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Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors

Health, Safety and Environment

U.S. Nuclear Regulatory Commission

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Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors

HEALTH, SAFETY & ENVIRONMENT

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U.S. Nuclear Regulatory Commission

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CHAPTER V

SAFEGUARDS REFERENCE

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SAFEGUARDS REFERENCE

Safeguards considerations for the implementation of recycle plutonium in light water reactors and the supporting fuel cycle are covered in the Safeguards Supplement NUREG-0100 (issue date to be announced). Included in this supplement on safeguards is an addendum to the CHAPTER XI of this final GESMO. This safeguards costs in the draft supplement are developed independently of the nuclear fuel cycle costs included in CHAPTER XI.

The Safeguards Supplement replaces completely the CHAPTER V that was in the GESMO Draft WASH-1327 issued August 1974.

GESMO

CHAPTER VI

PROBABLE ADVERSE ENVIRONMENTAL EFFECTS THAT CANNOT BE AVOIDED

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SUMMARY

Construction of new facilities for spent fuel reprocessing and MOX fuel fabrication will create a commitment of land until the proper decommissioning of each facility when it is no longer to be used.

Other potential adverse environmental effects of new facility construction are small changes in land use, destruction or degradation of plant life and animal habitat, and alteration of surface water drainage patterns.

Operation of facilities either for uranium and plutonium recycle or for recycle of uranium only will cause minor environmental impacts resulting from increased releases of small amounts of radioactive materials and discharges of heat, water vapor and chemicals to the biosphere, in all cases well below permissible levels.

1.0 INTRODUCTION

The National Environmental Policy Act of 1969, implemented by Executive Order 11514 and by the Council on Environmental Quality's (CEQ) Guidelines of August 1, 1973 (38 FR 20550), requires that detailed environmental statements clearly identify in one place environmental effects that are adverse and unavoidable under the proposed action.

CHAPTER IV contains a detailed analysis to determine the amounts by which the environmental effects associated with each component of the fuel cycle would change if plutonium recycle is introduced into the LWR industry. That analysis is based on the cumulative effects of the mixed oxide fuel cycle that would develop between 1975 and 2000 based on a low growth projection for the nuclear power industry, assuming continued utilization of today's technology.

This chapter summarizes, in accordance with the CEQ guidelines, the differential environmental effects that might occur if plutonium were recycled into LWR's, especially the effects that might be considered adverse and unavoidable. The information that forms the basis for this section is contained principally in CHAPTER IV and is summarized and addressed here in the same order.

For purposes of this statement, an adverse effect is considered to be one that is potentially detrimental to the environment through increasing exposure to radiation or releasing radioactive materials and noxious chemical effluents; another type of adverse effect is one that decreases the economic benefit or the efficiency of utilization of resources such as raw materials, land, labor, and plant and equipment. The differential environmental effects are the changes that occur between no recycle, recycle of uranium only, and recycle of both uranium and plutonium. The methods used to estimate the differential effects identified in CHAPTER IV have been conservative--they tend to overestimate the differential effects. That conservatism is continued in this chapter.

2.0 UNAVOIDABLE ADVERSE EFFECTS ASSOCIATED WITH THE MIXED OXIDE FUEL CYCLE COMPONENTS

2.1 LWR's with Recycle Plutonium

In evaluating the impact of recycling plutonium in LWR's on reactor safety and the environment, this report makes use of a model LWR power plant in which the quantity of recycled plutonium to be used is 115% of the self generation reactor (SGR) value. On the 115% SGR basis, the use of MOX fuel would increase the plutonium inventory in any one reactor by a factor of about 3 over what it would be without plutonium recycle. The important changes in reactor effluents would result from the different fission product distribution resulting from plutonium fission compared with uranium and an increase in the production of transplutonium isotopes in mixed oxide fuels as compared with low enrichment uranium fuel. The fission products will normally

be retained within the sealed fuel rods. Based on experience with UO_2 fuel rods, however, it can be expected that some fuel cladding defects will occur during normal reactor operation and some of the fission products will be released from the fuel matrix into the primary coolant. Some of the gaseous fission products released to the coolant are ultimately released to the atmosphere under controlled conditions via tall stacks. However, the Technical Specification limits with regard to primary coolant radioactivity and radioactive effluents will apply equally to the mixed oxide fuel assemblies and to the uranium fuel assemblies, and neither the probability of accidents nor the consequences will change significantly as a result of using MOX fuel. The hazards to the public, therefore, remain relatively unchanged by the substitution of MOX fuel for UO_2 fuel assemblies for normal and accident conditions.

On the basis of the detailed analysis in CHAPTER IV, Section C, it is concluded that, under both normal operation and accident conditions, the effects of fuel type (MOX fuel versus UO_2 fuel in LWR's) are not significant in terms of the radiological impact to the environment.

2.2 Fuel Reprocessing

If there is no recycle of uranium or plutonium, fuel reprocessing will not be necessary, and spent fuel will be stored as it is discharged from the reactors, without further treatment. Therefore the environmental effects of constructing and operating reprocessing and high level waste treatment facilities are adverse effects which cannot be avoided if uranium only or uranium and plutonium are recycled. However, the analyses presented in CHAPTER IV show the environmental effects to be small fractions of levels which have been established as permissible in the health, safety and environmental standards of the authoritative Federal, State, or international bodies.

Plutonium recycle is not expected to have significant effects on the capacity or effluents of the spent fuel reprocessing industry. The spent fuel to be reprocessed in the period from 1975 through the year 2000 is estimated to total 115,000 metric tons of uranium plus plutonium. About 11% of this amount would be mixed oxide fuel if both uranium and plutonium are recycled. A detailed discussion of the environmental effects of fuel reprocessing is contained in CHAPTER IV, Section E.

Since the same number of reprocessing plants would be required for the recycle of uranium and plutonium as for the recycle of uranium only, there would be no need for additional major construction to accommodate plutonium recycle. The use of the facilities for separation, purification and recycle of plutonium in addition to uranium will not add appreciably to the cost or to the health and safety precautions involved in decommissioning a reprocessing plant that may be shut down at some future date. Therefore, whatever plans were acceptable for decommissioning a reprocessing plant that had been used for the recycle of uranium only will be equally acceptable for a plant used to recycle both uranium and plutonium.

Although improved effluent control technology may be implemented at some future date, the assumption for this statement has been that all tritium, carbon-14 and krypton-85 in the irradiated fuel will be discharged at the reprocessing plants. With this assumption, the projected 1975-2000 total body dose commitment resulting from reprocessing activities is 1,080,000 person-rem for the U.S. population, and this decreases to 1,070,000 person-rem with plutonium recycle, because of the reduction in ^{14}C and ^{85}Kr formation in mixed oxide fuel. Of course, with no recycle, these dose commitments would be zero, because there would be no reprocessing plants. The recycle dose commitments are about 0.1% of the dose commitments from natural background.

Maximum levels of surface contamination near the plants, due to deposition of plutonium over the 26-year period as a result of reprocessing spent mixed oxide fuels, have been estimated to be so low as to represent an insignificant hazard potential.

2.3 Mixed Oxide Fuel Fabrication

Recycle of plutonium in LWR's requires production of a mixed uranium dioxide-plutonium dioxide fuel, a step that is not a part of the uranium LWR fuel cycle. Detailed assessments of this added step are given in CHAPTER IV, Section D.

The mixed oxide fuel generally contains less than 5% PuO_2 in natural UO_2. It has been projected that the annual production of mixed oxide fuel will reach approximately 2,600 MT of heavy metal by the year 2000. The model mixed oxide fuel fabrication plant has been assumed to have a capacity of approximately 360 MT heavy metal/year--enough for about 30 reactor reloads at the model 1.15 SGR level. With plant sizes varying from 300 to 400 MT per year, the industry is projected to have eight MOX fuel fabrication plants in operation in the latter part of the 26-year time period under study.

The annual releases of chemicals of possible environmental concern from the model mixed oxide fuel fabrication plant are 250 grams HF, 430 kg NO_x, and 60 kg NH_3. No damage to vegetation is expected as a result of these routine airborne releases under average meteorological conditions, since they are less than 0.1% of permissible levels. The quantity of HF accumulated in or on forage plants is not expected to reach, at any time, levels which are toxic to livestock.

It is estimated that each model fuel fabrication plant would generate approximately 1,430 drums of plutonium bearing solid waste each year. Low level plutonium waste would be sealed in containers and stored in a Federal repository where it is expected to have no appreciable environmental impact.

The mixed oxide fuel fabrication plants required to meet projected U.S. demands through the year 2000 are estimated to require a land commitment of about 8,000 acres, probably located in relatively remote areas. Thus it is judged that this loss in availability of land involves acreage that, in the short term, would be devoted to a primary industry such as forestry or farming. Such temporary loss appears to be

insignificant compared to the land that would be utilized as plant sites by this industry as a whole or compared to the large acreage of similar lands that are productive (or could be productive but presently are not). Approximately 90% of the land committed to mixed oxide fuel fabrication facilities would be undisturbed, but would probably be fenced and withdrawn from active use. Impacts of a long-lasting nature--which may remain for the life of the plants or even longer, depending upon disposition of the facilities at the time of decommissioning--are small changes in land use, some destruction or degradation of plant life and animal habitat, and small alterations of surface water drainage patterns.

While the MOX plants are in operation, the principal unavoidable adverse impacts of mixed oxide blending and fuel fabrication are associated with release of small amounts of radioactivity and chemicals. Small quantities of various radioactive isotopes of plutonium, americium, and uranium would be released to the environment. During the period 1975-2000, the industry (all MOX plants) would release to the biosphere about 770 mCi of alpha emitters, of which 640 mCi would be released to the atmosphere and 130 mCi would be released to rivers or streams. These amounts are less than 1% of permissible levels. There would be some ground deposition of particulate plutonium compounds but this is not expected to result in detectable changes in the terrestrial ecosystem.

The total plutonium release from the MOX fuel fabrication industry from 1975 through the year 2000 could cause a dose commitment to the bone of 14,000 person-rem and a commitment to the lung of 300 person-rem for the general population of the United States. The closest theoretical resident would receive an annual dose commitment of less than 20 millirems to any organ except the bone, which would receive an annual dose commitment of about 170 mrem. Theoretically, this would increase the risk of bone cancer fatalities in the U.S. population by 0.0078, and the risk of lung cancer fatalities by .0017, both increases imperceptible among the 150,000 cancer and 6,750,000 lung cancer fatalities that normally occur in the same population.

2.4 Supporting Uranium Fuel Cycle

The supporting uranium fuel cycle, which will be carried out following essentially the same procedures whether or not plutonium recycle is used, includes: uranium mining, uranium milling, conversion of the mill produced yellowcake to uranium hexafluoride, enriching the uranium-235 content of the hexafluoride, converting enriched uranium hexafluoride to uranium dioxide and fabricating uranium fuel assemblies for LWR's. When reprocessed uranium is fed to an enrichment plant, reactor produced isotopes ^{232}U, ^{233}U and ^{236}U are present with traces of reactor produced plutonium and neptunium, and traces of fission product isotopes of technetium, ruthenium, niobium and zirconium which are carried over with uranium in the reprocessing and purification steps. For enrichment of natural uranium in the no recycle case, almost 90% of the small amounts of radioactivity in airborne effluents and 50% of the even smaller releases of radioactivity in liquid effluents are due to the trace amounts of naturally occurring ^{234}U. With recycle uranium, over

90% of the radioactivity comes from ^{99}Tc. Comparatively weak radiation from these small quantities of radioactive materials does not cause an occupational dose of sufficient magnitude to necessitate the addition of shielding.

Enrichment Liquid and Gaseous Releases (Curies)

for the Period 1975 through 2000

	No Recycle	U Recycle	U & Pu Recycle
^{234}U	3.5	3.1	2.1
^{235}U	.104	.104	.104
^{238}U	.49	.59	.47
^{106}Ru	-	7.5	6.4
^{99}Tc	-	529.	451.
Others	-	.71	1.93
Total	4.094	541.0	462.0

These releases by the entire enrichment industry over a 26-year period are of negligible impact.

2.5 Transportation

Estimates of adverse environmental effects associated with the transportation component of the fuel cycle have been based on average conditions for such important parameters as shipping distance, radiation level, package content, population density, and accident frequency. The detailed analysis for the year 2000, given in CHAPTER IV, Section G, shows that the transportation steps in the mixed oxide fuel cycle cause an average radiation dose per person of 32 mrem per year in the highest exposed group (transportation workers). This is in contrast with the average dose of about 23 mrem per person in the highest exposed group with uranium only recycle and 22 mrem per person without uranium or plutonium recycle.

The cumulative radiation dose to all workers in the transportation steps affected by plutonium recycle is about 610 person-rem per year for the year 2000 in contrast to 390 person-rem per year for uranium only recycle and 390 person-rem per year for no recyle of uranium or plutonium. The number of miles accumulated in transporting fuel cycle materials for the 26-year period from 1975 through 2000 is greatest when there is no recycle (due to the shipment of irradiated fuel to the Federal repository), about 6% less when both uranium and plutonium are recycled, and lowest of all (17% less) when uranium only is recycled. The effect of fuel type is not significant in terms of the impact of heat, weight or traffic density resulting from the shipment of new fuel, spent fuel or high level waste. The differences are most significant in terms of handling increased quantities of natural uranium feed materials if there is no recycle, and in handling larger quantities of other than high level radioactive wastes if spent fuel is reprocessed.

Because of the package design and quality assurance, the probability that a package will be involved in an accident severe enough to breach the containment is estimated to be less than one chance in a thousand during the period from 1975 through the year 2000. This accident probability is not dependent upon whether plutonium is recycled.

2.6 Radioactive Waste Management

Radioactive wastes generated during fuel cycle operations are classified into two categories--high level wastes and other-than high level wastes. If there is no recycle of plutonium or uranium, all high level wastes will be contained in the spent fuel, thus the spent fuel elements themselves will constitute the waste product which will be permanently stored. Near-term management of high level wastes from reprocessing will include solidification of the wastes and storage of the solidified wastes in a Federal repository. Fuel cycle wastes which are other-than high level wastes and which do not contain significant quantities of plutonium will be disposed of in licensed commercial burial grounds. Proposed amendments of 10 CFR Part 20 will require storage of plutonium bearing wastes in a retrievable form at a Federal repository. CHAPTER IV, Section H, contains details on waste management programs.

The impact of plutonium recycle on waste management will be to reduce the quantity of wastes associated with the uranium feed chain activities (mining, milling, UF_6 production and enrichment) by about 12% in comparison to uranium only recycle, to increase plutonium bearing wastes generated at the reprocessing plant by 1% to 2%, and to generate low level alpha containing wastes from mixed oxide fabrication plants. Wastes generated during LWR fuel reprocessing operation will not be significantly altered in kind or quantity as a result of plutonium recycle. In comparison to not recycling uranium or plutonium, uranium only recycling will reduce the uranium feed materials requirements by 12% but will increase enrichment requirements by about 1% to provide additional ^{235}U content needed to compensate for the increased parasitic neutron capture caused by ^{236}U. See CHAPTER IV, Section F, paragraph 4.3.

Plutonium contaminated wastes in the other than high-level category requiring retrievable storage will be generated at the reprocessing plants and at the mixed oxide fuel fabrication plants. Plutonium recycle will result in about a 12% increase in the volume of these wastes--from a cumulative total volume of about 129,000 cubic meters for the period 1975-2000 without plutonium recycle (all generated at the reprocessing plants) to about 148,000 cubic meters with plutonium recycle. This increase in plutonium-contaminated wastes requiring storage at a Federal repository will result from operations at the mixed oxide fuel fabrication plants.

The high level solid wastes generated at the reprocessing plants are not judged to be increased in volume with plutonium recycle because the processing steps which generate high level wastes will be the same whether plutonium is recycled or only uranium is recycled. The heat emission of the wastes from an equilibrium plutonium

recycle will be increased over that emitted from high level wastes generated from reprocessing uranium oxide wastes only, because of the increased quantities of transuranium elements present. If the shipping cask is limited by its heat handling capability, then there could be an increase in the number of shipments of wastes.

Plutonium recycle does not significantly increase the radiation dose due to normal releases of radioactivity from waste management facilities. Reprocessing for plutonium or uranium recycle does not alter the quantity of high level wastes which must be stored. If there is no reprocessing the wastes will be contained in the fuel elements and will be stored in that form. Whether the fuel is reprocessed to recover uranium and plutonium or uranium only, essentially the same high level wastes will be generated. These wastes will be solidified and stored, and the quantity of radioactivity in it will be somewhat less than in the spent fuel elements, because the uranium or uranium and plutonium will have been removed and some of the gaseous fission products will have been released in the course of dissolving the fuel elements. In the case of the recycle of uranium only, it is assumed that plutonium will be left in the high level wastes and stored with them. It is not expected that this would increase the environmental impact of waste treatment or storage in normal operations.

It is conservatively estimated that radiation doses from the maximum credible accident involving a canister of segregated mixed oxide fuel waste would increase the 50-year bone commitment by a factor of about 2 (from 2.8 mrem to 5.6 mrem at 1,500 meters from the stack) and the whole body dose by about 10% (from 1.7 mrem to 1.9 mrem at 1,500 meters), as compared to an accident involving a canister containing only uranium oxide fuel waste. CHAPTER IV, Section H, gives details of the estimated environmental effects of various accidents.

Accidental opening of an improperly packaged container at a retrievable storage facility for plutonium-contaminated waste could result in significant radiation doses to a worker, but would have negligible impact on the general public at the reservation boundary which would be 500 meters from the incident on a 100-acre site.

The largest quantity of wastes expected to be consigned to licensed commercial burial grounds is that generated during reactor operation. The content and quantity of these wastes is not anticipated to vary substantially whether or not plutonium is recycled. The wastes generated at all LWR reactors during the period 1975-2000 will be about 3.8 million cubic meters, and will require about 500 acres of burial grounds.

2.7 Construction Impacts

MOX blending and fuel fabrication are plutonium recycle steps that would require construction of new facilities that would not have been required for uranium only recycle. Fuel reprocessing and the treatment of high level radioactive wastes from

reprocessing operations are additional fuel cycle steps requiring construction of new facilities that would not be needed if there were no recycle of uranium or plutonium. Unavoidable adverse construction impacts can be temporary, occurring only during construction, or relatively long term, at least for the life of the plant. Temporary impacts are dust and noise from construction activities and machinery, discharge of gaseous wastes from internal combustion engines, increased traffic on local roads, aesthetically undesirable appearance of construction activities and of temporary or incomplete buildings, increased suspended solids and siltation of nearby waterways, and possible social impacts on nearby communities because of the influx of a construction work force. As the level of construction activity declines, these effects will also tend to be reduced.

The land devoted to uranium and plutonium recycle facilities in the year 2000 is estimated to be approximately 8,000 acres for the projected eight MOX plants, with an additional 10,000 acres for the projected five reprocessing plants and their associated high level waste treatment facilities. The greatest environmental effect of decommissioning would occur if all 8,000 acres were permanently restricted against public access and controlled with respect to limitations in use. An associated permanent commitment for surveillance of the site would also be necessary.

2.8 Decommissioning Impacts

Construction of MOX fuel fabrication facilities involves a long term commitment for decommissioning the facility once its original use has been completed. The radiotoxicity and long half-life of plutonium are such as to require strict criteria for decommissioning. Three major approaches have been used in the past for assuring public safety after decommissioning:

- Thorough decontamination to reduce residual plutonium and other radionuclides to acceptably low levels, after which the facility may be reused for other nuclear (or non-nuclear) purposes;

- Decontamination followed by sealing of process equipment, rooms and the building to prevent access by the public; or

- Decontamination followed by removal of equipment and structures with restoration of the land to restricted or unrestricted use, according to conditions at the site.

Selection of the option to be followed will depend on a technical analysis and a cost-benefit study of the particular plant and site. It is possible that the building and some portion of the site will be permanently removed from public access, even after decommissioning. If the facility is permanently sealed to prevent public access and the site controlled to assure adherence to limitations in its use, it will be necesary to make provisions for long term surveillance to assure that requirements are being met.

In contrast to the no recycle option, the recycling of uranium alone or the recycling of uranium and plutonium will require facilities for reprocessing spent fuel and for treatment of the high level wastes from reprocessing. The construction and operation of these facilities also involve commitments for their decommissioning once the original use has been completed. The approaches to decommissioning the reprocessing and high level waste treatment facilities will be the same as these outlined above for MOX plants, but will be more difficult because of the large quantities of fission products which will have been processed in these facilities. Provisions for long term surveillance of the site will be required to ensure that criteria are being met for protection of public health and safety and of the environment.

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CHAPTER VII
MEANS FOR MITIGATING
ADVERSE ENVIRONMENTAL EFFECTS

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SUMMARY

The NRC, through its regulations and licensing review procedures, ensures that licensees provide effective means to limit the adverse environmental impact of their facilities and activities to levels that are as low as reasonably achievable (ALARA).

Measures and controls applied by NRC to limit environmental impacts include the establishment of standards and guides and the thorough technical review of site selection and design bases, quality assurance plans and procedures, construction activities, operating procedures, monitoring programs, transportation, waste management, and materials and plant protection considerations. To assure protection of public health and safety, the NRC staff must make a favorable determination on all of these factors prior to authorizing any activities with special nuclear material (e.g., plutonium).

Special requirements indicated by the above reviews may be appended as license conditions to cover such items as safety limits, safety systems limiting settings, limiting conditions of operation, design features, monitoring programs, administrative controls, and safeguards procedures.

NRC enforcement procedures provide for regular physical inspections of the facilities, equipment, operations, procedures and performance data.

Analyses contained in CHAPTER IV show that there will not be significant differential environmental impacts associated with plutonium recycle, taking into acount the measures and controls that are available today to limit adverse effects.

Additional mitigating measures may be feasible in the future to further reduce the differential adverse environmental effects through siting or design improvements, timing, monitoring, restoration, etc. Such potential mitigating measures are also identified and discussed in this chapter.

1.0 INTRODUCTION

The National Environmental Policy Act of 1969, implemented by Executive Order 11514 and the Council on Environmental Quality's (CEQ) Guidelines of August 1, 1973 (39 FR 20550), requires that detailed environmental impact statements clearly identify in one place the environmental effects that are adverse and unavoidable under the proposed action. The CEQ Guidelines also direct Federal agencies to include in their environmental statements, for purposes of contrast, a clear statement of how the avoidable adverse effects will be mitigated. This chapter addresses the latter issue.

Mitigation of the adverse effects identified in CHAPTER IV is a matter of course in NRC licensing practice. Through its licensing and inspection and enforcement functions, the agency routinely limits the adverse environmental impact of licensed activities to as low as reasonably achievable (ALARA) levels. For purposes of this statement, in evaluating each segment of the fuel cycle in CHAPTER IV, it has been assumed that, essentially, the technology available today will be utilized to achieve ALARA levels of impact on the environment. Thus, no credit has been taken for future technological advances. CHAPTER VI summarizes the differential environmental effects that could occur and which would be adverse and unavoidable should plutonium recycle be introduced into the LWR industry. This chapter summarizes the measures and controls now used to limit adverse effects and identifies some additional provisions that can reasonably be expected to be employed in the future. Possible future mitigating measures which could be taken to further reduce the differential adverse environmental effects--specific siting or design improvements, timing, monitoring, restoration, etc.--are identified and discussed. This chapter is not intended to be a discussion of the alternative dispositions of plutonium (see CHAPTER VIII).

2.0 PRESENT MEASURES AND CONTROLS TO LIMIT ADVERSE EFFECTS

A person or organization desiring to carry out activities involving plutonium (possession, use, processing, transfer, etc.) must have a Special Nuclear Materials (SNM) license, issued by NRC. Regulations require that, where appropriate, an applicant for such a license furnish to NRC a complete description of the applicant's proposed activities, organizational structure, managerial and administrative controls, materials and plant protection controls, equipment and facilities, health and safety programs, an accident risk evaluation, and a criticality analysis. This information provides a basis for the Commission to make the following determinations: whether the applicant is qualified by reason of training and experience to use the equipment, whether his procedures for protection of health and safety are adequate, and whether the SNM in his possession is adequately safeguarded.

In conjunction with the application for such a license, an applicant must also submit a detailed environmental impact report. The report must contain sufficient information to allow the NRC staff to assess the potential environmental effects of the proposed activity, including those of construction and operation of any facility in which activities involving licensed material will be carried out. To ensure that

issuance of a license will be consistent with the national environmental goals, as set forth by the National Environmental Policy Act of 1969, the staff then performs an independent assessment of the environmental consequences should the license be granted. The review process must include a balance or comparison of the environmental costs of the proposed activity versus the benefits gained, as well as consideration of the alternatives that may alter this balance.

Before authorizing plutonium recycle activities, the NRC must evaluate the safety, environmental, and materials and plant protection considerations involved and make a favorable determination on all considerations. Specific factors that can limit any adverse effects and which are considered in the safety review and analysis of the proposed activities of an applicant are: site selection for the planned facility, proposed design bases, proposed construction activities, proposed operational procedures, proposed monitoring programs, transportation and waste management plans. Plans for future decommissioning when the plant is no longer operating must be considered and adequately provided for before NRC will authorize construction of a new plant.

In addition to the licensing reviews of plans and specifications, the NRC performs inspections during construction, and later during operation, to assure that all requirements are being met. The physical inspections are performed by technical experts from the NRC field inspection staff who examine the facilities, equipment, procedures, and operating and monitoring data to assure compliance with all requirements of the NRC regulations and special conditions of the license. Items of noncompliance must be rectified by the licensee; flagrant or especially serious violations can result in NRC's requiring the facility to be shut down or imposing a fine upon the licensee. When decommissioning of a facility is proposed, NRC review of plans and inspections of performance at the site will be carried out to assure the enforcement of all regulatory requirements for protection of health, safety and the environment.

2.1 Site Selection

Since the fuel cycle involves a wide diversity of operations, it is not feasible to establish in advance all the environmental characteristics that are of critical importance for a particular function at a specific site. Thus, the details of siting are now, and will continue to be, handled on a case-by-case basis, balancing the risks associated with each combination of site and facility design against the benefits of construction and operation of the facility at that particular site. Fuel cycle facilities in which plutonium is processed are, in general, expected to be constructed on relatively remote sites. The NRC takes the following factors into consideration in determining the acceptability of a site:

- Population density and land use characteristics of the site environs
- Physical characteristics of the site, including seismology, meteorology, geology and hydrology

A site for a plutonium processing fuel cycle facility (as for all nuclear facilities) is, in general, acceptable only if its characteristics are such that the proposed facility with its engineered safety features can be constructed, operated and decommissioned thereon while:

- Presenting no undue hazard to employees, individual members of the public or the general public
- Having an acceptable impact on the environment
- Appropriately protecting special nuclear material

2.2 Design Bases

Each applicant for a license to operate a facility must submit a Safety Analysis Report (SAR) including information that describes the facility, presents the design bases and the limits on its operation, and provides a safety analysis of the structures, systems, and components and of the facility as a whole. It must also include, among other things, the following:

Descriptions and analyses of the structures, systems, and components of the facility must be provided, with emphasis upon performance requirements, the bases (with technical justification) upon which such requirements have been established, and the evaluations required to show that safety functions will be accomplished. The descriptions must be in sufficient detail to permit understanding of the system designs and their relationship to safety evaluations. For nuclear reactors, such items as the reactor core, reactor coolant system, instrumentation and control systems, electrical systems, containment systems, other engineered safety features, auxiliary and emergency systems, power conversion systems, radioactive waste handling systems, and fuel handling systems must be discussed insofar as they are pertinent. For facilities other than nuclear reactors, such items as the plant structures and the chemical, physical, metallurgical, or nuclear process to be performed, instrumentation and control systems, ventilation and filter systems, electrical systems, auxiliary and emergency systems, and radioactive waste handling systems must be discussed insofar as they are pertinent.

The SAR should describe the kinds and quantities of radioactive materials expected to be produced and/or handled in the operation and the means for controlling and limiting radioactive effluents and radiation exposures within the limits set forth in Part 20 of the NRC regulations.

The applicant is required to describe the managerial and administrative controls used to assure safe operation. Appendix B of Part 50, "Quality Assurance Criteria for Nuclear Power Plants," sets forth the requirements for the quality assurance program for nuclear power plants and fuel processing plants. The information on the program shall include a discussion of how the applicable requirements of Appendix B will be satisfied.

Each license authorizing operation of a production or utilization facility of a type described in Part 50 also includes Technical Specifications derived from the analyses and evaluation included in the Safety Analysis Report. Technical Specifications, where appropriate, include items in the following categories: safety limits and limiting safety system settings, limiting conditions for operation, surveillance requirements, design features, and administrative controls.

NRC regulations stipulate that radioactive materials in effluents released to unrestricted areas from licensed facilities must be kept as low as reasonably achievable. The as low as reasonably achievable concept takes into account the state of technology and the economics of improvement in relation to benefits to the public health and safety and in relation to the utilization of atomic energy in the public interest. The limitation of adverse environmental impacts to as low as reasonably achievable levels is an important objective in the design, construction, and operation of individual plutonium recycle facilities and the associated transportation operations. Construction of the principal structures, systems, and components of plutonium recycle facilities is reviewed by NRC to determine that the design bases of the principal structures, systems, and components, and the quality assurance program provide reasonable assurance that environmental releases are limited to levels as low as reasonably achievable and that the facilities include protection against natural phenomena and consequences of potential accidents.

The design criteria of mixed oxide fuel fabrication plants recognize that the unique characteristics of plutonium require additional safety features as compared to other chemical plants. Consequently, provision is made for the multiple confinement of all plutonium bearing materials. The building ventilation system is typically divided into separate supply and exhaust systems. All process steps are performed in airtight sealed enclosures (gloveboxes) designed specifically for the safe confinement of radioactive materials. These enclosures are constructed of stainless steel with transparent window material; special airtight gloves are installed to permit manual operations while protecting workers from contact with glovebox inventories. Transfer of materials out of a glovebox is accomplished by using bagging procedures that preclude release of radioactive material into operating areas. The air in the gloveboxes is exhausted through a number of high efficiency particulate air (HEPA) filters in series effectively removing radioactive particulates before discharge to the atmosphere.

Several of the plutonium isotopes emit neutrons by spontaneous fission. Gamma radiation is also emitted in the radioactive decay of plutonium, especially from the ^{238}Pu, ^{239}Pu, and ^{240}Pu isotopes and from the ^{241}Am formed by decay of ^{241}Pu. The neutron and gamma radiations are low intensity, but when large quantities of plutonium are handled or when the plutonium is in a relatively pure, concentrated form, shielding may be required and the use of gloves in gloveboxes may be sharply curtailed to minimize radiation exposures of hands. Design criteria for MOX fabrication equipment require the use of shielding and of mechanical handling equipment where needed to protect workers.

Plutonium has a smaller critical mass than highly enriched ^{235}U and a much smaller critical mass than the low enriched uranium used in LWR fuels. Therefore, the design criteria for MOX fuel fabrication plants require special techniques for preventing accidental criticality. Safety features such as safe-geometry vessels, built-in poison controls and operating procedures to limit plutonium masses and concentrations in processing equipment are required, in combination with administrative controls, to prevent plutonium from collecting in sufficient quantities to form a critical mass.

The structures and equipment serving as confinement barriers for radioactive materials in mixed oxide fuel fabrication plants and reprocessing plants are designed to withstand forces resulting from natural phenomena, such as tornados, hurricanes, floods and earthquakes.

Fuel reprocessing plants are designed to protect plant personnel and the public from inhaling, ingesting, or becoming contaminated by radioactive materials or from being exposed to radiation. The processing operations are performed within heavily shielded cells (restricted access). Processes are controlled from outside these shielded cells by remote operation from supporting galleries (limited access), stations, areas, and aisles (normal access). A control room and emergency utilities also are provided to enable the operating personnel to perform an orderly shutdown of the plant and maintain the process inventories in a safe condition, even in the event of an accident.

Process cells involve high levels of radiation and therefore have floors and walls several feet thick, constructed of reinforced concrete for adequate shielding.

Most of the process vessels within cells are designed to withstand a design basis earthquake with respect to support of the vessels and confinement of solutions within the vessels.

The reprocessing plant releases small quantities of gaseous radioactive effluents to the environment via the main process stack, which exhausts to the atmosphere about 100 meters above natural grade. Components of the radioactive effluents from reprocessing plants which contribute the largest population dose are tritium, carbon-14 and krypton-85, and these are well within permissible limits. Prior to release through the stack, gaseous effluents from the process and waste storage systems are filtered or chemically treated or both, to reduce the radioactive and chemical contents to as low as reasonably achievable levels.

The building ventilation exhaust air is routed through at least two series of high-efficiency (HEPA) filters which effectively remove radioactive particulates before discharge to the atmosphere. Excess process condensate is decontaminated by evaporation and condensation, and then the decontaminated water may be revaporized and discharged to the atmosphere through a 100-meter main stack. The process off-gases are routed through a decontamination equipment train including condensers, separators, scrubbers, absorbers, and multiple HEPA filters.

High level wastes and low level radioactive liquid wastes from off-gas systems, solvent washes, and other sources are concentrated and stored in stainless steel tanks within underground stainless steel lined vaults pending conversion to a solid form for eventual transfer to a Federal repository with other solid wastes. However, at least one proposed processing scheme calls for direct conversion of high level wastes to solid form with minimal storage as a liquid.

The cooling water discharged from the plant contains essentially no radioactive liquid effluents. All chemicals used in the reprocessing plant are retained for reuse, are consumed in the process, or are discharged to the waste storage tanks for interim storage pending ultimate solidification and transfer to a Federal repository for long term management.

The high value of plutonium, and incentives to minimize the volume of contaminated waste, give rise to efforts to recover the plutonium contained in wastes or off-specification products. Extensive scrap recovery operations are expected to be performed to minimize the quantity of plutonium requiring packaging for long term management.

2.3 Construction Activities

Many of the potential effects of construction activities of reprocessing and mixed oxide plants can be reduced by appropriate selection of a site and by applying proper construction practices and controls. For example, a site on previously industrialized land, strip-mined land, or a former power plant site would not be subject to the construction activity effects that would be encountered on farm or recreational land. Many techniques are known that can minimize wind and water erosion: protecting the bare soil by restoration of vegetation, covering with mulch, sprinkling, stabilizing with gravel, grading and shaping the spoil piles, scheduling the time that ground is disturbed to avoid critical periods such as spring thaw, conservation of topsoil to spread over exposed subsoil, and others. Some of these same methods can be used to reduce dust raised by vehicles traversing exposed soil.

Cleared woodland material may be used for commercial lumber or pulpwood, where possible. Otherwise it may be burned in accordance with local regulations.

The overburden must be stored in a way that minimizes erosion during construction, or be hauled to a sanitary landfill. At the end of construction, the stored overburden may be redistributed as top soil. Control of surface runoff is provided to minimize soil erosion and steam turbidity.

No concrete or watered cement should be dumped into nearby rivers or streams or indiscriminately dumped on land. A spoils area must be designated for the disposal of waste concrete mixtures.

Temporary buildings may be erected on the site for use during the construction of the plant. These generally are one story metal buildings that should not be

objectionable if seen. Any trees located on the periphery of the site may be left intact, in which case these buildings are not readily visible from offsite roadways. Of all the facilities temporarily constructed or used during construction, the only items that protrude above the tree lines are the construction cranes. The land areas disturbed during construction are landscaped as appropriate to minimize the long term impact on the environment.

2.4 Operational Procedures

Prior to authorizing activities involving plutonium, the NRC staff performs safety, environmental, and materials and plant protection reviews of the proposed activities to ensure protection of the public health and safety.

An application for a license to possess and use plutonium will be approved only after the applicant clearly demonstrates that, among other things:

- The applicant is qualified by reason of training and experience to use the material for the purpose requested in accordance with the regulations.

- The proposed equipment and facilities are adequate to protect health and minimize danger to life or property.

- The proposed procedures are adequate to protect health and to minimize danger to life or property.

Once a license has been issued, NRC makes periodic inspections, both announced and unannounced, to assure that the licensee is operating in accordance with the license conditions and the Federal regulations. State representatives may also make inspections.

Administrative and operating procedures of licensees are designed to prevent the occurrence of accidents. The probability of accidents resulting from operator error is minimized through a comprehensive training program conducted by the licensee and reviewed by the NRC covering activities involving plutonium, and through the design safety features of plants. The training program required by NRC regulations includes courses in radiological safety and nuclear safety for all employees who work in plutonium areas.

The content of such courses typically includes discussions of: radiation measurement units, the biological effects of exposure to penetrating radiation, means of limiting exposure to external radiation, methods for prevention of internal exposure, use of protective clothing and monitoring devices, radiation safety rules and policies, the concepts of nuclear criticality, alarm systems, emergency and evacuation procedures, use of survey instruments, administrative procedures, and government regulations.

Because of the possibility of a serious accident and because of the presence of hazardous materials, each applicant must establish a plan to cope with emergencies that might arise, to protect the health of employees and the public, and deal effectively with the emergency in a timely manner.

Elements of the emergency plan include the following: each licensee is required to have an alarm system in each area containing fissionable material so that a nuclear criticality excursion is immediately detected. The following equipment must be onsite or available on call: self-contained breathing apparatus, portable fire extinguishers, battery-operated lights, portable air samplers, radiation detectors, and protective clothing. Agreements must be made with various civil and private organizations for assistance in the event of a major emergency.

2.5 Monitoring Procedures

In order to quantify any environmental effects resulting from activities involving plutonium, the licensee must maintain a monitoring program that includes the sampling and analysis of plant effluents and biota and other environmental media exposed to the effluents.

In general, an applicant is required to have ecological study programs. The initial program establishes the baseline biological, chemical, physical, and ecological data before construction begins. It is followed by field programs during the construction and operation of the facility. The programs detect any significant adverse environmental impact and permit timely corrective action. The aquatic ecology program generally includes sampling of both surface and ground waters. The floral and faunal terrestrial program generally includes the gathering of information on species identification and population density in both forested and nonforested areas.

All air effluents from process systems and process areas that contain radioactive material in dispersible form must be continuously sampled. When analysis indicates a release of radioactivity from the stack in excess of some chosen limit (usually 10% or less of the restricted area maximum permissible concentration on an annual basis, as defined in 10 CFR Part 20, Appendix B), corrective action must be taken. When an action level is reached, an investigation will be made to clearly determine the reason for the abnormal releases. If it is indicated that the abnormal release of radioactive effluents will continue, the process activity must be curtailed as necessary to correct the defect and reduce releases to an acceptable level.

2.6 Transportation

Most shipments of radioactive materials move in routing commerce by conventional transportation equipment. Therefore, shipments are subject to the same transportation environment, including accidents, as nonradioactive cargo. Although a shipper may impose some conditions on his shipment, such as speed limitations, providing an escort, etc., most of the conditions to which his shipment is subjected and the probability of his shipment being involved in an accident are not subject to his control. The public and transport workers are protected from radiation during the

shipment of radioactive materials by the container designs and limitations on the contents, set according to the quantities and types of radioactivity and the standards and criteria for package design and control. Safety in transportation does not depend on special routing, although special routings are used at some bridges and tunnels to avoid possible interference with the flow of traffic if an accident should occur.

Primary reliance for safety in transport of radioactive material is placed on the packaging. The packaging must meet applicable Federal and State regulatory standards, which require that the packaging shall prevent the loss or dispersal of the radioactive contents, retain shielding efficiency, ensure nuclear-criticality safety, and provide adequate heat dissipation under normal conditions and under specified accident damage test conditions (i.e., the design basis accident). The allowable radioactive materials content of packages not designed to withstand accidents is severely limited.

Protection against external radiation is provided by limitations on the radiation levels at the outside surface of packages of radioactive materials and by storage and segregation provisions. The number of packages in a single vehicle or area is limited to control the aggregate radiation level and to provide nuclear criticality safety. Minimum separation distances from people are specified for loading and storing packages of radioactive material to keep exposures to a minimum.

2.7 Waste Management

As mentioned in CHAPTER IV, Section H, the radioactive wastes resulting from both enriched uranium and mixed oxide fuel cycles can be categorized as high level and other-than high level. The "high level liquid radioactive wastes" are those aqueous wastes resulting from the operation of the first cycle solvent extraction system and the concentrated wastes from subsequent extraction cycles in a facility for reprocessing irradiated reactor fuels. The NRC regulations governing such high level waste management are contained in 10 CFR Part 50, Appendix F, and briefly state that:

- Facilities for the temporary storage of high level radioactive wastes may be located on privately owned property.

- A fuel reprocessing plant's inventory of high level radioactive liquid waste will be limited to that produced in the prior 5 years.

- High level liquid wastes shall be converted to a dry solid as required to comply with this inventory limitation and placed in a sealed container prior to transfer to a Federal repository in a shipping cask meeting the requirements of 10 CFR Part 71.

- The dry solid shall be chemically, thermally, and radiolytically stable to the extent that the equilibrium pressure in the sealed container will not exceed the safe operating pressure for that container during the period

from canning through a minimum of 90 days after receipt at the Federal repository.

- All of these high level radioactive wastes shall be transferred to a Federal repository no later than 10 years following separation of fission products from the irradiated fuel.

- Upon receipt, the Federal repository will assume permanent custody of these radioactive waste materials, although industry will pay the Federal government a charge which, together with interest on unexpended balances, will be designed to defray all costs of disposal and perpetual surveillance.

- ERDA will take title to the radioactive waste material upon transfer to a Federal repository.

- Disposal of high level radioactive fission product waste material will not be permitted on any land other than that owned and controlled by the Federal government.

- Before decommissioning of a fuel reprocessing plant, transfer of all significant radioactive wastes to a Federal repository shall be completed.

- Criteria for the extent of decontamination to be required upon decommissioning and license termination will be developed by the NRC. Opportunity for public comment will be provided.

All safety and environmental aspects of managing high level radioactive wastes at the reprocessing plant site are controlled by the regulatory, licensing and inspection and enforcement process. 10 CFR Part 50, Appendix F, speaks generally to this point and all technical specifications regarding design and operation of the plant are defined in detail during the licensing review and stated in detail in the actual operating license. Requirements are imposed on the licensee for safe packaging design and other safety requirements with respect to transporting this solidified waste to a Federal repository.

Appendix F reflects the concept that high level radioactive waste from a reprocessing plant would be stored only temporarily at the reprocessing site, solidified and transferred to a Federal repository for disposal. ERDA's present plans are to construct a demonstration facility for disposal of high level radioactive wastes in a geologic formation. This would include surface facilities for temporary holding of waste containers prior to permanent disposal underground.

For other than high level waste, the NRC has under consideration a new rule prohibiting shallow ground burial of wastes containing transuranium alpha activity. Similar provisions are already in effect by ERDA at its burial grounds. The commercial burial grounds in the States of New York, Kentucky, South Carolina, Illinois and

Nevada are precluded from burial of transuranic waste by State action. Wastes containing transuranium elements will have to be sent to a Federal repository.

The NRC evaluation of a commercial burial site prior to making a licensing decision on acceptability involves two significant safety and environmental considerations. First, the geological, hydrological and climatological characteristics of the site must be such as to assure that buried radioactive waste will not migrate into water supplies or otherwise become available for inhalation or ingestion by man. Second, commercial burial sites must be on land owned by the Federal or a State government to assure long term control.

