic picture. Generally, as markets expand or as prices rise, an industry is motivated to look for, and tends to find, new reserves. This explains why reserve and resource estimates rise along with rising production.[4] One should, therefore, keep an open mind regarding the potential for incremental discoveries and large surprises.

Additionally, the costs associated with mining uranium were assumed to be fixed and no allocation was made for improved mining technology in the years ahead. This is to be compared to the analysis they used for reprocessing technology, which predicted that the costs would decrease with time.

According to the EPRI study, the supply of uranium from seawater is known to be extremely large potentially but only at a very high estimated cost of $800/kg U. Again, neglected in the analysis is what would happen to this per-kg cost in the next 50 years due to technology advances, especially under conditions where the market price of uranium is dramatically increasing. If the cost of obtaining the uranium from seawater were to drop significantly, this would exert downward price pressure on uranium.[5]

Based on the above reasoning the 50-year time estimate for the introduction of reprocessing is most likely premature. The conclusion is that the cost of even an infinite delay in the introduction of reprocessing may be zero. Thus the recommendation to defer reprocessing is easy on economic grounds because there is no penalty.

III. Environmental Benefits to Reprocessing?

An equally important consideration is whether reprocessing and recycle can improve the long term health consequences of nuclear waste disposal. The first step is to analyze and identify the species that contribute most to long-term individual doses from geological disposal. For this purpose it is sufficient to focus on the relative values of maximum annual dose to individuals from each radionuclide released from a geological repository.

An advantageous feature of the direct disposal of spent reactor fuel in a repository without reprocessing is that if chemically reducing conditions exist in the repository, the actinides are not readily moved in the groundwater pathways; they are quite insoluble under such conditions. However, for some invasive scenarios, e.g., human intrusion actinide release may occur and cause some risk. Otherwise, the principal doses to humans after long periods of time are due mainly to fission products ^{99}Tc and ^{129}I that are water-soluble and so are moved through groundwater pathways.

An analysis recently completed by the National Academy of Sciences Committee on Separations Technology and Transmutation Systems (STATS) studied the environmental effects of transmutation of all the actinides and found that there was no reason to abandon the once-through fuel cycle.[6] There could be some small reduction in the amount of long-term risk to the public if the two fission product species above were transmuted along with neptunium. The plutonium species appearing in the STATS report combine for less than 0.1% of the risk from these two fission products, and only under the circumstances that the plutonium is extremely mobile.

To the extent that plutonium would replace uranium as reactor fuel, the amount of uranium that needs to be mined, and therefore short-term radiation exposures from mining and milling, will be reduced. However, there will be a short-term increase in radiation exposure from reprocessing and other fuel-cycle activities not part of the once-through fuel cycle. The population doses from these sources, however, are small.

The solubility of neptunium is very sensitive to chemical environment, resulting in some uncertainty as to the risk from this species in the once-through fuel cycle. When all error limits are put to their highest values for solubility, the resulting doses from ^{237}Np can be higher than from ^{99}Tc and ^{129}I . The peak doses from ^{237}Np would tend to occur at about a million years in the future. If the effective solubility of neptunium does turn out to be near the high end of the range of possible values, reprocessing of spent fuel could be beneficial to repository performance only if neptunium is recycled along with the plutonium.

If the radioisotopes of concern were separated from the spent fuel process stream and packaged into specialized waste forms, reductions in long-term doses to the public may occur. This would involve separating the neptunium, technetium and iodine by chemical means and forming them into insoluble compounds. These compounds would be specially packaged in glass, ceramic or other material. This technology is well within reach, and the idea has been around since at least 1983, but reprocessing of spent fuel for this purpose alone would be extremely expensive.[7]

Despite the above considerations, the major conclusion from the STATS panel study and from all credible prior studies is that the estimated long-term effects from any of these actions are extremely small in an absolute sense. The National Council on Radiation Protection and Measurements estimates 0.3 latent cancer facilities per Gw_e-yr from the whole once-through fuel cycle. According to the STATS panel the elimination of long-term risk by reprocessing fuel and taking all these steps would amount to only 0.06 cancer fatalities per Gw_e-yr. This amount of reduction in risk has essentially no effect on the comparison of public health effects of nuclear power versus other forms of electrical power generation. Therefore the environmental argument in favor of nuclear energy does not improve in any meaningful way.

