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An Initial Look at Reprocessing, Recycle and the Waste Issue

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DRU-1368-DOE

April 1996

Prepared for the Department of Energy

PREFACE

This paper questions the claim that reprocessing of nuclear spent fuel can ease the tasks of waste management. This initial look should be of interest to analysts and policymakers in civilian nuclear fuel cycle alternatives and in nuclear nonproliferation.

This study was sponsored by the U.S. Department of Energy. The views expressed in the paper are those of the authors and do not necessarily reflect the opinions or policies of their affiliated organization or of their research sponsor. This paper can be cited or quoted.

INTRODUCTION

The United States and some of its major allies are marching down different paths in the management of nuclear material and waste. The most stark difference lies in whether nuclear spent fuel should be reprocessed and the recovered plutonium used in nuclear reactors. Some influential planners in various countries argue that countries should choose whatever path they want, based on their own situations in energy resource endowment and other needs. Different views and practices would not create any problem, if nuclear proliferation could be controlled locally and individually, rather than globally and cooperatively. Unfortunately, proliferation could germinate in countries where rules are lax, and the disastrous consequence could affect even those countries that have been exerting their utmost efforts to contain proliferation. Thus, countries need to resolve their differences in plutonium management and agree on a consistent policy. To do that, countries first need to have a clear picture of the impact of plutonium use on proliferation, nuclear power economics and nuclear waste management. The United States has been much more successful in conveying its assessments and views on the first two factors to other countries than on the last factor of nuclear waste management.

At the same time, plutonium advocates in the past several years have emphasized the environmental benefits of reprocessing and recycling--much more so than the economics. This is particularly apparent in international conferences. As the pro-plutonium side focuses on environmental benefits while the anti-plutonium side focuses on nonproliferation and dismal economics, their arguments are often so polarized that the conference participants bypass one another with little hope of arriving at a common course of actions.

The United States has a policy of not encouraging other countries to use plutonium.[1] To do so, it is just as important to point out where it disagrees with other countries' analyses as to show its own assessments. It needs to examine the plutonium-advocates' claims of waste management benefits. This is not the first time that these claims are made. They were also made in the 1970s, when the U.S. policy was shifting to no plutonium use. The analyses supporting these claims at that time were rather simplistic and they were shown to provide a misleading picture of the waste resulting from

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[1] See the fact sheet on the President's Nonproliferation and Export Control Policy, September 27, 1993.

reprocessing and recycling. The analyses supporting the current claims are more sophisticated, but the question remains--are the current claims any more justified than were the ones in the past?

REPROCESSING, RECYCLE AND THE WASTE ISSUE

The environmental benefits of reprocessing and recycle are usually attributed to two factors. One is the reduction in the waste volume and the other is the reduction in the radiotoxicity of the waste. In the 1970s, the claim that reprocessing reduced waste volume was simple--one compared the volume of spent fuel with the volume of high level waste (HLW) that resulted from reprocessing this spent fuel. The high level waste volume was only about one fifth that of the spent fuel.[2]

But a more in-depth analysis revealed that reprocessing also created large volumes of intermediate level waste (ILW) much of which had a sufficient transuranic content to require its long-term geologic disposal.[3] (Exactly what waste requires geologic disposal depends on the laws of the country in question). The total volume of HLW and ILW from reprocessing that required geologic disposal was 10 times that of the volume of the spent fuel. Even French reprocessing advocates now admit that, in 1980, the volume of reprocessing waste was twice that of the volume of unreprocessed spent fuel.[4] So it is clear that past claims of environmental benefits were mistaken.

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[2] *Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle*, Volume 1, ERDA-76-43, May 1976, pp. 1.3 and 1.8.

[3] Thomas D. Davies, U.S. Arms Control and Disarmament Agency, "Open Letter to the Principal Delegates to the Iran Conference on Transfer of Nuclear Technology," April 22, 1977. Reproduced in Albert Wohlstetter, Gregory Jones, Roberta Wohlstetter, and Henry S. Rowen, *Towards a New Consensus on Nuclear Technology*, Volume I, PH-78-04-832-33, July 6, 1979, pp. B-2 to B-19. One of the current authors (Jones) provided the analysis on nuclear waste volumes used in this letter.