Quantities of plutonium bearing wastes of commercial origin are presently very limited, and have until very recently been disposed of by burial in commercial facilities. The quantity of plutonium in commercial burial grounds is relatively small and is dispersed through large volumes of material. Chemical and physical characteristics of plutonium are such that migration in soil or ground water is unlikely.

A sharp increase in the amount of plutonium contaminated waste is expected to occur if plutonium recycle in LWR fuels is authorized. For example, it is estimated that there will be an increase in the cumulative total from about 4.5 to 5.2 million cubic feet of plutonium waste containing a few thousand kilograms of plutonium accumulated by the year 2000. The methods for safe management of this waste are discussed in CHAPTER IV, Section H.

2.8 Safeguards Considerations

The NRC regulations require that information on nuclear materials safeguards be submitted with each application for a license to possess at any one time special nuclear material in a quantity exceeding one effective kilogram of special nuclear material and to use such special nuclear material for activities other than those involved in the operation of a nuclear reactor or involved in a waste disposal operation, or as sealed sources. The safeguards considerations will be discussed in detail in a separate supplememt to GESMO.

3.0 POTENTIAL MEASURES TO FURTHER MITIGATE ADVERSE EFFECTS

The nuclear industry as it now exists is the product of nearly 30 years of development. Yet it is not static--inevitably an industrial technology as complex as this, in order to be responsive to the public interest and to exploit recent advances, must undergo continual refinement and development. Additional measures to further limit any adverse effects may be possible as a result of the development of regulatory criteria or guidelines for the industry or as a result of continued or newly initiated research and development efforts leading to improved facility design features. Decisions on use of these alternatives would be made during the planning, design and licensing activities required for individual facilities. The following is a discussion of measures that could further reduce any adverse effects.

3.1 Site Selection

The staff is developing qualitative and quantitative siting criteria to assist applicants for licenses for recycle plutonium facilities in the selection of sites acceptable to the Commission, based on considerations of potential impact of design basis accidents on individuals living at or near the exclusion area boundary. The guidelines will include general criteria and requirements for reporting information relevant to most facilities, and specific radiological and distance criteria for siting recycle plutonium plants.

The expected effect of the site selection criteria will be to provide assurance that all nuclear facilities are planned with careful attention to the following items. These siting criteria are being applied in present licensing reviews and will be included in the siting criteria being developed for publication:

- The radiation dose commitment from any design basis accident of high consequence and very low probability would not exceed certain specified values for any individual at any point outside the site exclusion area.

- Land and water uses, geology, meteorology, demography and aesthetics, the ecology of the site and environs, as well as natural and cultural resources affected by the facility are considered in siting the facility.

- Protection of employees and special nuclear materials is being considered.

A possible alternative in the siting of recycle plutonium facilities is to require the centralization of fuel cycle activities in integrated fuel cycle centers. Under such an option, spent fuel would be shipped to a regional site for reprocessing and refabrication. Reload fuel would be shipped from the site to a nuclear power reactor. Such an arrangement would decrease the reliance on materials and plant protection programs and would diminish the transportation impact.

3.2 Design Bases

The NRC is continually developing ALARA design criteria to assist license applicants in the planning and designing of facilities to carry out activities involving special nuclear material. The criteria are based upon the cost and effectiveness of effluent treatment systems that could be used at plants processing plutonium bearing fuels. These criteria may require added confinement barriers and added treatment systems to decrease the amount of radioactive and nonradioactive materials released to the environment. The effectiveness of the alternate treatment systems under consideration is measured by comparing the quantities of radioactive materials released by the various systems and the relative impact of each release on the environment. The impact on the environment is assessed and compared with the radwaste treatment costs as the basis for the cost-benefit analysis which is used in the decision making process. The criteria establish as low as reasonably achievable releases from plutonium processing facilities. These guides are reviewed and updated periodically

to reflect the results of continued or newly initiated research and development efforts that may lead to improved systems.

3.3 Construction Activities

Many of the potential effects of construction activities can be reduced by appropriate selection of a site and by applying proper construction practices and controls. Future improvements in such practices and controls are not tied to the issue of plutonium recycle but any improvements will be utilized by the industry.

3.4 Means for Simplifying Future Decommissioning

Advance planning in the design stages can provide features which facilitate decommissioning at some future date. Aspects of plant design which can be planned in ways which simplify decommissioning include the following:[1]

- Avoidance of inaccessible pockets and cracks in which plutonium or other activity can accumulate and from which removal would be difficult

- Provision of surfaces that are easy to decontaminate

- Provision of adequate and complete drainage in all equipment and in process areas so that decontamination solutions drain into a collection system

- Use of containment systems that prevent release of plutonium or other radioactive materials under all foreseeable circumstances. If there are no releases of radioactivity, decommissioning will require only decontamination of the interior surfaces of the process equipment exposed to plutonium or other activity and almost surely will not require restrictions on future uses of the land surrounding the facility.

These special design features facilitate decommissioning. In addition, the difficulty and cost of decommissioning activities can be reduced by operating the facility in such a way as to assure maximum confinement of plutonium and other radionuclides at all times, with prompt and complete decontamination of spills, leaks or other releases.

3.5 Operational Procedures

Process operations are continually being improved or upgraded. Should subsequent developments in the process demonstrate that substantial environmental benefits, on a cost-effective basis, can be gained from their use, modifications to individual plants may (by regulation or voluntarily) be made by the applicant. Measures which

may become available through ongoing research and development programs to reduce impacts include elimination of some process steps, minimization of wastes and effluents, minimization of exposures of plant personnel, additional remoting and automation of processes, and additional shielding.

Releases of radioactivity and other pollutants from fuel fabrication facilities would be very low, as discussed in CHAPTER IV, Section D.

The potential future measures to reduce releases of radioactivity from fuel reprocessing plants are centered on use of processes for removing tritium and krypton-85 from the feed material prior to dissolution and on means for recycling essentially all liquids and gases brought into the plant. Neither tritium removal processes, krypton removal processes, nor the fluids recycle technique have been tested in plant scale operation; hence, projected improvements in fission product retention are speculative. Use of the voloxidation process for tritium removal from irradiated oxide fuels may be able to achieve retention of from 90% to 99% of the tritium. Employment of fluids recycle technique in conjunction with treatment of all effluent streams by the most effective means available is expected to provide significantly higher normal operation confinement factors* for various nuclides, or classes of nuclides.

Use of recycle in the ventilation air streams is expected to significantly reduce releases of radioactivity by greatly reducing the amount of building air that must be filtered prior to release.

3.6 Transportation

Measures which could be taken to further reduce the impact of transportation, if determined to be necessary, include minimization of the amount of material shipped, shipment on selected routings, and shipment along the shortest distance. As previously mentioned, integrated fuel cycle facilities could lessen the number of shipments of plutonium bearing materials. This alternative is discussed in CHAPTER VIII.

To reduce the likelihood and severity of accidents, shipments of plutonium could be restricted to certain speeds, roadways, times of day, and weather conditions, if considered necessary on the basis of risk analysis.

As discussed in CHAPTER IV, Section G, casks and packages for shipping plutonium bearing materials could be constructed with additional shielding to further reduce radiation dose levels at the surface of the container. Shipments of plutonium could be restricted to forms which are not dispersible. Further, the casks/packages could be designed to withstand accidents more severe than the credible accident assumptions.

*Ratio of input radioactivity to released radioactivity.

From experience and analysis of a broad spectrum of conceivable accidents and potential package damage, the conclusion has been reached that spent fuel shipping casks designed to meet the current regulatory standards for type B fissile material packages provide a high degree of resistance to damage in severe transportation accidents and breach of a cask is highly unlikely. Regulatory requirements are aimed at achieving cask designs such that the probability of occurrence of a breach is so low that the risk to the environment is acceptable.

Fire and impact are the accident conditions of principal concern. Protection against impact damage is assured when the total kinetic energy associated with a cask in motion can be absorbed by the cask or surrounding objects or both without producing a leak rate in the cask containment of greater than a specified acceptable amount. The allowable leak rate for spent fuel shipments is limited in current cask design concepts by the very small release rates allowed for ^{131}I and ^{85}Kr.

During a fire, the massive gamma shield of the cask, along with the latent heat absorption capability of the neutron shield, can provide a large heat sink both for the heat absorbed from the fire and for the decay heat from the fuel. The degree of fire protection provided by a particular cask design is, therefore, dependent mainly upon the heat capacity of the shield and the heat transfer characteristics of the cask surface exposed to fire. These are the major determinants of the length of time that a cask, which contains a given quantity of heat producing fuel, can be exposed to a specified temperature. Simply stated, the cask can absorb a given quantity of heat before internal temperatures become unacceptable. The quantity absorbed is dependent on the heat input to the cask and the time of exposure to a fire. The cask can endure very high temperatures, and consequently can withstand high heat inputs for short periods of time or lower heat inputs for longer periods of time. Any design feature that effectively increases the heat capacity of the cask shield provides additional fire protection.

In addition, administrative controls are used to mitigate the consequences of any accident involving a cask. An example of administrative controls is the establishment of emergency response teams (under ERDA leadership) that are trained, equipped, and constantly on call to cope with the consequences of accidents involving radioactive materials.

3.7 Waste Management

The other-than high level wastes generated in fabrication and other operations could be reduced in volume by techniques such as incineration, leaching or compaction, or a combination of these techniques. Such treatment involves substantial cost additions and additional safety considerations. However, it is expected that there will be an economic incentive to find ways to minimize plutonium waste generation during plant operations and thus to reduce a potential safety problem and substantial extra handling cost.

3.8 Safeguards Considerations

In order for any safeguards program to be successful in the long term, provisions must be included for continuing evaluation of changing sociological and political conditions. Accordingly, the NRC has continuing studies and evaluations in progress to assess and update safeguards measures to provide the necessary protection. Further details of the safeguards measures will be discussed in the supplement to GESMO.

REFERENCES

1. R. B. Chitwood, "Decontamination and Decommissioning of Licensed Fuel Reprocessing Plants," Proceedings of the First Conference of Decontamination and Decommissioning (D&D) of ERDA Facilities, Energy Research and Development Administration and Aerojet Nuclear Company, Report No. CONF-750827, August 1975.

GESMO

CHAPTER VIII
ALTERNATIVE DISPOSITIONS OF PLUTONIUM

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SUMMARY

This chapter identifies and analyzes alternative dispositions of plutonium produced in light water reactors (LWR's). Environmental and economic considerations for six possible alternatives are discussed, based on three broad directions: storing the plutonium for future use, immediate use of the plutonium, and never using the plutonium. This discussion provides the basis for the comparative evaluation of incremental benefits, costs, and risks associated with each alternative presented in the cost-benefit analysis in CHAPTER XI.

Projected uses of plutonium for neutron sources and for research and development activities, primarily in the fast breeder reactor (FBR) programs, will require a small percentage of the 700 metric tons (MT) of fissile plutonium likely to be recoverable from LWR spent fuel by 2000. Based on the projected installation rate and design parameters of FBR's, the net plutonium requirements for fueling these reactors would be lower than the projected annual plutonium production rate in LWR's for the remainder of this century. Therefore the major potential use for the large quantities of plutonium produced between now and 2000 is as a recycle fuel in LWR's.

The following alternatives covering the range of feasible or likely methods of handling plutonium were postulated and analyzed:

1. Prompt recycle of the recovered uranium as fuel in LWR's (1978), with temporary storage of recovered plutonium (until 1983).

2. Temporary storage of spent fuel elements for later recovery (1986) of plutonium and uranium.

3. Prompt recovery, reprocessing, and recycle of uranium (1978) and plutonium (1981) as fuel in LWR's. This alternative is used as a reference to which the other alternatives are compared.

4. In the draft GESMO, an alternative of prompt plutonium recycle with upgraded safeguards was designated as Alternative 4. Further analysis of the safeguards program in the preparation of the draft supplement on safeguards indicates that one level of safeguards will be provided for all levels of Strategic Special Nuclear Material (SSNM). Thus consideration of the safeguards program will be factored into all alternatives handling SSNM (1, 2, 3, and 5), and Alternative 4 as a separate alternative will be deleted from the Final Statement.

5. Delayed recovery, reprocessing and recycling of uranium (1986) and final geologic storage of plutonium.

6. Final geologic storage of spent fuel elements without consideration for later use.

Detailed discussions of the environmental and economic considerations for each alternative are presented in this chapter. Appendix A contains estimated environmental effects for each alternative in tabular form. The following is a summary comparison of the alternatives referenced to Alternative 3 as the base case:

Alternative 1 (Early Reprocessing, Delayed Plutonium Recycle)

This alternative would result in a slightly higher demand for uranium than the reference case, a slightly smaller MOX fabrication demand, essentially the same environmental impact, and a $153 million present worth cost penalty. This alternative is less attractive than the reference case.

Alternative 2 (Delayed Reprocessing, Followed by Plutonium Recycle)

Compared to the reference case, the demand for uranium is higher, fuel storage is increased, MOX fabrication is decreased, the total environmental impact is essentially the same, and a present worth cost penalty of $74 million is incurred. This alternative is also less attractive than the reference case.

Alternative 3 (Early Reprocessing, Prompt Plutonium Recycle)

This alternative is the proposed industry action and is considered as the reference case. It has the lowest cost and in most instances the least environmental impact.

Alternative 5 (Delayed Reprocessing, No Plutonium Recycle)

Alternative 5 would result in a much higher demand for uranium, enrichment services, and spent fuel storage than does the reference. It involves no demand for MOX fabrication. It would result in a 7% higher radiological impact and a higher environmental impact in water, land, and most combustion products. It incurs a present worth cost penalty of $3 billion. Alternative 5 appears much less attractive than any of the preceding alternatives.

Alternative 6 (No Reprocessing, No Recycle)

Alternative 6, the throwaway fuel cycle, would result in a much greater demand for uranium resources, enrichment, and fuel storage. It requires no fuel reprocessing or MOX fabrication. Compared to the reference case, it would result in greater land, water, and energy consumption, and about the same radiological dose commitment. It incurs a present worth cost penalty of $3.2 billion.

1.0 INTRODUCTION

The National Environmental Policy Act of 1969, implemented by Executive Order 11514, and the Council on Environmental Quality (CEQ) Guidelines of August 1, 1973,[1] require all detailed environmental statements to contain an assessment of alternative actions that could avoid or minimize adverse impacts. Previous chapters of this environmental statement assess the impact of introducing plutonium recycle as fuel in LWR's on an industrywide basis and identify means for mitigating adverse environmental effects.

This chapter identifies and evaluates reasonable alternative dispositions of plutonium.

This analysis centers particularly on alternatives that might enhance environmental quality or avoid some adverse environmental effects and considers the relative benefits that could be realized with each alternative. Furthermore, this chapter provides a basis for the comparative evaluation of incremental benefits and costs associated with each individual alternative disposition presented in the cost-benefit analyses, CHAPTER XI.

The first part of this chapter presents information that forms a necessary framework for the analyses that follow. The information consists of

- Plutonium production (Section 2.0)
- An enumeration of potential alternatives and reasons for eliminating those not given further detailed consideration (Section 3.0)
- Brief descriptions of the five selected alternatives (Section 4.0)
- The general approaches and bases used to predict the impacts of the alternatives (Section 5.0)

Sections 6.0 through 11.0 include detailed descriptions and analyses of the environmental, economic, and materials considerations for the alternative dispositions of the plutonium generated in operating LWR's. Materials and plant protection considerations will be discussed in a safeguards supplement. The earliest feasible schedule for reprocessing spent fuel and recycling plutonium as fuel in LWR's is used as the reference case to which the other five alternatives are compared.

2.0 PLUTONIUM PRODUCTION IN LWR's

Plutonium is generated in LWR's fueled with uranium. The production of plutonium during the normal life of the uranium fuel helps to support the neutron chain reaction and is responsible for a considerable amount of the energy generated by LWR's.

At the end of the normal reactor operating cycle the spent ^{235}U fuel contains fissile plutonium as well as fissile ^{235}U. This residue of fissionable material represents a potential energy resource that can be utilized to reduce the amounts of uranium and separative work necessary in nuclear power generation, thus extending uranium resources and minimizing nuclear fuel costs.

Various projections of nuclear power growth were considered in CHAPTER III, and two cases (Low Growth and Moderate Growth (High)) are considered here since they appear to bound the realistic projections of future growth. The amount of plutonium available from LWR spent fuel for use as nuclear fuel will depend on the number of reactors in operation. Estimates for the two growth projections are displayed in Table VIII-1.

Table VIII-1

CUMULATIVE PLUTONIUM FROM LWR'S
(metric tons fissile)

	Nuclear Generation Assumption	
Year	Low Growth	Moderate Growth (High)
1980	15	15
1985	72	74
1990	190	246
1995	396	521
2000	690	950

By the year 2000 the total fissile plutonium potentially available for recovery from LWR spent fuel should be in the range of 690 to 950 metric tons (MT).

3.0 POTENTIAL DISPOSITION OF PLUTONIUM

3.1 Current Uses of Plutonium

3.1.1 Neutron Sources

Plutonium produced in LWR's can be mixed with beryllium to provide a source of neutrons from the (α, n) reaction with beryllium. Such neutron sources are used for oil well logging, reactor startup, research and training. However, in the past few years, sources using ^{239}Pu have been largely replaced by americium-beryllium and $^{238}PuO_2$-Be neutron sources. The Savannah River Laboratory (SRL) development work and production of ^{252}Cf also makes this material available for neutron sources.[2,3,4]

The use of plutonium as a neutron source once exceeded 20 kg/yr, but it is doubtful that demand will ever again reach even this relatively small amount. Plutonium use for this application was only about 1 kg in 1973. Even at the former higher demand, the total plutonium required for neutron sources is insignificant compared to the quantities that will be produced in LWR's. Hence the utilization of plutonium as a neutron source is not a viable disposition of the quantities of plutonium generated in LWR's.

3.1.2 Research and Development

Very small amounts of plutonium are used in biological and environmental studies. The demand for significant amounts of plutonium in research and development is currently limited to test elements for experimental fabrication and materials performance purposes in various reactor systems. As discussed in detail in CHAPTER II, significant irradiations have been or are continuing to be carried out in the United States and extensive programs have begun or are continuing abroad.

For the liquid metal fast breeder reactor (LMFBR) program, fuel containing plutonium has been fabricated for FBR critical experiments and is now being fabricated to fuel the fast test reactor (FTR). Even though the programs have not yet been fully defined, plutonium may also be required for research and development directed at high temperature gas cooled reactor (HTGR) or gas cooled breeder reactor applications.

Quantities required for all research and development programs probably will not exceed 2,000 kg/yr.[5] This amount is small compared to the quantities of plutonium that will be produced in LWR's after 1980.

3.2 Utilization of Plutonium in Reactor Systems

3.2.1 Plutonium Recycle in LWR's

The technical feasibility of recycling plutonium in LWR's has been established by development efforts begun in 1957 and carried through to the present time. Mixed oxide fuel assemblies fabricated by commercial vendors are presently under test irradiation at three utility-owned LWR's. In one of these (a small commercial reactor, 70 MWe) about one-tenth of the rods are loaded with MOX fuel.

Designs for MOX fuel assemblies have been developed, and fuel management schemes compatible with existing uranium fuel loadings have been proposed by reactor vendors and fuel fabricators. These are routinely offered as options in nuclear fuel supply contracts with the nation's electric utility companies. From the perspective of both technical feasibility and customer acceptance, there appear to be no obstacles to the recycle of plutonium as fuel in LWR's. CHAPTER IV, Section C, reviews in detail the impacts of using recycle plutonium as fuel in LWR's.

Reprocessing plants to separate the plutonium from spent nuclear fuel for recycle are necessary. No reprocessing plants are now in operation. However, one privately owned plant operated from 1966 to 1971. It is now shut down for possible modification and expansion. A second plant was built but may never be operated since the owners have concluded that technical difficulties prevent operation. One other plant is under construction and could be operational, according to the owners' schedule, in 1978. However, based on a more realistic assessment of conditions it appears that there will be a substantial delay beyond this data. Industry plans to build another plant, but it is not likely to be in operation until the mid-1980's.

The economic incentive for plutonium recycle as fuel in LWR's depends on many factors, such as costs of separative work, yellowcake (U_3O_8), fuel fabrication, reprocessing, and waste disposal. Projected values for these variables and the resultant

economic analyses are discussed in CHAPTER XI. In general, the economic analyses show a significant incentive for the recycle of both uranium and plutonium from spent fuel.

3.2.2 Plutonium Utilization in Fast Breeder Reactors

Fast breeder reactors, in which fission is induced by neutrons with an energy in the vicinity of 100 keV or greater, have the highest breeding ratios when fueled with plutonium rather than ^{235}U or ^{233}U as the initial fissile material. In some forecasts,[8] FBR's are assumed to penetrate the nuclear market at about the same rate that LWR's penetrated the total electricity generation market beginning in 1967. The first FBR demonstration plant of 350 MWe capacity is estimated to be on line in about 1983; the second FBR demonstration plant of 800 MWe capacity is estimated to be on line in about 1990, and the first commercial 1,200 MWe FBR is projected to be on line in about 1993.[6] Where the advent of the breeders is considered in this study, this projected breeder schedule is the basis for the breeder projection. Therefore appreciable quantities of plutonium will not be required for FBR's until the 1990's.

Based upon the data from the ERDA NUFUEL program (discussed in paragraph 5.2 of this chapter) and shown in Figure I-6 (CHAPTER I) the net annual plutonium requirements for fueling FBR's would not equal or exceed the projected annual production rate of plutonium in LWR's in this century, with or without plutonium recycle. Consequently, if the plutonium produced in LWR's is stored for fueling FBR's under the reference projections, the stored plutonium is not likely to be utilized. However, there may be some conditions under which the stored plutonium could be used for fueling FBR's. These conditions could occur if (1) the doubling time for plutonium generation in FBR's turns out to be much greater than the doubling time assumed in the projections; (2) if discharged FBR fuel is stored instead of being reprocessed promptly; or (3) if FBR's are introduced at a much higher rate than that assumed in the projections. For the low growth case projections given in Table VIII-1, the inventory of stored plutonium would be about 690 MT by year 2000 without Pu recycle. The annual addition rate of this stored inventory would be about 70 MT and projected breeder use would be about one-half that amount at that time. Thus, it would not appear to be practical to store the plutonium for future breeder use since the plutonium additions in the year 2000 are about double the projected breeder needs.

3.2.3 Plutonium Utilization in Gas Cooled Reactors

A gas cooled reactor concept that has developed to a stage at which it could penetrate the U.S. commercial reactor market is the high temperature gas cooled reactor (HTGR). The operation of HTGR's in the United States is based on the thorium fuel cycle, in which the ^{233}U (produced by neutron capture in thorium and subsequent β decay) is the bred fissile material. However, these reactors must initially be fueled with highly enriched ^{235}U or plutonium before ^{233}U is produced. Plutonium can be used in HTGR's as fuel in a mixed uranium-plutonium core or as fuel in an all-plutonium core.[7] For example, an all plutonium core for an 1,160 MWe HTGR would require about 2,600 kg for its initial charge.

A joint effort by the General Atomic Company and the Edison Electric Institute was begun in 1968 to evaluate plutonium utilization in the HTGR.[8] Phase I of the program called for technical and economic analysis of the situation. The general conclusions of phase I work indicated that plutonium, in addition to having economically attractive characteristics as an HTGR fuel material, posed no inherent technical problems with regard to use in the fuel cycle.[9,10] Feasibility studies determined that

- The fabrication of plutonium-bearing elements presented no problem areas beyond those anticipated for ^{233}U fuel.

- The use of coated particles resulted in the added advantage of greater control over adverse nuclear effects peculiar to ^{240}Pu.

- Benefits from the desirable nuclear performance of ^{233}U were maintained in plutonium-bearing HTGR fuel.

Phase II of the program resulted in the design of a test fuel element as well as an evaluation of analytical methods of predicting isotopic reaction rates for plutonium fuels in the high neutron flux HTGR environment. Phase III comprised the final design, fabrication, licensing, and irradiation of a test fuel element in the Peach Bottom Reactor. The phase IV, V, and VI programs call for the design and demonstration of a large scale plutonium recycle program for a commercial size HTGR (probably in the Fort St. Vrain Reactor).[8]

On October 3, 1975, the General Atomic Company announced that it was withdrawing from the commercial HTGR business and was placing the future of HTGR development in the hands of the Energy Research and Development Administration.[11] Since July 1974, six HTGR units that General Atomic had on order or in negotiation were canceled. On September 15, 1975, the company suspended work being done under a conditional purchase order on two 1,160,000 kW HTGR units for the Philadelphia Electric Company. General Atomic has since terminated its only remaining contract to supply the Delmarva Power and Light Company with two 770 MWe HTGR units for the Summit Station.[12]

In view of these developments the commercialization of the HTGR in the next 10 to 15 years is very much in doubt. Even if it were assumed that half the HTGR's expected to come on line after 1985 (on the original schedule before General Atomic withdrew from the HTGR business) were started up with plutonium fuel, the potential HTGR requirements in any one year could be no more than 40% of the total anticipated LWR plutonium production rate. Although such use could be significant, it appears inadequate to warrant prior plutonium storage. The unlikelihood of the HTGR penetrating the commercial reactor market in the next decade further decreases the incentive to store plutonium for eventual use in HTGR's.

3.2.4 Plutonium Utilization in Naval Reactors

There are no plans to use plutonium in naval reactors.

3.3 No Reactor Utilization of Plutonium

The above assessments show that there is no present or potential use for plutonium that can utilize the large quantities expected to be produced, other than recycle as fuel in LWR's. Therefore, if plutonium is not recycled as fuel in LWR's, some other disposition must be found. There are two possibilities:

- The spent fuel is reprocessed for its uranium value only, and the plutonium is disposed of with the high level waste or by other waste management means.

- The spent fuel is not reprocessed, but the fuel assemblies are stored for ultimate disposal.

The environmental and economic impacts of these two possible dispositions of plutonium are assessed in Sections 9.0 and 10.0 of this chapter.

4.0 ALTERNATIVES CONSIDERED IN DETAIL

Since the issuance of the draft GESMO, considerable thought has been given to alternative methods for the disposition of plutonium. As a result several changes have been made in the descriptions of the alternatives presented here to define them more clearly. Five basic alternatives remain as the major potential dispositions of plutonium. The numbering of the revised alternatives is as consistent as possible with alternative numbers used in the draft.

In the analysis of alternatives several subcases have been included to serve as a sensitivity analysis for certain key parameters. A more detailed discussion of the sensitivity analysis can be found in CHAPTER XI, Section 3.0. As far as feasible, specific dates for reprocessing spent fuel and recycling plutonium have been assigned to each alternative. In general the spent fuel reprocessing date indicates the first year of commercial reprocessing as well as the subsequent return of recovered uranium to the enrichment plant. The date projected for plutonium recycle indicates the earliest possible date for the inclusion of recycled plutonium as fuel in commercial LWR's.

Since Alternative 3 shows minimum costs and, in most cases, minimum environmental impact, it was chosen as the reference case, with which comparisons are made. This choice is consistent with several comments received on the draft statement.

The alternative dispositions of plutonium generated by LWR operation can be broadly classified into three logical categories:

- The use of plutonium is deferred until some later date.

- The plutonium is used as it becomes available.

- The plutonium generated in LWR's is never used.

There are several variations within each of these three broad disposition categories. Each alternative is shown schematically in Figure VIII-1, and the variations are identified in the following paragraphs.

The other potential uses of plutonium described in Section 3.0 of this chapter are not discussed further in this document since they are not considered capable of using all of the plutonium generated in LWR's; they do not appear to be feasible alternative methods of plutonium disposal, and they are, therefore, beyond the scope of this statement.

4.1 Storage of Plutonium (Deferred Use)

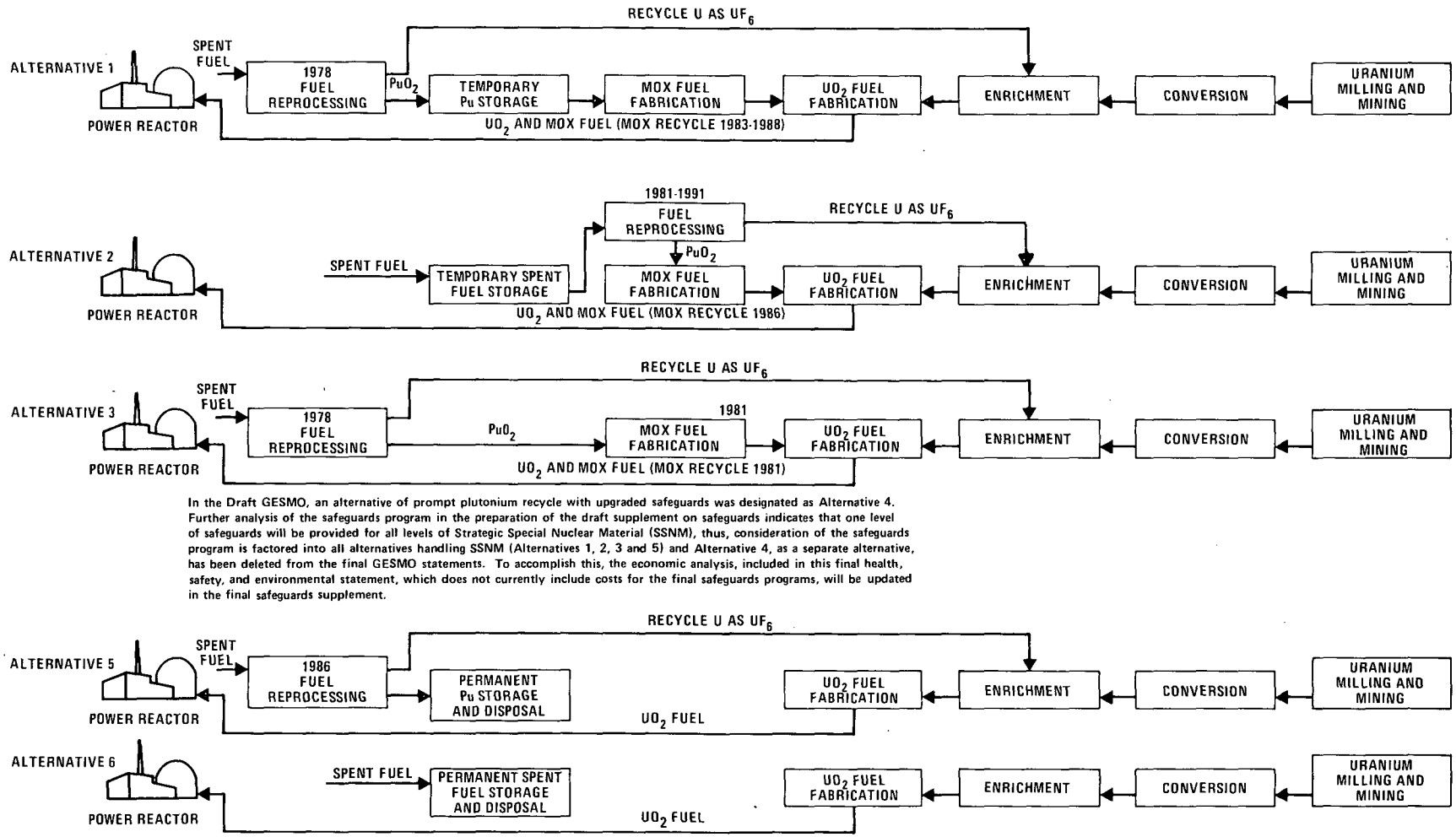
If plutonium is not to be used when it is available, it must be stored either in processed form or as spent fuel until some later date. One potential reason to defer recycle is that technological improvement of fuel cycle may occur before large scale recycle is undertaken, thus mitigating potentially undesirable environmental effects. However, it is difficult in this study to justify the storage of plutonium for some arbitrary period on the basis of some projected possible improvement. Two basic variations in the deferred use of plutonium that were considered in this analysis follow.

4.1.1 Spent Fuel Reprocessing Begins in 1978 and Plutonium Recycle Begins in 1983 (Alternative 1)

Under this alternative, discharged fuel from LWR's would be reprocessed beginning in 1978 (basically the earliest practical date), the uranium product being reclaimed and recycled. The plutonium would be stored for recycle as fuel in LWR's to begin in 1983, about a 2-year delay in plutonium recycle relative to the earliest date of 1981. See Alternative 3. Since the current capacity for the storage of plutonium at reprocessing plants is limited, this option would require the construction of additional plutonium storage facilities either at the reprocessing site or at some other location. Section 7.0 of this chapter presents details of the analysis of this alternative.

4.1.2 Spent Fuel Stored, With Reprocessing and Recycle Beginning in 1986 (Alternative 2)

In this case the spent fuel would be stored and neither plutonium nor uranium values would be recovered until 1986, when the reprocessing of this fuel would begin. This option implies storage at the reactor site, at a special storage-only facility, or at a reprocessing site for about 7 to 8 years prior to a decision to reprocess and recycle. This alternative represents a 5-year delay in plutonium recycle. Since the storage capacity at reactor sites is presently limited to somewhat more than one core, additional storage facilities for spent fuel would be required. The technology for these special facilities has been demonstrated in existing spent fuel storage pools at both reactor and reprocessing plant sites. Several reactor operators are planning to increase their onsite storage capacity. Extended spent fuel storage is discussed in CHAPTER IV, Section K. Detailed analysis of this alternative is contained in Section 8.0 of this chapter.



In the Draft GESMO, an alternative of prompt plutonium recycle with upgraded safeguards was designated as Alternative 4. Further analysis of the safeguards program in the preparation of the draft supplement on safeguards indicates that one level of safeguards will be provided for all levels of Strategic Special Nuclear Material (SSNM), thus, consideration of the safeguards program is factored into all alternatives handling SSNM (Alternatives 1, 2, 3 and 5) and Alternative 4, as a separate alternative, has been deleted from the final GESMO statements. To accomplish this, the economic analysis, included in this final health, safety, and environmental statement, which does not currently include costs for the final safeguards programs, will be updated in the final safeguards supplement.

Figure VIII-1 Alternatives for the Disposition of Plutonium

4.2 Immediate Use of Plutonium

Based on the discussion in Section 3.0 of this chapter, the only use for the quantities of plutonium produced in LWR's is as recycle fuel in LWR's. To permit recycle, the spent fuel must be reprocessed and the plutonium recovered. The recovered plutonium, which is in the form of a nitrate solution, must be converted to plutonium oxide and subsequently blended with uranium oxide. The mixed oxide must then be pelletized and fabricated into fuel rods and fuel assemblies. Commercial scale production plants for these mixed oxide fuel fabrication operations do not yet exist; hence there is some flexibility in the way the industry can develop.

4.2.1 Plutonium Recycled On Availability: Reprocessing Begins in 1978 and Recycle in 1981 (Alternative 3)

Under this option plutonium generated in LWR's would be reprocessed beginning in 1978 and recycled in 1981, the earliest projected availability of commercial reprocessing and MOX fuel fabrication facilities. This alternative is based on present technology, materials, and plant protection programs. The environmental evaluation of this alternative is detailed in CHAPTER IV; it is summarized along with an economic evaluation in Section 6.0 of this chapter. This alternative has been selected as the reference case.

The recovered plutonium would be blended with uranium to yield a MOX composition suitable for reactor fuel. Since fissile plutonium is in effect a replacement for ^{235}U, recycling plutonium reduces the natural uranium and separative work requirements compared to deferred use of plutonium as in Alternatives 1 and 2, and no use of plutonium in Alternatives 5 and 6.

Assuming NRC action in 1977 as projected and the action permits Pu recycle, then the GESMO Alternative 3 dates for the earliest possible initiation of the reprocessing and recycle of plutonium would be 1978 and 1981, respectively. These dates appear to be earliest possible dates and therefore were chosen to bound the analysis. If industry chooses to proceed as promptly as potential licensing provisions might permit, then these dates might be achieved, provided Pu recycle is approved. However, based on a more realistic assessment of conditions, it now appears that there will be substantial delays beyond these dates. Nonetheless, these dates are still appropriate for an analysis that bounds the prompt recycle case and since the effects of delays are not great, is also representative of most recycle cases.

In the draft GESMO, an alternative of prompt plutonium recycle with upgraded safeguards was designated as Alternative 4. In the preparation of the draft supplement on safeguards, further analysis of the safeguards program indicated that one level of safeguards will be provided for all levels of SSNM. Consideration of the safeguards program will thus be included in all alternatives handling SSNM (1, 2, 3, and 5), and Alternative 4 as a separate alternative has been deleted from the final GESMO. To accomplish this, the economic analyses included in this statement which do not currently include costs for the final safeguards programs will be updated in the final safeguards supplement to GESMO.

4.3 Plutonium Never Used

If plutonium is never to be used, it must be permanently stored. Two basic variations in this fuel cycle mode are described below.

4.3.1 Reprocessing of Spent Fuel Begins in 1986 and Plutonium is Stored Without Consideration for Later Use (Alternative 5)

This variation of permanent disposal allows the uranium resources to be reclaimed, but it differs from the alternatives discussed in paragraph 4.1 in that the recovered plutonium is stored without consideration for future use. Under this alternative the plutonium would be concentrated and solidified in a manner to prevent both criticality and environmental release. If this alternative is selected, the best date to begin reprocessing would be determined in a time-based analysis of economic factors. The environmental effects will be essentially the same for any starting date that permits reprocessing the same amount of fuel as assumed for the alternatives discussed above. In this case the starting date was deferred to permit an assumed rise in the price of U_3O_8 in order to reduce the economic penalty of reprocessing at a time when the value of the recovered uranium is less than the reprocessing cost. The starting date, 1986, was chosen to coincide with the date in Alternative 2 so that a value for plutonium could be derived by directly comparing Alternatives 2 and 5. Section 9.0 of this chapter contains a detailed discussion of Alternative 5.

4.3.2 Spent Fuel Stored Without Consideration for Future Use (Alternative 6)

In this manner of disposal both the uranium and plutonium resources in spent fuel are considered to be lost. From an economic standpoint this loss is offset to some extent by the relief from any reprocessing cost. The spent fuel would be allowed to cool for 5 years, then encapsulated in containers and stored in a manner similar to other high level transuranic wastes. This alternative has the greatest impact on LWR uranium requirements. A detailed discussion of this alternative is contained in Section 10.0 of this chapter.

5.0 GENERAL APPROACHES AND BASES FOR ASSESSING THE IMPACTS OF ALTERNATIVES

5.1 Comparison Methodology

For consistency between previous analyses (e.g., CHAPTER IV) and this analysis, the alternatives considered in this chapter were evaluated as follows:

- In each assessment, environmental factors and economic costs were the basic parameters considered. Upgraded safeguards considerations are evaluated in a supplement to GESMO.

- Incremental effects of implementing each alternative were assessed for the 26-year period, 1975 through 2000, by comparing the environmental and economic impacts of each fuel cycle component of the subject alternative to the impacts of using plutonium as soon as possible (reference case, Alternative 3).

- The overall, industrywide effects were assessed by summing the cumulative effects and calculating differences from the corresponding sums for the reference alternative from 1975 through the year 2000.

- All alternatives employing spent fuel reprocessing were developed so that there was little backlog of unreprocessed fuel, except for required inventories, and little excess of recovered plutonium inventories by the end of year 2000. This permits direct comparison of these alternatives, minimizes the effect of error in estimated environmental and economic factors, and eliminates the need to assess the effect of different inventories at the end of year 2000.

In a discussion of this sort, in which many systems and parameters are examined, quantification of the individual effects is not always possible. In each case, however, at least a qualitative analysis has been made in sufficient detail to provide a comparative evaluation of that parameter.

A detailed review of the environmental impact of industrial process effluents involves the consideration of three components:

- A source term or rate of effluent release

- A dilution term, or dispersion of the effluent throughout the medium under consideration

- A population term, giving the distribution of human beings or biota affected by the effluent

To evaluate the environmental impact of a specific facility these factors must be determined for the facility and analyzed together. For a projected industry estimate involving many different facilities and locations, the dilution and population factors are unknown and may vary widely. Trying to assess impact from a given effluent on an industrywide basis is difficult. However, chemical effluents from the nuclear fuel cycle are assessed and compared to the chemical effluents resulting from other large scale industries. They are much smaller than those of a fossil fuel industry producing equivalent power. No significant impacts from the chemical effluents of the nuclear fuel cycle are expected. However, before each new fuel cycle facility is licensed, assessments of chemical effluent impacts are made using the dispersion, dilution, and population distribution factors for that specific facility as a part of the licensing review discussed in CHAPTER VII.

In the special case of radioactive effluents, if the linear assumptions between dose and health effects is assumed, an average assessment of radioactive effluents can be made using nationwide (or worldwide, in the case of gases) average dispersion and population factors. This has been done for all radioactive effluents to calculate total dose commitments. Individual dose commitments, of course, may be more or less

than the average dose commitment; but under the linear assumption of radiation effects, the total health effect to the population at risk will be essentially unaffected by local variations in radioactive exposure.

5.2 Processing Requirements

The industry projections and the basis for analysis throughout this chapter come from the updated WASH-1139(74) forecast prepared by the ERDA Office of Planning and Analysis in early 1975.[13] The specific projection used is referred to as the low growth case.

Total energy growth assumed for this case is 2.0% per annum from 1973 to 1986 and 2.3% per annum from 1986 to 2000. It is assumed that stringent conservation measures in total energy consumption are combined with a situation in which electric energy captures an increasingly larger proportion of the total energy demand. Electricity production grows at a 5.8% rate through 1986 and at a 4.75% rate from 1986 through 2000. Combined with the low total and electric power projection, a low nuclear growth is also postulated that results in 500 GWe of LWR power generating capacity in the year 2000. The projected LWR share of electric power generating capacity under this scenario is shown in Table VIII-2.

Table VIII-2

LOW GROWTH NUCLEAR POWER CAPACITY PROJECTION

Year	Projected Capacity (10^3 MWe)
1975	37
1980	70
1985	156
1990	269
1995	399
2000	507

The HTGR plants included in the original projection are not considered in this analysis. It is assumed that they will be replaced by fossil-fueled plants. The LMFBR plants have also been removed from this projection, as discussed in some detail in CHAPTER XI, paragraph 3.10, and it is also assumed that FBR's will be replaced by fossil-fueled plants.

The fuel cycle process flow rates for the years 1975 through 2000 were developed by means of the computer program NUFUEL.[14] This program was developed by the former AEC Office of Planning and Analysis and utilized in preparing the WASH-1139 projections.

The NUFUEL program uses a library of reactor data and case input data to forecast the various quantities of raw materials and services required in the nuclear fuel cycle. The library of reactor data contains tabular information defining startup dates and associated reload dates, amount and enrichment of fuel required, and amount and composition of spent fuel discharged. The data file for reactors ordered or in operation

was prepared from information supplied by utilities, whereas data required for projected capacity not yet contracted were based on information supplied by vendors.