According to the STATS panel the elimination of long-term risk by reprocessing fuel under perfect conditions would amount to only 0.06 cancer fatalities per plant per year. This amount of reduction in risk has essentially no effect on the comparison of public health effects of nuclear power versus other forms of electrical power generation. Therefore the environmental argument in favor of nuclear energy would not improve in any meaningful way even with a perfectly clean reprocessing technology.

The small size of the health benefit relative to cost, even from perfect reprocessing, is indicated by the following. At $1 million per cancer avoided, this would be worth $60,000 per reactor-year of operation. However the cost of reprocessing would be over $10 million per reactor-year. This is certainly not a good return on a public-health investment.

IV. Other Objections to Burial of Spent Nuclear Fuel

Some reprocessing advocates have devised alternate arguments against the burial of spent nuclear fuel during the last two decades, which should be briefly examined. If there merit to any of these, it would not necessarily lead to a reprocessing imperative, however, because above-ground storage of spent fuel either at interim storage facilities for the next many decades is probably the most cost-effective option.

Sir Walter Marshall, when he headed Britain's nuclear power program, called a spent fuel repository a "plutonium mine." He was referring to the idea that the fuel could be re-excavated and processed to recover the plutonium component for weapons in the future. This risk with direct disposal of spent fuel develops as radioactivity of fission products decays and the dangers to persons from retrieving spent fuel and chemically separating the plutonium can be assessed as a function of time. Decades from now the radioactivity will be low enough to permit mining and reprocessing to separate the plutonium. Also, the plutonium itself becomes less rich in the shorter half-life heavier isotopes, making it a somewhat more attractive weapons material. For a nation wanting to construct a large number of warheads in a short period of time, re-excavating a nuclear repository may be a cheaper and faster route than creation of a new plutonium-production infrastructure.[8] It is therefore recommended that repositories or storage facilities only be located in a few countries, ones that are weapon states already. The fuel would still be under international safeguards at all times in the future.

If someday there is no separated plutonium or fresh MOX fuel available in large quantity above ground, old spent commercial fuel stored above ground would then be the relatively fastest route to new large-scale weapon production, followed by buried old spent fuel. Until this is the situation, however, these paths should not be considered a significant contributor to the overall proliferation threat.

Another recent claim was fissile material should not be buried underground because of the possibility of explosion.[9] Reviews of the theory during the last few years have concluded that the overall probability of such an occurrence is negligible and should be listed in the same category of risk with meteor strikes to the repository.[10] The reason is that probability of each of the major steps leading to such an occurrence is very small. The originators of the theory were never able to show how an initial supercritical configuration would ever come to pass. It has further been concluded that if any supercriticality event were to occur, the energy release would be very small and would have no public health consequences.

V. Proliferation Concerns

Whether a nation constructs nuclear weapons is mainly driven by a combination of perceived international threat and domestic politics. Access to nuclear materials is a third consideration.

Reprocessing spent commercial nuclear fuel has never been used as a path to weapons. This is true for all the major weapons states, including the US, who developed weapons capability through separate military programs. Therefore, reprocessing of commercial spent fuel cannot be said to cause nuclear weapons proliferation among nations.

A possible exception to this is India.[11] For years before the May 1998 nuclear weapons tests, the government of India has stockpiled plutonium in order to maintain the option to build weapons. It is believed that all of their weapon plutonium has originated in special-purpose reactors and that they have not used power reactors to build their stockpile. However, one of their special purpose reactors and one of the reprocessing facilities they used were originally obtained from other countries with the agreement that they were for peaceful purposes only.[12]

India's rival Pakistan developed its nuclear arsenal through uranium enrichment, bypassing the need for plutonium altogether. South Africa did the same during the 1980's but they have since dismantled their weapons.

It has long been feared, however, that clandestine diversion of plutonium from a commercial reprocessing stream could allow a sub-national or terrorist groups access to nuclear weapons. During the 1970's it was believed by many in the government that US influence on the world nuclear power industry could curtail reprocessing and diminish this threat.

This was the main reason for President Carter's decision to halt US reprocessing. However, it has become clear after 20 years that he misjudged the international response. The United States isolated itself from the other major players in nuclear power, many of which rejected the abandonment of the plutonium fuel cycle option.