[4] Mrs. Viala and M. Salvatores, "The Spin Program," *Global 1995--International Conference on Evaluation of Emerging Nuclear Fuel Cycle Systems*, American Nuclear Society Topical Meeting, September 11-14, 1995, p. 126.

However, a serious effort has been undertaken to reduce the volume of the waste produced by reprocessing. The French claim that, in 1993, (the latest year that data is available) the waste volumes were about the same for reprocessing and for spent fuel.[5] They further project that, by the year 2000, the volume of reprocessing waste will be further reduced to where it is only about one-third that of spent fuel.

Though this sort of analysis is more sophisticated than that of the 1970s, it still only gives a partial picture of the reprocessing waste problem. In particular, it looks only at reprocessing of the enriched uranium fuel and does not follow the plutonium further, even though the whole point of the reprocessing operation is to make the recovered plutonium available to the fuel cycle i.e. recycling. What is needed is a total systems approach which looks at the waste generated throughout all of the steps of the plutonium fuel cycle.

We have not done this in detail, but our preliminary examination has revealed several problems with the analyses used by the current advocates of reprocessing and recycle. For example, none of these analyses includes the MOX fabrication wastes even though work done in the 1970s showed that the volume of such waste alone could equal to or greater than that of the spent fuel.[6] Neither is the waste from the eventual decommissioning of the reprocessing plant included.

A even more serious omission is the failure to examine what happens to the spent MOX fuel. Each successive time that plutonium is recycled in an LWR, there is a buildup of the nonfissile plutonium even isotopes. To compensate for this buildup and maintain

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[5] *Ibid.*

[6] Thomas D. Davies, *op. cit.*

reactivity, there would need to be an increase in the plutonium content of the fuel. However, above a certain percentage of plutonium content in the fuel, the void coefficient of an LWR might become positive under certain conditions which is a serious safety problem. In the past, plans for plutonium recycle in LWRs were devised to deal with this problem by what was termed a "self-generation recycle". In this scheme, an LWR's core would contain only about 30% MOX fuel. The other 70% would continue to be low-enriched uranium fuel. In each recycle, the plutonium recovered from the spent MOX fuel would be mixed with the "first generation" plutonium produced in the low-enriched uranium fuel in the other part of the core. After a number of recycles, the plutonium even-isotope content reaches an equilibrium which though higher than that of first-generation plutonium, is lower than the level where reactor safety problems occur.[7] Since the amount of the plutonium produced in the enriched uranium part of the core matches the amount of plutonium burned up in the MOX part of the core, there is no net production of plutonium--hence the term "self-generation".

The high level of plutonium even isotopes in the equilibrium self-generation recycle has adverse consequences for waste management which are generally not explored by the proponents of plutonium recycle. In particular, the high Pu-242 content in the recycled plutonium leads, during the MOX fuel's irradiation in the reactor, to a significant increase in the production of americium and curium. Although most of the plutonium is separated from the waste during each recycle, all of the americium and curium wind up in the waste. We have not looked in detail at the impact of the increased quantities of americium and curium in the waste because it now seems likely that self-generation recycle will not be the

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[7] *Plutonium Fuel: An Assessment*, Nuclear Energy Agency, Organisation For Economic Co-operation and Development, Paris, 1989, p. 43.

way plutonium recycle will be conducted in LWRs.[8] Rather it appears that plutonium will likely be recycled in LWRs only once and the spent MOX stored or disposed of.