Each NUFUEL case requires input data specifying the startup dates for each reactor committed and forecast, the inventory periods for each fuel cycle service, capacity and availability dates of fuel cycle services, and estimates of annual uses for plutonium other than reactor fuel (i.e., research needs). The output from NUFUEL provides a series of tables listing the required raw materials and fuel cycle processing rates for each year of the problem. The NUFUEL printout used for this assessment is reprinted as Appendix A of CHAPTER III.

NUFUEL was selected for this analysis because it has been widely used for projections in the past and its data file contains considerable detail for generating stations under construction or planned. This detail permits inclusion of delays, deferrals, and cancellations of specific plants if required and reports the resultant material flows for the entire fuel cycle. NUFUEL has some limitations, as discussed in the following paragraphs, but these do not affect its basic usefulness.

NUFUEL did not include corrections to the raw material flows and services required to overcome the neutron-absorbing characteristics of recycled ^{236}U, ^{242}Pu, and their neutron capture products contained in the recycled uranium and plutonium. NUFUEL was modified to reduce the effective enrichment and change the value function of recovered uranium equivalent to an assumed content of 0.42% ^{236}U. It was also modified to reduce the effective recovery of fissile plutonium from MOX fuel by 17% to compensate for the increased ^{242}Pu. The justification for these changes and a more detailed analysis of the specific corrections are given in Appendix B of CHAPTER VIII.

The NUFUEL program provides a detailed accounting of fuel discharge, reprocessing, and refueling schedules for each reactor by quarter years. The material flows and services for each reactor are calculated for the entire period based on the order of the selection cards in the input card deck. Thus the entire backlog of spent fuel from the first reactor is processed as soon as adequate reprocessing capacity is available; subsequent discharges from the first reactor are processed two quarters after discharge. The second reactor is treated in a similar fashion, using any reprocessing capacity not used by the first reactor. Subsequent reactors, in turn, are treated the same way until the reprocessing capacity is used up; therefore all the unreprocessed fuel is from the last few reactors described in the input deck. The order of treatment is based on the order in the input deck, not necessarily the order of construction of the reactors. This sequential treatment causes an apparent surplus of plutonium for each reactor when reprocessing capacity is first made available to that reactor. Since it is expected that in practice several reactors will supply spent fuel to the reprocessing plant in each year and that it will take several years to work off the backlog of spent fuel, the program was modified to make the surplus plutonium available to other reactors. This also had the effect of better simulating the 1.15 self-generation model. Thus though the program indicates that some reactors receive plutonium for recycle before any of their fuel is reprocessed, in practice some of their fuel would

have been reprocessed and these reactors could have been fueled with their own plutonium for recycle.

In all three alternatives that consider recycle plutonium, nominal dates are given for plutonium recycle. Actual dates may be different. The reference case, Alternative 3, is described as recycle in 1981, which is the actual date of first use of plutonium as a fuel. This requires plutonium shipment and fabrication in 1980 to meet this schedule. Likewise, Alternative 1 is described as recycle in 1983, and this is the actual date of first use of plutonium fuel. However, Alternative 2 is described as reprocessing and recycle in 1986, but recycle does not actually begin until 1987.

The logistics and inventory requirements of plutonium shipping and MOX fuel fabrication and shipping require a full year from the start of reprocessing to reactor charging.

The assumed time intervals for various fuel cycle process steps used in the NUFUEL calculations are shown in Table VIII-3. The time from reactor discharge to reprocessing is shown as a 6-month minimum because reprocessing capacity is limited in the early years and some of the fuel is delayed 2 years or more before reprocessing. Similarly, the interval from the start of plutonium processing to reactor charge is shown as a 12-month minimum because the growth of MOX fuel fabrication capacity is restricted; in some cases the time lag may be greater than 12 months.

Table VIII-3

ASSUMED TIME INTERVALS FOR VARIOUS FUEL CYCLE PROCESS STEPS

U_3O_8 Procurement Through Enrichment and Fabrication to Reactor Charge:	
First Cores	21 Months
Reloads	12 Months
Reactor Discharge to Reprocessing	6 Months
Recovered Uranium Through Reprocessing, Reenrichment, and Fabrication to Reactor Charge	15-24 Months
Recovered Plutonium Through Reprocessing and MOX Fabrication to Reactor Charge	12 Months

The reprocessing plant startup schedule for use in the NUFUEL calculation is based on the following assumptions:

- The earliest possible startup dates for the Allied-General Nuclear Services (AGNS) Barnwell Nuclear Fuel Plant Separations Facility and Nuclear Fuel Services, Inc. (NFS) West Valley Reprocessing Facility plants are 1978 and 1982, respectively.

- The earliest startup date for the third fuel reprocessing plant, assumed to be EXXON, is 1985.

- The capacities of the reprocessing plants are assumed to be as follows:

AGNS	1,500 MTHM/yr
NFS	750 MTHM/yr
All others	2,000 MTHM/yr each

- Plants operate at one-third and two-thirds capacity in their first and second years, respectively, and rated capacity thereafter.

- Plants contract a 1-year inventory of spent fuel prior to startup and maintain this inventory thereafter.

- All cases with spent fuel reprocessing process the same quantity of spent fuel by the end of the year 2000.

The penultimate assumption is based on the capital-intensive nature of the reprocessing business and the resultant incentive to keep the plants operating at full capacity. It has the effect of a delay in assumed startup of reprocessing plants after 1982.

Assumption 6 was made to permit direct comparison between alternatives. It restricts the differences between alternatives to (1) delay in plutonium recycle, (2) delay in fuel reprocessing, or (3) no plutonium recycle when compared to Alternative 3. This assumption plus the use of the same nuclear growth projection minimizes the effects of errors in estimating environmental effects or costs since the material flows and releases will differ only by the amount caused by the difference described. The choice of the time period 1975 to 2000 for study has merit because it is within our ability to forecast technological advances. Even if some radically new energy source were developed in the next 10 to 15 years, it is safe to say that they have no chance of making a significant contribution to the country's power generation before the year 2000. For example, it has taken nuclear power some 25 years to achieve a level of 10% of the country's electric power generation.[15] A similar analysis done for the Atomic Industrial Forum by the NUS Corporation considered the period 1975-1995.[16]

The reprocessing plant startup schedules that result from these assumptions are shown in Table VIII-4. These schedules encompass all of the alternatives considered in CHAPTER VIII.

5.3 Environmental Comparisons

Comparisons of the environmental impacts of the alternatives are made by summing the cumulative environmental effects for the years 1975 to 2000. Tables VIII(A)-1 through VIII(A)-6 in Appendix A show the environmental factors for each of the five alternatives. Table VIII(A)-4 is omitted. These factors were developed in CHAPTER IV. In general, analysis of model plant effluents produced unit environmental effects, and these in turn were used to scale the effects for the period 1975 through 2000 based on the fuel cycle requirements calculated by NUFUEL. The cumulative environmental effects

Table VIII-4

REPROCESSING PLANT STARTUP SCHEDULES--LOW GROWTH CASE

Plant	Year Reprocessing Starts: Alternatives 1 and 3--1978	Alternatives 2 and 5--1986
AGNS	1978	1986
NFS	1982	1986
EXXON	1986	1986
No. 4	1990	1987
No. 5	1993	1988*
No. 6	1997	1997
No. 7	2002	2002

*To equalize total fuel reprocessing with the 1978 case, this plant is assumed to start up in mid-year 1988.

of the four plutonium recycle alternatives are essentially identical because nearly equivalent resources are used by the year 2000 in each of these alternatives.

The computer program NUEN was written to total the environmental effects. It uses as inputs NUFUEL flow data and CHAPTER IV environmental impact data for model plants for each step in the fuel cycle. The number of model plants for each step for each year is calculated. The environmental effects per plant multiplied by the number of plants operating each year is summed over the 26-year period to produce the total environmental effect. The results are presented in Appendix VIII-A.

CHAPTER IV, Section F, provided the components of the front-end uranium fuel processing (mining, milling, UF_6 conversion, enrichment, and UO_2 fabrication), the natural resource use and the quantities of effluents (chemical, radiological, and thermal).

The environmental factors for the mixed oxide fabrication component of the fuel cycle were obtained from CHAPTER IV, Section D. The quantities of combustion products released to the atmosphere were computed by using conversion factors from the EPA Compilation of Air Pollutant Emission Factors.[17]

The environmental factors for reactors were obtained by surveying a number of detailed environmental statements for nuclear power plants and multiplying average effects by the number of plants operating each year. The diesel fuel use is for emergency generators assumed to operate 1,000 hr/yr, and the diesel combustion products were obtained from an EPA compilation.[17] Water use estimates assumed that 2% of the plants would use once-through cooling, and 98% would use cooling towers. Data on radiological effluents were obtained from CHAPTER IV, Section C, assuming one-third BWR's and two-thirds PWR's, one-half with U-tube steam generators.

The environmental factors for reprocessing were obtained from CHAPTER IV, Section E. Electrical energy use and chemical effluents were developed from data provided in Safety Analysis Reports and Environmental Reports provided by AGNS and EXXON for their reprocessing plants.

CHAPTER IV, Section G, provided a basis for estimating the environmental factors for transportation.

The environmental factors for waste management were obtained from CHAPTER IV, Section H. The quantities of combustion products released to the atmosphere were computed by using conversion factors from the EPA compilation.[17]

The environmental factors for plutonium storage were obtained from CHAPTER IV, Section I.

For Alternative 2, delayed reprocessing, it was assumed that the spent fuel is stored outside the reactor.

For spent fuel disposal (Alternative 6), the water use, electrical use, corresponding combustion effluents, and thermal effluents are taken to be comparable to those of the waste management component in the reference case (Alternative 3). Land use is increased somewhat to account for the less compact storage configuration that is necessitated when the fission products are all contained within the spent fuel.

In this chapter, land commitments are described in terms of acre-years of land use, thus taking into account the cumulative effect of land in use each year. Land restored for its original or equivalent use is no longer considered committed to the nuclear industry.

Thermal effluents include the process requirements, the combined heat from radioactive decay, and the operation of trucks.

Data on diesel engine emissions were taken from the EPA compilation.[17]

The population dose commitments were calculated as explained in CHAPTER IV, Section J, Appendix A.

5.4 Economic Comparisons

To make the economic comparisons of the alternatives a computer program called NUCOST was developed. This program uses the quantities of material processed in each step of the fuel cycle as calculated by NUFUEL, applies unit-cost factors provided as input data, and calculates annual costs for each component of the fuel cycle. The program also sums up total costs over the period 1975 to 2000 for each component as well as for the complete fuel cycle. Discounted present worth costs and a levelized fuel cycle cost for the period 1975-2000 are also calculated.

Unit-cost factors (prices for the material or service) were held constant for each component over the time period with one exception: the cost of U_3O_8 was increased according to the cumulative amount of uranium utilized, as described in Appendix A of CHAPTER XI. Derivations of unit costs for each component of the fuel cycle are described in CHAPTER XI, paragraphs 2.1 through 2.11, and are summarized in Table VIII-5. The cost factor estimates are well developed as a range representing the uncertainties of the estimates. The reference unit-cost factors are used in CHAPTER VIII and represent the best estimates from available industry data. The effects of variations due to uncertainties in these estimates are discussed in Section 3.0 of CHAPTER XI. All costs are intended to represent 1975 constant-dollar estimates. Note that Table VIII-5 shows unit spent fuel transportation costs and unit reprocessing costs for MOX fuel as being 20% greater than those for UO_2 fuel. The increased transportation costs allow for possible increased neutron shielding requirements or for reduced loads and the increased reprocessing costs allow for possible slower dissolution rates and throughput limitations caused by the increased plutonium content. NUCOST estimates these flows and calculates an average transportation and reprocessing cost based on the fraction of each type of fuel; hence these costs will appear to vary with time and from case to case.

6.0 EARLIEST RECYCLE OF PLUTONIUM AS FUEL IN LWR's: REPROCESSING IN 1978 AND RECYCLE IN 1981 (ALTERNATIVE 3)

6.1 Description

This section briefly describes the workings of the LWR fuel cycle under the alternative that reprocessing is carried out beginning in 1978, with the earliest recycle of plutonium as fuel in LWR's beginning in 1981. This alternative is the basic disposition of plutonium planned by industry; its environmental effects are assessed in CHAPTER IV and it serves as a reference case to which all other alternatives will be compared.

The primary fuel material would still be virgin uranium. However, this would be supplemented by recycle uranium and plutonium as soon as these materials become available after spent fuel reprocessing. The virgin uranium in the form of U_3O_8 would be shipped from uranium mills to conversion plants, and the UF_6 product would then be shipped to enrichment plants for isotope separation. Recycle uranium, when it becomes available, would enter the main fuel cycle stream as UF_6 moving from reprocessing plants to enrichment plants. The uranium would lose its identity at this point. Enriched uranium would then be shipped from the reprocessing plants to mixed oxide fuel fabrication plants. Also, a required amount of natural uranium process intermediate in the form of UO_2 would be shipped to these facilities from UF_6 conversion plants. Fuel rods containing MOX fuel would be fabricated in the MOX fabrication plants and shipped to uranium fuel fabrication plants. Only fuel rods containing uranium would be manufactured in uranium fuel fabrication plants. Subsequently, fuel elements containing both uranium and MOX fuel rods would be assembled. After assembly, the fuel elements would be shipped from the uranium fuel fabrication plants to the reactors.

Table VIII-5

MATERIAL AND SERVICE UNIT COSTS, 1975-2000*
(1975 Dollars)

Item	Low	Reference	High
Mining and Milling, $/lb U_3O_8**	15	28	58
UF_6 Conversion, $/kg U	3.5	3.5	3.5
Uranium Enrichment, $/SWU	60	75	110
UO_2 Fabrication, $/kg HM	85	95	105
MOX Fabrication, $/kg HM***	150	200	300
Spent Fuel Transportation, $/kg HM UO_2	5	15	30
MOX	6	18	36
Spent Fuel Storage, $/kg HM-yr	3	5	10
Reprocessing, $/kg HM† UO_2 fuel	110	150	190
MOX fuel	132	180	226
Waste Disposal, $/kg HM††	30	50	70
Plutonium Transportation, $/g	0.02	0.04	0.06
Plutonium Storage, $/g-yr	1	2	3
Spent Fuel Disposal, $/kg†††	50	100	150
Added Materials and Plant Protection	(to be developed in Safeguards Supplement)		

*Data from CHAPTER XI, Section 2.0.
**Use weighted average, varies with consumption. See CHAPTER XI, Appendix A, and paragraph 2.1.
***Includes MOX shipping to reactor.
†Includes waste solidification.
††Includes waste shipment to Federal waste repository.
†††Approximately 5 years' spent fuel storage costs and shipping to Federal waste repository will be incurred in addition to disposal cost.

After irradiation of approximately 3 to 4 years, spent fuel assemblies are to be shipped from the reactors (after allowing onsite cooling for a number of months) to reprocessing plants. At the reprocessing plants the fuel assemblies are suitably treated and dissolved to obtain three primary output streams. One stream is recycled uranium (as UF_6), and this, as indicated above, goes to the enrichment plants. A second stream is the recovered plutonium, which would be converted to PuO_2 and shipped to MOX fuel fabrication plants. A third stream is high level fission product waste, which would be stored on site as a liquid for an interim period of time. Eventually it would be solidified and transferred to the government for final custody.

To allow for differences in reprocessing and MOX fabrication schedules, some facilities would be required for plutonium storage. Such facilities could be located at the reprocessing plant for storage as either nitrate solution or oxide, or at separate storage facilities whose sole purpose would be plutonium oxide storage, or at fabrication plants where facilities for the storage of oxide could be provided.

6.2 Effects on LWR Fuel Cycle Operations

6.2.1 Industry Overview for Alternative 3, Earliest Reprocessing and Recycle

A low growth projection for the LWR industry was used. This growth projection assumed an expansion from 37 GWe in 1975 to 507 GWe in 2000. The total energy generated is projected to be 35×10^{12} kWh.

The principal environmental considerations for each component of the UO_2 LWR fuel industry, and the aggregate considerations are summarized in Table VIII(A)-3 of Appendix A. In general, rounded values are used.

6.2.2 Materials Processed

During the 26-year period, 1975 through 2000, the LWR industry will require the mining and milling of about 1.2 billion tons of ore to obtain about 1.2 million tons of U_3O_8, roughly 120 times the 1974 requirements.

The uranium feed chain will require the conversion of 0.9 million MT of uranium to UF_6 and the consumption of 500 million separative work units (SWU). The makeup of the enrichment plants is projected to be the three existing gaseous diffusion plants, with the remainder being new gas centrifuge plants.

The projections indicate that 163,000 MT of uranium will be fabricated in UO_2 fabrication plants. Approximately 115,000 MT of spent fuel will be reprocessed, with about 790 MT plutonium fissile recovered. About 780 MT plutonium fissile will be recycled as fuel in LWR's and 10 MT sold for research uses, primarily to the breeder program. Recycle of plutonium as fuel in LWR's will require the fabrication of about 25,000 MT of MOX fuel.

6.2.3 Use of Natural Resources

The entire UO_2 LWR industry, including nuclear reactors, will require roughly 23 million acre-years of occupied land during the 26-year period. This compares to a land area in the United States of over 2 billion acres, or about 58 billion acre-years over a 26-year period; thus the 23 million acre-years corresponds to the occupation of about .04% of the United States land area over a 26-year period.

The segment of the industry requiring the largest land commitment is the mining-milling operation, which requires 18 million acre-years of committed land, 82% of the industry total. On an equivalent power generation basis, 30 to 35 times more land

would be disturbed from strip-mining coal. The reactor sites require the second largest commitment of land, 2.5 million acre-years, 11% of the nuclear industry total. Land commitments attributable to reactors are independent of the issue of alternative dispositions of plutonium and therefore are constant throughout this chapter.

Water is used in the nuclear industry both for coolant and process requirements. Water uses have been grouped into three categories based on the method of returning the water to the biosphere: water is evaporated into the air, discharged into water bodies, or returned to the ground.

Total water usage is projected to be approximately 120,000 billion gallons, roughly one-third of the water used in the U.S. electric power industry. However, with about 29% evaporation losses, approximately 71% of the water is returned to the water body from which it is withdrawn.

The largest quantity of water involved is the 66,000 billion gallons (55% of the total) required to remove waste heat from the nuclear reactors, of which 33,000 billion gallons are discharged to water bodies and 33,000 billion gallons are discharged to air. The reactor water requirements are independent of the issue of alternative dispositions of plutonium and therefore are constant throughout this chapter.

Exclusive of reactor cooling, a total of 57,000 billion gallons of water must be circulated for LWR fuel cycle requirements. Of this water that is involved in the fuel cycle and would be affected by alternative dispositions of plutonium, the largest quantity is the 53,000 billion gallons required to remove waste heat from the power stations supplying electrical energy to the enrichment step of the fuel cycle. Assuming once-through cooling at these power stations, most of which are existing, all of this water is returned to surface water bodies. The balance of the discharged water, 4,500 billion gallons, is used at the other fuel cycle plants for cooling, process, and dewatering (at the mine) requirements.

Excluding the reactors, the LWR fuel cycle industry evaporates 1,880 billion gallons of water to the atmosphere; 51% of this water is released from the cooling towers at the enrichment facilities and 47% is evaporated from the retention ponds at the mills.

The reactors are expected to produce 4,000 GWy* of electrical energy during the 26-year period. This figure is the net generation; an additional 6% or 240 GWy are generated for lighting, pumping, instruments, etc., at the reactor site. Some of this 240 GWy is required whether the reactor is operating or not, and hence for the purpose of this study it was assumed that this energy is fed into the transmission system and an equivalent amount is withdrawn from the system. This reactor consumption amounts to 62% of the electrical energy consumption of the LWR fuel cycle industry and is independent of the issue of alternative disposition of plutonium.

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*GWy = Gigawattyear

The uranium enrichment component of the fuel cycle requires 88% of the electrical energy required by the fuel cycle (excluding reactor use). The electrical requirement of the nuclear fuel cycle to produce fuel for the LWR's is about 4% of the energy produced by the reactors. Assuming that coal is used to generate two-thirds of the electrical energy, the electrical energy requirements of the fuel cycle that may be affected by alternative dispositions of plutonium correspond to the consumption of 340 million tons of coal.

Approximately 10.0 billion therms of natural gas are consumed by the LWR fuel cycle industry for process heat, nearly 90% of which is used in the milling operation. This quantity of natural gas could be used to generate roughly 100 billion kWh of electricity, which is less than 0.3% of the output of the LWR's.

6.2.4 Effluents

6.2.4.1 Chemical

On the assumption that coal comprises the bulk of fossil fuel utilization, the combustion products of coal account for nearly all of the airborne chemical effluents attributable to the LWR UO_2 fuel cycle industry. The main contributor of these gaseous effluents is the uranium enrichment step, which consumes over 88% of the electrical energy required by the fuel cycle. To the extent that power is supplied by nuclear power plants, the total quantity of sulfur dioxide, nitrogen oxides, carbon monoxide, and airborne particulates would be greatly reduced.

Fluorine is introduced into the fuel cycle during the UF_6 production step and is removed from the fuel material in the fuel fabrication step. As a result, fluoride becomes an airborne effluent from several steps of the nuclear fuel cycle. Although most of the fluorine gaseous wastes are removed by scrubber treatment systems, approximately 530 MT will be released to the environment as an airborne contaminant. Based on estimated present day releases of the phosphate industry and the aluminum, steel, brick, tile, and glass manufacturing industries,[19] the emission of fluorides as a result of the nuclear industry constitutes about 0.03% of the total quantity of fluoride emissions.

The largest quantity of liquid effluents created in the milling processes contains sulfuric acid and other spent chemicals. This waste liquor, however, is discharged to the tailings pond, and since it does not normally contaminate unrestricted ground or surface bodies of water, it does not actually become an effluent stream.

Significant quantities of a number of chemicals are discharged in liquid effluents from the UF_6 conversion, enrichment, fuel fabrication, and reprocessing steps. The UF_6 conversion plant releases sulfate, nitrate, fluoride, chloride, sodium, potassium, ammonia, and iron in its liquid waste, whereas the UO_2 fabrication plant releases fluoride, nitrate, and ammonia in its liquid waste. The liquid effluent quantities given in Table VIII(A)-3 appear large, but they do not constitute a potential for adverse environmental effects, since they are discharged at low concentrations as required by discharge permits which should assure no adverse environmental effects.

The greatest bulk of solid materials will be generated in the open pit mining and milling operations. The barren rock and earth overburden produced by the mine will temporarily constitute a waste material, but will be essentially returned to the barren mine as backfill. The tailings from the mill will be primarily sandstone and clays and constitute the major quantity (590 million cubic meters) of solid waste from the fuel cycle. The tailings will be pumped as a slurry to the tailings pond and will be permanently stored as solids in a chemical form similar to that of the original ore but less radioactive because uranium has been removed.

The 67,000 cubic meters of ash generated by the Hydrofluor UF_6 production dry process consists of nonvolatile fluorides. Since the ash residue contains traces of radionuclides it will be packaged and shipped for burial at a licensed commercial disposal site and thus not become an effluent to the environment.

Most of the fluoride added to the fuel cycle during the UF_6 production step is precipitated as CaF_2 in the fuel fabrication step. It is calculated from UO_2 requirements that approximately 160,000 MT of precipitated calcium fluoride will be generated, occupying a volume of approximately 130,000 cubic meters. This may be buried at the site of the fuel fabrication plant and covered with backfill.

6.2.4.2 Radiological

The total body dose commitment to the world's population (excluding occupational)* is estimated to be 5.1 million person-rem, 0.5 million of which is attributable to reactor operation and is independent of the issue of plutonium recycle. For comparison, the worldwide population dose commitment from natural background for the period is estimated to be 13 billion person-rem. Thus the general population dose commitment from the total industry is less than 0.04% of background. The dose commitment to the occupational group is estimated to be 3.8 million person-rem, 2.3 million person-rem resulting from reactor operation and being independent of the issue of plutonium recycle. The most significant gaseous radioactive release from the fuel cycle occurs during the fuel reprocessing step. Nearly all of the ^{85}Kr, most of the tritium and ^{14}C, small quantities of radioiodine, and very small quantities of other fission products and transuranium isotopes created in the nuclear reactor fuel are released to the atmosphere from the reprocessing plant operations.** The reprocessing step contributes about 39% of the dose commitment to the general population for the fuel cycle (excluding reactor operation). The dose commitments to the general population as a result of reprocessing about 115,000 MT of spent fuel are estimated to be 1.1 million person-rem to the general population plus 0.08 million person-rem to the occupational group.

Small quantities of uranium and its daughters are released to the atmosphere in several steps of the fuel cycle. Data are unavailable for the total quantity of radioactivity released from the mining operation, but attempts to measure radon concentrations in an open pit mine revealed no significant alpha concentrations. However, it is estimated that 18 million curies of ^{222}Rn could be released. Approximately 3.4

*See CHAPTER IV, Section J, Appendix A, for explanation of exposure modes and duration incorporated into the dose commitment determination.

**See CHAPTER IV, Section E, for a detailed discussion of effluents from reprocessing plant operations.

million curies of radon will be released during the milling operations. Estimates of the site boundary concentrations of ^{230}Th from the model mill are approximately 15% of the regulatory limits for unrestricted areas.[21] The mining and milling steps contribute 1.4 million person-rem to the occupational group, which is 88% of the dose commitment for the fuel cycle (excluding reactor operations).

Small quantities of uranium and its daughters are released in liquid effluents from each step of the fuel cycle. In the mining operation, several curies of radioactivity that are dissolved and suspended in the mine drainage water are returned to the ground. In the remaining components of the fuel cycle, small quantities of radioactivity are released to receiving bodies of water. Offsite measurements in the vicinity of a UF_6 production plant indicate that the annual mean concentrations of radionuclides in effluent streams from enrichment and fuel fabrication plants are below 1% and 10%, respectively, of the regulatory limits before dilution in receiving waters.[20]

Solid wastes containing radioactive isotopes are generated in all segments of the nuclear industry. The largest quantity of wastes expected to be consigned to licensed commercial burial grounds is the 1.4 million cubic meters of wastes generated during reactor operation. The high level waste volume is estimated to be 6,500 cubic meters.

6.2.4.3 Thermal

Approximately 290 x 10^{15} Btu of waste heat will be discharged as a result of the LWR industry. Of this total, approximately 95% will be the direct result of the operation of the LWR's. The projected 270 x 10^{15} Btu discharge from nuclear reactors is independent of the issue of alternative dispositions of plutonium and remains a constant throughout this chapter.

The thermal effluents from the supporting fuel cycle constitute approximately 5% (13 x 10^{15} Btu) of the thermal releases of the industry. About 80% of the waste heat from the supporting fuel cycle originates in the enrichment process, wherein 11 x 10^{15} Btu will be discharged.

6.2.5 Economic Considerations

The cumulative undiscounted direct cost of the nuclear fuel cycle for the 26-year period from 1975 through 2000 (see CHAPTER XI, Table XI-28) amounts to $157 billion for the reference case (Alternative 3) using the low growth projection. The levelized fuel cycle cost was estimated to be 4.46 mills/kWh. The cost of U_3O_8 accounts for nearly one-half of the total cost, or $70 billion. Enrichment costs are next in importance at $39 billion, or 25%, followed by reprocessing at $18 billion, or 11%, and UO_2 fabrication at $16 billion, or 10%. Together these four items account for 91% of the total fuel cycle costs. In terms of either undiscounted or discounted total costs or levelized fuel cycle costs, the proportions accounted for by these four items are nearly identical. Conversion to UF_6 and waste disposal each account for approximately 2% of the total, and MOX fabrication accounts for 3%. The remaining 1.6% is divided: 1.2% to spent fuel transportation, 0.5% to spent fuel storage, 0.04% to plutonium storage, 0.03% to

plutonium transportation, and a credit of 0.15% for plutonium sales for non-LWR uses.

6.3 Safeguards

6.3.1 Availability of Plutonium

Under Alternative 3, bulk plutonium would be present at the reprocessing plant load-out and storage areas. From there it would continue to need safeguarding during transport to, and storage at, MOX fuel fabrication plants. Then it would become available in process and storage as bulk MOX before being fabricated into fresh fuel assemblies and stored again. The fresh fuel assemblies would require safeguarding during transit to, and storage at, LWR power plants prior to loading into cores. Plutonium would become available again in irradiated assemblies. This would be stored at the reactor and then transported to storage facilities at reprocessing plants. Bulk plutonium mixed with fission products would be present in process at the reprocessing plant prior to separations processing.

6.3.2 Safeguards Cost Considerations

The requirements for safeguarding materials and plants are currently under review by NRC. Methods and costs are being analyzed under present and proposed regulations. A safeguards supplement to GESMO describes the recommended safeguards procedures and estimated costs. For the present portion of the analysis the cost of meeting present protective standards is included in the various fuel cycle unit costs.

6.4 Value of Plutonium Use

Since plutonium is a replacement for U_3O_8 and separative work, the plutonium value will increase as the costs of these components increase. The anticipated costs of U_3O_8 and separative work are presented in CHAPTER XI for the plutonium recycle cases and the cases not involving recycle.

The average value of plutonium recycle can be estimated by summing the U_3O_8, UF_6 conversion, and separative work savings between Alternative 5 (uranium recycle only) and Alternative 2 (uranium and plutonium recycle) and then reducing the savings by the additional total fabrication cost. The average unit value is found by dividing the present worth savings by the present worthed weights of fissile plutonium used for Alternative 2 ($2.9 billion savings per 121 million grams fissile* = $24.04/gram). The specific value for any alternative or any given year is affected by the limitation on usage and the U_3O_8 cost. Because the estimated price of U_3O_8 increases with consumption, the decrease in demand with plutonium recycle will reduce the unit price for all uranium purchased in a given year.

The value of plutonium can also be estimated on an annual basis using the same technique as for the overall system estimate, but differences in timing between the

*This value can be computed from Table XI-30. The discounted MOX fabrication cost is $810 million, divided by $200/kg, times the average fissile content of 30 g/kg.

year of plutonium use and uranium savings make the annual calculation of plutonium value by such a method unreliable. Equations that describe the relationship between plutonium value and fuel cycle cost components without regard for annual usage have been developed for LWR's, as noted below:[21]

$$\text{Pu value} = U \left(0.85 - 1.6 \frac{^{242}Pu}{^{239}Pu + ^{241}Pu}\right) - \frac{\text{Pu fabrication penalty, \$/kg MOX}}{\text{grams fissile/kg MOX}} \quad (1)$$

where

U = value of 93% enriched uranium at the time of fabrication, $/g

^{239}Pu = ^{239}Pu weight in grams

The value of a gram of 93% enriched uranium is the sum of the costs of the separative work and of the natural uranium required to make it. The cost of the uranium is the sum of U_3O_8 cost and the cost of conversion to UF_6. These terms can be substituted for U in the above equation.

The impact of isotopic change as evidenced by the percentage of ^{242}Pu is already accounted for in the NUFUEL computer program, and thus the above equation can be simplified by removing the term containing plutonium composition. In consideration of the additional costs associated with MOX fuel reprocessing and shipping after irradiation, an additional term must be added that incorporates this increased cost. Because the additional cost takes place in the future, discounting is required to the time of reactor introduction (6 years, at 10% per year). The equation from Reference 21 is therefore revised as follows:

$$\text{Pu value} = K[0.2 \text{ SW cost, \$/kg} + 0.226 (2.6\ U_3O_8 \text{ cost, \$/lb} + \text{conversion cost, \$/kg})] - \frac{\text{Pu fabrication penalty, \$/kg MOX}}{\text{grams fissile/kg MOX}} - \frac{PW (\text{MOX shipping and reprocessing penalties, \$/kg MOX})}{\text{grams fissile/kg MOX}} \quad (2)$$

where

$$PW = \frac{1}{(1 + r)^6};\ r = 0.10$$

The term K in this equation is estimated by adjusting the value of K until the sale of various amounts of plutonium to an external market has no impact on the systems fuel cycle costs. This condition is normally referred to as the indifference price in that the reactor system would be indifferent from a cost viewpoint to the recycle use or sale. Using this technique, the value of the term K for Alternative 3 was established

at 0.91; this is somewhat greater than previous estimates by other investigators, which range from 0.8 to 0.9.[22,23] Because of the different constraints presented by the various alternatives, some variation (2% to 3%) in the K term is found.

The value of plutonium recycle to the nuclear economy is greater than the simple annual estimates of plutonium value as a substitute in a given year. Plutonium recycle over a number of years will reduce the average price of uranium to the uranium portion of the fuel cycle. The portion of plutonium value attributed to this source is estimated by setting the uranium price at a constant equal to the average price. This eliminates the uranium savings effect and results in a plutonium value that is approximately 5% to 10% less than the above estimate. This also explains why the K term in Equation (2) is higher than that found in other studies.

The uranium price algorithm used assumes that uranium prices rise with cumulative consumption. Therefore the plutonium value is derived from the displacement of the maximum priced uranium used in a time period. This price is often referred to as the marginal price or the price one must pay for the next unit of uranium. Plutonium values are only estimated for alternatives where plutonium is recovered and sold. Based on Equation (2), the plutonium values in Table VIII-6 were estimated for Alternative 3 as a function of time.

The average influence of fabrication costs on plutonium value can be assessed in the same way as average plutonium value. Comparing Alternative 2 with Alternative 5 shows a differential fabrication (plutonium fabrication penalty) cost of $425 million discounted, whereas the corresponding quantity of plutonium recycle is 121 million fissile grams. The effect on plutonium value is $425/121 = $3.51/g. This differential can also be derived from unit fabrication costs. A cost difference of $105/kg divided by 30 grams of plutonium contained in each kilogram of MOX fuel yields $105/30 = $3.50/g. Through this technique the influence of changing MOX fabrication costs on plutonium value can be estimated.

Table VIII-6

INFLUENCE OF URANIUM PRICES ON PLUTONIUM VALUE
(ALTERNATIVE 3)

Year	U_3O_8 Cost, $/lb	Plutonium Value, $/g Fissile
1980	17.70	20.39
1985	23.40	23.43
1990	28.50	26.17
1995	32.50	28.32
2000	33.10	28.61

7.0 EARLIEST REPROCESSING AND URANIUM RECYCLE, DELAYED PLUTONIUM RECYCLE (ALTERNATIVE 1)

7.1 Description

Alternative 1 is the reprocessing of spent fuel in 1978, recycling the uranium in 1978, but not beginning recycling the recovered plutonium in the existing UO_2 LWR fuel industry until 1983. Plutonium could be stored at the reprocessing plants in the form of nitrate solution. If separate facilities are used, the plutonium nitrate solution would be converted to plutonium oxide at the reprocessing plants, followed by shipment of the oxide to a plutonium storage facility. The period of time for which plutonium is stored has an important bearing on the type of storage that must be provided. Due precautions must be taken to ensure safety and to ensure strict materials accountability during storage and when plutonium is transferred from point to point. If short term storage is anticipated, a storage facility would be designed as an active facility in which almost daily movement of material might occur. In short, the storage facility would be more like an operating plant in which movement of material is frequent and operating procedures are established to ensure safety and strict accountability. Such a storage facility would most likely be built at the reprocessing site.

On the other hand, if long term storage is anticipated, the storage facility could be of a passive type in which material would move primarily from the reprocessing plants to the facility. Once the material is logged in and set in place, there would be little need for subsequent handling. Ultimately, even under this alternative, it is expected that the plutonium would be utilized for recycle as fuel in LWR's.

More detailed presentations of the effects of Alternative 1 are given below.

7.2 Effects on LWR Fuel Cycle Operation

The environmental and economic effects of Alternative 1 for each fuel cycle step are discussed in the following paragraphs. The environmental considerations are summarized in Table VIII(A)-1 of Appendix A. In general, rounded values are used.

7.2.1 Industry Overview for Alternative 1

In Alternative 1 reprocessing begins in 1978 and the recovered uranium is used as soon as possible as in the reference case (Alternative 3), but plutonium recycle is delayed until 1983 (a 2-year delay relative to the reference case). The major perturbations occur in 1980 to 1982, when increased demand on the uranium portion of the fuel cycle is caused by delayed plutonium recycle. This is followed by 3 years of reduced demand on the uranium portions of the fuel cycle relative to the reference case, caused by the increased use of plutonium as the stored plutonium is recycled.

7.2.2 Materials Processed

The largest impact of Alternative 1 is the requirement for storing 29 MT of plutonium in 1982 compared to the storage of 10 MT in 1980 for the reference case. The delay causes a negligible reduction in the total amount of plutonium recycled. Through

1982 this alternative would require the mining and milling of an extra 4,500 tons of U_3O_8 and an increased load on enriching facilities of 2.3 million SWU. However, for the period 1975-2000, the total mining, milling, and enrichment requirements of these two alternatives are essentially equal.

7.2.3 Use of Natural Resources

A 2-year delay in plutonium recycle would cause a trivial increase in the use of natural resources described in paragraph 6.2.3.

7.2.4 Effluents

A 2-year delay in plutonium recycle would cause a negligible change in effluents as described in paragraph 6.2.4. The environmental considerations for this alternative are summarized in Table VIII(A)-1 in Appendix A.

7.2.5 Economic Considerations

For Alternative 1 the cumulative undiscounted direct cost of the nuclear fuel cycle for the period from 1975 through 2000 amounts to $157 billion, approximately $0.2 billion more than the reference case.

The levelized fuel cycle cost is 4.474 mills/kWh, or 0.019 mill/kWh above the 4.455 mills/kWh for the reference case.

Reprocessing starts at the same time (1978) as in the reference case. The difference is in delaying plutonium recycle 2 years from 1981 to 1983. In terms of total discounted fuel cycle cost which for the various alternatives range from about $36 to $39 billion, this results in relatively small additional costs: $100 million for additional plutonium storage, $36 million for additional U_3O_8, $32 million for additional separative work, $3 million for additional UF_6 conversion, and $11 million for additional UO_2 fabrication. A savings in MOX fuel fabrication costs of $25 million produces a net increase of $153 million, or 0.019 mill/kWh. These costs are summarized in Table VIII-7.

The cost difference is small in terms of levelized fuel cycle costs over the 26-year period. This is largely because substantial costs in the early years are compensated by savings in the following years. The increased costs in 1981 and 1982 are $182 million and $121 million, respectively. This amounts to additional costs of $1 to $2 million per operating reactor in each of these years. In this case, reprocessing costs have been paid for starting in 1978 while a major share of resulting economic benefit has been withheld until 1983 and later.

7.3 Safeguards

7.3.1 Availability of Plutonium

Spent fuel reprocessing under this option would start in 1978, as in the reference case (Alternative 3). The recovered plutonium would be retained for recycle use starting in 1983, a 2-year delay relative to Alternative 3.

Table VIII-7

NET DIFFERENCE BETWEEN DISCOUNTED FUEL CYCLE COSTS FOR ALTERNATIVES 1 AND 3 (MILLIONS OF DOLLARS, DISCOUNT RATE 10%)

Fuel Cycle Component	Alternative 1 Minus Alternative 3 Discounted
U_3O_8	+ 36
UF_6 Conversion	+ 3
Enrichment	+ 32
UO_2 Fabrication	+ 11
Spent Fuel Shipping	0
Reprocessing	-3
Plutonium Transportation	0
Plutonium Storage	+100
MOX Fuel Fabrication	-25
Spent Fuel Storage	0
Waste Disposal	0
Plutonium Sales	0
Net Difference	+153

Plutonium dioxide must be stored in a way to ensure nuclear criticality safety, necessary containment because of toxicity, and preclude the possibility of sabotage or diversion. Thus a sophisticated repository capable of meeting these stringent requirements with construction features that meet the criteria for withstanding natural phenomena would be required.

If the repository is not located at the reprocessing plant, transportation of PuO_2 from the reprocessing plants to and from the central storage repository and at the repository would be a potentially vulnerable activity that would require careful safeguarding. A separate supplement to GESMO will be issued describing the recommended safeguards procedures.

Under Alternative 1, transportation of PuO_2 to fabrication plants and the availability of pure PuO_2 and PuO_2 mixed with UO_2 within fabrication plants during processing would be deferred to 5 years after reprocessing begins. Similarly, the availability of PuO_2 in fresh fuel assemblies in storage at the fabrication plant, in transit to power reactors, and in storage at reactor sites before loading would also be deferred until 1983.

7.3.2 Safeguards Cost Considerations

The requirements for the protection of materials and plants are currently under review. The results of this work, including the costs of implementing these safeguards,

will be published in the Safeguards Supplement. In the interim the fuel cycle costs used in CHAPTER XI include protective costs required to meet present standards.

7.4 Cost of Delayed Plutonium Use

Costs incurred for plutonium storage are to a degree counterbalanced by an increase of plutonium value with time. See paragraph 6.4. This increase is caused by the dependence on uranium costs, which are expected to increase with time even if the effect of inflation is not considered. Paragraph 2.1 and Appendix A of CHAPTER XI discuss the subject in detail. Consequently, if plutonium is eventually used for LWR recycle, the value of such plutonium will increase while it is being stored. This may also be the case if the plutonium were ultimately used for FBR refueling; however, the component costs that make up the plutonium value would differ somewhat from the LWR example. Between 1980 and 2000, the average plutonium value is expected to increase by about $0.41/g per year. This is to be compared with the anticipated annual plutonium storage cost of about $1.00/g per year for long term passive storage and $3.00/g per year for short term active storage. The anticipated increase in plutonium value, if recycle as fuel in LWR's is eventually implemented, will be less than the long term storage costs. However, this does not consider the carrying charge on the plutonium value. At approximately 15% per year (the effective before tax utility cost of capital), with an initial plutonium value of $17.00/g, this amounts to $2.50/g per year. If short term active plutonium storage were contemplated, with total storage costs of $5.50/g per year, the $0.41/g per year plutonium value increase would be inadequate to cover the storage cost. Hence under no conditions is the storage of plutonium for later use economically attractive.

Plutonium fissile content decreases during storage because the fissile ^{241}Pu component decays with a half-life of 15 years (about 5% per year) to the nonfissile ^{241}Am. Since fissile plutonium at 1 year after reactor discharge (when it could be used if prompt use were contemplated) is composed of approximately 15% ^{241}Pu, the decay of ^{241}Pu over a 15-year time span would reduce the fissile quantity of plutonium available by about 7.5%. Based on the above, the average rate of decay of the total fissile plutonium is about 0.5% per year. Consequently, the average annual plutonium value increase during storage is slightly reduced from the per gram value indicated in paragraph 6.4. This buildup of ^{241}Am also causes handling and neutronic penalties. If the americium is removed, incremental costs not included in these calculations may occur.

During the 5-year storage period (1978-1982) for recovered plutonium, 4,500 tons U_3O_8 and 2.3 million SWU are required to replace the plutonium. The added cost during the storage period discounted to 1975 is $234 million: $109 million for U_3O_8, $94 million for separative work, and $55 million for plutonium storage. Beginning in 1983, the introduction of the stored plutonium to the fuel cycle reduces the future U_3O_8 and separative work by nearly equivalent amounts. The net effect on the average fuel cycle cost over the period from 1975 to 2000 is 0.019 mill/kWh, or $153 million discounted, primarily from the additional storage costs. The maximum quantity of plutonium stored is 29 MT in 1982. A detailed discussion of plutonium value for recycle as fuel in LWR's was presented previously in paragraph 6.4 of this chapter.