A number of countries, including France,[13] Japan[14] and Russia[15] continue to pursue plutonium reprocessing and recycle today. These countries have invested in nuclear energy programs that include reprocessing and in some cases breeder reactors that they feel will give them lasting energy independence. France and Japan have no other domestic energy resources. This seemingly uneconomic solution to their energy problems reflects their desire to maintain independence from Middle East oil supplies and the potential vulnerability to trade disruption. In France, nuclear energy represents a majority of electrical power production and recycle of plutonium in power reactors is common. Japan is even more fuel-poor and is driven by a deep-rooted desire for energy self sufficiency going back to its experience during the World War II blockade.

The fact that these countries have stayed with reprocessing does not mean the policy would be good for the US. Moreover, the decision to stay with reprocessing in the Former Soviet Union (FSU) might have consequences for world security over the next few decades.

VI. Russian Plutonium

With the end of the Cold War the proliferation risks associated with the potential leakage of plutonium and highly-enriched uranium from the Russian program are now of the highest importance. Attempts by our government to discourage Russia's reprocessing of their fuel have met with little success. Rather, the US is providing assistance in the creation of secure storage facilities for their excess plutonium.

Although material shortages were common in the Soviet Union, there was apparently never any shortage of weapon-usable material. It is estimated that Russia's nuclear material inventory, which is distributed over 50 sites, consists of 1100-1300 tons of HEU and 165 tons of weapons-grade plutonium. There are significant quantities of nuclear materials in the other post-Soviet states as well. The declared inventory tends to rise with time, as more new caches of material are discovered. For instance, the declared inventory at one research institute in Ukraine grew from 15 to 75 kg during 1996.

Increased presence of IAEA inspectors in the FSU and US-initiated safeguards measures are helping to decrease risk throughout the plutonium and uranium fuel cycles. However, there remains much work to be done. While the introduction of spent fuel reprocessing in the US at this time would not make matters any worse with respect to proliferation originating in the FSU, it also would not help.

The Russian nuclear program continues to be driven by the remnants of its centrally-planned economy, where their planners view their plutonium and related infrastructure as extremely valuable, a resource not to be wasted. The majority of leaders and citizens feel that an expanding nuclear energy program is necessary. There is no inertia to cease reprocessing of spent fuel even though there is a dramatic oversupply of nuclear fuels and not enough money to pay for continued operation of many of the existing nuclear power stations. Because of a drop in demand for uranium and plutonium the various reprocessing and materials-production sites in Russia are attempting to sell nuclear services to other countries.[16]

They also strongly are in favor of using plutonium from dismantled nuclear weapons as fuel for their power reactors. Mainly because of our need to act in unity in disarmament, the US is planning for the option of burning weapon plutonium in reactors. The use of excess plutonium from eliminated nuclear weapons in MOX fuel in commercial nuclear reactors is simply a good method of disposing of existing separated plutonium by using it as a reactor fuel. After irradiation it will be no more accessible to theft or diversion than plutonium from normal spent fuel from commercial reactors. To understand that this plutonium is no longer considered a proliferation threat once it has been burned in a reactor is important. It joins the thousands of tons in the nation's spent fuel inventory.

The evidence today is that there is a slow but growing increase in the rate of diversions of proliferation-significant materials from the former Soviet Union.[17] There have been several confirmed cases of illegal export of nuclear material, including the discovery of 560 grams of mixed oxides of uranium and plutonium on a Lufthansa Airlines flight from Moscow to Munich. It is thought that the powder was meant for an experimental MOX-fueled reactor in Russia, but no final determination has been made of the source. In any case, security seems to be lacking in many of the smaller, research-related facilities and naval fuel facilities in Russia.

Further expansion of US nuclear infrastructure so that we could accept the tons of surplus plutonium from Russian stockpiles may be in our own security interests. The material could be made into MOX fuel for irradiation in US reactors and the Russians could be paid for it. Such an action would constitute a one-time, one-way transfer of weapon material into relatively harmless spent fuel in a fashion similar to the way we are taking $12 billion worth of highly-enriched uranium from the Russians. It would not involve reprocessing of our spent fuel.

Progress is being made in providing Western assistance in upgrading MPC&A at key Russian and former Soviet Union facilities. US assistance to Russia through the various government-to-government programs has contributed significantly to the safeguarding of Russia's nuclear assets. The impact of this assistance can be increased by a relationship of true cooperation. Foremost this means creating a sense of a shared mission between the former Cold War rivals, without brazen attempts by the US to alter the Russian commercial fuel cycle. However, this does not mean that the US should adopt the Russian fuel cycle. Rather we need to work in cooperative fashion with them in plugging the leaks in their fuel cycle as much as possible. It is in this spirit that the agreement to convert some of each of the nations' excess weapon plutonium into spent fuel was made.