This change is the result of two factors. First, there is a vast oversupply of separated first-generation plutonium[9] and storing it would be costly. Since it is highly toxic and weapon-usable, expensive remote-control equipment and heavy security would be required to handle the material. Second, even after one recycle, there is already a considerable buildup of the even isotopes in the plutonium. This makes the plutonium undesirable from a neutronic and fuel fabrication (due to increased radiation) point of view. Therefore, there is no incentive to reprocess spent MOX fuel to recover second-generation plutonium, when one can more easily use already separated first-generation plutonium. The French utility, Electricite de France (EdF), has made clear that it currently does not plan to reprocess spent MOX fuel but rather intends to store it until such time as its plutonium is needed for breeder reactors.[10] But breeder commercialization programs worldwide have been either canceled or greatly postponed. Plutonium will have to be

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[8] Our preliminary look at the impact of self-generation recycle on the nuclear waste indicates that the short-term heat output of the waste will actually increase (despite the removal of the plutonium) relative to direct disposal of the spent fuel. See Thomas D. Davies, *op. cit.*. Self-generation recycle will cause little change to the short-term (the first 500 years or so) radiotoxicity of the waste as measured by ingestion hazard and significantly increase it as measured by inhalation hazard compared to the direct disposal of spent fuel. Self-generation recycle will cause a decline of the longer-term (after 500 years) radiotoxicity of the waste on both hazard measures compared to the direct disposal of the spent fuel. The importance of the short-term heat output of the waste and of the radiotoxicity of waste are discussed later in this paper.

[9] *Problems concerning the accumulation of separated plutonium*, IAEA-TECDOC-765, International Atomic Energy Agency, Vienna, 1994, p. 8.

[10] Bernard Esteve, "Aval Du Cycle Du Combustible Nucleaire Positionnement D'Electricite De France A Moyen Et Long Terme," *Global 1995, op. cit.*, pp. 63-72. The EdF's plans are the ones that count since it is the entity that pays the bills.

stored for many decades and the storage cost could be high.[11] Thus, disposing spent MOX fuel is a distinct possibility. Yet, the volume of this disposed MOX fuel is left out of most of the waste comparisons of reprocessing advocates.

Another key question is whether total waste volume is even the proper metric to measure the environmental impact of the waste. After all, if waste volume were important, it would be a relatively simple matter to reduce the volume of the spent fuel by removing the void in the fuel elements. But no one has proposed doing so. In a geologic repository, the actual volume of the high level waste or spent fuel will have little to do with how much space it takes up in the repository. Rather, the short-term heat output of these wastes will determine how densely the waste can be put into the repository. Since reprocessing does not remove very much of the radioactive products that generate the short-term heat, there will be little difference in the heat output of reprocessing waste and spent fuel. Moreover, when the disposal of the americium and curium generated in the MOX fuel or of the MOX spent fuel itself is factored in, the short-term heat output of the waste generated by reprocessing and recycle may actually be higher than that of spent fuel. This is due to the buildup of shorter half-life actinides in the MOX fuel (principally Cm-244 with a half-life of 18.1 years and Pu-238, 87.7 years).

Turning now to the radiotoxicity of the waste. The radiotoxicity of the waste is determined by the amount of each isotope present weighted by the toxicity of each isotope.[12] The total toxicity is the sum of the toxicities of each isotope. In the arguments

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[11] For example, even Japan, an ardent plutonium advocate, does not plan to commercialize breeders until the year 2030. "Japan slows fuel cycle development," *Nuclear Engineering International*, September 1994, p. 3.

[12] A simple way to measure radiotoxicity is by hazard index. The hazard index is the number of curies of an isotope divided by its maximum permissible concentration (MPC) in either water or air. The MPC is

of reprocessing advocates in the 1970s, reprocessing caused a dramatic reduction in the radiotoxicity of the waste. This resulted from comparing the radiotoxicity of just the reprocessing waste with that of the spent fuel. This type of comparison always favors reprocessing, because taking some of the radioactive isotopes out of the waste can never increase the total toxicity. But this amounts to treating the plutonium recovered by reprocessing as if it had vanished from the face of the earth. Since the plutonium is the main source of the radiotoxicity in the period for about 500 years after disposal to roughly 100,000 years after disposal and since reprocessing removed over 99% of the plutonium from the waste, this comparison showed roughly a factor of 10-100 reduction (depending on whether the hazard considered was due to ingestion or inhalation) in the radiotoxicity during this time period.[13]