8.0 SPENT LWR FUEL STORED FOR LATER RECOVERY OF PLUTONIUM AND URANIUM (ALTERNATIVE 2)

8.1 Description

Under this alternative the only fuel material used would be virgin uranium until 1986, at which time the spent fuel would begin to be processed. Spent fuel assemblies would be stored at the reactor site or a central storage facility (which may be at the site of a future reprocessing plant) for an extended period of time. For the purposes of the following discussion, reprocessing plants can begin to work off this inventory in 1986.

More detailed presentations of the effects on the LWR fuel cycle of storing LWR fuel for recovery of plutonium and uranium, beginning in 1986, are given below.

8.2 Effects on LWR Fuel Cycle Operations

The environmental and economic effects of Alternative 2 for each fuel cycle step are discussed in the following paragraphs. The environmental considerations are summarized in Table VIII(A)-2 of Appendix A. In general, rounded values are used.

8.2.1 Industry Overview of Alternative 2

In Alternative 2 reprocessing is delayed until 1986. The recycle of both uranium and plutonium begins as soon as possible thereafter. This assumes an 8-year delay in uranium recycle and a 6-year delay in the start of plutonium recycle relative to the reference case (Alternative 3). Substantial increases in the provision for spent fuel storage will be required.

8.2.2 Materials Processed

The major perturbation in this case is the substantial spent fuel storage requirements, which amount to over 20,000 MT in the peak year, 1987, compared to about 6,000 MT in the reference case. Spent fuel inventories are reduced to the norm of the reference case by 1994. Substantial increases are required in the uranium portion of the industry through 1987 relative to the reference case. The growth of the uranium portion of the fuel cycle in subsequent years is less than in the reference case, but the net result is an increase in the consumption of U_3O_8 by 300 tons. Similarly, UF_6 conversion and UO_2 fabrication increase by 500 and 170 MT, respectively. However, separative work requirements decrease by 1 million SWU because less spent MOX fuel has been reprocessed and the uranium degradation has not yet affected the enrichment facilities. The total amount of plutonium recycled is about 9 MT less than in the reference case, and the total amount of MOX fabricated is about 170 MT less.

8.2.3 Use of Natural Resources

An 8-year delay in reprocessing and recycle would cause a negligible increase in the use of natural resources as described in paragraph 6.2.3.

8.2.4 Effluents

An 8-year delay in reprocessing and recycle would cause a negligible change in effluents as described in paragraph 6.2.4.

8.2.5 Economic Considerations

For Alternative 2, the cumulative undiscounted direct cost for the nuclear fuel cycle over the period from 1975 through 2000 amounts to $157 billion, approximately $0.4 billion more than the reference case (Alternative 3). In terms of levelized fuel costs the cost is 4.47 mills/kWh or 0.01 mill/kWh above the reference alternative.

The delay in reprocessing from 1978 to 1986 results in reduced costs for spent fuel shipping, reprocessing, and waste disposal (due primarily to the discounting effect). It also causes reduced plutonium transportation and MOX fuel fabrication costs (reduces the quantity of plutonium utilized); increased U_3O_8, UF_6 conversion, enrichment, and UO_2 fabrication costs (making up for the lower plutonium utilization); increased spent fuel storage cost (result of delayed reprocessing); reduced plutonium storage costs; and reduced revenue from plutonium sales (since they are delayed). These differences are summarized in Table VIII-8.

Table VIII-8

NET DIFFERENCES BETWEEN FUEL CYCLE COSTS
FOR ALTERNATIVE 2 AND THE REFERENCE CASE (ALTERNATIVE 3)
(MILLIONS OF DOLLARS, DISCOUNT RATE 10%)

Fuel Cycle Component	Alternative 2 Minus Alternative 3, Present Worth
U_3O_8	520
UF_6 Conversion	30
Enrichment	152
UO_2 Fabrication	63
Spent Fuel Shipping	-63
Reprocessing	-573
Plutonium Transportation	-1
Plutonium Storage	-33
MOX Fuel Fabrication	-134
Spent Fuel Storage	205
Waste Disposal	-116
Plutonium Sales	22
Net Difference	+74*

*Total does not add exactly due to rounding.

The difference in discounted costs between the two alternatives is only $74 million. Some of the cost uncertainties (see Section 3.0 of CHAPTER XI) are considerably greater than this, and hence one could argue that such small differences are not

significant. This argument is not strictly correct, for any estimating errors will tend to affect both alternatives. Thus the absolute totals for any alternative will be more highly influenced by estimating uncertainties than will differences. On the other hand, the $74 million represents the algebraic sum of many large numbers. A 20% change in any of the larger ones could have a significant influence on the magnitude, and possibly the sign, of the difference value.

The cost of delayed recycle is not shared equally by all generating units. The cost is borne primarily by the plants operating or starting up in the early years of the period. The larger number of plants starting up in the later years of the period masks any significant cost of delay in plutonium utilization when expressed as levelized fuel cycle costs. Thus the impact of delayed recycle is larger for the early plants than is indicated by the small difference in the total industry levelized fuel cycle cost over the 26-year period. In addition, the $573 million saving in reprocessing may not be real since substantial investment is in place and the unit costs may rise in an attempt to recover the interest on this investment over the period of delay.

8.3 Safeguards

8.3.1 Availability of Plutonium

For this option plutonium would be present but would be entirely contained within irradiated fuel assemblies until reprocessing and recycle commence in 1986. Reprocessing plants and LWR MOX fuel fabrication plants would not be immediately required. The spent fuel could be stored (1) at nuclear power plants, (2) at reprocessing plant sites, or (3) at a central repository. The first choice would postpone the transportation of spent fuel but would require significantly increased spent fuel storage capacity. The second choice would also require increased storage capacity. At some subsequent date, some of the fuel might have to be retransported to new reprocessing plants. The third choice would entail the construction of new storage facilities. Transportation requirements from nuclear power plants to storage at reprocessing plants or at a central repository would be essentially the same, but the latter would eventually require a second shipment.

The theft of spent fuel is less likely than is the theft of plutonium that has already been separated. Sophisticated equipment and personnel would be required to separate the plutonium from the fuel before the plutonium could be used for any purpose. Spent fuel is not readily dispersible or physically accessible. Accordingly, sabotage involving spent fuel could be expected to have effects confined to a small local area, compared to sabotage involving separated plutonium. Since commercial handling of plutonium would be delayed in Alternative 2, the safeguards risks at fixed sites and during transport would be substantially reduced until 1986.

8.3.2 Safeguards Cost Considerations

As discussed in paragraph 6.3.2, safeguards methods are under intensive review at present. Until the results of this review are available, the fuel cycle unit costs used in this analysis are adequate to meet present regulations.

8.4 Cost of Delayed Plutonium and Uranium Use

Although reprocessing at an early date and delaying plutonium recycle appears uneconomic (see paragraph 7.4), delaying plutonium recycle by delaying reprocessing may involve a smaller economic penalty. The residual uranium value contains both an equivalent U_3O_8 and a separative work component. The separative work component is small because the residual uranium has an enrichment not far above natural uranium and the ^{236}U penalty may reduce it to zero or even a small negative value. As in the case of plutonium, as the U_3O_8 costs increase with time, the value of the residual uranium also increases. The anticipated costs of U_3O_8 and separative work are presented in CHAPTER XI. The value increase of both uranium and plutonium yields a total increase in value of about \$7/kg spent fuel per year. Subtracting spent fuel storage costs of \$5/kg year results in a net \$2/kg value increase. Carrying charges for spent fuel, assuming that both the contained uranium and plutonium have recycle value, must be compared with savings resulting from the deferral of reprocessing charges. In the 1980's these charges are nearly equal. Thus deferral has a small net effect on fuel cycle costs in this time period. In the 1990's fuel values usually exceed reprocessing charges, and annual net carrying charges of up to \$10/kg are incurred. However, in the present situation two reprocessing plants have already made a substantial investment and are expecting an early startup date. If the startup date is delayed, the accumulated interest on money already spent will increase the effective capital cost and tend to increase the unit cost.

As a result of an 8-year delay (1978 to 1986) in the startup of reprocessing plants, there are substantial increases in the requirements for U_3O_8, separative work and spent fuel storage. Alternative 2 is estimated to require 40,800 tons more U_3O_8 than Alternative 3 through 1986. The extra separative work amounts to 9 million SWU by the end of 1987. The maximum additional spent fuel storage of 14,000 MT occurs in 1987. The costs of the extra requirements are compensated by deferring costs of reprocessing and waste management. By the end of 1994, the backlog of spent fuel is processed and the recovered plutonium and uranium are made available for recycle as fuel in LWR's. By the end of year 2000, the excess requirements are reduced to 300 tons of U_3O_8 and a saving of 1 million SWU. The reader is referred to paragraph 8.2.5 for the details of the cost of delay by fuel cycle step. The net cost of delayed plutonium and uranium until 1986 is \$74 million, or 0.01 mill/kWh.

The reader is also referred to the discussion of the values of plutonium use in paragraph 6.4.

9.0 SPENT FUEL REPROCESSING, URANIUM RECYCLE, PLUTONIUM DISPOSAL (ALTERNATIVE 5)

9.1 Description

Under Alternative 5 the reprocessing of spent fuel will begin in 1986 and the plutonium will be discarded. This alternative is similar to Alternative 2, except that the plutonium will be discarded rather than recycled.

The reprocessing date of 1986 was selected for several reasons. A date earlier than 1986 would result in large capital investments for reprocessing plants early in the analysis, resulting in higher present value costs. Recovered uranium would replace natural uranium but at a lower price than in 1986 and would therefore provide smaller benefits than the current alternative. On the other hand, beginning reprocessing later than 1986 may leave unprocessed at the end of the year 2000 some uranium that could be economically recovered.

Storage of plutonium without consideration of further use would require treatment for plutonium similar to that used for high level wastes. Undoubtedly, the plutonium would have to be solidified using procedures similar to those described in CHAPTER IV, Sections E and H. Also, because of the potential for nuclear criticality, the plutonium may have to be mixed with a neutron absorbing material, depending on the size of the stored units and their distribution in space. Although specific permanent storage facilities for reprocessed plutonium have neither been built nor proposed, technology used for engineered waste storage could probably be applied to this alternative. No insurmountable technical factors in this regard are apparent. See paragraph 2.7 of CHAPTER XI for a further discussion of the design and cost factors involved in plutonium storage.

9.2 Effects on LWR Fuel Cycle Operations

The environmental considerations of this alternative are summarized in Table VIII(A)-5, and the differences between this alternative and Alternative 3 are discussed below.

9.2.1 Industry Overview of Alternative 5

In Alternative 5 reprocessing is delayed until 1986. Uranium recycle begins as soon as possible thereafter. This assumes an 8-year delay in uranium recycle and no plutonium recycle relative to the reference case (Alternative 3). Substantial increase in the provision for spent fuel storage and in the uranium portions of the LWR industry will be required. There will be no MOX fabrication, but methods for the permanent disposal of plutonium will have to be developed.

The plutonium present in the spent fuel is assumed to become a waste product and, in keeping with its high biological hazard and long decay times, is assumed to undergo disposal in Federal waste repositories as are high level wastes and other wastes contaminated with transuranium elements. For the purposes of this study, the waste plutonium has been assumed to be handled in a manner similar to that used for solidified

high level wastes. This assumption leads to conservative estimates of effluents from normal operations and consequences of accidents associated with waste generating and disposal facilities and transportation. Under this alternative the overall costs for reprocessing spent fuel and placing the plutonium waste in a form and package suitable for disposal and the costs for waste disposal are assumed to be the same (dollars/kgHM) as those for reprocessing spent fuel and handling the plutonium product and for waste disposal in which both uranium and plutonium are recycled.

9.2.2 Materials Processed

The major perturbation in this case is the substantial increase in the uranium portion of the fuel cycle (15% to 19%) and the elimination of the plutonium recycle portion. The U_3O_8 consumption increases by 190,000 tons; UF_6 conversion, separative work reqirements, and UO_2 fabrication increase by 170,000, 90,000 and 25,000 MT, respectively. In addition, there is a substantial increase in the spent fuel storage requirements: over 20,000 MT in the peak year 1987 compared to about 6,000 MT in the reference case (Alternative 3). The spent fuel inventories are reduced to the reference level by 1994.

9.2.3 Use of Natural Resources

The increase in size of the uranium portion of the industry and the elimination of the plutonium recycle portion of the industry results in an increase of 3 million acre-years of occupied land (13%) during the 26-year period. It also causes an increased use of 10,000 billion gallons of water (6% of nonreactor use), and 2 billion therms of natural gas (16%).

9.2.4 Effluents

9.2.4.1 Chemical

The increased uranium conversion requirements increase the fluoride emissions by about 40 MT, or 9%.

Liquid releases of sulfate, nitrate, fluoride, sodium, calcium, ammonia, and iron also increase slightly.

The solid waste from the milling operations will increase by about 100 million cubic meters, or 17%.

9.2.4.2 Radiological

Primarily as a result of increased uranium production, airborne radon release will increase by 2 million curies (10%), and radium and actinide releases will also increase slightly. As a result of not reprocessing MOX fuel, plutonium release will decrease by 33%, and transplutonium isotopes by 50%. Not reprocessing MOX fuel also decreases the release of tritium by 1.0 million curies (about 2%).

The liquid releases will no longer contain measurable amounts of plutonium or transuranium isotopes, but the releases of uranium and its decay products will increase by about 18%.

The whole body dose commitment will increase by 190,000 person-rem to the occupational group and by 400,000 person-rem to the general population (increases of 5 and 9%, respectively).

9.2.4.3 Thermal

The waste heat is essentially unchanged for Alternative 5 relative to Alternative 3.

9.2.5 Economic Considerations

For Alternative 5 the cumulative undiscounted cost of the nuclear fuel cycle for the 1975-2000 period amounts to $175 billion, approximately $18 billion more than the reference case. In terms of levelized fuel cycle costs, the cost is 4.82 mills/kWh, or 0.37 mill/kWh above the 4.46 mills/kWh for the reference case (Alternative 3).

The unit reprocessing costs are lower when no MOX fuel is reprocessed. Also, the delay in reprocessing from 1978 to 1986 reduces spent fuel shipping and reprocessing costs due to the discounting effect but increases the spent fuel storage costs. Without plutonium recovery there is no credit for plutonium sales. The difference in U_3O_8 costs (see Table VIII-9) is $2.64 billion, of which $0.52 billion can be attributed to the delay (see Alternative 2). The corresponding costs for UF_6 conversion are $127 million and $30 million, respectively, and for enrichment the costs are $1.27 billion and $0.15 billion, respectively. The remaining cost increases are caused by the loss of plutonium use as a fuel in LWR's. The UO_2 fuel fabrication costs increase because there is no displacement by MOX fuel. Plutonium transportation and storage, and MOX fuel fabrication costs are eliminated because no plutonium is recycled. The delay in reprocessing also delays waste disposal charges, the net effect being reduced waste disposal costs. These differences are summarized in Table VIII-9. The net difference in discounted cost--$3 billion, or 0.37 mill/kWh--indicates a substantial economic penalty for this alternative.

9.3 Safeguards

9.3.1 Availability of Plutonium

The prime purpose of spent fuel reprocessing done for Alternative 5 would be to recover the contained uranium values for recycle and to concentrate and isolate fission products. Plutonium would be disposed of permanently. Since this alternative assumes that the plutonium will not be purified, minimum safeguards will be required at the reprocessing plant load-out area. Plutonium must be stored so as to ensure

Table VIII-9

NET DIFFERENCE BETWEEN FUEL CYCLE COSTS FOR ALTERNATIVES 5 AND 3 DISCOUNT RATE 10%

Fuel Cycle Component	Alternative 5 Minus Alternative 3, Discounted, $ Millions
U_3O_8	+2,639
UF_6 Conversion	+127
Enrichment	+1,267
UO_2 Fuel Fabrication	+448
Spent Fuel Shipping	-67
Reprocessing	-614
Plutonium Transportation	-9
Plutonium Storage	-34
MOX Fuel Fabrication	-994
Spent Fuel Storage	+205
Waste Disposal	-116
Plutonium Sales	+93
Net Difference	+2,995

safe criticality control and absolute containment because of toxicity, as well as to preclude the possibility of sabotage or theft. Thus a final geologic storage facility would need to be developed to meet these stringent requirements. Encapsulation and special processing to put the plutonium in a form suitable for long term storage would also be required.

Depending on the form in which the plutonium would be placed for storage and ultimate disposal, transportation of plutonium from the reprocessing plants to the final storage repository would require essentially the same safeguards procedures as the shipment of irradiated fuel. Transportation of PuO_2 to fabrication plants would not be required.

There would be no PuO_2 within fabrication plants during reprocessing and in storage after dilution to bulk MOX. In addition, the availability of PuO_2 in fresh fuel assemblies, in storage at the fabrication plant, in transit to power reactors, and in storage at reactor sites before loading would also be eliminated. Commercial handling of plutonium at transfer points and outside secure areas would be significantly reduced.

Thus the safeguards threat at fixed sites and during transportation would be substantially reduced. Safeguards threats would be further reduced by plutonium being in some matrix form to reduce its dispersibility. The retention of substantial amounts of fission products would also make illicit separation much more difficult.

9.3.2 Safeguards Cost Considerations

As explained in paragraph 6.3.2, the unit costs in the fuel cycle analysis of CHAPTER XI are judged to be adequate to meet present regulations.

9.4 Loss of Plutonium Use

If reprocessing is performed for the recovery of uranium only and begins in 1986, all plutonium value will be lost. Comparing this alternative with prompt plutonium and uranium recycle results in a need for an additional 189,000 tons U_3O_8. In addition, the cost of U_3O_8 rises as much as \$3/lb in some years, and the average cost of all U_3O_8 used rises \$0.80/lb because a larger total quantity is needed by the year 2000. The present worth cost of additional U_3O_8 purchased is \$2.64 billion, and the cost of additional separative work is \$1.27 billion.

The total present worth cost of the loss of plutonium estimated from the difference between Alternatives 5 and 2 (both begin reprocessing in 1986) is \$2.92 billion. The cost of plutonium loss is \$2.85 billion from plutonium that would have been used as fuel in LWR's plus \$71 million from plutonium that would have been sold. On comparing Alternative 5 with Alternative 3 (reprocessing begins in 1978) to estimate the cost of plutonium loss, it is found an additional cost of \$74 million is incurred, and this additional cost is entirely due to a difference in reprocessing time schedule.

10.0 SPENT LWR FUEL STORED WITHOUT CONSIDERATION FOR LATER RECOVERY OF PLUTONIUM AND URANIUM VALUES (ALTERNATIVE 6)

10.1 Description

This alternative assumes that the spent fuel assemblies would be placed in storage for approximately 5 years and would then be shipped to a government operated geologic disposal site. These shipments are assumed to begin in 1986. This will allow sufficient lead time to develop the method of preparing the fuel elements for ultimate disposal. Consequently, neither the uranium nor the plutonium contained in spent fuel would be available for LWR utilization.

There would be some difference in the form of storage relative to the high level wastes from the other alternatives, but it would not affect any effluents and would have an insignificant effect on land use. The significant difference is that this alternative implies that the uranium and plutonium values would never be recovered. Certain environmental benefits are associated with the disposal of all irradiated fuel. In particular, the permanent disposal of all irradiated fuel implies that no fuel reprocessing or MOX fabrication plants would be needed and their environmental impacts would not occur. The transportation and handling of plutonium in a readily dispersible form are eliminated, with a resultant reduction in the possibility of inadvertent release of plutonium. As discussed below, however, there are also definite environmental costs associated with the "throwaway" fuel cycle, particularly in regard to normal operations.

10.2 Effects on LWR Fuel Cycle Operations

The environmental considerations associated with this alternative for each fuel cycle step are given in Table VIII(A)-6 of Appendix A. The following discussion highlights differences between Alternative 6 and Alternative 3.

10.2.1 Industry Overview of Alternative 6

With this mode of operation the spent fuel is aged a minimum of 5 years and sent to final geologic storage beginning in 1986. There is no reprocessing and no plutonium or uranium recycle.

10.2.2 Materials Processed

The major perturbation in this case is the substantial increase in the uranium portion of the fuel cycle and the elimination of the reprocessing and recycle portions of the fuel cycle. In addition, there is a substantial increase in spent fuel storage requirements to provide the minimum of 5 years' cooling for the spent fuel.

On the basis of the low growth projection, the U_3O_8 consumption increases by 357,000 tons and the UF_6 conversion, separative work requirements, and UO_2 fabrication increase by 294,000, 85,000, and 25,000 MT, respectively. The spent fuel storage requirements increase by 392,000 MT-yr. These are increases of 29%, 32%, 16%, 15%, and 235% for U_3O_8, UF_6 conversion, separative work, UO_2 fabrication, and spent fuel storage, respectively.

10.2.3 Natural Resources

The increased size of the uranium portion of the industry and the elimination of the reprocessing and recycle portions of the industry result in an increase of about 6 million acre-yr (about 25%) of occupied land during the 26-year period. It also causes an increased use of 10,000 billion gallons of water (6% of nonreactor use), 3 billion therms of natural gas (30%), and a decreased use of 1 billion gallons of fuel oil (5%).

10.2.4 Effluents

10.2.4.1 Chemical

Elimination of reprocessing reduces the gaseous emissions of sulfates and nitrates, but the increased electrical consumption increases the emission of SO_x and NO_x by larger amounts; the emission of particulates also increases. Emissions of carbon monoxide and fluorides decrease, but these changes are insignificant in relation to amounts released to the atmosphere by other industries.

All liquid releases increase by small amounts.

The solid wastes from the milling operation will increase by 190 million cubic meters, or 32%.

10.2.4.2 Radiological

Chiefly as a result of the increased uranium requirements, airborne releases of radon increase by 5 million curies (22%), and the releases of radium and actinides increase by 25 to 30%. As a result of not reprocessing spent fuel, releases of plutonium, americium, and curium are essentially eliminated. Tritium and ^{85}Kr releases are reduced at least tenfold, and releases of other long-lived fission products are virtually eliminated. Releases of ^{14}C are reduced by 62%. Releases of short-lived fission products, such as ^{131}I, are essentially unchanged because these releases are dominated by the reactor operations.

Liquid releases of uranium and its decay products all increase by 20% to 30%, whereas the transplutonium and plutonium releases will be virtually eliminated. Tritium and other radioactive releases from the reactors will be reduced by less than 10%.

Although the spent fuel sent to geologic storage will occupy about 8 times the volume compared to the high level waste from Alternative 3, the geologic storage area required for disposal is essentially the same.

The dose commitment to the occupational group will increase by 300,000 person-rem, whereas that to the general population group will decrease by 300,000 person-rem for a net decrease of zero.

10.2.4.3 Thermal

The waste heat is essentially unchanged for this alternative relative to Alternative 3.

10.2.5 Economic Considerations

For Alternative 6 the cumulative undiscounted cost is $175 billion, or $18 billion more than in the reference case (Alternative 3). In terms of the discounted costs, the incentive to recycle (Alternative 6 minus Alternative 3) is $3 billion. The failure to recycle increases the levelized fuel cycle cost from 4.46 to 4.85 mills/kWh. The difference in costs between Alternative 6 and Alternative 3 for each fuel cycle component are given in Table VIII-10.

The increased cost of U_3O_8 has two components: more is purchased in each year after 1976, and the unit cost is higher in most years after 1978 as a result of the increased demand. The increased costs for UF_6 conversion, enrichment, and UO_2 fabrication are entirely due to the increased demand. The saving in spent fuel transportation is due to the 5-year delay in shipments in spite of the slight increase (about 0.8%) in total shipments. The savings in reprocessing, plutonium transportation, plutonium storage, and MOX fabrication result from the complete elimination of these portions of the industry. The increased charges for spent fuel storage result from the increased storage time of approximately 5 years compared to the approximately 1-year storage time assumed for the reference case. Alternative 6 does not have the $93

Table VIII-10

NET DIFFERENCE BETWEEN DISCOUNTED FUEL CYCLE COSTS FOR ALTERNATIVES 6 AND 3 (MILLIONS OF DOLLARS)

Fuel Cycle Component	Alternative 6 minus Alternative 3, Discounted (Discounted Rate 10%)
U_3O_8	+4,675
UF_6 Conversion	+204
Enrichment	1,201
UO_2 Fabrication	+448
Spent Fuel Shipping	-160
Reprocessing	-3,599
Plutonium Transportation	-9
Plutonium Storage	-34
MOX Fuel Fabrication	-944
Spent Fuel Storage	+397
Waste Disposal	+930
Plutonium Sales	+93
Net Difference	+3,202

million benefit of sales of plutonium available under Alternative 3. The $930 million shown as the increased cost of waste disposal is the difference between the spent fuel disposal costs shown in Table XI-32 and the waste disposal costs shown in Table XI-28. In both cases the charges for disposal are assessed 5 years before the disposal occurs, and therefore the cost is discounted 5 years at 10% (i.e., divided by 1.61) because the material is assumed to be committed for disposal at that time. Thus the quantities committed are not the same since the delay is 5 years in Alternative 6 and 6 years in Alternative 3 (1 year as spent fuel before reprocessing and 5 years as waste after reprocessing).

10.3 Safeguards

For Alternative 6, plutonium would be present only within irradiated fuel assemblies. Reprocessing plants and LWR MOX fabrication plants would not be required. However, the construction of a final geologic storage facility capable of storing the spent fuel in a safe geometry and with provisions to contain potentially mobile fission products and actinides would be required.

The diversion of spent fuel is less likely to occur than diverson of separated plutonium. Spent fuel is not readily dispersible or physically accessible, and sabotage involving spent fuel could be expected to have effects confined to a small local region in contrast to sabotage involving PuO_2. Thus the safeguards threats at fixed sites and during transportation would be substantially reduced. The costs used in the analysis (CHAPTER XI) include the necessary safeguards systems.

10.4 Loss of Plutonium and Uranium Use

The combined loss of the use of plutonium and uranium will require an additional 357,000 tons U_3O_8 and 85,000 MT of separative work by year 2000. The value loss to LWR's of $6.1 billion includes U_3O_8 at $4.7 billion, separative work at $1.2 billion, and $93 million in plutonium value that would have been sold. Thus the true total loss in value is $6.2 billion discounted. However, the difference in cost between Alternative 6 and Alternative 3 is only $3.2 billion. This apparent anomaly is due predominantly to the savings in reprocessing.

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CHAPTER VIII
APPENDIX A

TABLE VIII (A) - 1

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 1

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVER-SION	ENRICH-MENT	UO2 FUEL FABRI-CATION	MOX FUEL FABRI-CATION	REACTOR	REPROCES-SING	TRANSPOR-TATION	WASTE MANAGE-MENT	SPENT FUEL STORAGE	TOTAL
RESOURCE USE												
ACRE-YRS OCCUPIED	1.8E+07	9.6E+05	9.9E+04	4.7E+04	1.2E+05	7.8E+04	2.5E+06	1.4E+05	- -	8.0E+04	- -	2.2E+07
DISTURBED ACRES	2.3E+05	2.6E+04	8.4E+02	1.1E+03	2.0E+02	2.0E+03	4.2E+04	1.2E+03	- -	1.6E+03	- -	3.0E+05
COMMITTED ACRES	8.0E+03	2.2E+04	6.0E+01	- -	- -	- -	8.3E+02	1.2E+03	- -	1.1E+03	- -	3.4E+04
WATER (GALLONS)												
DISCHARGED TO AIR	- -	8.9E+11	1.0E+10	9.6E+11	- -	3.0E+08	3.3E+13	2.2E+10	- -	5.4E+06	8.1E+09	3.5E+13
DISCHARGED TO WATER	- -	- -	8.6E+10	5.3E+13	2.7E+10	9.2E+09	3.3E+13	1.8E+11	- -	- -	- -	8.6E+13
DISCHARGED TO GROUND	2.3E+12	- -	- -	- -	- -	- -	- -	7.5E+08	- -	7.5E+07	- -	2.3E+12
TOTAL DISCHARGED	2.3E+12	8.9E+11	9.6E+10	5.3E+13	2.7E+10	9.5E+09	6.6E+13	2.0E+11	- -	8.0E+07	8.1E+09	1.2E+14
BTU DISSIPATED	3.0E+14	1.1E+15	1.2E+14	1.1E+16	4.6E+13	9.1E+12	2.7E+17	2.1E+14	5.9E+12	3.7E+13	6.8E+13	2.9E+17
TONS COAL	- -	- -	- -	3.1E+06	- -	- -	- -	- -	- -	- -	- -	3.1E+06
THERMS GAS	- -	9.3E+09	9.3E+08	- -	1.8E+08	- -	- -	- -	- -	5.4E+07	- -	1.0E+10
GALLONS FUEL OIL	1.6E+09	- -	- -	1.1E+07	- -	- -	1.7E+10	7.5E+08	4.3E+07	4.0E+06	- -	2.0E+10
GWY ELECTRICITY	2.2E+00	5.2E+00	9.9E-01	1.3E+02	1.0E+00	6.1E+00	2.4E+02	1.5E+00	- -	5.8E-02	2.5E-02	3.8E+02
COAL EQUIVALENT OF 2/3 GWY ELECTRICITY USED												
COAL BURNED (TONS)	5.2E+06	1.2E+07	2.3E+06	3.9E+08	2.3E+06	1.4E+07	5.5E+08	3.5E+06	- -	1.3E+05	5.9E+04	8.9E+08
SLUDGE (TONS)	7.2E+05	1.7E+06	3.2E+05	4.2E+07	3.2E+05	2.0E+06	7.6E+07	4.9E+05	- -	1.9E+04	8.1E+03	1.2E+08
SOX TO ATMOS. (MT)	5.9E+04	1.4E+05	2.6E+04	3.4E+06	2.6E+04	1.6E+05	6.2E+06	4.0E+04	- -	1.5E+03	6.7E+02	1.0E+07
NOX TO ATMOS. (MT)	4.7E+04	1.1E+05	2.1E+04	2.7E+06	2.1E+04	1.3E+05	5.0E+06	3.2E+04	- -	1.2E+03	5.3E+02	8.1E+06
CO TO ATMOS. (MT)	9.5E+02	2.2E+03	4.2E+02	5.5E+04	4.2E+02	2.6E+03	1.0E+05	6.4E+02	- -	2.5E+01	1.1E+01	1.6E+05
PART. TO ATMOS. (MT)	2.8E+03	6.6E+03	1.3E+03	1.6E+05	1.3E+03	7.8E+03	3.0E+05	1.9E+03	- -	7.4E+01	3.2E+01	4.9E+05
HYDROCARBONS (MT)	4.7E+02	1.1E+03	2.1E+02	2.7E+04	2.1E+02	1.3E+03	5.0E+04	3.2E+02	- -	1.2E+01	5.3E+00	8.1E+04
PLANT EFFLUENTS TO ATMOSPHERE (METRIC TONS)												
SOX	6.4E+04	4.3E+02	2.6E+04	3.9E+04	- -	- -	4.8E+05	1.8E+04	8.3E+02	3.5E+01	- -	6.3E+05
NOX	5.3E+04	8.5E+04	1.3E+04	3.1E+04	- -	3.0E+01	2.8E+05	7.2E+04	6.3E+03	4.1E+01	- -	5.4E+05
CO	- -	- -	- -	6.3E+02	- -	- -	1.8E+04	1.4E+03	4.0E+03	2.5E+01	- -	2.5E+04
PARTICULATES	7.7E+03	4.3E+03	4.2E+02	1.9E+03	3.1E+04	- -	6.4E+04	1.9E+03	3.6E+02	1.0E-01	- -	1.1E+05
NH3	- -	- -	1.5E+02	- -	- -	4.1E+00	- -	- -	- -	- -	- -	3.5E+02
FLUORIDES	- -	- -	2.2E+02	1.3E+02	2.7E+01	2.6E-02	- -	1.6E+02	- -	- -	- -	5.3E+02
HYDROCARBONS	3.8E+03	1.7E+04	1.9E+03	3.1E+02	- -	- -	2.0E+04	1.6E+03	8.9E+02	- -	- -	4.6E+04
ALDEHYDE	- -	- -	- -	- -	- -	- -	- -	- -	7.2E+01	4.0E-01	- -	7.2E+01
ORGANIC ACID	- -	- -	- -	- -	- -	- -	- -	- -	9.0E+01	- -	- -	9.0E+01

Table VIII (A) - 1 (Continued)

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 1

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVER-SION	ENRICH-MENT	UO2 FUEL FABRI-CATION	MOX FUEL FABRI-CATION	REACTOR	REPROCES-SING	TRANSPOR-TATION	WASTE MANAGE-MENT	SPENT FUEL STORAGE	TOTAL
PLANT EFFLUENTS TO ATMOSPHERE (CURIES)												
RN-222	1.8E+07	3.4E+06	2.6E-02	- -	- -	- -	- -	- -	- -	2.4E+01	- -	2.2E+07
RA-226	- -	1.0E+01	7.5E-03	- -	- -	- -	- -	- -	- -	- -	- -	1.0E+01
URANIUM	- -	4.1E+02	5.4E+00	2.8E+00	1.0E+00	- -	- -	1.5E-01	- -	1.6E-08	- -	4.2E+02
PU (ALPHA)	- -	- -	- -	2.4E-08	- -	6.1E-01	- -	3.9E+00	- -	1.2E-04	- -	4.5E+00
PU-241 (BETA)	- -	- -	- -	- -	- -	1.6E+01	- -	1.0E+02	- -	3.4E-04	- -	1.2E+02
TRANS-PU NUCLIDES	- -	- -	- -	- -	- -	2.5E-02	- -	1.1E+01	- -	6.2E-03	- -	1.1E+01
H-3	- -	- -	- -	- -	- -	- -	4.1E+06	6.0E+07	- -	2.4E-02	- -	6.4E+07
C-14	- -	- -	- -	- -	- -	- -	4.3E+04	7.5E+04	- -	- -	- -	1.2E+05
KR-85	- -	- -	- -	- -	- -	- -	1.5E+06	1.3E+09	- -	3.8E-01	1.7E+05	1.3E+09
SR-90	- -	- -	- -	- -	- -	- -	- -	1.8E+01	- -	3.7E-02	- -	1.8E+01
TC-99	- -	- -	- -	3.2E+01	- -	- -	- -	3.4E-03	- -	- -	- -	3.2E+01
I-129	- -	- -	- -	- -	- -	- -	- -	1.1E+02	- -	- -	- -	1.1E+02
I-131	- -	- -	- -	- -	- -	- -	6.5E+02	2.7E+03	- -	- -	- -	3.4E+03
OTHER RADIOACTIVITY	- -	- -	- -	5.3E-01	- -	- -	5.3E+07	1.1E+03	- -	1.1E+00	- -	5.3E+07
PLANT EFFLUENTS TO WATER BODIES (METRIC TONS)												
SO4=	- -	- -	4.1E+04	2.8E+03	- -	5.8E+00	1.4E+07	5.8E+01	- -	- -	- -	1.4E+07
NO3-	- -	- -	7.3E+02	2.6E+03	5.3E+03	1.2E+02	- -	- -	- -	- -	- -	8.7E+03
CL-	- -	- -	1.2E+04	1.3E+03	- -	- -	1.2E+06	2.9E+02	- -	- -	- -	1.2E+06
FLUORIDES	- -	- -	7.2E+02	2.9E+01	1.5E+02	- -	- -	- -	- -	- -	- -	9.0E+02
NA+	- -	- -	3.8E+04	- -	- -	- -	- -	5.8E+01	- -	- -	- -	3.8E+04
CA++	- -	- -	3.0E+03	- -	7.6E-01	- -	- -	- -	- -	- -	- -	3.0E+03
NH3	- -	- -	1.3E+04	- -	6.0E+01	- -	- -	- -	- -	- -	- -	1.3E+04
FE	- -	- -	1.8E+02	- -	- -	- -	- -	- -	- -	- -	- -	1.8E+02
PLANT EFFLUENTS TO WATER BODIES (CURIES)												
TRANS-PU NUCLIDES	- -	- -	- -	- -	- -	5.1E-03	- -	- -	- -	- -	- -	5.1E-03
PU (ALPHA)	- -	- -	- -	4.7E-07	- -	1.2E-01	- -	- -	- -	- -	- -	1.2E-01
URANIUM	- -	- -	2.1E+02	1.8E-01	2.4E+02	- -	- -	- -	- -	- -	- -	4.5E+02
TH-230	- -	- -	3.2E+01	- -	- -	- -	- -	- -	- -	- -	- -	3.2E+01
RA-226	- -	- -	1.1E+00	- -	- -	- -	- -	- -	- -	- -	- -	1.1E+00
I-129	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
TC-99	- -	- -	- -	4.2E+02	- -	- -	- -	- -	- -	- -	- -	4.2E+02
SR-90	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
C-14	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
H-3	- -	- -	- -	- -	- -	- -	9.5E+05	- -	- -	- -	- -	9.5E+05
OTHER RADIOACTIVITY	- -	- -	- -	6.9E+00	- -	- -	1.2E+03	- -	- -	- -	- -	1.2E+03

Table VIII (A) - 1 (Continued)

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 1

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVER-SION	ENRICH-MENT	UO2 FUEL FABRI-CATION	MOX FUEL FABRI-CATION	REACTOR	REPROCES-SING	TRANSPOR-TATION	WASTE MANAGE-MENT	SPENT FUEL STORAGE	TOTAL
PLANT WASTE GENERATED (CUBIC METERS)												
CHEMICAL COMPOUNDS	- -	- -	1.4E+05	3.1E+02	1.3E+05	- -	- -	2.3E+04	- -	- -	- -	3.0E+05
MILL TAILINGS	- -	5.9E+08	- -	- -	- -	- -	- -	- -	- -	- -	- -	5.9E+08
TRANS-U SOLIDS	- -	- -	- -	- -	- -	1.8E+04	- -	1.3E+05	- -	- -	- -	1.5E+05
HIGHLEVEL SOLIDS	- -	- -	- -	- -	- -	- -	- -	6.5E+03	- -	- -	- -	6.5E+03
OTHER RAD. SOLIDS	- -	- -	6.7E+04	2.2E+04	- -	- -	3.8E+06	- -	- -	- -	1.0E+03	3.9E+06
PERSON-REM COMMITMENT - OCCUPATIONAL												
TOTAL BODY	9.4E+05	4.4E+05	3.3E+03	2.7E+03	4.4E+04	2.5E+04	2.3E+06	7.8E+04	8.1E+03	3.0E+03	3.3E+03	3.8E+06
G.I. TRACT	9.4E+05	1.6E+05	2.0E+03	1.4E+03	4.3E+04	2.5E+04	2.3E+06	7.8E+04	8.1E+03	3.1E+03	3.3E+03	3.5E+06
BONE	1.4E+06	1.8E+06	3.8E+04	2.4E+04	5.7E+04	2.5E+04	2.3E+06	7.8E+04	8.1E+03	3.3E+04	3.3E+03	5.6E+06
LIVER	9.4E+05	1.6E+05	4.0E+03	2.7E+03	4.3E+04	2.5E+04	2.3E+06	7.8E+04	8.1E+03	5.0E+03	3.3E+03	3.5E+06
KIDNEY	1.4E+06	2.0E+05	9.8E+03	6.6E+03	4.6E+04	2.5E+04	2.3E+06	7.8E+04	8.1E+03	4.4E+03	3.3E+03	4.0E+06
THYROID	9.4E+05	1.6E+05	3.3E+03	2.7E+03	4.3E+04	2.5E+04	2.3E+06	7.8E+04	8.1E+03	3.0E+03	3.3E+03	3.5E+06
LUNG	5.1E+06	3.8E+06	2.6E+04	5.8E+04	1.7E+06	2.9E+04	2.3E+06	7.8E+04	8.1E+03	2.5E+03	3.3E+03	1.3E+07
SKIN	9.4E+05	1.6E+05	1.0E+04	8.9E+03	4.3E+04	2.5E+04	2.3E+06	7.8E+04	8.1E+03	2.5E+03	3.3E+03	3.6E+06
PERSON-REM COMMITMENT - OFF-SITE U.S. POPULATION												
TOTAL BODY	2.3E+06	4.5E+05	3.1E+04	1.1E+02	2.2E+03	3.0E+02	3.1E+05	1.1E+06	2.0E+03	3.5E+00	8.5E+00	4.2E+06
G.I. TRACT	9.1E+04	1.7E+04	4.3E+03	6.2E+03	2.4E+03	1.8E+01	3.1E+05	1.6E+06	2.0E+03	8.9E-01	8.5E+00	2.1E+06
BONE	7.5E+06	1.5E+06	7.6E+04	8.0E+02	3.6E+04	1.4E+04	1.1E+06	2.6E+06	2.0E+03	1.4E+01	8.5E+00	1.3E+07
LIVER	1.9E+06	3.5E+05	5.5E+02	1.9E+02	4.5E+00	1.4E+03	3.2E+05	1.1E+06	2.0E+03	3.2E+00	8.5E+00	3.6E+06
KIDNEY	8.8E+06	1.7E+06	9.2E+03	2.5E+03	5.9E+03	1.2E+03	3.1E+05	1.1E+06	2.0E+03	1.2E+01	8.5E+00	1.2E+07
THYROID	5.7E+03	1.2E+03	3.7E+01	1.5E+01	4.0E+00	5.6E+00	4.9E+05	1.9E+06	2.0E+03	4.6E-01	8.5E+00	2.4E+06
LUNG	7.1E+05	1.4E+05	7.3E+02	3.7E+02	1.3E+02	3.1E+02	3.1E+05	1.1E+06	2.0E+03	1.5E+00	1.8E+01	2.3E+06
SKIN	5.7E+03	1.2E+03	2.8E+01	1.0E+02	4.0E+00	5.6E+00	3.1E+05	6.4E+06	2.0E+03	4.6E-01	7.2E+02	6.7E+06
PERSON-REM COMMITMENT - TO FOREIGN POPULATION FROM U.S. INDUSTRY												
TOTAL BODY	- -	- -	- -	- -	- -	- -	2.1E+05	6.7E+05	- -	- -	3.8E+01	8.8E+05
G.I. TRACT	- -	- -	- -	- -	- -	- -	2.1E+05	6.7E+05	- -	- -	3.8E+01	8.8E+05
BONE	- -	- -	- -	- -	- -	- -	1.0E+06	2.2E+06	- -	- -	3.8E+01	3.2E+06
LIVER	- -	- -	- -	- -	- -	- -	2.1E+05	6.7E+05	- -	- -	3.8E+01	8.8E+05
KIDNEY	- -	- -	- -	- -	- -	- -	2.1E+05	6.7E+05	- -	- -	3.8E+01	8.8E+05
THYROID	- -	- -	- -	- -	- -	- -	2.1E+05	6.7E+05	- -	- -	3.8E+01	8.8E+05
LUNG	- -	- -	- -	- -	- -	- -	2.1E+05	1.0E+06	- -	- -	9.3E+01	1.2E+06
SKIN	- -	- -	- -	- -	- -	- -	2.4E+05	2.5E+07	- -	- -	3.2E+03	2.5E+07