VII. Irradiation of Weapon Plutonium as MOX Fuel

The US is currently undertaking a dual-track approach to disposal of some 50 tons of excess weapon plutonium. One track is to manufacture the plutonium into MOX fuel for irradiation in commercial reactors (the electrical utilities involved would be compensated for the extra cost of any reactor modifications necessary to burn the fuel). The other track is to immobilize the plutonium in ceramic with a mixture of neutron absorbers and radioactive materials. Some of the 50 tons will go to each track. Either track produces a functionally similar final state, one that resembles spent commercial nuclear fuel of which there is already 70,000 tons. This material would then be disposed-of with the spent nuclear fuel in a national geological repository.

For the US or the FSU it makes little sense to be concerned with governmental diversion of reactor plutonium into a weapon program for now because of the tremendous quantity of plutonium remaining within military boundaries. Additionally, many thousands of warheads are still in the stockpile. It is sometime argued by arms-control advocates that in a future treaty-breakout scenario, the United States (or Russia) could draw on its historical nuclear test data and predictive capabilities to reconfigure weapons and reconstitute a large arsenal, even from plutonium isotopically degraded to reactor grade by irradiation as MOX. This supposedly constitutes an argument against the irradiation of weapon plutonium as MOX fuel. However if this were true both the US and Russia already have thousands of tons of spent commercial fuel from which they could quickly and easily re-build their arsenals if they so wanted.

Thus, irradiated MOX fuel poses (for practical purposes, for the near-term) an infinite barrier to re-militarization of warhead plutonium in weapon states. The National Academy of Sciences, in its comparison of the MOX and immobilization options, found that "[t]he plutonium in the spent fuel assembly would be of lower isotopic quality for weapons purposes than the still weapons-grade plutonium in the glass log, but since nuclear weapons could be made even with the spent fuel plutonium this difference is not decisive." In future years, if the spent fuel had been "disposed of" in a geological repository, it would make little difference to a determined government, who could certainly dig it up again without difficulty. Thus the term "Spent Fuel Standard" has been coined to signify that there is simply no reason to assure that a given material has greater resistance to proliferation than spent fuel. Any other highly-radioactive material that contains weapon-usable material mixed with low-enriched uranium meets this standard. It is a realistic standard that we should strive for in future nuclear fuel cycles.

The MOX option for weapon plutonium disposition, however, should not be used to encourage the civil use of plutonium and should not be portrayed as giving credibility to the claim that plutonium recycle in light water reactors is essential to nuclear waste management. Reprocessing proponents should not attempt to exploit the use of MOX in the disposition process as proof of a new US government policy on plutonium recycle.

VII. Conclusions

The role of nuclear power in the US has declined from all of the projections that were being made twenty years ago. The market price of uranium has dropped precipitously and many new reserves have been found. For this reason there is no economic incentive to reprocess spent nuclear fuel. The readers of this paper are aware that there are many reasons for the decline in nuclear plant construction. Lack of fuel reprocessing capacity is not one of them. It is unlikely that an economic incentive to reprocess will appear for many decades, if ever.

The Carter reprocessing decision should not be made a scapegoat for lack of public acceptance of nuclear power. The public acceptance problems of the industry would still exist regardless of that decision. In contrast, dry storage of spent nuclear fuel has been licensed by the Nuclear Regulatory Commission at many sites and has been implemented usually without excessive difficulty. Expansion of dry storage either at reactor sites or at interim storage facilities should continue until there is a national repository ready to accept the spent fuel.

It is to be remembered that the policy against reprocessing does not damage the nuclear power industry. In fact, the introduction of a new and very costly fuel cycle which provides no significant environmental or waste disposal benefits could only do the industry great damage. While there is no immediate prospect for investment in nuclear power plants, things could change. If nuclear energy is to again become a viable option in the US, it will be with uranium fuel first rather than more expensive fuels. In a few decades the nation will need new power plants to meet growing needs for electricity and to replace obsolete plants. And when that time does come, it is hoped that issues involving nuclear energy can be debated openly and honestly, not just emotionally as has often been the case.

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