But as was discussed above, this is not the correct comparison. The plutonium may well be recycled only once and the spent MOX fuel could then be disposed. The French National Evaluation Commission, which was created to review yearly progress on nuclear waste programs, has noted that the disposal of large quantities of spent MOX fuel is now a possibility. It has stated that if this does occur, "the advantage of eliminating long-lived radionuclides in first-generation (UO_2) fuels would disappear completely."[14]

The British Nuclear Fuels plc (BNFL) has done a more complete analysis, which examines the impact of MOX disposal on the radiotoxicity of the waste, though even their

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isotope dependent. If it is a MPC in water then it is an ingestion hazard index and if it is a MPC in air then it is an inhalation hazard index. See Manson Benedict, Thomas H. Pigford and Hans Wolfgang Levi, *Nuclear Chemical Engineering*, Second Edition, McGraw-Hill Inc., New York, 1981, p. 572.

[13] Bernard L. Cohen, "High-level radioactive waste from light-water reactors," *Review of Modern Physics*, Vol. 49, No. 1, January 1977, p. 7.

[14] Mia Trinephi and Ann MacLachlan, "Blue Ribbon Panel Says France Needs Waste Management Strategy," *Nucleonics Week*, July 6, 1995, p. 19.

case is optimistic since it assumes that the plutonium is recycled twice before disposal instead of once which seems more likely.[15] Instead of a factor of 10-100 reduction, reprocessing and recycle reduce the radiotoxicity of the waste (measured as an ingestion hazard) by only 5% to 20% in the period 500 years to 100,000 years after disposal. Also, although the paper is not explicit, the radiotoxicity, in the period less than 500 years after disposal, appears to be actually increased--again due to the increase in Cm-244 and Pu-238.

Radiotoxicity is a theoretical measure of the hazard level of the waste. What will ultimately matter is actual human exposure to radiation. Reprocessing is sure to increase this exposure, at least in the short run. Reprocessing leads to the release of some fraction of the isotopes which would otherwise remain safely locked in the spent fuel. For most isotopes, the fraction released during reprocessing is quite small (on the order of 10^{-5}). But at one large commercial reprocessing plant (THORP), the fraction of some isotopes released is quite large--Kr-85, 100%; I-129, 99%; H-3, 49% and C-14, 3%[16] (some of these isotopes are in gaseous form and are released into the atmosphere and some are in the low-level liquid waste and are released into the ocean). None of these isotopes would be released if the spent fuel was disposed of directly.

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[15] D. M. Beaumont *et al.*, "The Environmental Benefits of MOX Recycle," *Proceedings of the Fifth International Conference on Radioactive Waste Management and Environmental Remediation*, Volume 1, ICEM '95, edited by S. Slate *et al.* , September 3-7 1995, The American Society of Mechanical Engineers, New York, p. 519.

[16] A. P. Jeapes and L. Yule, "A Clean Technology Approach to Reprocessing," *Global 1995, op. cit.*, p. 966.

FINDINGS AND RECOMMENDATIONS

We found that the claim, that plutonium reprocessing and recycle make waste management easier, is based on incomplete assessments and inappropriate metrics. The waste from fabricating MOX fuel is often not included. Neither is the waste which results from reprocessing plant decommissioning. Since it now seems likely that plutonium may be recycled in LWRs only once, the disposal of spent MOX fuel should also be included in the management of a closed cycle. Moreover, the disposal cost depends more on short-term heat production in the high-level waste or spent fuel rather than the volume. The recycling of plutonium (either only once or in a self-generation mode) is likely to cause this heat production to increase. As to radiotoxicity, reprocessing actually releases some of the radioisotopes now, as opposed to leaving them contained in the spent fuel canisters indefinitely.

The United States needs to take a systems approach to compare the waste management benefits of reprocessing/recycle fuel cycle versus once-through fuel cycle. The results can then be shared with other countries. Otherwise, some countries may pursue plutonium activities for benefits that do not exist in the first place.