Table VIII (A) - 2

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 2

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVER-SION	ENRICH-MENT	UO2 FUEL FABRI-CATION	MOX FUEL FABRI-CATION	REACTOR	REPROCES-SING	TRANSPOR-TATION	WASTE MANAGE-MENT	SPENT FUEL STORAGE	TOTAL
RESOURCE USE												
ACRE-YRS OCCUPIED	1.8E+07	9.6E+05	1.0E+05	4.6E+04	1.2E+05	7.7E+04	2.5E+06	1.3E+05	- -	8.0E+04	- -	2.2E+07
DISTURBED ACRES	2.3E+05	2.6E+04	8.4E+02	1.1E+03	2.0E+02	2.0E+03	4.2E+04	1.2E+03	- -	1.6E+03	- -	3.1E+05
COMMITTED ACRES	8.1E+03	2.2E+04	6.0E+01	- -	- -	- -	8.3E+02	1.2E+03	- -	1.1E+03	- -	3.4E+04
WATER (GALLONS)												
DISCHARGED TO AIR	- -	8.9E+11	9.9E+09	9.7E+11	- -	3.0E+08	3.3E+13	2.2E+10	- -	5.4E+06	1.4E+10	3.5E+13
DISCHARGED TO WATER	- -	- -	8.4E+10	5.3E+13	2.7E+10	9.2E+09	3.3E+13	1.8E+11	- -	- -	- -	8.6E+13
DISCHARGED TO GROUND	2.3E+12	- -	- -	- -	- -	- -	- -	7.5E+08	- -	7.5E+07	- -	2.3E+12
TOTAL DISCHARGED	2.3E+12	8.9E+11	9.4E+10	5.4E+13	2.7E+10	9.5E+09	6.6E+13	2.0E+11	- -	8.0E+07	1.4E+10	1.2E+14
BTU DISSIPATED	3.0E+14	1.1E+15	1.2E+14	1.1E+16	4.6E+13	9.1E+12	2.7E+17	2.1E+14	5.9E+12	3.7E+13	1.1E+14	2.9E+17
TONS COAL	- -	- -	- -	3.1E+06	- -	- -	- -	- -	- -	- -	- -	3.1E+06
THERMS GAS	- -	9.3E+09	9.1E+08	- -	1.8E+08	- -	- -	- -	- -	5.4E+07	- -	1.0E+10
GALLONS FUEL OIL	1.6E+09	- -	- -	1.1E+07	- -	- -	1.7E+10	7.5E+08	4.3E+07	4.0E+06	- -	2.0E+10
GWY ELECTRICITY	2.2E+00	5.2E+00	9.8E-01	1.3E+02	1.0E+00	6.1E+00	2.4E+02	1.5E+00	- -	5.8E-02	4.2E-02	3.8E+02
COAL EQUIVALENT OF 2/3 GWY ELECTRICITY USED												
COAL BURNED (TONS)	5.2E+06	1.2E+07	2.3E+06	3.0E+08	2.3E+06	1.4E+07	5.5E+08	3.5E+06	- -	1.3E+05	9.8E+04	8.9E+08
SLUDGE (TONS)	7.2E+05	1.7E+06	3.1E+05	4.2E+07	3.2E+05	2.0E+06	7.6E+07	4.9E+05	- -	1.9E+04	1.4E+04	1.2E+08
SOX TO ATMOS. (MT)	5.9E+04	1.4E+05	2.6E+04	3.4E+06	2.6E+04	1.6E+05	6.2E+06	4.0E+04	- -	1.5E+03	1.1E+03	1.0E+07
NOX TO ATMOS. (MT)	4.7E+04	1.1E+05	2.1E+04	2.8E+06	2.1E+04	1.3E+05	5.0E+06	3.2E+04	- -	1.2E+03	8.9E+02	8.1E+06
CO TO ATMOS. (MT)	9.5E+02	2.2E+03	4.1E+02	5.5E+04	4.2E+02	2.6E+03	1.0E+05	6.4E+02	- -	2.5E+01	1.8E+01	1.6E+05
PART. TO ATMOS. (MT)	2.8E+03	6.6E+03	1.2E+03	1.7E+05	1.3E+03	7.7E+03	3.0E+05	1.9E+03	- -	7.4E+01	5.3E+01	4.9E+05
HYDROCARBONS (MT)	4.7E+02	1.1E+03	2.1E+02	2.8E+04	2.1E+02	1.3E+03	5.0E+04	3.2E+02	- -	1.2E+01	8.9E+00	8.1E+04
PLANT EFFLUENTS TO ATMOSPHERE (METRIC TONS)												
SOX	6.5E+04	4.3E+02	2.7E+04	3.9E+04	- -	- -	4.8E+05	1.6E+04	8.3E+02	3.5E+01	- -	6.3E+05
NOX	5.3E+04	8.5E+04	1.3E+04	3.1E+04	- -	3.0E+01	2.8E+05	7.2E+04	6.3E+03	4.1E+01	- -	5.4E+05
CO	- -	- -	- -	6.3E+02	- -	- -	1.8E+04	1.4E+03	4.0E+03	2.5E+01	- -	2.5E+04
PARTICULATES	7.7E+03	4.3E+03	4.1E+02	1.9E+03	3.1E+04	- -	6.4E+04	1.9E+03	3.6E+02	1.0E-01	- -	1.1E+05
NH3	- -	- -	3.7E+02	- -	- -	4.1E+00	- -	- -	- -	- -	- -	3.7E+02
FLUORIDES	- -	- -	2.1E+02	1.3E+02	2.7E+01	2.6E-02	- -	1.6E+02	- -	- -	- -	5.2E+02
HYDROCARBONS	3.8E+03	1.7E+04	1.8E+03	3.1E+02	- -	- -	2.0E+04	1.6E+03	8.9E+02	- -	- -	4.6E+04
ALDEHYDE	- -	- -	- -	- -	- -	- -	- -	- -	7.2E+01	4.0E-01	- -	7.2E+01
ORGANIC ACID	- -	- -	- -	- -	- -	- -	- -	- -	9.0E+01	- -	- -	9.0E+01

Table VIII (A) - 2 (Continued)

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 2

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVERSION	ENRICHMENT	UO2 FUEL FABRICATION	MOX FUEL FABRICATION	REACTOR	REPROCESSING	TRANSPORTATION	WASTE MANAGEMENT	SPENT FUEL STORAGE	TOTAL
PLANT EFFLUENTS TO ATMOSPHERE (CURIES)												
RN-222	1.8E+07	3.4E+06	2.7E-02	- -	- -	- -	- -	- -	- -	2.4E+01	- -	2.2E+07
RA-226	- -	1.0E+01	7.8E-03	- -	- -	- -	- -	- -	- -	- -	- -	1.0E+01
URANIUM	- -	4.1E+02	5.4E+00	2.8E+00	1.0E+00	- -	- -	1.5E-01	- -	1.6E-08	- -	4.2E+02
PU (ALPHA)	- -	- -	- -	2.4E-08	- -	6.0E-01	- -	3.6E+00	- -	1.2E-04	- -	4.4E+00
PU-241 (BETA)	- -	- -	- -	- -	- -	1.5E+01	- -	1.0E+02	- -	3.4E-04	- -	1.2E+02
TRANS-PU NUCLIDES	- -	- -	- -	- -	- -	2.5E-02	- -	1.0E+01	- -	6.2E-03	- -	1.0E+01
H-3	- -	- -	- -	- -	- -	- -	4.1E+06	6.0E+07	- -	2.4E-02	- -	6.4E+07
C-14	- -	- -	- -	- -	- -	- -	4.3E+04	7.5E+04	- -	- -	- -	1.2E+05
KR-85	- -	- -	- -	- -	- -	- -	1.5E+06	1.3E+09	- -	3.8E-01	2.8E+05	1.3E+09
SR-90	- -	- -	- -	- -	- -	- -	- -	1.8E+01	- -	3.7E-02	- -	1.8E+01
TC-99	- -	- -	- -	3.2E+01	- -	- -	- -	3.4E-03	- -	- -	- -	3.2E+01
I-129	- -	- -	- -	- -	- -	- -	- -	1.1E+02	- -	- -	- -	1.1E+02
I-131	- -	- -	- -	- -	- -	- -	6.5E+02	2.7E+03	- -	- -	- -	3.4E+03
OTHER RADIOACTIVITY	- -	- -	- -	5.3E-01	- -	- -	5.3E+07	1.1E+03	- -	1.1E+00	- -	5.3E+07
PLANT EFFLUENTS TO WATER BODIES (METRIC TONS)												
SO4=	- -	- -	4.3E+04	2.8E+03	- -	5.8E+00	1.4E+07	5.8E+01	- -	- -	- -	1.4E+07
NO3-	- -	- -	7.0E+02	2.5E+03	5.3E+03	1.2E+02	- -	- -	- -	- -	- -	8.6E+03
CL-	- -	- -	1.2E+04	1.3E+03	- -	- -	1.2E+06	2.9E+02	- -	- -	- -	1.2E+06
FLUORIDES	- -	- -	7.2E+02	2.9E+01	1.5E+02	- -	- -	- -	- -	- -	- -	9.0E+02
NA+	- -	- -	4.0E+04	- -	- -	- -	- -	5.8E+01	- -	- -	- -	4.0E+04
CA++	- -	- -	2.8E+03	- -	7.6E-01	- -	- -	- -	- -	- -	- -	2.8E+03
NH3	- -	- -	1.3E+04	- -	6.0E+01	- -	- -	- -	- -	- -	- -	1.4E+04
FE	- -	- -	1.8E+02	- -	- -	- -	- -	- -	- -	- -	- -	1.8E+02
PLANT EFFLUENTS TO WATER BODIES (CURIES)												
TRANS-PU NUCLIDES	- -	- -	- -	- -	- -	5.9E-03	- -	- -	- -	- -	- -	5.9E-03
PU (ALPHA)	- -	- -	- -	4.7E-07	- -	1.2E-01	- -	- -	- -	- -	- -	1.2E-01
URANIUM	- -	- -	2.1E+02	1.3E-01	2.4E+02	- -	- -	- -	- -	- -	- -	4.5E+02
TH-230	- -	- -	3.2E+01	- -	- -	- -	- -	- -	- -	- -	- -	3.1E+01
RA-226	- -	- -	1.1E+00	- -	- -	- -	- -	- -	- -	- -	- -	1.1E+00
PB-210	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
TC-99	- -	- -	- -	4.1E+02	- -	- -	- -	- -	- -	- -	- -	4.1E+02
SR-90	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
C-14	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
H-3	- -	- -	- -	- -	- -	- -	9.5E+05	- -	- -	- -	- -	9.5E+05
OTHER RADIOACTIVITY	- -	- -	- -	5.9E+00	- -	- -	1.2E+03	- -	- -	- -	- -	1.2E+03

Table VIII (A) - 2 (Continued)

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 2

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVER-SION	ENRICH-MENT	UO2 FUEL FABRI-CATION	MOX FUEL FABRI-CATION	REACTOR	REPROCES-SING	TRANSPOR-TATION	WASTE MANAGE-MENT	SPENT FUEL STORAGE	TOTAL
PLANT WASTE GENERATED (CUBIC METERS)												
CHEMICAL COMPOUNDS	- -	- -	1.4E+05	2.8E+02	1.3E+05	- -	- -	2.3E+04	- -	- -	- -	3.0E+05
MILL TAILINGS	- -	5.9E+08	- -	- -	- -	- -	- -	- -	- -	- -	- -	5.9E+08
TRANS-U SOLIDS	- -	- -	- -	- -	- -	1.8E+04	- -	1.3E+05	- -	- -	- -	1.5E+05
HIGHLEVEL SOLIDS	- -	- -	- -	- -	- -	- -	- -	6.5E+03	- -	- -	- -	6.5E+03
OTHER RAD. SOLIDS	- -	- -	6.7E+04	2.2E+04	- -	- -	3.8E+06	- -	- -	- -	1.7E+03	3.9E+06
PERSON-REM COMMITMENT - OCCUPATIONAL												
TOTAL BODY	9.4E+05	4.4E+05	3.4E+03	2.7E+03	4.4E+04	2.4E+04	2.3E+06	7.7E+04	8.1E+03	3.0E+03	5.6E+03	3.8E+06
G.I. TRACT	9.4E+05	1.6E+05	2.1E+03	1.4E+03	4.3E+04	2.4E+04	2.3E+06	7.7E+04	8.1E+03	3.1E+03	5.6E+03	3.5E+06
BONE	1.4E+06	1.8E+06	3.9E+04	2.4E+04	5.7E+04	2.4E+04	2.3E+06	7.7E+04	8.1E+03	3.3E+04	5.6E+03	5.6E+06
LIVER	9.4E+05	1.6E+05	4.1E+03	2.7E+03	4.3E+04	2.4E+04	2.3E+06	7.7E+04	8.1E+03	5.0E+03	5.6E+03	3.5E+06
KIDNEY	1.4E+06	2.0E+05	1.0E+04	6.5E+03	4.6E+04	2.4E+04	2.3E+06	7.7E+04	8.1E+03	4.4E+03	5.6E+03	4.0E+06
THYROID	9.4E+05	1.6E+05	3.4E+03	2.7E+03	4.3E+04	2.4E+04	2.3E+06	7.7E+04	8.1E+03	3.0E+03	5.6E+03	3.5E+06
LUNG	5.1E+06	3.8E+06	2.6E+04	5.8E+04	1.7E+06	2.8E+04	2.3E+06	7.7E+04	8.1E+03	2.5E+03	5.6E+03	1.3E+07
SKIN	9.4E+05	1.6E+05	9.8E+03	6.8E+03	4.3E+04	2.4E+04	2.3E+06	7.7E+04	8.1E+03	2.5E+03	5.6E+03	3.6E+06
PERSON-REM COMMITMENT - OFF-SITE U.S. POPULATION												
TOTAL BODY	2.3E+06	4.5E+05	3.3E+04	1.1E+02	2.2E+03	2.9E+02	3.1E+05	1.1E+06	2.0E+03	3.5E+00	1.4E+01	4.2E+06
G.I. TRACT	9.1E+04	1.7E+04	4.2E+03	6.2E+03	2.4E+03	1.7E+01	3.1E+05	1.6E+06	2.0E+03	8.9E-01	1.4E+01	2.1E+06
BONE	7.5E+06	1.5E+06	7.7E+04	9.0E+02	3.6E+04	1.3E+04	1.1E+06	2.6E+06	2.0E+03	1.4E+01	1.4E+01	1.3E+07
LIVER	1.9E+06	3.5E+05	5.3E+02	1.9E+02	4.5E+00	1.3E+03	3.2E+05	1.1E+06	2.0E+03	3.2E+00	1.4E+01	3.6E+06
KIDNEY	8.8E+06	1.7E+06	9.0E+03	2.5E+03	5.9E+03	1.2E+03	3.1E+05	1.1E+06	2.0E+03	1.2E+01	1.4E+01	1.2E+07
THYROID	5.7E+03	1.2E+03	3.7E+01	1.5E+01	4.0E+00	5.5E+00	4.9E+05	1.9E+06	2.0E+03	4.6E-01	1.4E+01	2.4E+06
LUNG	7.1E+05	1.4E+05	7.4E+02	3.7E+02	1.3E+02	3.0E+02	3.1E+05	1.1E+06	2.0E+03	1.5E+00	3.1E+01	2.3E+06
SKIN	5.7E+03	1.2E+03	2.8E+01	9.9E+01	4.0E+00	5.5E+00	3.1E+05	6.4E+06	2.0E+03	4.6E-01	1.2E+03	6.7E+06
PERSON-REM COMMITMENT - TO FOREIGN POPULATION FROM U.S. INDUSTRY												
TOTAL BODY	- -	- -	- -	- -	- -	- -	2.1E+05	6.8E+05	- -	- -	6.4E+01	8.9E+05
G.I. TRACT	- -	- -	- -	- -	- -	- -	2.1E+05	6.8E+05	- -	- -	6.4E+01	8.9E+05
BONE	- -	- -	- -	- -	- -	- -	1.0E+06	2.2E+06	- -	- -	6.4E+01	3.2E+06
LIVER	- -	- -	- -	- -	- -	- -	2.1E+05	6.8E+05	- -	- -	6.4E+01	8.9E+05
KIDNEY	- -	- -	- -	- -	- -	- -	2.1E+05	6.8E+05	- -	- -	6.4E+01	8.9E+05
THYROID	- -	- -	- -	- -	- -	- -	2.1E+05	6.8E+05	- -	- -	6.4E+01	8.9E+05
LUNG	- -	- -	- -	- -	- -	- -	2.1E+05	1.0E+06	- -	- -	4.4E+02	1.2E+06
SKIN	- -	- -	- -	- -	- -	- -	2.4E+05	2.5E+07	- -	- -	5.4E+03	2.5E+07

Table VIII (A) - 3

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 3

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVER-SION	ENRICH-MENT	UO2 FUEL FABRI-CATION	MOX FUEL FABRI-CATION	REACTOR	REPROCES-SING	TRANSPOR-TATION	WASTE MANAGE-MENT	SPENT FUEL STORAGE	TOTAL
RESOURCE USE												
ACRE-YRS OCCUPIED	1.8E+07	9.5E+05	1.0E+05	4.7E+04	1.2E+05	8.1E+04	2.5E+06	1.4E+05	- -	8.0E+04	- -	2.2E+07
DISTURBED ACRES	2.3E+05	2.6E+04	8.4E+02	1.1E+03	2.0E+02	2.0E+03	4.2E+04	1.2E+03	- -	1.6E+03	- -	3.0E+05
COMMITTED ACRES	8.0E+03	2.2E+04	6.0E+01	- -	- -	- -	8.3E+02	1.2E+03	- -	1.1E+01	- -	3.4E+04
WATER (GALLONS)												
DISCHARGED TO AIR	- -	8.9E+11	1.0E+10	9.6E+11	- -	3.0E+08	3.3E+13	2.2E+10	- -	5.4E+06	8.1E+09	3.5E+13
DISCHARGED TO WATER	- -	- -	8.5E+10	5.3E+13	2.7E+10	9.2E+09	3.3E+13	1.8E+11	- -	- -	- -	8.6E+13
DISCHARGED TO GROUND	2.3E+12	- -	- -	- -	- -	- -	- -	7.5E+08	- -	7.5E+07	- -	2.3E+12
TOTAL DISCHARGED	2.3E+12	8.9E+11	9.5E+10	5.3E+13	2.7E+10	9.5E+09	6.6E+13	2.0E+11	- -	8.0E+07	8.1E+09	1.2E+14
BTU DISSIPATED	3.0E+14	1.1E+15	1.2E+14	1.1E+16	4.6E+13	9.1E+12	2.7E+17	2.1E+14	5.9E+12	3.7E+13	6.8E+13	2.9E+17
TONS COAL	- -	- -	- -	3.1E+06	- -	- -	- -	- -	- -	- -	- -	3.1E+06
THERMS GAS	- -	9.3E+09	9.3E+08	- -	1.8E+08	- -	- -	- -	- -	5.4E+07	- -	1.0E+10
GALLONS FUEL OIL	1.6E+09	- -	- -	1.1E+07	- -	- -	1.7E+10	7.5E+08	4.3E+07	4.0E+06	- -	2.0E+10
GWY ELECTRICITY	2.2E+00	5.2E+00	9.8E-01	1.3E+02	1.0E+00	6.1E+00	2.4E+02	1.5E+00	- -	5.8E-02	2.5E-02	3.8E+02
COAL EQUIVALENT OF 2/3 GWY ELECTRICITY USED												
COAL BURNED (TONS)	5.2E+06	1.2E+07	2.3E+06	3.0E+08	2.3E+06	1.4E+07	5.5E+08	3.5E+06	- -	1.3E+05	5.9E+04	8.9E+08
SLUDGE (TONS)	7.2E+05	1.7E+06	3.2E+05	4.2E+07	3.2E+05	2.0E+06	7.6E+07	4.9E+05	- -	1.9E+04	8.1E+03	1.2E+08
SOX TO ATMOS. (MT)	5.9E+04	1.4E+05	2.6E+04	3.4E+06	2.6E+04	1.6E+05	6.2E+06	4.0E+04	- -	1.5E+03	6.7E+02	1.0E+07
NOX TO ATMOS. (MT)	4.7E+04	1.1E+05	2.1E+04	2.7E+06	2.1E+04	1.3E+05	5.0E+06	3.2E+04	- -	1.2E+03	5.3E+02	8.1E+06
CO TO ATMOS. (MT)	9.5E+02	2.2E+03	4.2E+02	5.5E+04	4.2E+02	2.6E+03	1.0E+05	6.4E+02	- -	2.5E+01	1.1E+01	1.6E+05
PART. TO ATMOS. (MT)	2.8E+03	6.6E+03	1.3E+03	1.6E+05	1.3E+03	7.8E+03	3.0E+05	1.9E+03	- -	7.4E+01	3.2E+01	4.9E+05
HYDROCARBONS (MT)	4.7E+02	1.1E+03	2.1E+02	2.7E+04	2.1E+02	1.3E+03	5.0E+04	3.2E+02	- -	1.2E+01	5.3E+00	8.1E+04
PLANT EFFLUENTS TO ATMOSPHERE (METRIC TONS)												
SOX	6.4E+04	4.3E+02	2.6E+04	3.9E+04	- -	- -	4.8E+05	1.8E+04	8.3E+02	3.5E+01	- -	6.3E+05
NOX	5.3E+04	8.5E+04	1.3E+04	3.1E+04	- -	3.0E+01	2.8E+05	7.2E+04	6.3E+03	4.1E+01	- -	5.4E+05
CO	- -	- -	- -	6.3E+02	- -	- -	1.8E+04	1.4E+03	4.0E+03	2.5E+01	- -	2.5E+04
PARTICULATES	7.7E+03	4.3E+03	4.2E+02	1.9E+03	3.1E+04	- -	6.4E+04	1.9E+03	3.6E+02	1.0E-01	- -	1.1E+05
NH3	- -	- -	3.5E+02	- -	- -	4.1E+00	- -	- -	- -	- -	- -	3.6E+02
FLUORIDES	- -	- -	2.1E+02	1.3E+02	2.7E+01	2.6E-02	- -	1.6E+02	- -	- -	- -	5.3E+02
HYDROCARBONS	3.8E+03	1.7E+04	1.9E+03	3.1E+02	- -	- -	2.0E+04	1.6E+03	8.9E+02	- -	- -	4.6E+04
ALDEHYDE	- -	- -	- -	- -	- -	- -	- -	- -	7.2E+01	4.0E-01	- -	7.2E+01
ORGANIC ACID	- -	- -	- -	- -	- -	- -	- -	- -	9.0E+01	- -	- -	9.0E+01

Table VIII (A) - 3 (Continued)

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 3

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVER-SION	ENRICH-MENT	UO2 FUEL FABRI-CATION	MOX FUEL FABRI-CATION	REACTOR	REPROCES-SING	TRANSPOR-TATION	WASTE MANAGE-MENT	SPENT FUEL STORAGE	TOTAL
PLANT EFFLUENTS TO ATMOSPHERE (CURIES)												
RN-222	1.8E+07	3.4E+06	2.6E-02	- -	- -	- -	- -	- -	- -	2.4E+01	- -	2.2E+07
RA-226	- -	1.0E+01	7.6E-03	- -	- -	- -	- -	- -	- -	- -	- -	1.0E+01
URANIUM	- -	4.1E+02	5.4E+00	2.8E+00	1.0E+00	- -	- -	1.5E-01	- -	1.6E-08	- -	4.2E+02
PU (ALPHA)	- -	- -	- -	2.4E-08	- -	6.1E-01	- -	3.9E+00	- -	1.2E-04	- -	4.5E+00
PU-241 (BETA)	- -	- -	- -	- -	- -	1.6E+01	- -	1.0E+02	- -	3.4E-04	- -	1.2E+02
TRANS-PU NUCLIDES	- -	- -	- -	- -	- -	2.5E-02	- -	1.1E+01	- -	6.2E-03	- -	1.1E+01
H-3	- -	- -	- -	- -	- -	- -	4.1E+06	6.0E+07	- -	2.4E-02	- -	6.4E+07
C-14	- -	- -	- -	- -	- -	- -	4.3E+04	7.5E+04	- -	- -	- -	1.2E+05
KR-85	- -	- -	- -	- -	- -	- -	1.5E+06	1.3E+09	- -	3.8E-01	1.7E+05	1.3E+09
SR-90	- -	- -	- -	- -	- -	- -	- -	1.8E+01	- -	3.7E-02	- -	1.8E+01
TC-99	- -	- -	- -	3.2E+01	- -	- -	- -	3.4E-03	- -	- -	- -	3.2E+01
I-129	- -	- -	- -	- -	- -	- -	- -	1.1E+02	- -	- -	- -	1.1E+02
I-131	- -	- -	- -	- -	- -	- -	6.5E+02	2.7E+03	- -	- -	- -	3.4E+03
OTHER RADIOACTIVITY	- -	- -	- -	5.3E-01	- -	- -	5.3E+07	1.1E+03	- -	1.1E+00	- -	5.3E+07
PLANT EFFLUENTS TO WATER BODIES (METRIC TONS)												
SO4=	- -	- -	4.1E+04	2.8E+03	- -	5.6E+00	1.4E+07	5.8E+01	- -	- -	- -	1.4E+07
NO3-	- -	- -	7.2E+02	2.6E+03	5.3E+03	1.2E+02	- -	- -	- -	- -	- -	8.7E+03
CL-	- -	- -	1.2E+04	1.3E+03	- -	- -	1.2E+06	2.9E+02	- -	- -	- -	1.2E+06
FLUORIDES	- -	- -	7.2E+02	2.9E+01	1.5E+02	- -	- -	- -	- -	- -	- -	9.0E+02
NA+	- -	- -	3.9E+04	- -	- -	- -	- -	5.8E+01	- -	- -	- -	3.9E+04
CA++	- -	- -	2.9E+03	- -	7.6E-01	- -	- -	- -	- -	- -	- -	2.9E+03
NH3	- -	- -	1.3E+04	- -	6.0E+01	- -	- -	- -	- -	- -	- -	1.3E+04
FE	- -	- -	1.8E+02	- -	- -	- -	- -	- -	- -	- -	- -	1.8E+02
PLANT EFFLUENTS TO WATER BODIES (CURIES)												
TRANS-PU NUCLIDES	- -	- -	- -	- -	- -	5.1E-03	- -	- -	- -	- -	- -	5.1E-03
PU (ALPHA)	- -	- -	- -	4.7E-07	- -	1.2E-01	- -	- -	- -	- -	- -	1.2E-01
URANIUM	- -	- -	2.1E+02	1.9E-01	2.4E+02	- -	- -	- -	- -	- -	- -	4.5E+02
TH-230	- -	- -	3.2E+01	- -	- -	- -	- -	- -	- -	- -	- -	3.2E+01
RA-226	- -	- -	1.1E+00	- -	- -	- -	- -	- -	- -	- -	- -	1.1E+00
I-129	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
TC-99	- -	- -	- -	4.2E+02	- -	- -	- -	- -	- -	- -	- -	4.2E+02
SR-90	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
C-14	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
H-3	- -	- -	- -	- -	- -	- -	9.5E+05	- -	- -	- -	- -	9.5E+05
OTHER RADIOACTIVITY	- -	- -	- -	6.9E+00	- -	- -	1.2E+03	- -	- -	- -	- -	1.2E+03

Table VIII (A) - 3 (Continued)

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 3

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVER-SION	ENRICH-MENT	UO2 FUEL FABRI-CATION	MOX FUEL FABRI-CATION	REACTOR	REPROCES-SING	TRANSPOR-TATION	WASTE MANAGE-MENT	SPENT FUEL STORAGE	TOTAL
PLANT WASTE GENERATED (CUBIC METERS)												
CHEMICAL COMPOUNDS	- -	- -	1.4E+05	3.1E+02	1.3E+05	- -	- -	2.3E+04	- -	- -	- -	3.0E+05
MILL TAILINGS	- -	5.9E+08	- -	- -	- -	- -	- -	- -	- -	- -	- -	5.9E+08
TRANS-U SOLIDS	- -	- -	- -	- -	- -	1.8E+04	- -	1.3E+05	- -	- -	- -	1.5E+05
HIGHLEVEL SOLIDS	- -	- -	- -	- -	- -	- -	- -	6.5E+03	- -	- -	- -	6.5E+03
OTHER RAD. SOLIDS	- -	- -	6.7E+04	2.2E+04	- -	- -	3.8E+06	- -	- -	- -	1.0E+03	3.9E+06
PERSON-REM COMMITMENT - OCCUPATIONAL												
TOTAL BODY	9.4E+05	4.4E+05	3.3E+03	2.7E+03	4.4E+04	2.5E+04	2.3E+06	7.8E+04	8.1E+03	3.0E+03	3.3E+03	3.8E+06
G.I. TRACT	9.4E+05	1.6E+05	2.0E+03	1.4E+03	4.3E+04	2.5E+04	2.3E+06	7.8E+04	8.1E+03	3.1E+03	3.3E+03	3.5E+06
BONE	1.4E+06	1.8E+06	3.8E+04	2.4E+04	5.7E+04	2.5E+04	2.3E+06	7.8E+04	8.1E+03	3.3E+04	3.3E+03	5.6E+06
LIVER	9.4E+05	1.6E+05	4.0E+03	2.7E+03	4.3E+04	2.5E+04	2.3E+06	7.8E+04	8.1E+03	5.0E+03	3.3E+03	3.5E+06
KIDNEY	1.4E+06	2.0E+05	9.8E+03	6.6E+03	4.6E+04	2.5E+04	2.3E+06	7.8E+04	8.1E+03	4.4E+03	3.3E+03	4.0E+06
THYROID	9.4E+05	1.6E+05	3.3E+03	2.7E+03	4.3E+04	2.5E+04	2.3E+06	7.8E+04	8.1E+03	3.0E+03	3.3E+03	3.5E+06
LUNG	5.1E+06	3.8E+06	2.6E+04	5.8E+04	1.7E+06	2.9E+04	2.3E+06	7.8E+04	8.1E+03	2.5E+03	3.3E+03	1.3E+07
SKIN	9.4E+05	1.6E+05	9.9E+03	8.9E+03	4.3E+04	2.5E+04	2.3E+06	7.8E+04	8.1E+03	2.5E+03	3.3E+03	3.6E+06
PERSON-REM COMMITMENT - OFF-SITE U.S. POPULATION												
TOTAL BODY	2.3E+06	4.5E+05	3.2E+04	1.1E+02	2.2E+03	3.0E+02	3.1E+05	1.1E+06	2.0E+03	3.5E+00	8.5E+00	4.2E+06
G.I. TRACT	9.1E+04	1.7E+04	4.3E+03	6.2E+03	2.4E+03	1.8E+01	3.1E+05	1.6E+06	2.0E+03	8.9E-01	8.5E+00	2.1E+06
BONE	7.5E+06	1.5E+06	7.7E+04	8.0E+02	3.6E+04	1.4E+04	1.1E+06	2.6E+06	2.0E+03	1.4E+01	8.5E+00	1.3E+07
LIVER	1.9E+06	3.5E+05	5.5E+02	1.9E+02	4.5E+00	1.4E+03	3.2E+05	1.1E+06	2.0E+03	3.2E+00	8.5E+00	3.6E+06
KIDNEY	8.8E+06	1.7E+06	9.1E+03	2.5E+03	5.9E+03	1.2E+03	3.1E+05	1.1E+06	2.0E+03	1.2E+01	8.5E+00	1.2E+07
THYROID	5.7E+03	1.2E+03	3.7E+01	1.5E+01	4.0E+00	5.6E+00	4.9E+05	1.9E+06	2.0E+03	4.6E-01	8.5E+00	2.4E+06
LUNG	7.1E+05	1.4E+05	7.3E+02	3.7E+02	1.3E+02	3.1E+02	3.1E+05	1.1E+06	2.0E+03	1.5E+00	1.8E+01	2.3E+06
SKIN	5.7E+03	1.2E+03	2.8E+01	1.0E+02	4.0E+00	5.6E+00	3.1E+05	6.4E+06	2.0E+03	4.6E-01	7.2E+02	6.7E+06
PERSON-REM COMMITMENT - TO FOREIGN POPULATION FROM U.S. INDUSTRY												
TOTAL BODY	- -	- -	- -	- -	- -	- -	2.1E+05	6.7E+05	- -	- -	3.8E+01	8.8E+05
G.I. TRACT	- -	- -	- -	- -	- -	- -	2.1E+05	6.7E+05	- -	- -	3.8E+01	8.8E+05
BONE	- -	- -	- -	- -	- -	- -	1.0E+06	2.2E+06	- -	- -	3.8E+01	3.2E+06
LIVER	- -	- -	- -	- -	- -	- -	3.1E+05	6.7E+05	- -	- -	3.8E+01	8.8E+05
KIDNEY	- -	- -	- -	- -	- -	- -	2.1E+05	6.7E+05	- -	- -	3.8E+01	8.8E+05
THYROID	- -	- -	- -	- -	- -	- -	2.1E+05	6.7E+05	- -	- -	3.8E+01	8.8E+05
LUNG	- -	- -	- -	- -	- -	- -	2.1E+05	1.0E+06	- -	- -	3.8E+01	1.2E+06
SKIN	- -	- -	- -	- -	- -	- -	2.4E+05	2.5E+07	- -	- -	3.2E+03	2.5E+07

Table VIII (A) - 5

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 5

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVER-SION	ENRICH-MENT	UO2 FUEL FABRI-CATION	MOX FUEL FABRI-CATION	REACTOR	REPROCES-SING	TRANSPOR-TATION	WASTE MANAGE-MENT	SPENT FUEL STORAGE	TOTAL
RESOURCE USE												
ACRE-YRS OCCUPIED	2.1E+07	1.1E+06	1.2E+05	5.3E+04	1.4E+05	0.0	2.5E+06	1.3E+05	- -	8.0E+04	- -	2.5E+07
DISTURBED ACRES	2.8E+05	3.2E+04	1.3E+03	1.5E+03	2.3E+02	0.0	4.2E+04	1.2E+03	- -	1.6E+03	- -	3.6E+05
COMMITTED ACRES	9.9E+03	2.7E+04	9.0E+01	- -	- -	0.0	8.3E+02	1.2E+03	- -	1.1E+01	- -	4.0E+04
WATER (GALLONS)												
DISCHARGED TO AIR	- -	1.0E+12	1.2E+10	1.0E+12	- -	0.0	3.3E+13	2.2E+10	- -	5.4E+06	1.4E+10	3.5E+13
DISCHARGED TO WATER	- -	- -	9.8E+10	5.6E+13	3.1E+10	0.0	3.3E+13	1.8E+11	- -	- -	- -	8.9E+13
DISCHARGED TO GROUND	2.7E+12	- -	- -	- -	- -	0.0	- -	7.5E+08	- -	7.5E+07	- -	2.7E+12
TOTAL DISCHARGED	2.7E+12	1.0E+12	1.1E+11	5.7E+13	3.1E+10	0.0	6.6E+13	2.0E+11	- -	8.0E+07	1.4E+10	1.3E+14
BTU DISSIPATED	3.5E+14	1.3E+15	1.4E+14	1.1E+16	5.3E+13	0.0	2.7E+17	2.1E+14	5.4E+12	3.0E+13	1.1E+14	2.9E+17
TONS COAL	- -	- -	- -	3.7E+06	- -	0.0	- -	- -	- -	- -	- -	3.7E+06
THERMS GAS	- -	1.1E+10	1.1E+09	- -	2.1E+08	0.0	- -	- -	- -	5.4E+07	- -	1.2E+10
GALLONS FUEL OIL	1.8E+09	- -	- -	1.3E+07	- -	0.0	1.7E+10	7.5E+08	3.9E+07	4.0E+06	- -	2.0E+10
GWY ELECTRICITY	2.6E+00	6.0E+00	1.1E+00	1.4E+02	1.2E+00	0.0	2.4E+02	1.5E+00	- -	5.8E-02	4.2E-02	3.8E+02
COAL EQUIVALENT OF 2/3 GWY ELECTRICITY USED												
COAL BURNED (TONS)	6.0E+06	1.4E+07	2.7E+06	3.2E+08	2.7E+06	0.0	5.5E+08	3.5E+06	- -	1.3E+05	9.8E+04	9.0E+08
SLUDGE (TONS)	8.3E+05	1.9E+06	3.7E+05	4.4E+07	3.7E+05	0.0	7.6E+07	4.9E+05	- -	1.9E+04	1.4E+04	1.2E+08
SOX TO ATMOS. (MT)	6.8E+04	1.6E+05	3.0E+04	3.6E+06	3.1E+04	0.0	6.2E+06	4.0E+04	- -	1.5E+03	1.1E+03	1.0E+07
NOX TO ATMOS. (MT)	5.5E+04	1.3E+05	2.4E+04	2.9E+06	2.4E+04	0.0	5.0E+06	3.2E+04	- -	1.2E+03	8.9E+02	8.2E+06
CO TO ATMOS. (MT)	1.1E+03	2.5E+03	4.9E+02	5.8E+04	4.9E+02	0.0	1.0E+05	6.4E+02	- -	2.5E+01	1.8E+01	1.6E+05
PART. TO ATMOS. (MT)	3.3E+03	7.6E+03	1.5E+03	1.7E+05	1.5E+03	0.0	3.0E+05	1.9E+03	- -	7.4E+01	5.3E+01	4.9E+05
HYDROCARBONS (MT)	5.5E+02	1.3E+03	2.4E+02	2.9E+04	2.4E+02	0.0	5.0E+04	3.2E+02	- -	1.2E+01	8.9E+00	8.2E+04
PLANT EFFLUENTS TO ATMOSPHERE (METRIC TONS)												
SOX	7.4E+04	4.9E+02	3.2E+04	4.6E+04	- -	0.0	4.8E+05	1.8E+04	7.9E+02	3.5E+01	- -	6.5E+05
NOX	6.1E+04	9.8E+04	1.5E+04	3.7E+04	- -	0.0	2.8E+05	7.2E+04	6.3E+03	4.1E+01	- -	5.7E+05
CO	- -	- -	- -	7.4E+02	- -	0.0	1.8E+04	1.4E+03	4.0E+03	2.5E+01	- -	2.5E+04
PARTICULATES	8.9E+03	4.9E+03	4.8E+02	2.2E+03	3.5E+04	0.0	6.4E+04	1.9E+03	3.4E+02	1.0E+01	- -	1.2E+05
NH3	- -	- -	4.4E+02	- -	- -	0.0	- -	- -	- -	- -	- -	4.4E+02
FLUORIDES	- -	- -	2.5E+02	1.4E+02	3.1E+01	0.0	- -	1.6E+02	- -	- -	- -	5.7E+02
HYDROCARBONS	4.4E+03	1.9E+04	2.1E+03	3.7E+02	- -	0.0	2.0E+04	1.6E+03	8.6E+02	- -	- -	4.9E+04
ALDEHYDE	- -	- -	- -	- -	- -	0.0	- -	- -	7.0E+01	4.0E-01	- -	7.0E+01
ORGANIC ACID	- -	- -	- -	- -	- -	0.0	- -	- -	8.6E+01	- -	- -	8.6E+01

Table VIII (A) - 5 (Continued)

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 5

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVERSION	ENRICHMENT	UO2 FUEL FABRICATION	MOX FUEL FABRICATION	REACTOR	REPROCESSING	TRANSPORTATION	WASTE MANAGEMENT	SPENT FUEL STORAGE	TOTAL
PLANT EFFLUENTS TO ATMOSPHERE (CURIES)												
RN-222	2.1E+07	4.0E+06	3.2E-02	- -	- -	0.0	- -	- -	- -	2.4E+01	- -	2.5E+07
RA-226	- -	1.2E+01	9.4E-03	- -	- -	0.0	- -	- -	- -	- -	- -	1.2E+01
URANIUM	- -	4.7E+02	6.4E+00	3.3E+00	1.2E+00	0.0	- -	1.3E-01	- -	97.E-09	- -	4.8E+02
PU (ALPHA)	- -	- -	- -	2.8E-08	- -	0.0	- -	2.7E+00	- -	2.8E-01	- -	3.0E+00
PU-241 (BETA)	- -	- -	- -	- -	- -	0.0	- -	7.4E+01	- -	3.7E-01	- -	7.4E+01
TRANS-PU NUCLIDES	- -	- -	- -	- -	- -	0.0	- -	5.3E+00	- -	1.1E-03	- -	5.3E+00
H-3	- -	- -	- -	- -	- -	0.0	3.8E+06	5.9E+07	- -	2.4E-02	- -	6.3E+07
C-14	- -	- -	- -	- -	- -	0.0	4.3E+04	7.8E+04	- -	- -	- -	1.2E+05
KR-85	- -	- -	- -	- -	- -	0.0	2.1E+06	1.3E+09	- -	3.8E-01	2.8E+05	1.3E+09
SR-90	- -	- -	- -	- -	- -	0.0	- -	1.8E+01	- -	3.1E-02	- -	1.8E+01
TC-99	- -	- -	- -	3.8E+01	- -	0.0	- -	3.4E-03	- -	- -	- -	3.8E+01
I-129	- -	- -	- -	- -	- -	0.0	- -	1.1E+02	- -	- -	- -	1.1E+02
I-131	- -	- -	- -	- -	- -	0.0	6.0E+02	2.7E+03	- -	- -	- -	3.3E+03
OTHER RADIOACTIVITY	- -	- -	- -	6.2E-01	- -	0.0	5.4E+07	1.1E+03	- -	1.1E+00	- -	5.4E+07
PLANT EFFLUENTS TO WATER BODIES (METRIC TONS)												
SO4=	- -	- -	5.1E+04	3.3E+03	- -	0.0	1.4E+07	5.8E+01	- -	- -	- -	1.4E+07
NO3-	- -	- -	8.1E+02	3.7E+03	6.1E+03	0.0	- -	- -	- -	- -	- -	1.1E+04
CL-	- -	- -	1.4E+04	1.5E+03	- -	0.0	1.2E+06	2.9E+02	- -	- -	- -	1.2E+06
FLUORIDES	- -	- -	8.5E+02	3.7E+01	1.8E+02	0.0	- -	- -	- -	- -	- -	1.1E+03
NA+	- -	- -	4.7E+04	- -	- -	0.0	- -	5.8E+01	- -	- -	- -	4.7E+04
CA++	- -	- -	3.2E+03	- -	8.8E-01	0.0	- -	- -	- -	- -	- -	3.2E+03
NH3	- -	- -	1.6E+04	- -	6.9E+01	0.0	- -	- -	- -	- -	- -	1.6E+04
FE	- -	- -	2.1E+02	- -	- -	0.0	- -	- -	- -	- -	- -	2.1E+02
PLANT EFFLUENTS TO WATER BODIES (CURIES)												
TRANS-PU NUCLIDES	- -	- -	- -	- -	- -	0.0	- -	- -	- -	- -	- -	- -
PU (ALPHA)	- -	- -	- -	5.5E-07	- -	0.0	- -	- -	- -	- -	- -	5.6E-07
URANIUM	- -	- -	2.4E+02	2.3E-01	2.8E+02	0.0	- -	- -	- -	- -	- -	5.3E+02
TH-230	- -	- -	3.6E+01	- -	- -	0.0	- -	- -	- -	- -	- -	3.6E+01
RA-226	- -	- -	1.3E+00	- -	- -	0.0	- -	- -	- -	- -	- -	1.3E+00
I-129	- -	- -	- -	- -	- -	0.0	- -	- -	- -	- -	- -	- -
TC-99	- -	- -	- -	4.9E+02	- -	0.0	- -	- -	- -	- -	- -	4.9E+02
SR-90	- -	- -	- -	- -	- -	0.0	- -	- -	- -	- -	- -	- -
C-14	- -	- -	- -	- -	- -	0.0	- -	- -	- -	- -	- -	- -
H-3	- -	- -	- -	- -	- -	0.0	8.8E+05	- -	- -	- -	- -	8.8E+05
OTHER RADIOACTIVITY	- -	- -	- -	8.1E+00	- -	0.0	1.1E+03	- -	- -	- -	- -	1.2E+03

Table VIII (A) - 5 (Continued)

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 5

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVER-SION	ENRICH-MENT	UO2 FUEL FABRI-CATION	MOX FUEL FABRI-CATION	REACTOR	REPROCES-SING	TRANSPOR-TATION	WASTE MANAGE-MENT	SPENT FUEL STORAGE	TOTAL
PLANT WASTE GENERATED (CUBIC METERS)												
CHEMICAL COMPOUNDS	- -	- -	1.6E+05	7.1E+02	1.5E+05	0.0	- -	2.3E+04	- -	- -	- -	3.3E+05
MILL TAILINGS	- -	6.9E+08	- -	- -	- -	0.0	- -	- -	- -	- -	- -	6.9E+08
TRANS-U SOLIDS	- -	- -	- -	- -	- -	0.0	- -	1.3E+05	- -	- -	- -	1.3E+05
HIGHLEVEL SOLIDS	- -	- -	- -	- -	- -	0.0	- -	6.5E+03	- -	- -	- -	6.5E+03
OTHER RAD. SOLIDS	- -	- -	7.9E+04	6.5E+04	- -	0.0	3.8E+06	- -	- -	- -	1.7E+03	3.9E+06
PERSON-REM COMMITMENT - OCCUPATIONAL												
TOTAL BODY	1.1E+06	5.0E+05	4.0E+03	3.5E+03	5.1E+04	0.0	2.3E+06	7.2E+04	5.4E+03	3.0E+03	5.6E+03	4.0E+06
G.I. TRACT	1.1E+06	1.9E+05	2.4E+03	1.8E+03	5.0E+04	0.0	2.3E+06	7.2E+04	5.4E+03	3.1E+03	5.6E+03	3.7E+06
BONE	1.6E+06	2.0E+06	4.7E+04	3.2E+04	6.6E+04	0.0	2.3E+06	7.2E+04	5.4E+03	3.3E+04	5.6E+03	6.1E+06
LIVER	1.1E+06	1.9E+05	4.9E+03	3.5E+03	4.9E+04	0.0	2.3E+06	7.2E+04	5.4E+03	5.0E+03	5.6E+03	3.7E+06
KIDNEY	1.6E+06	2.3E+05	1.2E+04	8.5E+03	5.4E+04	0.0	2.3E+06	7.2E+04	5.4E+03	4.4E+03	5.6E+03	4.2E+06
THYROID	1.1E+06	1.9E+05	4.0E+03	3.5E+03	5.0E+04	0.0	2.3E+06	7.2E+04	5.4E+03	3.0E+03	5.6E+03	3.7E+06
LUNG	5.8E+06	4.3E+06	3.1E+04	7.5E+04	2.0E+06	0.0	2.3E+06	7.2E+04	5.4E+03	2.5E+03	5.6E+03	1.5E+07
SKIN	1.1E+06	1.9E+05	1.1E+04	1.1E+04	5.0E+04	0.0	2.3E+06	7.2E+04	5.4E+03	2.5E+03	5.6E+03	3.7E+06
PERSON-REM COMMITMENT - OFF-SITE U.S. POPULATION												
TOTAL BODY	2.7E+06	5.2E+05	3.9E+04	1.3E+02	2.6E+03	0.0	3.1E+05	1.1E+06	1.6E+03	3.2E+00	1.4E+01	4.6E+06
G.I. TRACT	1.0E+05	2.0E+04	5.0E+03	7.3E+03	2.8E+03	0.0	3.0E+05	1.6E+06	1.6E+03	7.3E−01	1.4E+01	2.0E+06
BONE	8.7E+06	1.7E+06	9.2E+04	9.4E+02	4.2E+04	0.0	1.1E+06	2.6E+06	1.6E+03	1.6E+01	1.4E+01	1.4E+07
LIVER	2.2E+06	4.0E+05	6.2E+02	2.2E+02	5.2E+00	0.0	3.1E+05	1.1E+06	1.6E+03	3.2E+00	1.4E+01	4.0E+06
KIDNEY	1.0E+07	1.9E+06	1.1E+04	3.0E+03	6.8E+03	0.0	3.0E+05	1.1E+06	1.6E+03	1.1E+01	1.4E+01	1.3E+07
THYROID	6.5E+03	1.4E+03	4.3E+01	1.7E+01	4.7E+00	0.0	4.8E+05	1.9E+06	1.6E+03	3.8E−01	1.4E+01	2.4E+06
LUNG	8.1E+05	1.6E+05	8.8E+02	4.4E+02	1.5E+02	0.0	3.0E+05	1.2E+06	1.6E+03	1.4E+00	3.1E+01	2.4E+06
SKIN	6.5E+03	1.4E+03	3.4E+01	1.2E+02	4.7E+00	0.0	3.1E+05	6.6E+06	1.6E+03	3.8E−01	1.2E+03	6.9E+06
PERSON-REM COMMITMENT - TO FOREIGN POPULATION FROM U.S. INDUSTRY												
TOTAL BODY	- -	- -	- -	- -	- -	0.0	2.1E+05	7.0E+05	- -	- -	6.4E+01	9.1E+05
G.I. TRACT	- -	- -	- -	- -	- -	0.0	2.1E+05	7.0E+05	- -	- -	6.4E+01	9.1E+05
BONE	- -	- -	- -	- -	- -	0.0	1.0E+06	2.3E+06	- -	- -	6.4E+01	3.3E+06
LIVER	- -	- -	- -	- -	- -	0.0	2.1E+05	7.0E+05	- -	- -	6.4E+01	9.1E+05
KIDNEY	- -	- -	- -	- -	- -	0.0	2.1E+05	7.0E+05	- -	- -	6.4E+01	9.1E+05
THYROID	- -	- -	- -	- -	- -	0.0	2.1E+05	7.0E+05	- -	- -	6.4E+01	9.1E+05
LUNG	- -	- -	- -	- -	- -	0.0	2.1E+05	1.1E+06	- -	- -	1.4E+02	1.3E+06
SKIN	- -	- -	- -	- -	- -	0.0	2.5E+05	2.6E+07	- -	- -	5.4E+03	2.6E+07

Table VIII (A) - 6

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 6

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVER-SION	ENRICH-MENT	UO2 FUEL FABRI-CATION	MOX FUEL FABRI-CATION	REACTOR	REPROCES-SING	TRANSPOR-TATION	WASTE MANAGE-MENT	SPENT FUEL STORAGE	TOTAL
RESOURCE USE												
ACRE-YRS OCCUPIED	2.3E+07	1.2E+06	1.3E+05	5.2E+04	1.4E+05	0.0	2.5E+06	0.0	- -	7.1E+04	- -	2.8E+07
DISTURBED ACRES	3.3E+05	3.7E+04	1.3E+03	1.5E+03	2.3E+02	0.0	4.2E+04	0.0	- -	1.6E+03	- -	4.1E+05
COMMITTED ACRES	1.1E+04	3.1E+04	9.0E+01	- -	- -	0.0	8.3E+02	0.0	- -	1.1E+03	- -	4.5E+04
WATER (GALLONS)												
DISCHARGED TO AIR	- -	1.2E+12	1.3E+10	1.0E+12	- -	0.0	3.3E+13	0.0	- -	1.7E+07	1.1E+10	3.5E+13
DISCHARGED TO WATER	- -	- -	1.1E+11	5.5E+13	3.1E+10	0.0	3.3E+13	0.0	- -	- -	- -	8.8E+13
DISCHARGED TO GROUND	3.0E+12	- -	- -	- -	- -	0.0	- -	0.0	- -	6.1E+07	- -	3.0E+12
TOTAL DISCHARGED	3.0E+12	1.2E+12	1.3E+11	5.6E+13	3.1E+10	0.0	6.6E+13	0.0	- -	7.8E+07	1.1E+10	1.3E+14
BTU DISSIPATED	3.9E+14	1.4E+15	1.6E+14	1.1E+16	5.3E+13	0.0	2.7E+17	0.0	4.9E+12	3.5E+13	9.5E+13	2.9E+17
TONS COAL	- -	- -	- -	3.7E+06	- -	0.0	- -	0.0	- -	- -	- -	3.7E+06
THERMS GAS	- -	1.2E+10	1.2E+09	- -	2.1E+08	0.0	- -	0.0	- -	4.5E+07	- -	1.3E+10
GALLONS FUEL OIL	2.0E+09	- -	- -	1.3E+07	- -	0.0	1.7E+10	0.0	3.5E+07	3.2E+06	- -	1.9E+10
GWY ELECTRICITY	2.9E+00	6.7E+00	1.3E+00	1.4E+02	1.2E+00	0.0	2.4E+02	0.0	- -	4.4E−02	8.4E−02	3.8E+02
COAL EQUIVALENT OF 2/3 GWY ELECTRICITY USED												
COAL BURNED (TONS)	6.7E+06	1.6E+07	3.0E+06	3.2E+08	2.7E+06	0.0	5.5E+08	0.0	- -	1.0E+05	2.0E+05	9.0E+08
SLUDGE (TONS)	9.3E+05	2.2E+06	4.2E+05	4.4E+07	3.7E+05	0.0	7.6E+07	0.0	- -	1.5E+04	2.7E+04	1.2E+08
SOX TO ATMOS. (MT)	7.6E+04	1.8E+05	3.5E+04	3.6E+06	3.1E+04	0.0	6.2E+06	0.0	- -	1.2E+03	2.2E+03	1.0E+07
NOX TO ATMOS. (MT)	6.1E+04	1.4E+05	2.8E+04	2.9E+06	2.4E+04	0.0	5.0E+06	0.0	- -	9.3E+02	1.8E+03	8.1E+06
CO TO ATMOS. (MT)	1.2E+03	2.8E+03	5.5E+02	5.8E+04	4.9E+02	0.0	1.0E+05	0.0	- -	1.8E+01	3.6E+01	1.6E+05
PART. TO ATMOS. (MT)	3.7E+03	8.5E+03	1.7E+03	1.7E+05	1.5E+03	0.0	3.0E+05	0.0	- -	5.6E+01	1.1E+02	4.9E+05
HYDROCARBONS (MT)	6.1E+02	1.4E+03	2.8E+02	2.9E+04	2.4E+02	0.0	5.0E+04	0.0	- -	9.3E+00	1.8E+01	8.1E+04
PLANT EFFLUENTS TO ATMOSPHERE (METRIC TONS)												
SOX	8.3E+04	5.5E+02	3.4E+04	4.6E+04	- -	0.0	4.8E+05	0.0	8.8E+02	2.9E+01	- -	6.5E+05
NOX	6.8E+04	1.1E+05	1.8E+04	3.7E+04	- -	0.0	2.8E+05	0.0	6.4E+03	3.3E+01	- -	5.2E+05
CO	- -	- -	- -	7.4E+02	- -	0.0	1.8E+04	0.0	4.1E+03	2.0E+01	- -	2.3E+04
PARTICULATES	9.9E+03	5.5E+03	5.5E+02	2.2E+03	3.5E+04	0.0	6.4E+04	0.0	3.8E+02	8.0E−02	- -	1.2E+05
NH3	- -	- -	4.7E+02	- -	- -	0.0	- -	0.0	- -	- -	- -	4.7E+02
FLUORIDES	- -	- -	2.8E+02	1.4E+02	3.1E+01	0.0	- -	0.0	- -	- -	- -	4.5E+02
HYDROCARBONS	4.9E+03	2.2E+04	2.5E+03	3.7E+02	- -	0.0	2.0E+04	0.0	9.3E+02	- -	- -	5.1E+04
ALDEHYDE	- -	- -	- -	- -	- -	0.0	- -	0.0	7.5E+01	3.3E−01	- -	7.5E+01
ORGANIC ACID	- -	- -	- -	- -	- -	0.0	- -	0.0	9.6E+01	- -	- -	9.6E+01

Table VIII (A) - 6 (Continued)

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 6

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVER-SION	ENRICH-MENT	UO2 FUEL FABRI-CATION	MOX FUEL FABRI-CATION	REACTOR	REPROCES-SING	TRANSPOR-TATION	WASTE MANAGE-MENT	SPENT FUEL STORAGE	TOTAL
PLANT EFFLUENTS TO ATMOSPHERE (CURIES)												
RN-222	2.4E+07	4.4E+06	3.4E-02	- -	- -	0.0	- -	0.0	- -	2.0E+01	- -	2.8E+07
RA-226	- -	1.3E+01	1.0E-02	- -	- -	0.0	- -	0.0	- -	- -	- -	1.3E+01
URANIUM	- -	5.3E+02	7.1E+00	3.9E+00	1.2E+00	0.0	- -	0.0	- -	7.9E-09	- -	5.4E+02
PU (ALPHA)	- -	- -	- -	- -	- -	0.0	- -	0.0	- -	2.3E-03	- -	2.3E-03
PU-241 (BETA)	- -	- -	- -	- -	- -	0.0	- -	0.0	- -	3.0E-02	- -	3.0E-02
TRANS-PU NUCLIDES	- -	- -	- -	- -	- -	0.0	- -	0.0	- -	9.0E-04	- -	9.0E-04
H-3	- -	- -	- -	- -	- -	0.0	3.8E+06	0.0	- -	- -	- -	3.8E+06
C-14	- -	- -	- -	- -	- -	0.0	4.3E+04	0.0	- -	- -	- -	4.3E+04
KR-85	- -	- -	- -	- -	- -	0.0	2.1E+06	0.0	- -	- -	5.6E+05	2.6E+06
SR-90	- -	- -	- -	- -	- -	0.0	- -	0.0	- -	2.5E-02	- -	2.5E-02
TC-99	- -	- -	- -	- -	- -	0.0	- -	0.0	- -	- -	- -	- -
I-129	- -	- -	- -	- -	- -	0.0	- -	0.0	- -	- -	- -	- -
I-131	- -	- -	- -	- -	- -	0.0	6.0E+02	0.0	- -	- -	- -	6.0E+02
OTHER RADIOACTIVITY	- -	- -	- -	- -	- -	0.0	5.4E+07	0.0	- -	9.0E-01	- -	5.4E+07
PLANT EFFLUENTS TO WATER BODIES (METRIC TONS)												
SO4=	- -	- -	5.4E+04	3.2E+03	- -	0.0	1.4E+07	0.0	- -	- -	- -	1.4E+07
NO3-	- -	- -	9.6E+02	3.6E+03	6.1E+03	0.0	- -	0.0	- -	- -	- -	1.1E+04
CL-	- -	- -	1.6E+04	1.5E+03	- -	0.0	1.2E+06	0.0	- -	- -	- -	1.2E+06
FLUORIDES	- -	- -	9.5E+02	3.7E+01	1.8E+02	0.0	- -	0.0	- -	- -	- -	1.2E+03
NA+	- -	- -	5.1E+04	- -	- -	0.0	- -	0.0	- -	- -	- -	5.1E+04
CA++	- -	- -	3.9E+03	- -	8.8E-01	0.0	- -	0.0	- -	- -	- -	3.9E+03
NH3	- -	- -	1.7E+04	- -	6.9E+01	0.0	- -	0.0	- -	- -	- -	1.7E+04
FE	- -	- -	2.3E+02	- -	- -	0.0	- -	0.0	- -	- -	- -	2.3E+02
PLANT EFFLUENTS TO WATER BODIES (CURIES)												
TRANS-PU NUCLIDES	- -	- -	- -	- -	- -	0.0	- -	0.0	- -	- -	- -	- -
PU (ALPHA)	- -	- -	- -	- -	- -	0.0	- -	0.0	- -	- -	- -	- -
URANIUM	- -	- -	2.8E+02	2.2E-01	2.7E+02	0.0	- -	0.0	- -	- -	- -	5.5E+02
TH-230	- -	- -	4.2E+01	- -	- -	0.0	- -	0.0	- -	- -	- -	4.2E+01
RA-226	- -	- -	1.4E+00	- -	- -	0.0	- -	0.0	- -	- -	- -	1.4E+00
I-129	- -	- -	- -	- -	- -	0.0	- -	0.0	- -	- -	- -	- -
TC-99	- -	- -	- -	- -	- -	0.0	- -	0.0	- -	- -	- -	- -
SR-90	- -	- -	- -	- -	- -	0.0	- -	0.0	- -	- -	- -	- -
C-14	- -	- -	- -	- -	- -	0.0	- -	0.0	- -	- -	- -	- -
H-3	- -	- -	- -	- -	- -	0.0	8.8E+05	0.0	- -	- -	- -	8.8E+05
OTHER RADIOACTIVITY	- -	- -	- -	- -	- -	0.0	1.1E+03	0.0	- -	- -	- -	1.1E+03

Table VIII (A) - 6 (Continued)

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 6

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVER-SION	ENRICH-MENT	UO2 FUEL FABRI-CATION	MOX FUEL FABRI-CATION	REACTOR	REPROCES-SING	TRANSPOR-TATION	WASTE MANAGE-MENT	SPENT FUEL STORAGE	TOTAL
PLANT WASTE GENERATED (CUBIC METERS)												
CHEMICAL COMPOUNDS	- -	- -	1.8E+05	6.9E+02	1.5E+05	0.0	- -	0.0	- -	- -	- -	3.2E+05
MILL TAILINGS	- -	7.8E+08	- -	- -	- -	0.0	- -	0.0	- -	- -	- -	7.8E+08
TRANS-U SOLIDS	- -	- -	- -	- -	- -	0.0	- -	0.0	- -	- -	- -	- -
HIGHLEVEL SOLIDS	- -	- -	- -	- -	- -	0.0	- -	0.0	- -	- -	5.5E+04	5.5E+04
OTHER RAD. SOLIDS	- -	- -	8.8E+04	6.5E+04	- -	0.0	3.8E+06	0.0	- -	- -	3.4E+03	4.0E+06
PERSON-REM COMMITMENT - OCCUPATIONAL												
TOTAL BODY	1.2E+06	5.6E+05	4.4E+03	3.4E+03	5.1E+04	0.0	2.3E+06	0.0	5.4E+03	3.0E+03	1.1E+04	4.1E+06
G.I. TRACT	1.2E+06	2.1E+05	2.7E+03	1.7E+03	5.0E+04	0.0	2.3E+06	0.0	5.4E+03	3.0E+03	1.1E+04	3.8E+06
BONE	1.7E+06	2.3E+06	5.0E+04	3.1E+04	6.6E+04	0.0	2.3E+06	0.0	5.4E+03	2.0E+04	1.1E+04	6.5E+06
LIVER	1.2E+06	2.1E+05	5.3E+03	3.4E+03	5.0E+04	0.0	2.3E+06	0.0	5.4E+03	4.5E+03	1.1E+04	3.8E+06
KIDNEY	1.7E+06	2.6E+05	1.3E+04	8.5E+03	5.4E+04	0.0	2.3E+06	0.0	5.4E+03	4.1E+03	1.1E+04	4.4E+06
THYROID	1.2E+06	2.1E+05	4.4E+03	3.4E+03	5.0E+04	0.0	2.3E+06	0.0	5.4E+03	3.0E+03	1.1E+04	3.8E+06
LUNG	6.5E+06	4.8E+06	3.5E+04	7.5E+04	2.0E+06	0.0	2.3E+06	0.0	5.4E+03	2.5E+03	1.1E+04	1.6E+07
SKIN	1.2E+06	2.1E+05	1.3E+04	1.1E+04	5.0E+04	0.0	2.3E+06	0.0	5.4E+03	2.5E+03	1.1E+04	3.8E+06
PERSON-REM COMMITMENT - OFF-SITE U.S. POPULATION												
TOTAL BODY	3.0E+06	5.8E+05	4.2E+04	7.6E+01	2.5E+03	0.0	3.1E+05	0.0	1.5E+03	2.6E+00	2.8E+01	3.9E+06
G.I. TRACT	1.2E+05	2.2E+04	5.6E+03	6.6E+01	2.7E+03	0.0	3.0E+05	0.0	1.5E+03	5.9E-01	2.8E+01	4.5E+05
BONE	9.7E+06	1.9E+06	1.0E+05	9.2E+02	4.1E+04	0.0	1.1E+06	0.0	1.5E+03	1.3E+01	2.8E+01	1.3E+07
LIVER	2.4E+06	4.5E+05	7.2E+02	2.0E+01	5.2E+00	0.0	3.1E+05	0.0	1.5E+03	2.6E+00	2.8E+01	3.2E+06
KIDNEY	1.1E+07	2.1E+06	1.2E+04	5.2E+02	6.5E+03	0.0	3.0E+05	0.0	1.5E+03	4.0E+00	2.8E+01	1.4E+07
THYROID	7.3E+03	1.5E+03	4.8E+01	1.8E+01	4.6E+00	0.0	4.8E+05	0.0	1.5E+03	3.1E-01	2.8E+01	4.9E+05
LUNG	9.1E+05	1.8E+05	9.7E+02	4.8E+02	1.4E+02	0.0	3.0E+05	0.0	1.5E+03	1.1E+00	6.1E+01	1.4E+06
SKIN	7.3E+03	1.5E+03	3.7E+01	1.8E+01	4.6E+00	0.0	3.1E+05	0.0	1.5E+03	3.1E-01	2.4E+03	3.3E+05
PERSON-REM COMMITMENT - TO FOREIGN POPULATION FROM U.S. INDUSTRY												
TOTAL BODY	- -	- -	- -	- -	- -	0.0	2.1E+05	0.0	- -	- -	1.3E+02	2.1E+05
G.I. TRACT	- -	- -	- -	- -	- -	0.0	2.1E+05	0.0	- -	- -	1.3E+02	2.1E+05
BONE	- -	- -	- -	- -	- -	0.0	1.0E+06	0.0	- -	- -	1.3E+02	1.0E+06
LIVER	- -	- -	- -	- -	- -	0.0	2.1E+05	0.0	- -	- -	1.3E+02	2.1E+05
KIDNEY	- -	- -	- -	- -	- -	0.0	2.1E+05	0.0	- -	- -	1.3E+02	2.1E+05
THYROID	- -	- -	- -	- -	- -	0.0	2.1E+05	0.0	- -	- -	1.3E+02	2.1E+05
LUNG	- -	- -	- -	- -	- -	0.0	2.1E+05	0.0	- -	- -	2.8E+02	2.1E+05
SKIN	- -	- -	- -	- -	- -	0.0	2.5E+05	0.0	- -	- -	1.1E+04	2.6E+05

CHAPTER VIII
APPENDIX B

NEUTRONIC PENALTIES FOR ^{236}U AND ^{242}Pu CONTENTS

Accounting for ^{236}U and ^{242}Pu

The isotopes ^{236}U and ^{242}Pu are present in LWR fuel cycles. Neither fertile nor fissile, these isotopes are parasitic neutron absorbers in LWR fuel. Their presence should be accounted for in cost evaluations of the fuel cycle.

^{236}U Penalty

Uranium-236 is formed by neutron capture in ^{235}U. Because ^{236}U parasitically absorbs neutrons, additional ^{235}U is needed when ^{236}U is initially present in the fuel to produce the same energy as fuel containing only the ^{236}U formed during fuel use. The requirement for additional ^{235}U is a direct economic penalty in the cost of the fuel cycle.

The penalty assigned depends on how the uranium recovered from reprocessing spent fuel is used in subsequent cycles and how great the neutron absorption of the ^{236}U is in the reactor. Most analyses made to date assume that all recovered uranium is delivered to the diffusion cascades as feed for the enrichment process rather than being used directly for other purposes (e.g., in MOX).

The results of studies[1,2] of ^{236}U in the LWR fuel cycle show that the added enrichment to compensate for ^{236}U initially in the fuel can be expressed quite well with a linear relationship

$$\Delta e = k(^{26}N)$$

where Δe is incremental ^{235}U enrichment in weight percent (wt%), k is a proportionality constant depending on reactor type and operation and on the amount of ^{236}U present in the fuel, and ^{26}N is the concentration of ^{236}U in the enriched fuel charge (wt%).

Sprague[3] reports values of k ranging from 0.3 to 0.6, where k = 0.6 corresponds to a fuel with a low ^{236}U concentration[2] and k = 0.3 corresponds to a fuel with a high ^{236}U concentration ($\sim$1 wt%). Other investigators[1,4] indicate that a value of about 0.3 better represents expected industrial and government practice. In addition, de la Garza[5] has shown the effects of recycle uranium on enrichment plant operations (dose rates and efficiency) to be small.

The ALTHAEA computer program[6] was used to calculate the value of k at three concentrations of ^{236}U in the initial fuel. The results are given in Table VIII(B)-1.

Table VIII(B)-1

EXTRA ^{235}U REQUIRED WHEN ^{236}U IS INITIALLY PRESENT

^{236}U in Fuel	k, Grams ^{235}U per Gram of Initial ^{236}U
0.05%	0.32
0.25%	0.30
1.2%	0.24

These results confirm the conclusion of Peak[1] and Geller and Gueron[4] and indicate that a value of 0.3 $\pm$ 0.03 is an adequate representation of k for ^{236}U concentrations of up to about 0.7%.

Recycle uranium is assumed to be returned to the enrichment facilities to reduce the requirements for natural uranium. Blumkin[7] has shown that not all the ^{236}U in the delivered uranium is found in the enriched product from the cascades. Based on the input data to NUFUEL, 70% of the enriched product required from the cascades is in the range of 3.0 to 3.3% ^{235}U, with the remainder ranging from 1.4% to 2.5% ^{235}U (for startup cores and certain BWR pins). According to NUFUEL data, the average enrichment of the discharged U delivered to the cascades is 0.84% ^{235}U without plutonium recycle and about 0.78% ^{235}U with plutonium recycle. For these enrichment plant conditions 50% to 60% of the ^{236}U in the recovered uranium can be expected to be found in the enriched product.

The recovered uranium will contain from 0.2% to 0.45% ^{236}U, depending on initial enrichment and residence time in the reactor. For the purposes of modifying the calculations in NUFUEL it was assumed that each kilogram of recycle uranium delivered to the cascades contained 4.2 g of ^{236}U; 60% of this ^{236}U will be found in the enriched product of the enrichment facilities. This would require an additional 0.75 g of ^{235}U (4.2 x 0.6 x 0.3) in the enriched product for each kilogram of recycle uranium returned to the enrichment facilities.

The NUFUEL program can be adjusted to satisfy this requirement by reducing the average effective enrichment of the recovered uranium from 0.78% to 0.705%. This was done by multiplying the NUFUEL quantity representing the ^{235}U "returns" of each batch by 0.904. This correction will result in desired NUFUEL adjustment to the natural uranium requirements. However, this correction by itself will not result in the proper adjustment to the separative work requirements.

The desired increase in separative work (corresponding to the additional required 0.75 gram of ^{235}U) is 0.138 kg for each kilogram of recycle uranium. This correction was made to the value function characterizing each batch of recycle uranium delivered to the cascades. See pp 34-36 of Reference 14 (WASH-1348).

The second-order effects were neglected. These effects include the reappearance in the second recycle of a portion of the ^{236}U introduced to the fuel in the first recycle of uranium. Likewise the discharged portion of the extra ^{235}U added in the recycle is ignored. These two effects are self-compensating. In addition, plutonium

recovered from recycle fuel contains more ^{238}Pu than does plutonium from UO_2 fuel. This is due to the presence of ^{236}U in the recycle fuel and may increase MOX costs, depending on the design of the fabrication plant.

^{242}Pu Penalty

Plutonium-242 is formed by neutron capture in ^{241}Pu. Since ^{242}Pu is a parasitic neutron absorber, it is a penalty in neutron economy and consequently a cost penalty on the fuel cycle. All investigators studying the value of plutonium in LWR's assign a negative term for ^{242}Pu in the plutonium value equation (for example, see Reference 8) and represent this term as a coefficient times the ^{242}Pu concentration in the fuel. The negative value of ^{242}Pu indicates that the replacement value of a gram of fissile plutonium in the second recycle would be about 83% of the value of a gram of fissile plutonium in the first recycle, and its value would be reduced correspondingly in subsequent recycles. NUFUEL was modified to reduce the effective recovery of fissile plutonium from spent MOX fuel to 83% of the expected quantity. This indicates plutonium inventories and plutonium shipments less than the actual physical quantities, but the MOX fabrication and uranium replacement amounts will be better estimated. This correction also has the effect of reducing the replacement value of the third recycle to $(0.83)^2$ or 69% of the value used for the first recycle.

In this study the rather low replacement value of 0.8 g of ^{235}U per gram of plutonium fissile was used. This value was chosen to be conservative and to compensate for process losses in reprocessing and MOX fabrication and the decay of ^{241}Pu from the time of reactor discharge to the time MOX fuel is charged to the reactor. Neither of these effects is accounted for in NUFUEL. Hellens and Shapiro[9] estimated the replacement value of plutonium; their values are compared with the values used in this study in Table VIII(B)-2.

Table VIII(B)-2

PLUTONIUM REPLACEMENT VALUE COMPARISON FOR A SINGLE REACTOR

Plutonium Recycle Period	Plutonium Replacement Value, Grams ^{235}U per Gram Pu Fissile		
	Segregated Plutonium, This Report	Plutonium for a Reactor on SGR	
		This Report	Hellens and Shapiro[9]
First	0.80	0.80	0.87 to 0.97
Second	0.66	0.74	0.80 to 0.85
Third	0.55	0.70	0.75 to 0.79
Fourth	0.45	0.68	0.71 to 0.74

It should be noted that in an expanding industry the amount of plutonium available from UO_2 is continually increasing and being mixed with recycled plutonium previously produced. The degrading effect of ^{242}Pu is substantially reduced when plutonium is blended on an industrywide basis. Table VIII(B)-3 presents the effective replacement value on an industrywide basis for Alternative 3 using the low growth projection without FBR's.

Table VIII(B)-3

EFFECTIVE PLUTONIUM REPLACEMENT VALUE FOR ALTERNATIVE 3

Year	Plutonium Replacement Value, Grams ^{235}U per Gram Pu Fissile
1980	0.80
1981	0.80
1982	0.80
1983	0.80
1984	0.80
1985	0.80
1986	0.79
1987	0.77
1988	0.76
1989	0.77
1990	0.77
1991	0.77
1992	0.77
1993	0.76
1994	0.76
1995	0.76
1996	0.75
1997	0.75
1998	0.75
1999	0.74
2000	0.74

In the event substantial sales of plutonium are made to FBR's, the degrading effect is reduced even more because this represents a continued bleedoff of ^{242}Pu from the LWR system.

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CHAPTER IX

RELATIONSHIP BETWEEN LOCAL SHORT TERM USES OF MAN'S ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG TERM PRODUCTIVITY

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CHAPTER IX

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RELATIONSHIP BETWEEN LOCAL SHORT TERM USES OF MAN'S ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG TERM PRODUCTIVITY

SUMMARY

The short term environmental effects are associated with the processing of plutonium in fuel recycle operations, and the net effect, excluding the societal risks associated with safeguards, is a reduction in environmental impact.

The long term effects are associated with conservation of uranium ore reserves and the future disposition of radioactive materials, particularly uranium mill tailings, fuel reprocessing wastes and plutonium contaminated wastes; the net effect of these also is a reduction in environmental impact.

The fundamental trade-off associated with the recycle of plutonium is between the conservation of energy resources at the head end of the fuel cycle, giving a major gain in long term productivity and a reduction in environmental impacts, and the added radiological impacts to the environmental from the spent fuel reprocessing and mixed oxide fuel fabrication steps at the back end of the fuel cycle.

It is estimated that between the years 1975 and 2000, the mining of a total of about 360 million tons of uranium ore would have been saved by recycling the uranium and plutonium recovered from spent fuel.

By the year 2000 about 34 MT of plutonium-241 would be irretrievably lost through the radioactive decay process, if plutonium is not recycled. This loss, approximately equivalent to the fuel supply for two 1,000 MWe LWR's for 30 years, would occur even if plutonium were stored for future use.

1.0 INTRODUCTION

The major additional steps necessary for recycling uranium and plutonium are chemical reprocessing of spent fuel, storing high level wastes from reprocessing (as opposed to storing unprocessed spent fuel), and fabricating fuel elements containing PuO_2 as well as UO_2. Analysis of the facilities, equipment, and processing steps used in fabricating MOX fuel for LWR's shows the environmental impacts to be of negligible consequences. The reprocessing step is the one with the largest environmental impact. Offsetting this impact is the reduction in requirements for uranium mining, milling, UF_6 preparation and enrichment, for which there will be less demand if plutonium is substituted for some of the fissile uranium in the fuel. The net effect of all the changes is negligible with respect to exposure to radioactive materials or to radiation, being much less than the normal variations in natural background.

The largest beneficial impacts will be the visual, aesthetic, environmental and economic effects of reducing the requirements for uranium mining and milling.

The radioactive waste management processes are quite different for the no recycle case where spent fuel elements are stored without processing, and for either the uranium only recycle case or the uranium and plutonium recycle case, where the high level radioactive wastes from reprocessing must be stored. The uranium recycle case is assumed to involve disposal of plutonium with the high level wastes. However, the total quantities of radioactive material are about the same and the net environmental impact of waste management activities is not appreciably affected by the choice of recycle alternatives.

2.0 RADIOLOGICAL IMPACT

CHAPTER IV, Section J, presents the calculated radiological impact coincident with plutonium recycle and indicates that the fuel reprocessing plant and the mixed oxide fabrication plant are the major contributors to the slight increase in radiological dose estimates. Compared to the no recycle case, there is a decrease in dose commitment in other parts of the fuel cycle because of the decrease in enriched uranium requirements. The average dose commitments for the U.S. population during the period 1975 through 2000 have been calculated in terms of person-rem per GWe potential of the fuel produced. The values are 1,800 person-rem for no recycle; 2,100 person-rem for uranium only recycle; and 2,000 person-rem for uranium and plutonium recycle. All of these levels are about 1% to 2% of the natural background exposure in the United States. The advance of technology will affect the actual radiological impact of the various alternatives. The differential radiological impact coincident with recycle may increase or decrease, even as a result of improvements that are not directly associated with plutonium recycle. One example of this is the development and implementation of an off-gas treatment process for the removal and safe retention of krypton-85 from reprocessing plant effluents, independent of whether or not plutonium is being recycled.

The lower yields of krypton-85 from thermal fission of plutonium-239 and plutonium-241 would decrease the quantities released from the reprocessing plants by

about 4% when plutonium is being recycled. The worldwide dose, therefore, would also be decreased by the same percentage. If it becomes technically feasible, most of the krypton-85 can be removed and not released at the reprocessing plant, the associated impact would be greatly reduced, and a 4 percent change would be insignificant.

Tritium, carbon-14 and krypton-85 are formed during the irradiation of nuclear fuel and are released during reprocessing. Of these, carbon-14 is a transmutation product formed by the reaction of neutrons with nitrogen impurities in the fuel. Because the fission cross of plutonium is higher than that of uranium, MOX fuel requires a lower neutron flux in the reactor, and about 4% less carbon-14 is formed. Releases of carbon-14 are correspondingly lower when MOX fuel is being reprocessed than when UO_2 fuel is reprocessed. When there is no recycle of uranium or plutonium, the radioactive materials remain confined in the spent fuel elements in the storage repository.

3.0 URANIUM RESOURCES

Implementation of plutonium recycle in LWR fuel has the beneficial environmental effect of conserving energy resources. If plutonium were not recycled, additional uranium would have to be mined and processed to low enrichment for use in LWR fuel. This reduction in uranium requirements is a long term effect.

Each kilogram of fissile plutonium recycled saves about 205 kilograms of natural uranium feed to the enrichment plant, the exact amount being dependent on tails assay, initial enrichment, and utilization in the reactor. Between 1975 and the year 2000, about 780 metric tons (MT) of fissile plutonium could be recycled and the annual usage could increase to a rate of about 80 MT per year in light water reactors. By the year 2000 the total uranium resources conserved by plutonium recycle in LWR fuels could amount to about 360,000 short tons of U_3O_8. This represents about 22% of the total quantity of U_3O_8 that otherwise would be needed through the year 2000; it also represents about 10% of known plus potential U.S. ore reserves containing 0.08% or more of U_3O_8. It is noted that without plutonium and uranium recycle, about 88% of the known plus probable U.S. reserves would be exhausted by the year 2000; whereas, with uranium and plutonium recycle, only 67% of the U.S. reserves would have been used. The 360,000 tons of U_3O_8 conserved represents more than three years' total nuclear fuel supply in the year 2000 or approximately the total uranium required for all LWR needs through 1986 with no recycle. See CHAPTER IV, Section F, Table IV F-2 for total estimated U_3O_8 resources.

4.0 CONSTRUCTION ACTIVITIES

As discussed in CHAPTER III, paragraph 2.1.2, it is estimated that eight mixed oxide fabrication plants will be required by the year 2000 if plutonium is recycled to LWR's. Counterbalancing the necessary construction activities associated with these plants is the lessening of construction activity involved in other parts of the fuel cycle. Using the information developed in CHAPTER IV, Section F, for mines and mills, and in CHAPTER III for the other facilities, there would probably be about 1,710 fewer mines, 32 fewer mills, and one less enrichment facility constructed by

the year 2000 if plutonium is recycled than if there is no recycle of fissile materials recovered from spent fuel. In addition, if fuel enrichment is accomplished in gaseous diffusion plants and the power for the plants comes from nuclear generating stations, two of these power plants (and associated construction activity) would not be required. Even if fossil fueled power plants were provided, there would be construction activity comparable to that for nuclear plants. These plant requirements are shown in Table IX-1.

5.0 LAND USE

5.1 Short term

By the year 2000, eight mixed oxide fabrication plants will be required for recycling plutonium but fewer plants will be needed in some other steps of the fuel cycle. The land commitments for these differential plant requirements are shown in Table IX-1. It should be recognized that the numbers of plants estimated are based on capacities expected for each plant, and plant capacities may vary. The negative differential land use shown, 52,000 acres in comparison to recycle of uranium only, or 100,000 acres in comparison to no recycle, is mainly attributable to temporarily-committed land associated with mining operations.

With respect to land productivity, the sites committed for mining and milling probably would have no other productive use. Land commitments for other fuel cycle plants, however, could involve some productive use, probably farming, when the likely rural location of these facilities is considered. Normally none of the sites would be chosen for its value for farming; rather, the land would be chosen on the basis of siting criteria for nuclear fuel cycle plants. If it is assumed that one-half of the land committed for these sites is arable, then it can be estimated that plutonium recycle would result in a net loss of about 6,000 acres of productive farm land during the life of the facilities. There would also be a 50,000- to 100,000-acre reduction in permanently committed acreage for mining and milling, even though mining and milling usually involve land that is mostly nonarable.

5.2 Long term

Some of the radioactive waste products associated with the fuel processing and fabrication activities have long-lived radioactivity. The differential quantities of these waste products associated with the recycle of plutonium are discussed in CHAPTER IV, Section H. Storage space (and, therefore, land) is required to isolate and confine these radioactive waste products. Plutonium contamination of the waste requires long term retention, primarily because of the 24,000-year half-life of the plutonium-239 constituent, but this occurs with or without plutonium recycle. By the end of the century, the cumulative volume associated with this radioactive waste storage is about 148,000 cubic meters. It is projected that two Federal repositories would be needed for this permanent storage.

Table IX-1

DIFFERENTIAL LAND USE

Fuel Cycle Segment	Number of Plants in the year 2000			Reduction in Land Use With Plutonium Recycle, Acres	
	No Recycle	Uranium Recycle	U + Pu Recycle	Compared to Uranium Recycle	Compared to No Recycle
Uranium Mines	5,840	5,064	4,125	-52,000	- 97,000
Uranium Mills	109	95	77	- 5,400	- 9,300
Uranium Enrichment Plants	6	6	5	- 350	- 350
Nuclear* Power Plants	7.3	7.4	6.7	- 1,000	- 1,000
Uranium Fuel Fabrication	9	9	8	- 1,000	- 1,000
MOX Fuel Fabrication	0	0	8	+ 8,000	+ 8,000
				-51,750	-100,650

*Used to provide power for the enrichment plant; if not nuclear, the land commitment would still be similar. Fractions of a plant represent quantities of electricity that might be purchased from outside power networks.

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CHAPTER X

IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

CHAPTER X

IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

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CHAPTER X
IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

SUMMARY

The purpose of this chapter is to identify the commitments of fuel resources, land and manpower involved with the proposed recycling of plutonium and to estimate the extent to which these commitments might limit or preclude future uses of these resources. This generic environmental statement is concerned with the resource commitments which are incremental as a result of the recycle of plutonium as compared with no recycle.

Uranium resources would be conserved by recycling plutonium in the fuel of LWR's. The land, material, and manpower resources which are irreversibly committed for new reprocessing and mixed oxide fuel fabrication plants would be more than compensated by a decrease of resource commitments in other portions of the fuel cycle.

The implementation of plutonium recycle would reduce the manpower requirements of the nuclear fuel cycle by 20% and would reduce the land commitments by 100,000 acres. The environmental impacts of radioactive materials released to the environment in plutonium recycle processing or stored as wastes are negligible.

CHAPTER X
IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

1.0 NUCLEAR FUEL RESOURCES

The recycling of uranium and plutonium from LWR spent fuel will conserve nuclear fuel resources. The uranium mining and milling requirements will be reduced by 22%, and this will be reflected in a reduction of the irreversible and irretrievable commitments of resources which will have occurred by the year 2000. About 100,000 acres less land will be disturbed for mining and milling if uranium and plutonium are recycled. The quantity of mill tailings to be stored and kept under surveillance will be reduced by 1.2 billion cubic meters between 1975 and 2000. Atmospheric releases of radium, radon, and uranium from mining and milling activities will be proportionally reduced, although that reduction will be offset to some extent by the reprocessing releases of plutonium, transuranium elements, fission products, tritium and carbon-14, which will occur if uranium and plutonium are recycled. However, both the increased releases from reprocessing and the decreased releases from mining and milling are insignificant in their environmental impacts and in their effects on public health and safety.

It is estimated that with no recycle of uranium or plutonium through the year 2000, 88% of the known plus probable U.S. uranium reserves recoverable at costs up to $30 per pound will have been irreversibly and irretrievably committed to nuclear fuel applications. With recycle of uranium and plutonium, the commitment of the more economically obtainable uranium resources will be reduced to about two-thirds of the U.S. supply. Further information on U.S. uranium resources is given in CHAPTER IV, Section F.

If spent fuel from LWR's is stored, as in the no recycle case, the fissile uranium and plutonium still contained in the fuel could theoretically be recovered by reprocessing at some future date, should this prove desirable. However, there is one irreversible and irretrievable loss which would occur. If plutonium is not promptly recycled, some of the fissile plutonium-241 will be lost by radioactive decay to americium-241. Plutonium-241 decays with a 13.2-year half-life, in contrast to the 25,000-year half-life of the more abundant fissile isotope, plutonium-239. About 12% of the total plutonium content of spent nuclear fuel is plutonium-241 and half of the plutonium-241 is lost during each 13.2-year period. It is estimated that about 34 metric tons of the fissile plutonium-241 will be irretrievably lost by radioactive decay over the 26 years from 1975 through 2000. The 34 MT of plutonium-241 is equivalent in potential fission energy to a 30-year fuel supply for two LWR's.

The estimate of 34 MT of plutonium-241 lost if there is no plutonium recycle through the year 2000 is based on calculated decay of the quantity of plutonium produced, whether or not it is separated and purified for possible use. It is obvious that, even with recycle, some plutonium-241 would be lost through decay to americium-241. Thus, all other considerations being equal, the shorter the period before recycling into the reactor, the more the savings in this energy resource.

2.0 ENVIRONMENTAL RESOURCES

The recycling of uranium and plutonium affects the generation of wastes which must be stored or disposed of. Chemical wastes from processing operations involved in converting U_3O_8 to UF_6, enriching it, and reconverting it to UO_2 would be reduced with the decrease in demand for these services if uranium and plutonium are recycled, but this decrease would be partially offset by increases in chemical wastes from reprocessing and MOX fuel fabrication, giving a net reduction of 20,000 cubic meters in the volume of chemical wastes between 1975 and 2000. Wastes contaminated with plutonium and transuranium elements would increase during this period to 148,000 cubic meters with plutonium recycle, but high level radioactive wastes would decrease from 55,000 to 6,500 cubic meters. Solidified high level wastes from fuel reprocessing occupy less space than spent fuel elements, but require nearly the same area for geologic storage because the containers are more widely separated in storage to allow for dissipation of the heat of radioactive decay. The low level wastes generated from 1975 through 2000 would decrease by 87,000 cubic meters with plutonium recycle as a result of reductions in wastes from UF_6 conversion and enrichment plus reductions in spent fuel storage. The environmental impact data summarized in CHAPTER VIII, Appendix A, show that uranium and plutonium recycle would reduce the resources committed to waste storage or disposal by significant amounts.

The use of nuclear power to meet energy needs of the United States reduces the irreversible and irretrievable commitments of fossil fuel resources but creates radioactivity which would not exist if nuclear power were not used. The recycling of uranium and plutonium makes the nuclear fuel resources go further, but creates reprocessing and MOX fuel fabrication wastes and environmental releases which would not be encountered if there were no recycle. The irreversible and irretrievable effects of radioactive wastes and environmental releases associated with plutonium recycle have been calculated and found to be negligible. The radiation dose commitments, for example, are less than 1% of natural background.

The five fuel reprocessing and eight MOX fuel fabrication plants are facilities required for plutonium recycle which would not be needed if there were no recycle. It has been shown that the environmental effects of these plants are well within permissible limits and that the resources committed to their construction and operation are far more than offset by gains in the conservation of nuclear fuel resources.

3.0 MANPOWER RESOURCES

It is estimated that in the year 2000 there will be about 400,000 people working in the commercial nuclear fuel cycle industry, including mining and transportation of materials. Plutonium recycle would create about 2,400 new jobs at the mixed oxide fuel fabrication plants and 6,000 jobs at reprocessing plants, but the overall work force would be reduced by approximately 40,000 workers because of the decrease in needs in other segments of the fuel cycle, mainly mining and transportation. This represents approximately a 20% decrease in manpower requirements. Although this conserves manpower resources, it is not considered significant in the U.S. total employment picture, since it simply represents a slower growth in employment opportunities.

4.0 PERMANENT LAND COMMITMENTS

Land commitments associated with the recycle of plutonium are discussed in CHAPTER IX. The only irreversible incremental commitment with respect to land is that portion permanently set aside for storage of plutonium-contaminated wastes from the plutonium fabrication and reprocessing plants. For the period 1975-2000, the volume of plutonium wastes to be permanently stored in Federal repositories is about 148,000 cubic meters. About 500 acres of land surface might be occupied by the two Federal repositories projected for the year 2000. As discussed in CHAPTER IV, Section F, by the year 2000 a permanent commitment of 100,000 acres of land associated with mining and milling operations would be avoided if plutonium is recycled. A large part of this land would have been used for mill tailings and mine waste piles.

GESMO

CHAPTER XI

ECONOMIC ANALYSIS AND COST-BENEFIT BALANCING

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SUMMARY

The various LWR fuel cycle alternatives were analyzed for their economic impact on each of the fuel cycle elements. Little, if any, difference was found in most fuel cycle steps among Alternatives 1, 2, and 4. Uranium recycle only, Alternative 5, was found to involve a higher demand on most of the services, particularly mining and milling, UF_6 conversion, and enrichment. This alternative eliminates the need for plutonium storage and mixed oxide fuel fabrication. The throwaway fuel cycle (Alternative 6) results in even greater demands for U_3O_8 and associated services. With no reprocessing required for Alternative 6, most of the back-end services will be no longer needed. The exception to this is increased waste management cost, resulting from charges for the disposal of waste fuel elements that are considerably larger in volume than the concentrated wastes from reprocessing. An overall fuel cycle analysis showed that there are minor cost penalties (on the order of $100 million when discounted at 10%) for delaying plutonium recycle for a short time (Alternatives 1 and 2) as compared to the reference case (earliest possible plutonium-uranium recycle), Alternative 3. If there is no recycle of plutonium (Alternatives 5 and 6), substantial economic penalties--about $18 billion total, $3 billion discounted at 10%--will be incurred.

Parametric studies were made to analyze the sensitivity of the results to the unit costs of the various fuel cycle steps, to economic assumptions, and to the growth in electricity demand. It was found that as the total electric power generated in nuclear plants increases by 42% (over the time period 1975 through 2000), the economic incentive for recycle doubles. The price of uranium was found to have the largest single effect in the economic analysis. Within the range of prices considered in this analysis, halving of the uranium costs could reduce the recycle incentive by about $2 billion discounted at 10%. Doubling of the uranium costs could increase the economic advantage of recycle by about $5 billion. Separative work, in the range of unit prices considered, showed about 10% of the effect of changing uranium prices in the recycle economic analysis. The sensitivity of the recycle incentive to changes in estimated spent fuel storage and mixed oxide fuel fabrication costs was found to be similar to its sensitivity to the separative work cost. The economic recycle incentives were quite sensitive to the reprocessing and spent fuel disposal costs over the ranges considered. Both of these fuel cycle steps had an influence on the incentive of plus or minus $1 billion. As the reprocessing cost rises, the incentive to recycle decreases. On the other hand, as spent fuel disposal cost increases, so does the incentive to recycle. Items such as spent fuel transportation, plutonium transportation, and plutonium storage were found to have a small influence on the economics of recycle.

In the highly unlikely event that all of the key fuel cycle costs were unfavorable to recycle to the maximum extent, the incentive would disappear and the economics would indicate an advantage of about $2 billion for the throwaway fuel cycle. In the equally unlikely event that all costs favored to the maximum degree the recycle situation, the incentive to recycle would increase to $11 billion.

Of all the economic (as contrasted to fuel cycle) variables examined, the greatest effects were exerted by variations in the discount rate. When this is reduced from 10% to 6%, the incentive to recycle increases from $3 to $6 billion. Delays of less than 5 years in the start of recycle were found to have relatively small impacts under the conditions assumed.

Each of the LWR fuel cycle alternatives was examined for both economic benefits and environmental costs. It was found that Alternatives 1, 2, and 5 each have higher economic costs and higher environmental impacts in comparison to Alternative 3. The advantages of Alternative 3 over Alternatives 1, 2, and 5 are clear. Alternative 6 (the throwaway fuel cycle) incurs the highest economic penalty in comparison to Alternative 3. On the other hand, this alternative shows some decreased environmental impacts (radioactive gas releases, alpha-emitting actinides in high-level wastes, and radiological dose commitments). The decrease of 9.7×10^5 person-rem in the dose commitment to the general population in Alternative 6 (6.7×10^5 person-rem decrease in total dose commitment when the occupational doses are included) is the most significant decrease in environmental impact. Alternative 6 also indicated some environmental impacts higher than those of the reference case (land use, electricity consumption, and water consumption).

Although there are some fundamental problems in comparing economic benefits with environmental costs on a dollar basis, this comparison of costs was performed for Alternative 6. The environmental costs of the dose commitment were evaluated at a value of $1,000 per person-rem (a high value for this unit). When the 9.7×10^5 person-rem decrease in dose commitment is evaluated in this manner and compared to the undiscounted cost savings, the benefits of prompt recycle outweigh the costs by a ratio of 19 to 1.

1.0 INTRODUCTION

LWR fuel cycle alternatives are described in detail and evaluated in CHAPTER VIII. In this chapter these alternatives are compared with respect to their effects on the environmental impact and economic cost of each step in the LWR fuel cycle. A balancing of environmental and economic factors is made. The costs and environmental effects of a final safeguards system are still under study and are not included in this balancing. These factors will be included in the balancing contained in the final Safeguards Supplement.

In response to some comments on the draft, Alternative 3 was picked as the reference case in lieu of Alternative 1. Other alternatives are compared to Alternative 3 for the purposes of analysis. Alternative 3 incurs the smallest economic costs among the alternatives and, in most cases, the minimum environmental effects. Hence most differences expressed when comparing alternatives are positive, making Alternative 3 a convenient and logical choice for reference. Sufficient information is presented to show how the operations conducted in each fuel cycle step might be expected to evolve under the various alternatives. Sensitivity analyses are made of all the major variables. In addition, a summary cost-benefit analysis is presented to permit a ready comparison of the projected environmental effects and costs resulting from each plutonium disposition procedure considered.

Section 2 of this chapter examines the variations of each fuel cycle operation that could be expected under the various recycle options. Section 3 is devoted to the parametric studies and a discussion of the major variables. Section 4 summarizes the economic and environmental factors for each alternative and balances them for Alternative 6 vs Alternative 3.

2.0 COMPARISON OF EFFECTS OF ALTERNATIVE DISPOSITION OF PLUTONIUM ON LWR FUEL CYCLE OPERATIONS

To refresh the reader's memory, the alternatives analyzed in this chapter are

Alternative 1 - Prompt recycle of recovered uranium as fuel in LWR's (1978), with temporary storage of recovered plutonium (until 1983).

Alternative 2 - Temporary storage of spent fuel elements for the later recovery (1986) of plutonium and uranium values.

Alternative 3 - Prompt recovery, reprocessing, and recycle of uranium (1978) and plutonium (1981) as fuel in LWR's.

Alternative 4 - In the Draft GESMO, an alternative of prompt plutonium recycle with upgraded safeguards was designated Alternative 4. Further analysis of the safeguards program in the preparation

of the draft supplement on safeguards indicates that one level of safeguards will be provided for all levels of strategic special nuclear materials (SSNM). Thus consideration of the safeguards program will be factored into all alternatives involving SSNM (Alternatives 1, 2, 3, and 5), and Alternative 4 as a separate alternative will be deleted from the Final Statements. To accomplish this, the economic analyses included in the Final Environmental Statement - Health, Safety & Environment, which do not currently include costs for the final safeguards program, will be updated in the Final Safeguards Supplement.

Alternative 5 - Delayed recovery, reprocessing, and recycling of uranium (1986) and disposal of plutonium.

Alternative 6 - Final storage of spent fuel elements without consideration for later use.

In the section to follow, unit prices of the various fuel cycle components are discussed. The fuel cycle segments for which unit prices are developed are the following:

- Mining, milling
- UF_6 conversion
- Uranium enrichment
- Uranium fuel fabrication
- Spent fuel storage
- Reprocessing
- Plutonium storage
- Mixed oxide fuel fabrication
- Waste management
- Transportation

Published literature, industry contacts, experience and judgment have been used to arrive at an expected range of prices for each of these items during the 26-year

period between 1975 and 2000. The ranges include low, reference (most likely) and high prices for each of these components.*

2.1 Mining and Milling

The recycle of both uranium and plutonium would significantly reduce the requirement for uranium ore. The development of relatively inaccessible uranium resources would therefore not be needed as early with plutonium and uranium recycle. Consequently, at any point in time the price of U_3O_8 would be expected to be greater if the values in spent fuels were not recycled. This increased unit price and the increased quantities required compound the monetary impact of not recycling. These factors are analyzed in the subsequent paragraphs. The detailed rationale for the uranium-pricing algorithm used in these projections is presented in Appendix XI-A.

A comparison of the cumulative demands for U_3O_8 is shown in Table XI-1. The reference case (Alternative 3) has the lowest total requirements during the early 1980's. Alternatives 1, 2, and 3 have essentially the same total U_3O_8 requirements (year 2000 in Table XI-1) after the effect of delays has been compensated for by the lower usage once Pu recycle occurs. In effect, the recycle delay of Alternatives 1 and 2 requires more rapid use of U_3O_8 in the early years. When U and Pu start to be recycled, the demand for new U_3O_8 eases and the system equilibrates, with essentially the same total quantity of U_3O_8 required by the year 2000 for Alternatives 1, 2, and 3.

*A draft of an unpublished ERDA study, ERDA 76-121, "Light Water Reactor Fuel Cycle: Its Value to Energy Independence," has recently been provided to NRC.

This report was developed independently from the GESMO analysis, however, there is unusually good agreement between the final results of the two efforts. The GESMO final statement indicates an expected savings of $18.2 billion by Pu recycle and the ERDA draft report indicates $18.5 billion for the same value. The present worth of these savings, discounted at 10%, are projected by GESMO to be $3.2 billion and by the ERDA draft report to be $2.3 billion. When these savings are translated into unit electrical generation costs, they result in a reduction of 0.4 mills/kWh and 0.5 mills/kWh respectively, for the GESMO and the draft ERDA report.

Insofar as possible, the final GESMO attempts to project industry costs by using actual and estimated commercial data. The ERDA draft report generally reflects somewhat different design and fuel cycle cost assumptions made from a governmental viewpoint. As a result, as might be expected, some of the individual unit costs vary. In general, the GESMO statement includes a more detailed breakdown of these components and the range of cost included in the final GESMO generally spans the comparable values utilized in the draft ERDA report when the two sets of data are expressed on the same basis. A significant difference in individual costs is noted in reprocessing and waste management plant costs. ERDA has assumed a completely remote maintenance design estimated to cost $1 billion (1977 dollars). Industry, on the other hand, has used a hybrid arrangement with some contact maintenance areas which is projected by AGNS and Exxon to cost $600 million (1976 dollars). The GESMO plant costs are based on current industry data which uses the hybrid philosophy, $500 million (1975 dollars). For further discussion of this factor, see Section 2.6 of this chapter.

Table XI-1

CUMULATIVE U_3O_8 REQUIREMENTS

(Starting in 1975, Thousands of Short Tons)

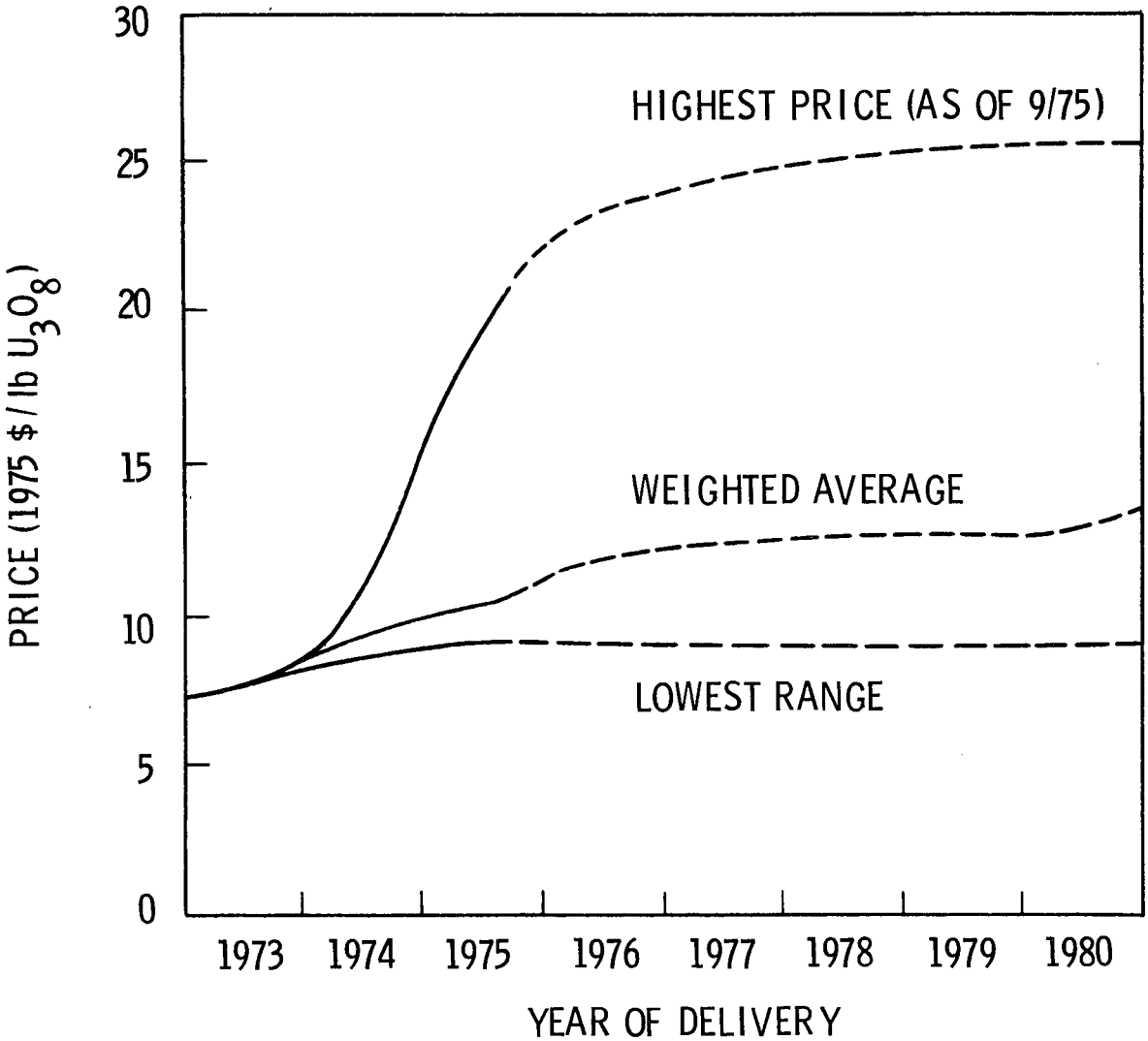
Year	Alternative 1	2	3	5	6
1980	98.8	104	96.7	104	104
1985	259	295	258	295	295
1990	515	532	514	573	610
1995	853	853	852	959	1056
2000	1,240	1,240	1,240	1,430	1,600

Alternatives 5 and 6 show the effects of not recycling either uranium or plutonium. Alternative 5 (uranium recycle only, starting in 1986) requires an additional 190,000 MT U_3O_8 by the year 2000. Alternative 6 (no recycle of either uranium or plutonium) would require 360,000 MT of U_3O_8 over the basic requirements of Alternative 3. The characteristics of industry expansion to meet these demands are discussed in detail in CHAPTER III.

An important feature of a study such as this is the current and forecasted price of uranium. For many reasons a trend based on past prices or current spot market prices will not adequately predict the price. The industry is not mature; it has not grown over a period of time under normal market conditions. It developed rapidly with only a single customer (U.S. Government), and when that customer's needs decreased, there was essentially no market. The new market (commercial nuclear power) was slow to develop and is still attended by many uncertainties:

- Cancellations and delays in the construction of new nuclear power plants
- New enrichment facilities; government or private ownership
- Timing and selection of technology
- Government policies; enrichment tails assay; export and import of uranium
- Recycle of uranium and plutonium

All these uncertainties have limited investment in new mine/mill complexes and make future prices very uncertain. Some idea of the spread in prices is seen in Figure XI-1, which shows the lowest, highest and weighted average prices for uranium deliveries. It is quite apparent that the bulk of the deliveries are in the lowest range, representing contracts made in the past. The higher figures are more representative of the "spot" market price. By most estimates the low price uranium[1] is not generating the cash flow necessary to provide for the expansion required to support a growing demand. Hence a sharp increase in prices is needed to support the required exploration and construction of new mine/mill complexes.



(see Reference 1)

Figure XI-1 Reported Uranium Prices

Methods of contracting for uranium supplies are also changing. Instead of fixed-price contracts as in the past, such terms as "take or pay," "market price at time of delivery," "built-in escalation rates," "payment in advance," and others are making it difficult to determine a firm price. In addition, utilities are beginning to participate in uranium exploration and production ventures as a means of ensuring a supply of fuel.

The delays in investment in new nuclear power plants have also produced a "seller's market" for uranium. It is expected that sufficient uranium and sufficient production capacity can be available in time to meet industry requirements, but this capacity does not exist now. Only about half the utilities' forecasted requirements are under contract, and the current low cost uranium reserves cannot supply that need.[1]

All of the above information has led us to attempt to portray a mature market, in which a balance exists between supply and demand and in which there are adequate incentives to keep the balance. To this end an algorithm based on the rate of usage has been developed. The algorithm is discussed in detail in Appendix XI-A. This calculation is performed in NUCOST, described in CHAPTER VIII, paragraph 5.4.

The rate at which resources are consumed will then determine the unit prices as a function of time for the various alternatives. Estimates of these prices are shown in Table XI-2. The prices estimated by this demand-driven algorithm are industry-average prices. This should not be confused with the marginal prices often quoted in industry journals. For example, many contracts exist for U_3O_8 delivery in 1980 at prices of $12/lb or less. On the other hand, there have been some spot purchases (for 1980 delivery) as high as $40/lb. The current market is also severely perturbed by the announced inability of one supplier to deliver more than a fraction of his contracted uranium.

Because of the diversity of price estimates, the U_3O_8 price is treated parametrically in the analysis: a price range of $14 to $56/lb U_3O_8, with $28 being the reference value.

Table XI-2

AVERAGE U_3O_8 UNIT PRICE

(Dollars per Pound)

Year	Alternative 1	2	3	5	6
1980	17.8	18.2	17.7	18.2	18.2
1985	23.5	25.0	23.4	25.8	25.0
1990	28.5	28.5	28.5	28.5	28.5
1995	32.5	32.6	32.5	33.0	33.0
2000	33.1	33.1	33.1	34.2	37.6

The estimated mining and milling costs for each alternative over the time period 1975-2000 are shown in Table XI-3.

Table XI-3

CUMULATIVE U_3O_8 COSTS
(Billions of Dollars)

Year	Alternative 1	2	3	5	6
1980	2.67	2.85	2.59	2.85	2.85
1985	9.69	11.5	9.64	11.5	11.5
1990	24.0	25.0	24.0	27.3	29.5
1995	44.1	44.1	44.1	51.1	57.5
2000	69.8	69.8	69.8	82.7	95.3

The figure for the year 2000 in Table XI-3 represents the total mining and milling cost for each alternative over the time period. From the demand and unit cost data projected in Tables XI-1 and XI-2, the total costs for Alternatives 1, 2, and 3 are essentially the same. When only uranium is recycled, as in Alternative 5, the total cost for U_3O_8 goes up markedly, $12.9 billion over the reference. In Alternative 6, where neither uranium nor plutonium is recycled, the U_3O_8 cost increment rises to $25.5 billion over the reference. When discounted at 10%, these increments are $2.6 and $4.7 billion, respectively. As will be seen in later sections, there are some compensating savings in other fuel cycle services, but these differences in uranium costs represent the major cost advantage for plutonium recycle.

As discussed above, considerable uncertainty exists as to the size of the uranium resource and the price at which it can be delivered. In an effort to gather the most recent judgments on this matter, a special survey was conducted.* Some 28 organizations connected with the nuclear industry were contacted. These included producers, agents, reactor vendors, utilities, and government agencies. Although there was no unanimity of opinion, the consensus of this group was not in conflict with the assumptions used in this analysis. The complete report of this survey is included as Appendix D.

2.2 Conversion to Uranium Hexafluoride

The conversion of U_3O_8 to UF_6 is the step before isotope enrichment and is the final step in processing U_3O_8; it thus has a direct correlation to U_3O_8 requirements. The capability exists for expanding to meet requirements through 1978. This near term situation is projected to be essentially independent of the recycle of either uranium or plutonium since only small quantities of these materials would become available for recycle in the early 1980's.

The projected industry demand for UF_6 is shown in Table XI-4. Details of the expansion through which industry is expected to meet these demands can be found in CHAPTER III.

*Karl H. Puechl, nuclear consultant, Atlanta, Georgia.

Table XI-4

CUMULATIVE DEMANDS FOR CONVERSION TO UF_6

(Thousands of Metric Tons of Uranium)

Year	Alternative 1	2	3	5	6
1980	73.4	76.8	72.2	76.8	76.8
1985	190	218	189	218	218
1990	380	397	380	429	456
1995	628	630	628	722	795
2000	915	916	915	1,082	1,210

The pattern of demand growth is similar to that for U_3O_8 (see preceding section). Alternatives 1, 2, and 3 have identical total demands (year 2000). The failure to recycle plutonium (Alternative 5) results in a demand that is about 18% greater than that of the reference case, whereas the throwaway fuel cycle (Alternative 6) has a 32% greater demand.

Unit costs of conversion to UF_6 were estimated to be \$3.50/kg U, with a possible range of \$3 to \$4.[2] This cost was derived from an examination of a number of commercial contracts, which showed no more than 10% deviation from this number. This relatively small variation is attributed to today's ample industry capacity. Because of the small uncertainty in these unit costs, this fuel cycle component was not parametrized. See Section 3.0 of this chapter.

The resulting industry costs for conversion to UF_6 are shown in Table XI-5.

Table XI-5

CUMULATIVE COST FOR CONVERSION TO UF_6

(Millions of Dollars)

Year	Alternative 1	2	3	5	6
1980	257	268	253	268	268
1985	664	762	661	762	762
1990	1,330	1,390	1,330	1,500	1,590
1995	2,200	2,200	2,200	2,530	2,780
2000	3,210	3,210	3,210	3,790	4,430

Cumulative demands and costs for Alternatives 1, 2, and 3 are essentially identical by the year 2000. Additional costs for UF_6 for Alternatives 5 and 6 are \$580 and \$1,020 million, respectively. Discounted at 10%, these added costs are \$127 and \$204 million, respectively.

2.3 Uranium Enrichment

A decision regarding plutonium recycle could significantly affect enrichment requirements, since plutonium is basically a substitute for ^{235}U. In addition to the continuing impact on enrichment requirements, there is also a potential impact on the schedule for added enrichment facilities. It is, however, difficult to project precisely the development of the enrichment stage of the fuel cycle because of the many factors involved: foreign competition, private versus public ownership of new capacity, the preproduction capability of the present ERDA complex, etc. These factors are discussed in Appendix XI-B.

Table XI-6 shows the cumulative separative work requirements for the various alternatives.

As can be seen in Table, XI-6, Alternatives 1, 2, and 3 have essentially identical cumulative total separative work demands (see year 2000 in table). Alternative 5 has an approximately 17% greater demand than the reference case, whereas Alternative 6 has about 16% greater demand. It is interesting to compare these increases with those calculated for UF_6 conversion (see preceding section), in which the additional demand was 18 and 32% for Alternatives 5 and 6, respectively. This apparent discrepancy can be explained by the fact that recycled uranium (Alternative 5) has approximately the same concentration of ^{235}U as does natural uranium. Hence the differences between Alternatives 5 and 6 should be large for U_3O_8 and UF_6 demand but should be relatively small for enrichment demand.

The separative work requirements for the uranium only recycle (Alternative 5) are slightly greater than those for the no recycle case (Alternative 6). This is caused by the need to add enrichment (in Alternative 5) to overcome the neutron poison effects of recycled ^{236}U. The basis on which this ^{236}U correction is calculated is discussed in detail in Appendix VIII-B.

Table XI-6

CUMULATIVE REQUIREMENTS FOR SEPARATIVE WORK

(Millions of Separative Work Units)

	Alternative				
Year	1	2	3	5	6
1980	36.6	36.8	36.2	32.8	36.8
1985	100	107	99.3	107	107
1990	204	209	204	225	224
1995	349	350	349	398	395
2000	523	522	523	613	608

The pattern of the demand buildup for enrichment services is of considerable interest, for it may exert some influence on the types of facilities that are built in the future. Table XI-7 illustrates the buildup in annual requirements for separative work for the reference case and for the throwaway fuel cycle (Alternative 6).

The introduction of plutonium recycle may delay the required startup of the first new enrichment plant by about 1 year. If plutonium is not recycled, the earlier requirement for new capacity indicates that the first additional enrichment plant would most probably be a diffusion plant with a capacity of 8.75×10^6 SWU/yr. The later date for added capacity with plutonium recycle might make the use of a centrifuge plant possible. Accordingly, the first additional enrichment plant with plutonium recycle is assumed to be a centrifuge plant with a capacity of 8.75×10^6 SWU/yr. This type of enrichment facility uses far less electricity than does an equivalent diffusion plant.

Table XI-7

ANNUAL REQUIREMENTS FOR SEPARATIVE WORK

(Millions of Separative Work Units)

	Alternative				
Year	1	2	3	5	6
1980	9.0	8.9	8.6	8.9	8.9
1985	15.7	17.9	16.2	17.9	17.9
1990	24.2	22.5	24.3	28.0	27.7
1995	31.7	31.0	31.8	38.4	38.0
2000	36.1	35.8	36.1	45.5	45.0

The pattern of the buildup of enrichment facilities is discussed in detail in CHAPTER III.

The reference unit cost for separative work in the calculations is $75/SWU. Some typical price quotations for separative work are as follows: CENTEC/URENCO originally asked $58/SWU but has recently (March 1975) raised the quotation to $100/SWU plus inflation adjustment; EURODIF quoted $73 to $75/SWU as a base price; UEA was projecting a $75 price;[3,4] a price of $63/SWU escalated at 5% per year has been assumed by Price.[5] ERDA's price last year was $53.35 and $60.75/SWU for fixed commitments and requirements contracts, respectively. These are to go up to $59.05 and $67.25, respectively, in the summer of 1976.

Many of the quotations are future price projections and include the effects of inflation. The quotations in 1975 constant dollars tend to cluster around the $75/SWU price, and hence this is taken as the reference value, but the uncertain nature of the projections leads to a parametrization with a range of $60 to $110/SWU in constant dollars. The basis for this range of values is described below.

If these services are provided in new government-built diffusion facilities with no profits and lower costs of capital, it is estimated that the cost would be $60/SWU. Other estimates, particularly foreign ones, indicate higher costs for separative work when performed in privately owned facilities. In the parametric studies of CHAPTER XI, Section 3, a high value of $110/SWU was chosen. These estimates do not include the possible impact of new technologies, such as centrifuge and laser separation, which are at various stages of development and may significantly

affect future prices. Learning effects should help keep the price down. The range of values studied ($60 to $110/SWU) is thought to adequately cover the likely price range.

The cumulative costs for separative work are shown in Table XI-8. Again, Alternatives 1, 2, and 3 have essentially the same total costs (see year 2000 in table) over the time period. Alternatives 5 and 6 have added costs for enrichment services of $6.8 and $6.4 billion, respectively. When discounted at 10% these costs are $1.27 and $1.20 billion, respectively. Although these increases are not as significant as the costs for U_3O_8, they are still one of the major economic increments between recycle and nonrecycle, as will be seen in subsequent sections. They are comparable in size to the cost differences projected for reprocessing and spent fuel disposal.

Table XI-8

CUMULATIVE COSTS FOR SEPARATIVE WORK

(Billions of Dollars)

Year	Alternative 1	2	3	5	6
1980	2.75	2.76	2.72	2.76	2.76
1985	7.50	7.98	7.45	7.98	7.98
1990	15.32	15.66	15.30	16.87	16.80
1995	26.18	26.25	26.17	29.87	29.64
2000	39.25	39.16	39.24	46.00	45.62

There is invariably a direct relationship between enrichment tails and U_3O_8 feed requirements: the higher the former, the higher the latter.

Throughout the calculations a tails assay of 0.3% was assumed. This is in accord with the announced ERDA policy of raising the transaction tails assay in order to maintain enough enrichment capacity to serve the commitments to the utility industry. The effect is to raise the U_3O_8 feed requirements to the enrichment facilities but to lower the separative work requirements per unit of fuel out.

Using the reference case as an example, the use of 0.2% tails assay (corresponding approximately to the optimum for current uranium prices) would result in the following changes in requirements:

Less U_3O_8	222,000 ST @ $33/lb	= -$14.7 billion
Less conversion to UF_6	164 x 106 kg $3.5my	= - 0.55 billion
More separative work	134 x 10^6 SWUC C $75/sur	= + 10.1 billion
	Net saving	-$ 5.2 billion

Thus a saving of 4.6% of the cost of these three items would be realized. (The quantities cited are the differences in the cumulative totals.) The price of U_3O_8 corresponds to the highest price projected for the reference case or the price of the last increment of purchase that would not otherwise be required.

Although it appears significant, this saving must be balanced against the policy goal. It is not within the scope of this study to analyze ERDA enrichment policy, but it is clear that the failure of this policy to provide adequate enrichment capacity at all times would have a major impact on the U.S. economy.

2.4 Uranium Fuel Fabrication

Uranium fuel fabrication plants provide for the conversion of UF_6 to UO_2, powder milling, pelletizing, sintering, and grinding. After the ceramic operations, pellets are loaded into Zircaloy fuel tubes, and end caps are welded in place to seal the tubes. The loaded fuel rods are then assembled into fuel elements. CHAPTER IV, Section D, discusses in detail the nature of the uranium oxide fuel fabrication portion of the fuel cycle and its environmental impacts.

Present industry plans indicate that, at least in the early years of plutonium recycle, fully sealed and quality-verified rods containing MOX fuel pellets will be shipped to uranium fabrication plants for final assembly into fuel bundles[6] or, conversely, UO_2 fuel rods will be shipped to MOX plants for assembly. Consequently, fuel fabrication plant requirements for the assembly operation would be essentially unchanged through the mid 1980's whether plutonium is recycled or not. With plutonium recycle, the uranium processing and pelletizing portions of the uranium fabrication plants could be designed for somewhat lesser capacity (approximately 10%), but this is probably within the range of designed excess capacity that is reasonable for manufacturing flexibility. Hence it is not expected that plutonium recycle would have a significant effect on uranium plant facilities.

The cumulative industry demand for UO_2 fabrication is illustrated in Table XI-9.

Table XI-9

CUMULATIVE DEMAND FOR UO_2 FABRICATION

(Thousands of Metric Tons of Uranium)

	Alternative				
Year	1	2	3	5	6
1980	11.5	11.5	11.4	11.5	11.5
1985	32.9	34.6	32.7	34.6	34.6
1990	65.6	67.3	65.5	71.3	71.3
1995	111	111	110	124	124
2000	163	163	163	189	189

As can be expected from the results discussed earlier in this chapter, the demand for UO_2 fabrication is nearly identical in Alternatives 1, 2, and 3. There is an estimated increase in demand for Alternatives 5 and 6 of about 16%. This difference is accounted for by the fact that in the latter two alternatives UO_2 fuel is not displaced by MOX fuel. Details on the manner in which the UO_2 fabrication industry is expected to grow to meet this demand can be found in CHAPTER III.

Unit cost estimates for UO_2 fabrication are based on a variety of industry data and publications. Based on recent data, UO_2 fuel fabrication costs range from \$70 to \$112/kg.* These estimates are judged to bracket the range of current values. Discussions with industry indicate that the lowest estimates will probably not be maintained except possibly for BWR fuel manufactured in existing facilities (because the fuel rods are larger, BWR fuel is cheaper on the basis of dollars per kilogram than is PWR fuel). Fabrication costs in new plants are expected to be higher. A \$100/kg estimate has been cited several times[9,10] as a reference fabrication cost.

Fabrication costs may decline somewhat in terms of constant dollars, due to increased experience, improved plant utilization, and competition. Market factors, (i.e., supply and demand), are expected to greatly influence selling prices of fuel fabrication. Consideration of these factors produces a rounded-off estimate range of \$85 to \$105/kg HM, with a reference estimate of \$95/kg HM (all in 1975 dollars). This range is judged to cover the expected costs for the anticipated PWR/BWR mix of UO_2 fabrication. The above costs are believed to be typical of fuel manufacturing in new commercial production plants, such as the present General Electric-Wilmington and Westinghouse-Columbia facilities.

The cumulative undiscounted cost for UO_2 fabrication for each of the alternatives is shown in Table XI-10.

Table XI-10

CUMULATIVE COST OF UO_2 FABRICATION

(Billions of Dollars)

Year	Alternative 1	2	3	5	6
1980	1.09	1.09	1.09	1.09	1.09
1985	3.12	3.29	3.10	3.29	3.29
1990	6.23	6.39	6.22	6.78	6.78
1995	10.5	10.5	10.5	11.8	11.8
2000	15.5	15.5	15.5	17.9	17.9

*The Washington Public Power Supply Service estimates[7] 1975 UO_2 fabrication costs at \$70/kg, whereas a recent study[8] by the General Electric Company estimated UO_2 fuel fabrication to be available at a cost no higher than \$112/kg.

As would be expected from the corresponding demand data (Table XI-9), Alternatives 1, 2, and 3 have essentially the same total cost for UO_2 fabrication. The two nonrecycle alternatives, Alternatives 5 and 6, have an approximately 15% greater total cost. This difference amounts to about $2.4 billion, which is equivalent to approximately $420 million when discounted at 10%. While this factor is not the highest of the fuel cycle cost elements, it is still significant. However, the reduced UO_2 fuel fabrication costs for Alternatives 1, 2, and 3 are more than offset by the added costs for MOX fuel fabrication: $5.1 billion, or $810 million when discounted.

2.5 Spent Fuel Storage

In the uranium fuel cycle, as presently conceived, spent fuel will be stored at the power plant site after discharge from the reactor. To recover materials for recycling, it would then be shipped to a reprocessing plant. The storage period is required to allow the fuel assemblies to cool (for both thermal and radioactive decay) to a level more suitable for shipment. In this economic analysis a minimum of 6 months, storage in the reactor storage basins has been assumed. Because of delays in the startup of reprocessing plants, it is probable that, at least for several years, storage periods may be much longer. Source terms for the environmental impacts of reprocessing CHAPTER IV, Section E), are based on 160 days' cooling prior to reprocessing.

A relatively large spent fuel inventory at the reprocessing plants may be desirable. It would ensure feed for the plant, which, because of its extremely high capital costs, should be operated at high throughput rates.

In the alternatives considered, delays in the startup of reprocessing plants may require some incremental storage in addition to that assumed to be provided normally in the reactor basins and reprocessing plants. Extra storage may be required for periods ranging from 5 to 15 years. In many cases for existing reactor storage basins increased storage can be provided by installing more compact storage racks. Additional storage may be provided at new reactors, at central depots, or in expanded reprocessing plant basins. For a more detailed discussion see CHAPTER IV, Section K.

The demand for incremental fuel element storage can be affected by a number of factors. Storage of fuel elements awaiting delayed reprocessing or burial (the throwaway fuel cycle) is one of the most important of these factors. Table XI-11 illustrates the cumulative demand for incremental storage for each of the alternatives.

Table XI-11

CUMULATIVE DEMAND FOR FUEL STORAGE

(Thousands of Metric Tons of Heavy Metal)

Year	Alternative 1	2	3	5	6
1980	17	22	17	22	22
1985	37	84	37	84	84
1990	70	175	70	175	182
1995	115	227	114	227	336
2000	167	279	167	279	559

Alternatives 1 and 3, having the same reprocessing schedule, predictably require the same spent fuel storage. The delayed reprocessing in Alternatives 2 and 5 results in an increased demand for spent fuel storage services. Alternative 6 eventually requires almost double the storage facilities of any other alternative.

The principal factors affecting the unit costs of spent fuel storage are: type of storage facility (reactor basin, reprocessing plant basin, or central storage); facility design characteristics (new facility or modification of an old one); facility utilization factor.

Reactor vendors, engineering and consulting firms, and some utilities have developed designs that increase storage capacity at nuclear power plants with more compact racks.[11,12] In general, these designs, with the use of neutron poisons, increase capacity by four to six annual discharges. For this analysis it was estimated that reactor basin storage capacity for an existing 1,000 MWe plant could be expanded to hold an additional five discharges (150 MTHM) at a cost of approximately $2 million. This agrees with a news report[11] indicating that pool modification costs were all being forecast at less than $3 million. A new reactor would have the option of either increasing basin size, using compact racks, or a combination of the two; added capacity in this case might be somewhat less expensive.

As an alternative to spent fuel storage at each reactor site, particularly where expanded capacity could not be provided, storage could be accommodated at one or more central storage facilities. A proposal[13] to build a 1,000 MT capacity storage basin indicated a cost of $20 million for this size basin. A very large storage basin of 4,000 MT capacity is estimated to cost on the order of $70 million.

The unit cost of spent fuel storage is sensitive not only to the cost of facilities but also to their effective useful life (amortization) and utilization. The estimated unit storage costs, for several possible storage options, are shown in Table XI-12.

Table XI-12

ESTIMATED UNIT STORAGE COST FOR
SEVERAL SPENT FUEL STORAGE OPTIONS

(Dollars per kilogram of Heavy Metal per Year)

	Capacity Utilization 50%	80%
High Density Racks in Reactor Basins:		
5-Year Amortization	8.00	5.00
10-Year Amortization	5.20	3.30
30-Year Amortization	3.75	2.30
Central Storage Basin with 15-Year Amortization:		
1,000 MT Capacity	8.80	5.50
4,000 MT Capacity	7.70	4.80

The costs of using high density racks in reactor basins are based on a 7% effective cost of capital, believed a conservative representation of utility financing costs in a constant-dollar scenario. The costs for the central storage basin are based on an 11.5% effective cost of money (average of a 9 to 14% range) to represent private industry financing in a similar constant dollar scenario. Considering that added capacity in reactor basins may have a relatively short useful life, perhaps 5 to 10 years, and a utilization factor of about 50%, the cost of this type of storage is estimated to be in the range of $5 to $8/kg HM-yr. The same type of storage in new reactors could result in storage costs as low as $2/kg HM-yr. A central storage basin with long-term contracts with a number of utilities could be expected to be utilized more effectively, although the capital cost per unit of capacity is greater. Thus the cost of central basin storage might be in the range of $4 to 6/kg HM-yr. Published estimates* have generally ranged toward the high end of these estimates, indicating that the lower estimates may be optimistic. A reference cost of $5/kg HM-yr was selected for use in this analysis within a possible range from $2 to $10/kg.

Cumulative costs for the alternatives are shown in Table XI-13. Alternatives 1 and 3, and Alternatives 2 and 5 have identical costs.

In comparison to the reference case, alternatives 2 and 5 have an increased cost for fuel storage of $565 million, or $205 million discounted at 10% per year. The increment for Alternative 6 is $1,965 million, or $400 million discounted at 10% per year. This is a rather significant factor in the overall fuel cycle analysis, particularly in Alternative 6. In that case the differential costs are comparable in importance to those of uranium fabrication.

*For example, an E.R. Johnson and Associates proposal[13] indicated $5/Kg HM-yr, B. Wolfe[14] estimated $7/Kg HM-yr and, more recently, L.J. Colby[15] cited $7-10/Kg HM-yr.

Table XI-13

CUMULATIVE FUEL STORAGE COSTS
(Millions of Dollars from 1975)

	Alternative		
Year	1 and 3	2 and 5	6
1980	86	110	110
1985	187	423	423
1890	349	876	915
1995	572	1,130	1,680
2000	835	1,400	1,800

2.6 Reprocessing

Fuel reprocessing consists of processes for dissolving spent fuel and chemically separating the components into uranium and plutonium product streams and a waste component. The uranium product will be UF_6, ready for return to the enrichment plant for reenrichment. The plutonium product will be plutonium oxide, PuO_2, which will be suitable for shipment to the MOX fuel fabrication plants. The waste will be processed to a form suitable for shipment to a Federal waste repository.

There are at present no operating fuel reprocessing plants. The separations and uranium conversion portions of the Allied-General Nuclear Services (AGNS) plant in Barnwell, South Carolina, are nearly complete and presumably could be ready for operation sometime in 1977, with the exception of the facilities for converting plutonium nitrate to plutonium dioxide. For this reason the earliest possible reprocessing startup date of January 1978 is assumed in the reference alternative.*

The industry cumulative reprocessing capacity is shown in Table XI-14. Details of the manner in which the industry is expected to expand to meet the demand can be found in CHAPTER III. In Alternatives 1 and 3 reprocessing starts in 1978, and capacity is the same in both alternatives. In Alternatives 2 and 5 reprocessing starts in 1986, and capacity is the same in both of these cases. Although reprocessing starts 8 years later in Alternatives 2 and 5, capacity is added more rapidly and meets the same demand as in Alternatives 1 and 3 by 1995. In a special case the assumption was made that the reprocessing capacity would not catch up by the year 2000. This case is discussed in Section 3.9 of this chapter.

*The GESMO Alternative 3 dates for earliest possible initiation of reprocessing and recycle of plutonium, 1978 and 1981, respectively, were chosen to bound the analysis. If industry had chosen to proceed as promptly as potential interim licensing provisions might have permitted, then those dates might have been achieved. However, based on a more realistic assessment of conditions, it now appears that there will be substantial delays beyond those dates. Nonetheless, those dates are still appropriate to present an analysis that bounds the prompt recycle case and since the effects of delays are not great, the analysis also represents most recycle cases. Alternative 2 treats a delay of about the same magnitude as those now contemplated, i.e., reprocessing beginning in 1981 and Pu recycle also beginning in 1981. The analyses indicate that the economic costs to the overall LWR industry of such a delay are very small, viz., $21 million present worth at a 10% discount rate, and the environmental costs for the period 1975-2000 are essentially unchanged by such a delay.

Table XI-14

CUMULATIVE SPENT FUEL REPROCESSED
(Thousands of Metric Tons of Heavy Metal)

	Alternatives				
Year	1	2	3	5	6
1980	3.0	0	3.0	0	0
1985	13	0	13	0	0
1990	32	26	32	26	0
1995	67	67	67	67	0
2000	115	115	115	115	0

Unlike most of the other fuel cycle services, no reprocessing plant is currently operating. Hence it is necessary to estimate the cost of reprocessing from published data on capital and operating costs. Other fuel cycle costs can be estimated from historical price trends. Fuel reprocessing unit cost estimates are based on an assumption of a 1,500 MT/yr plant. Reprocessing plants following the AGNS plant are expected to have a somewhat higher capacity than 1,500 MT/yr.* For this reason the model reprocessing plant discussed in CHAPTER IV, Section E, is based on a 2,000 MT/yr plant. However, virtually all of the available reprocessing plant costs data relate to a 1,500 MT/yr size. For this reason reprocessing costs were developed on the basis of a 1,500 MT/yr plant. There is expected to be a cost scaling advantage for a larger plant. Because of the scaling effect, costs based on a 1,500 MT/yr plant would tend to overstate reprocessing costs (possibly on the order of $5/kg). On the other hand, there are recent indications that the capital costs estimate used here may somewhat understate requirements. In any event there are large uncertainties in the estimated unit reprocessing costs, and these are reflected in the range of unit costs used in this analysis.

A 15-year economic life (investment recovered in 15 years) was assumed in the cost calculations in accordance with industry practice for this type of facility. However, the actual useful life of the facility would most likely extend to a period of 20 or 30 years. Even so, because of the large discounting effect for terms longer than 15 years at the return-on-investment rates used here, an assumed economic life of 20 or 30 years would not significantly reduce the calculated unit costs.

Although a period of 8 to 10 years is anticipated from the start of a reprocessing plant project to plant startup, the level of expenditures would be relatively low for several years during the preparation of scope designs, the Preliminary Safety Analysis Report, the environmental report, the license application, etc. It was assumed here that major capital expenditures for plant construction would not start until 5 years prior to plant startup. For purposes of the unit cost calculations this was taken as the project starting point. Capital expenditures during the 5-year construction period were assumed to be 5, 10, 30, 45, and 10% per year, respectively, for years 1 through 5.

*For example, the Exxon Nuclear Company has announced plans for a 1,500-MT/yr plant expandable to 2,100 MT/yr.

Unit reprocessing costs were calculated with the use of a discounted cash flow procedure.

A 2-year startup period was assumed during which throughput was limited to 50 and 75% of full capacity. Because of the importance in a discounted cash flow analysis of capital expenditure patterns and revenue in the initial years of a project, the long period of capital expenditures prior to startup and the reduced capacity during the first 2 years significantly increase the levelized capital charge portion of the unit costs. Capital funds were assumed to be obtained internally rather than through borrowing. (The effective costs are higher than would be the case with borrowed funds.) In actuality, a project of this magnitude would probably be financed by new debt and equity issues. Any debt financing would reduce the capital charge component calculated here. Income taxes are based on a 50% rate (Federal plus State) and sum-of-years depreciation.

The appropriate range of return on investment (ROI) for this analysis is the range of returns, adjusted for inflation, actually realized by the industry investing in reprocessing facilities. This is distinguished from the somewhat higher ROI that these companies may use to evaluate potential investments. Investors in reprocessing facilities are expected to be large chemical or petroleum refining companies. The average ROI after taxes for the four largest chemical companies and the four largest petroleum refining companies for the 10-year period from 1962 to 1971 ranged from 9 to 17% and 10 to 16%, respectively.[16] Inflation during this period ranged from less than 1% at the beginning of the period to 5 to 6% per year at the end of the period. Inflation averaged 3% per year. This reduces the after-tax ROI range in constant dollars 6 to 14%, which corresponds to a range of fixed charge rates at capacity from 15 to 36%. Borrowed capital that could range from 20 to 40% of total capital requirements could further reduce the effective required ROI on total plant investment. For this analysis an after-tax ROI range of 9 to 14% with an 11.5% median value was selected.

Several current reports and papers[8,14,17-19] indicate capital costs for a 1,500 MTHM/yr plant to be on the order of $500 to $600 million in 1975 dollars. This estimate includes the following conversion facilities:

- Conversion of plutonium nitrate to plutonium dioxide
- Conversion of uranium to uranium hexafluoride
- Conversion of liquid wastes to encapsulated solid wastes

This estimate also includes the consolidation of solid wastes and any other required treatments. These references also indicate operating costs on the order of $45 million per year. However, discussions by Pacific Northwest Laboratories with industry have indicated that operating costs might be as high as $100 million per year. A range of $50 to $100 million per year was assumed.

Table XI-15 indicates estimated reprocessing costs under various assumptions of capital costs and operating costs. As this table shows, the total cost varies from $110 to $190/kg.

Table XI-15

ESTIMATED REPROCESSING COSTS FOR
A 1,500 MTHM/YR PLANT

ITEM	Cost of Capital (After-Tax ROI)		
	9%	11.5%	14%
Effective Fixed Charge* Rate at Capacity (%)	(22.5)	(28.5)	(36.0)
Levelized Fixed Charges on Capital ($/Kg)	75	95	120
Levelized Operating Costs ($/kg)	35-70	35-70	35-70
TOTAL ($/kg)	110-145	130-165	155-190

*For readers interested in fixed charge rates, the equivalent fixed charge rates are noted in parentheses.

In the case of reprocessing for uranium recovery only, it was assumed the plutonium would be handled in a manner similar to that used for high level wastes. See paragraph 2.9 of this chapter. This would result in simplified separations and plutonium conversion processes. It was assumed that the reduced reprocessing costs would be offset by increased waste disposal costs. Thus reprocessing charges are assumed to be identical with those obtaining in the plutonium recycle cases.

The estimated unit reprocessing costs developed here are comparable to several recently published estimates. However, it is difficult to make exact comparisons between different estimates because of differences in the bases used. For example, the cost of waste processing and disposal is clouded by the use of such terms as "waste management," "waste handling," and "waste disposal," which have different meanings for different users. Walton Rodger[19] of Nuclear Safety Associates estimated $170/kg including capital and operating costs plus "waste handling" and extra safeguards but excluding transportation. Bertram Wolfe,[14] General Manager, of the Fuel Recovery and Irradiation Products Department, of the General Electric Company, estimated $120/kg excluding transportation, "final waste management," and plutonium conversion to PuO_2. Frank Schwoerer[20] of Pickard Lowe and Associates estimated $150/kg for reprocessing, shipping, and "disposal." More recently W. J. Price,[5] Executive Vice President of Allied-General Nuclear Services, estimated $153/kg in 1976 dollars for reprocessing, including UF_6 conversion, PuO_2 conversion and storage, and onsite waste management (the same basis as this analysis). Price's estimate of unit costs is based on a $596 million capital cost and an operating cost in 1976 dollars of $41 million per year. This indicates that our capital cost may be somewhat low and our operating cost may be too high. However, the net result for unit cost is essentially identical with our median estimate ($150/kg).

Based on the estimates developed here and the comparison with other estimates, a $150/kg cost was selected as the reference or best estimate unit reprocessing cost, and a range from $110 to $190/kg was selected as the range of interest for sensitivity analysis. See Section 3.0 of this chapter. Reprocessing costs for the MOX fuel component were increased by 20% to cover added costs resulting from the processing of larger quantities of plutonium in the separations and the PuO_2 conversion sections.

Cumulative reprocessing costs for the six alternatives based on the reference unit reprocessing costs are shown in Table XI-16.

Table XI-16

CUMULATIVE COSTS FOR REPROCESSING
(Millions of Dollars)

Year	Alternative 1	2	3	5	6
1980	450	0	450	5	0
1985	1,900	0	1,900	0	0
1990	4,900	3,850	4,900	3,850	0
1995	10,200	10,100	10,200	10,050	0
2000	17,600	17,600	17,600	17,300	0

Alternatives 1 and 3 have identical cumulative costs of $17.6 million ($3.6 billion discounted at 10%). Alternative 2 has the same total cumulative costs (see year 2000), but discounted total ($3.0 billion) for Alternative 2 is $610 million less than that of Alternatives 1 and 3. This cost savings results from a delayed reprocessing schedule: reprocessing begins in 1986 rather than in 1978 as in Alternatives 1 and 3. Alternative 5, while beginning reprocessing 1986, costs $0.3 billion less than Alternative 3. This cost difference results because plutonium recycle is not included in Alternative 5 and thus the extra 20% charge for reprocessing MOX fuels is not incurred.

2.7 Plutonium Storage

Whenever plutonium is recovered and recycled, plutonium storage will be required to accommodate differences in schedules between reprocessing and MOX fuel fabrication. The operation of such facilities would be dynamic, with material being withdrawn and/or added to storage frequently. Plutonium storage facilities would be located at both reprocessing plants and MOX fabrication plants to provide a working inventory of plutonium at each facility.

Special facilities may also evolve for the single purpose of storing plutonium. This plutonium storage facility could be a more passive one if the plutonium storage is to be undertaken for a number of years. Material would go into the facility, but nothing would be removed for some period of time. Once the materials were appropriately placed and accounted for, material inventory and control requirements would be minimal. Such a facility could be separate from the reprocessing plants and might be independent of MOX fabrication plants as well.

If the plutonium were never to be used, there would be no incentive to purify it from the residual fission products, and it could be sent to disposal along with the high-level wastes. In this event no plutonium storage facilities would be needed. That is the assumption for Alternative 5 in this analysis.

Storage costs associated with these different kinds of facilities can be considerably different. Major emphasis in design concepts to date has been on the active facilities required in association with generally prompt recycle of plutonium. Storage costs associated with this active type of storage have been estimated to be considerably higher than storage costs for the more passive type of facility. Facility design studies have been undertaken on plutonium storage facilities required to support a plutonium recycle economy.[21]

As in the case of spent fuel storage, the cost of plutonium storage is sensitive to the amortization period and the degree of utilization of the facility. A storage facility utilized only for a short period for a transitory requirement that may never recur will have a much higher unit cost than would a facility with a long useful life. Costs for the continuously active facilities are included as part of the component fuel cycle costs (i.e., MOX fuel fabrication and reprocessing). The transitory requirements resulting from differences in startup schedules between reprocessing and MOX fuel fabrication facilities (i.e., incremental plutonium storage) are the concern in the discussion that follows.

The form of storage is also important. Storage as plutonium nitrate will cost substantially more than storage as oxide. For this reason and because PuO_2 is the probable form for shipping, any significant plutonium storage has been assumed to be in the PuO_2 form.

The cumulative demand for incremental plutonium storage is shown in Table XI-17.

Table XI-17

CUMULATIVE DEMAND FOR INCREMENTAL PLUTONIUM STORAGE

(Thousands of Kilogram-Years)

	Alternative				
Year	1	2	3	5	6
1980	23	0	18	0	0
1985	126	0	25	0	0
1990	129	0	26	0	0
1995	129	1.3	27	0	0
2000	137	7.9	35	0	0

Here it can be seen that Alternatives 5 and 6 require no plutonium storage since plutonium is not recovered. Alternative 1 requires about 100,000 kg-yr more plutonium storage than does Alternative 3. In both Alternatives 1 and 3, spent fuel reprocessing begins in 1978. However, Alternative 1 does not recycle plutonium until 1983, whereas Alternative 3 begins recycling plutonium in 1981. In Alternative 2, spent fuel

reprocessing does not begin until 1986, with plutonium recycle beginning in the same year; it requires relatively little incremental storage capacity.

Some estimates of storage costs have varied from $0.30 to $1/g-yr.[22] These estimates assume a fully utilized storage facility. However, in this case the estimates on utilization are on the order of 30%. This decrease in utilization with an attendant increase in the capital cost component results in a range of estimates from $1 to $3/g-yr, with a best estimate value of $2/g-yr. This agrees with the estimated $1 to $3/g-yr cited by Wolfe and Lambert.[14]

Plutonium storage costs based on a $2/g-yr unit cost are shown in Table XI-18.

Table XI-18

CUMULATIVE PLUTONIUM STORAGE COSTS

(Millions of Dollars)

	Alternative				
Year	1	2	3	5	6
1980	45.5	0	36.2	0	0
1985	251	0	51.4	0	0
1990	257	0	52.0	0	0
1995	258	2.5	54.0	0	0
2000	273	15.9	69.0	0	0

Alternative 1 incurs $204 million more in plutonium storage charges than does Alternative 3 (see year 2000). This increased storage charge amounts to a $100 million increase in total costs discounted at 10%. On the other hand, Alternative 3 incurs $53 million more in cumulative storage charges (see year 2000) than does Alternative 2. The $204 million plutonium storage cost is essentially the only difference in total costs between Alternatives 1 and 3. The $100 million discounted total cost accounts for about two-thirds of the difference in total discounted costs between Alternatives 1 and 3. Thus plutonium storage costs are the most significant cost penalty resulting from a delay in implementing plutonium recycle once the fuel has been reprocessed.

2.8 Mixed Oxide Fuel Fabrication

The plutonium oxide powder received at the MOX fabrication plant is blended with uranium oxide powder. This is followed by powder treatment, pressing into pellets, sintering, loading into the fuel tubes, and welding the end caps to produce the sealed fuel rods. Initially these rods will probably be shipped to UO_2 fuel fabrication plants for assembly, but this operation may ultimately be incorporated into the MOX fuel fabrication plant.

Cumulative MOX fabrication demand is shown in Table XI-19.

Table XI-19

CUMULATIVE MOX FABRICATION DEMAND

(Metric Tons of Heavy Metal)

Year	Alternative 1	2	3	5	6
1980	0	0	75	0	0
1985	1,700	0	1,950	0	0
1990	5,720	4,070	5,800	0	0
1995	13,800	13,300	13,800	0	0
2000	25,300	25,200	25,300	0	0

Alternatives 1, 2, and 3 all have similar total cumulative MOX fabrication demands (see year 2000). However, MOX fabrication capacity for each of these three alternatives is brought on at differing rates. Alternatives 5 and 6 require no MOX fabrication because they do not involve plutonium recycle.

The costs of fabricating MOX fuel in existing small-scale facilities may be quite high[8]: $350 to $400/kg HM. However, larger plants with a capacity of 200 to 400 MT/yr are expected to result in reduced fabrication costs. The unit cost estimates used in this analysis are intended to represent average costs over the 1975-2000 period; that is, costs that are initially high but decline as MOX fuel fabrication plant capacity and production increase.

Estimates of MOX fuel fabrication costs vary over a broad range. The estimates used in this analysis are the result of reviewing a number of recent reports[7-10,17,18,23] and discussions with industry. Consideration was given both to citations of estimated costs and to estimates developed from projections of capital and operating costs. Major uncertainties in these estimates include the degree of automation required to maintain low levels of radiation exposure; the reliability and operating efficiency (capacity factor) that will be achieved with automated operations; and the extent of new safeguards requirements.

Plant sizes in the range of 200 to 400 MT/yr are expected to be typical of the new plants constructed for plutonium recycle. Once the industry matures, plants as large as 600 MT/yr may be desired, but the economies of scale may not be large beyond 400 MT/yr. For the larger sized plants, costs on the order of $150 to $200/kg HM are projected. For smaller plants, costs on the order of $175 to $275/kg HM appear feasible. These costs are representative of costs expected for the planned Westinghouse (Anderson, S.C.) MOX fuel plant with present safeguards requirements. On these bases, $200/kg HM was judged to be most representative of the average 1975-2000 costs, with a range of $150 to $300/kg HM for the low and high estimates, respectively.

Cumulative MOX fabrication costs based on the reference unit cost of $200/kg HM are shown in Table XI-20.

Table XI-20

CUMULATIVE MOX FABRICATION COSTS

(Millions of Dollars)

Year	Alternative 1	2	3	5	6
1980	0	0	15	0	0
1985	340	0	390	0	0
1990	1,140	810	1,160	0	0
1995	2,760	2,660	2,760	0	0
2000	5,070	5,030	5,060	0	0

Alternatives 1 and 3 have essentially the same total cumulative cost (see year 2000) and also essentially the same total discounted cost. This results from both Alternatives 1 and 3 having the same MOX fabrication demands over the entire time period. Alternative 2 has nearly the same total cumulative MOX fabrication cost as Alternative 3. However, the discounted cost of Alternative 2 is only $810 million compared to $940 million for Alternative 3. This occurs because MOX fabrication requirements in Alternative 2 do not occur prior to 1986. Therefore Alternative 2 MOX fabrication costs are discounted more than are those in Alternative 3. With no plutonium recycle, Alternatives 5 and 6 do not require MOX fabrication.

2.9 Waste Management

Waste management involves the treatment, storage, and monitoring of high level wastes, cladding hulls, transuranic wastes, and low level beta-gamma wastes. Of primary concern are the high level wastes and the transuranic wastes, which include most of the radioactivity of the spent fuel and comprise the largest component of waste management costs. The ERDA Division of Waste Management and Transportation has a large ongoing program for the development of waste management methods. Research and development efforts to date have concentrated on processing and storing high level wastes. Little work has been done on the ultimate disposition of plutonium or unreprocessed fuel. Since the volumes involved are relatively small, the wastes can easily be stored until ultimate disposal methods are fully developed. Because the final disposal methods have not been fully defined, considerable uncertainty surrounds cost estimates for potential ultimate disposal methods.

In calculating waste disposal charges, it was assumed for Alternatives 1, 2, 3, and 5 that charges would be incurred at the time the spent fuel is shipped to the reprocessing facility. However, it is assumed that the wastes will not be disposed of until approximately 5 years after the spent fuel arrives at the reprocessing plant. For this reason, charges are discounted for a period of 5 years to reflect the correct charge for waste disposal at the time of reprocessing. Alternative 6 does not involve shipment to a reprocessing plant, but it is assumed that the spent fuel will be shipped to the waste disposal facility after approximately 5 years' cooling at the reactor site. Therefore waste disposal charges for Alternative 6 are also discounted for a period of 5 years and assessed at the time of availability along with a 5-year storage charge. Table XI-21 shows the estimated volumes of waste per ton of spent fuel and the transportation and disposal unit costs necessary for

calculating disposal charges for each of the six alternatives. These wastes will be generated under all of the alternatives except Alternative 6, where spent fuel disposal will be the only waste management operation.

High level wastes are stored for up to 5 years and then solidified, and possibly stored for up to 5 years more, followed by ultimate disposal. The storage, solidification, and packaging costs are included in the reprocessing costs. The high level wastes are assumed to be packed into canisters that are 1 foot in inside diameter and 10 feet long (6.3 cu ft volume) and are shipped in sealed cask cars on a special train. Transportation costs include freight charges, special train charges, and the amortized costs of the shielded casks. Disposal costs are based on an estimated Federal repository charge of $31,000 per canister. Although the heat content of high level waste increases with plutonium recycle, the uncertainty in the solidified volume and transportation cost estimates is so large that varying the high level waste composition does not alter the unit cost within the limits of the accuracy of the estimates. Quantities of high level waste generated are the same for all alternatives that include reprocessing.

Table XI-21

WASTE MANAGEMENT UNIT COSTS

Type of Waste	Volume from 1 MT Spent Fuel (cu ft) Uncompacted	Compacted	Unit Costs ($/kg fuel) Transportation Costs* Low	High	Disposal Costs	Total Costs Low	High
High Level Wastes, solidified**	2-4	--	2	5-8	10-20***	12	28
Cladding Hulls	7.4†	2.1†	1	3	10.5††	12	14
Transuranic:	--	--	2	5	8.3†††	10	13
TRU-Gamma	110†	11†	--	--	--	--	--
Transuranic	371*	127.3*	--	--	--	--	--
Low Level Beta-Gamma	116§	58†	0.5	1	0.15§§	0.7	1.2
Total Costs $/kg Fuel						35	56

*Data from Ref. 24.
**Data from Ref. 25.
***Estimated, based on a Federal repository charge of $31,000 per 6.3-cu ft canister.
†Data from Ref. 26.
††Estimated, based on a charge of $17,500 per 3.5-cu ft canister.
†††Estimated, based on $60/cu ft.
§Data from Ref. 26, with allowance for volume reduction.
§§Current charge of $2.50 per cu ft from the Nuclear Engineering Company.

Cladding and associated hardware are assumed to be compacted and packaged in steel disposal canisters with a volume of 3.5 cu ft each. Thirty-six of these canisters are packed in a shielded shipping cask for shipment by special train to the Federal repository. The Federal repository charge is estimated to be $17,500 per canister.

Transuranic wastes are assumed to be packed in drums and shipped in shielded rail cars to a Federal repository, where an estimated fee of $60/cu ft will be charged. Costs for transuranic wastes arising from MOX fabrication are included in the mixed oxide fabrication costs. Low level beta-gamma wastes will be packed in drums and shipped by truck to a commercial burial site, where a $2.50/cu ft fee is charged.

Based on the costs just presented, a reference cost of $50/kg spent fuel for waste management is used for alternatives requiring reprocessing. Because of the considerable uncertainty in the above figure, high and low values of $70 and $30/kg of spent fuel were selected for parametric studies (see Section 3 of this chapter).

Since waste disposal policies have not yet been finalized, very little discussion of waste transportation and disposal costs has been published. The major uncertainties are whether or not special trains will be required for waste transportation, the adoption of the proposed changes to 10 CFR Part 20 requiring transfer of all transuranic wastes to ERDA, and the ERDA waste disposal charges. In developing the above estimates, conservative assumptions were made; that is, special trains are used and all transuranic wastes are transferred to ERDA. The waste disposal charges are based on current ERDA recommendations. A West German estimate of $35/kgU for ultimate disposal,[27] is consistent with the $30 to $70/kg U cost used in GESMO. A cost of $150/kg U for reprocessing, waste disposal, and transportation in 1985 is forecast by Schwoerer.[20] This estimate would correspond to the low figures used in this analysis ($110/kg reprocessing + $30/kg waste disposal + $5/kg transportation). Historically, estimates of these waste management costs have been low, primarily as a result of changing Federal policies. Cost estimates used in GESMO are based on the assumption of rather conservative Federal policy. High estimates of waste management costs provide a conservative basis for the analysis of plutonium recycle, since these costs diminish its potential economic benefits.

In the uranium only recycle option, the plutonium present in the spent fuel is assumed to become a waste product and, in keeping with its high biological hazard and long decay times, is assumed to undergo disposal in Federal repositories, as are high level wastes and other-than-high level wastes contaminated with transuranics. For the purposes of this study, the waste plutonium has been assumed to be handled in a manner similar to that used for solidified high level wastes. This assumption leads to conservative estimates of effluents from normal operations and consequences of accidents associated with waste generating and disposal facilities and transportation. Under the uranium only recycle option, the overall costs for reprocessing spent fuel and placing the plutonium waste in a form and package suitable for disposal and the costs for waste disposal are assumed to be the same ($/kgHM) as those for reprocessing spent fuel and handling the plutonium product and for waste disposal where both uranium and plutonium are recycled.

Alternative 6 incurs no waste management charges; however, a spent fuel disposal cost is incurred. The major components of spent fuel disposal are packaging, shipping, and Federal repository charges. The shipping costs are assumed to be about the same as the shipment of spent fuel to reprocessing plants and consequently are not included

in the disposal costs. Packaging costs are primarily the costs of the canister and the expense of its remote loading and welding. Pacific Northwest Laboratories estimates these costs to be about $9,000; the cost of an overpack may add another $4,000. Assuming that each canister holds one fuel assembly, about 500 kg of spent fuel, and the Federal repository charge is $31,000 per canister, the total spent fuel disposal cost is in the range of $80 to $90/kg spent fuel. Because of the large uncertainty involved, high, reference, and low values of $150, $100, and $50/kg spent fuel are used.

Spent fuel disposal has not been seriously considered until very recently; thus almost no discussion of spent fuel disposal economics has been published. An analysis by Colby[15] concludes that such costs will be in the range of $50 to $300/kg U, with a reasonable figure of $150/kg U. The large uncertainty in Colby's analysis occurs because waste disposal charges may be based either on heat generation or on volume. The estimates used in this study ($50 to $150/kg U with a median of $100/kg) are on the low side of Colby's estimates, primarily because his estimate of waste disposal costs for high level wastes is twice as high ($20 to $50/kg U) as that currently recommended by ERDA ($10 to $20/kg U). The $10 to $20/kg U estimate is in accordance with the current ERDA recommendation; the higher estimates seem to include the cost of some waste handling facilities at reprocessing plants, which would not be built for the throwaway case, Alternative 6. It should be noted that low estimates of the spent fuel disposal cost provide a conservative basis since they tend to reduce the economic benefit of plutonium recycle.

The cumulative high level waste disposal requirements for each of the alternatives are shown in Table XI-22.

Table XI-22

CUMULATIVE HIGH LEVEL WASTE DISPOSAL*

(Metric Tons of Spent Fuel)

	Alternative				
Year	1	2	3	5**	6***
1980					
1985	3.0		3.0		
1990	12.7		12.7		17.5
1995	32.5	25.7	32.5	25.7	40.2
2000	66.9	66.9	66.9	66.9	76.3
2005	115.0	115.0	115.0	115.0	126.0

*Waste disposal requirements are shown through the year 2005 to take care of wastes generated through the year 2000.
**Includes plutonium.
***Total spent fuel disposal.

The total cumulative waste disposal requirements for Alternatives 1, 2, 3, and 5 are about 67,000 MTHM. Alternative 5 includes disposition of plutonium in addition to the wastes disposed of in Alternatives 1, 2, and 3. Alternative 6 assumes that after discharge from the reactor the spent fuel cools for a period of approximately 5 years at the reactor site. The spent fuel is then encapsulated and shipped to a

waste disposal facility and placed in ultimate disposal. Since ultimate disposal probably will not be feasible prior to 1986, no spent fuel disposal occurs before that date.

Total cumulative waste management costs through the year 2000 are shown in Table XI-23. The total cumulative costs of $3,600 million are the same for Alternatives 1, 2, 3, and 5. The discounted present worth cost for Alternatives 1 and 3 is $730 million, while the present worth cost for Alternative 2 is $620 million. This reduced present worth cost for Alternative 2 is due to the delayed reprocessing and consequent delay in accrued costs. Total waste management costs under Alternative 5 are the same as those for the reference case, but the costs discounted at 10% are $116 million less due to the difference in timing. Spent fuel disposal (Alternative 6) results in a total cumulative cost of $7,850 million, with a discounted total cost of $1,670 million. The primary reason for spent fuel disposal appearing to be more costly than waste management under any of the other alternatives is that the cost of encapsulating the waste is included in the reprocessing cost for Alternatives 1, 2, 3, and 5, and these alternatives dispose of the waste in a more concentrated form (approximately 3 versus 0.5 MT/canister) than does Alternative 6.

Table XI-23

CUMULATIVE WASTE MANAGEMENT CHARGES

(Millions of Dollars)

	Alternative				
Year	1	2	3	5	6
1980	94	0	94	0	0
1985	400	0	400	0	1,100
1990	1,000	800	1,000	800	2,500
1995	2,100	2,000	2,100	2,100	4,700
2000	3,600	3,600	3,600	3,600	7,850

2.10 Transportation

CHAPTER IV, Section G, discusses those aspects of transportation that are significant to plutonium recycle. That analysis indicates that two transportation steps are of primary importance in evaluating the costs of fuel cycle alternatives: the (1) transport of spent fuel from reactors to reprocessing plants and (2) the transport of plutonium from reprocessing plants to storage facilities or to MOX fuel fabrication plants. The transport of radioactive wastes is also an important cost component and was treated in the waste management discussion in paragraph 2.9 of this chapter. From the cost standpoint, spent fuel transport is the most significant transport component.

Cumulative spent fuel shipments for each alternative are shown in Table XI-24.

Table XI-24

CUMULATIVE SPENT FUEL SHIPMENTS

(Thousands of Metric Tons of Heavy Metal)

Year	Alternative				
	1	2	3	5	6
1980	4.5	0	4.5	0	0
1985	15.6	1.3	15.6	1.3	0
1990	38	33.9	38	33.9	17.5
1995	75.2	75.2	75.2	75.2	40.2
2000	125	125	125	125	76.3

Each alternative discharges the same amount of spent fuel; the total cumulative spent fuel shipments (see year 2000) are approximately 125,400 MTHM for Alternatives 1, 2, 3, and 5. Spent fuel shipments for Alternative 6 total only 76,300 MTHM since a 5-year cooling period at the reactor site before disposal is assumed. However, this analysis includes the discounted costs for transporting all the spent fuel generated before the year 2000, since this spent fuel will have to be transported. The only difference between spent fuel shipments for the first five alternatives is the timing of the shipments.

Spent fuel transportation costs will vary with location, frequency of shipments, mode of transportation, loading and unloading times, and special requirements imposed on the transport. The basic freight charges, the use charges for the shipping casks, and the special train charges are the three important components of spent fuel shipping costs. Shipping casks for rail shipment weigh on the order of 100 tons and are estimated to cost on the order of $2.5 million. Each cask can hold from 3.25 to more than 6 MTHM of spent fuel. Based on an average cask holding 5 MTHM, an average shipping distance of 1,000 miles, an average rate of travel of 200 miles per day, and a turnaround time of 6 days for loading and unloading, the cost of spent fuel shipment by rail is estimated to be as follows:

Freight	$ 3.30/kg HM
Cask Use Charges	8.90
Special Train Service	3.60
Total Cost	$15.80/kg HM

Although truck casks are smaller and hold less fuel (about 0.4 to 1.0 MTHM) than rail casks, trucks may travel slightly faster. The net result is that truck shipments cost about the same as rail shipments without the special train charge, or $10 to $12/kg HM for a 1,000-mile shipment. Truck shipments are expected to be used primarily for shipments of a few hundred miles or less.

Mixed-mode shipments are another possibility, with large casks transported short distances from a reactor to a railhead by special overweight permit and then by rail to the reprocessing plant.

Assuming that at least 60% of the spent fuel shipments would be by rail with special train service, a transport cost of $15/kg HM was determined for use in this analysis. For shipments of only a few hundred miles the cost could be as low as $5/kg HM, and for cross-country shipments this cost could be as high as $30/kg HM. Since MOX fuel increases the heat generation in the spent fuel by about 20%, a decrease in spent fuel per shipment has been assumed in this analysis for MOX fuel shipments. To account for the increase in spent fuel transportation with MOX fuels, the transportation cost is increased by 20%, to $18/kg HM for the MOX spent fuel shipments.

Published estimates of spent fuel transportation costs generally fall in the range of $10 to $20/kg HM. Bertram Wolfe and R. L. Lambert of the General Electric Company estimate the costs to be $12-$18/kg HM;[14] W. A. Rodger, a nuclear consultant, uses an estimate of $10/kg HM;[19] L. J. Colby of Allied-General Nuclear Services uses an estimate of $10-$20/kg HM;[15] F. Schwoerer forecasts $150/kg HM for reprocessing, shipping, and waste disposal, apparently using a shipping cost on the order of $10/kg HM.[20] The variation among these estimates is primarily attributable to differing assumptions about the requirements of special trains. Wolfe and Lambert's $12/kg HM assumes that special trains are not required, and their $18/kg HM assumes that special trains are required both ways (one way with spent fuel in cask cars, and one way with empty cask cars). These estimates are all within the range of costs used for this analysis.

The cumulative total cost of spent fuel transportation is shown in Table XI-25 for each of the alternatives.

Table XI-25

CUMULATIVE TOTAL COST OF SPENT FUEL TRANSPORTATION

(Millions of Dollars)

	Alternative				
Year	1	2	3	5	6
1980	66	0	66	0	0
1985	233	20	233	20	165
1990	573	510	573	510	376
1995	1,1140	1,140	1,140	1,130	713
2000	1,920	1,920	1,920	1,880	1,180

The same quantity of spent fuel is shipped for each of the first five alternatives. However, since no MOX spent fuel is shipped in Alternative 5, the total cumulative cost for spent fuel transportation (see year 2000) under Alternative 5 is slightly less, about $40 million, than that for Alternatives 1, 2, and 3. Because of the 5-year cooling period for spent fuel at the reactor site in Alternative 6, shipping costs are discounted 5 years and the total cumulative cost is smaller (totaling $1,180 million). The discounted total cost varies among alternatives depending on the total cumulative cost and the timing of the shipments. Alternative 6 has the lowest discounted total cost at $250 million, resulting from fewer total spent fuel shipments

and no shipments before 1986. The total discounted costs for Alternatives 2 and 5 are $350 and $340 million, respectively. The higher cost for Alternative 2 reflects the higher transportation cost of MOX spent fuel shipments. The discounted total costs for Alternatives 2 and 5 are smaller than the $410 million discounted total cost for Alternatives 1 and 3, because of the spent fuel shipments made before 1985 in Alternatives 1 and 3 (Table XI 2-24). There are only small differences in the costs of spent fuel transportation for all alternatives. The lower costs for Alternative 6 are due to delayed spent fuel shipments.

For plutonium and MOX fuel shipments, present NRC regulations prescribe transportation in a manner that offers high confidence against misrouting, hijacking, or accidental discharge. To this effect, the regulations require direct routing, time-to-time communications from the transport vehicle to an appropriate facility, and either a special vehicle or a supplemental armed escort vehicle.

The objective of the special vehicle is to thwart or at least delay hijack attempts sufficiently for armed help to arrive. A concept recently described (refer to safeguards supplement for details) is constructed around a close-coupled (cab-over) van truck. The vehicle cab would be armored, the vehicle would be self-immobilizing and would exceed helicopter lifting capability, and the van body would be designed to prevent (or significantly delay) entry. The van body interior could possibly contain other deterrents that would activate on unauthorized entry. It has been estimated that for this vehicle the capital cost would be $150,000 or more. One vehicular carrier has published a tariff for such transport. Based on these tariffs and a 300-kg Pu shipment, the direct freight cost for a PuO_2 shipment would not be more than $0.01 to $0.02/g Pu.

Another important cost in PuO_2 shipments would be use charges on the shipping container. These containers are costly, estimated at $20,000 for a 28-kg Pu container. Depending on the time they are held up in the loading and unloading activities, these charges may amount to as much as $0.02/g or more. Based on these considerations, total PuO_2 shipping costs were estimated at $0.04/g Pu, with an uncertainty range from $0.02 to $0.06/g Pu.

Cumulative plutonium shipping requirements are shown in Table XI-26 for each of the alternatives.

Table XI-26

CUMULATIVE PLUTONIUM SHIPMENTS

(Metric Tons of Heavy Metal)

Year	Alternative				
	1	2	3	5	6
1980	0	0	5	0	0
1985	83	0	93	0	0
1990	27	203	273	0	0
1995	632	607	633	0	0
2000	1,170	1,160	1,170	0	0

Alternatives 1, 2, and 3 all require similar total plutonium shipments. Alternatives 5 and 6 require no shipments. It is obvious from this table that only minor differences exist in plutonium shipment requirements among Alternatives 1, 2, and 3.

The cumulative total cost of plutonium transportation is shown in Table XI-27, where Alternatives 1 and 3 have similar total costs of $47 million ($8.5 million discounted). Alternative 2 is slightly lower at $46 million, and since all of its plutonium shipments occur after 1985, it has a discounted transportation cost of $7.5 million.

Table XI-27

CUMULATIVE TOTAL COST OF PLUTONIUM TRANSPORTATION

(Millions of Dollars)

	Alternative				
Year	1	2	3	5	6
1980	0	0	0.2	0	0
1985	3.3	0	3.7	0	0
1990	10.8	8.1	10.9	0	0
1995	25.3	24.3	25.3	0	0
2000	46.7	46.3	46.7	0	0

The plutonium shipping costs are only slightly more than 2% of the spent fuel shipping costs and are not an important cost factor in the fuel cycle.

2.11 Fuel Cycle Flows and Costs

The year-by-year fuel cycle flows and costs for each of the five alternatives are shown in Tables XI-28 through XI-32. These are the output tables from the NUCOST computer program described in CHAPTER VIII, paragraph 5.4.

Each table is divided into four sections: The first (upper) section shows the material flows for each fuel cycle component. The second section shows the unit cost for each component. Constant unit costs were used for all but the U_3O_8 cost, which increases with cumulative consumption. It should be noted that costs shown here do not include incremental safeguards costs for special nuclear material. Similar computer runs including these costs will be contained in the draft safeguards supplement. Reprocessing and spent fuel transportation costs change with time, but this is a correction for the MOX component. When plutonium is diverted to the fast breeder reactor program (Alternatives 1, 2, and 3), a credit is taken for the current value of the plutonium at the "indifference" price. See Section 6.4 of CHAPTER VIII. This credit shows up in Tables XI-28 through XI-30 as negative costs. The third section shows total undiscounted annual costs for each fuel cycle component. The fourth section shows the discounted (10% per year) annual costs for each component. The final item at the bottom of each table converts the costs to levelized fuel cycle costs in mills per kilowatt-hour (the level annual charges for power that would recover all fuel cycle costs over the entire period with the cost of money at 10% per year).

TABLE XI-28

SECTION 1. PROCESS FLOW

ALT. I CASE 31 - LOW GROWTH - 70' CF - 1978 REPROCESSING - 1983 RECYCLE - NO FBR

YEAR	MINING MILLING 1000 ST	UF6 CONVR 1000 MTU	ENRICHMNT 1000 MT-SWU	U FUEL FAB MTU	SPENT FUEL TRAN MT-HM	REPROCESS MT-HM	PU TRANS KG-TOT	INCR PU STORAGE KG-TOT	MOX FAB MT-HM	INCR SPENT FUEL STOR MT-HM	WASTE DISPOSAL MT-HM W/O PU	PU SALES KG FISS	SPENT FUEL DISP MT-HM
75	10.5	6.2	3.6	919.	0.	0.	0.	0.	0.	1167.	0.	0.	0.
76	13.4	10.4	4.8	1337.	0.	0.	0.	0.	0.	1962.	0.	0.	0.
77	14.8	11.5	5.7	1758.	500.	0.	0.	0.	0.	2317.	0.	0.	0.
78	16.7	13.0	5.9	1972.	999.	500.	0.	1928.	0.	3514.	0.	0.	0.
79	20.1	14.7	7.6	2345.	1499.	999.	0.	5918.	0.	3737.	0.	1000.	0.
80	23.3	17.6	9.0	3181.	1498.	1499.	0.	14913.	0.	3568.	0.	1200.	0.
81	26.3	19.2	10.5	2826.	1748.	1498.	0.	25047.	0.	3644.	0.	1200.	0.
82	26.9	20.3	11.4	4162.	1998.	1748.	8981.	29021.	148.	3686.	0.	1000.	0.
83	31.1	21.6	11.1	4130.	2249.	1998.	21255.	23726.	402.	3951.	500.	800.	0.
84	37.1	26.0	14.7	5066.	2248.	2249.	25412.	16308.	542.	4143.	999.	750.	0.
85	38.7	29.2	15.7	5212.	2849.	2248.	27749.	8793.	608.	4836.	1499.	400.	0.
86	42.4	31.3	16.5	5239.	3549.	2849.	29787.	2639.	710.	5483.	1498.	300.	0.
87	47.5	35.7	19.4	5982.	4249.	3549.	32508.	336.	721.	6035.	1748.	250.	0.
88	51.7	38.2	21.1	6816.	4249.	4249.	35169.	65.	687.	6394.	1998.	250.	0.
89	55.4	41.3	23.0	6984.	4846.	4249.	39189.	0.	893.	7072.	2249.	250.	0.
90	58.6	43.6	24.2	7699.	5545.	4846.	48669.	0.	1008.	7698.	2248.	250.	0.
91	61.7	45.1	25.9	8152.	6248.	5545.	58416.	165.	1292.	8284.	2849.	250.	0.
92	65.1	48.2	27.4	8553.	6848.	6248.	65103.	87.	1411.	8705.	3549.	250.	0.
93	68.0	50.6	29.3	9115.	7548.	6848.	71214.	146.	1577.	9007.	4249.	250.	0.
94	70.1	51.0	30.5	9469.	8248.	7548.	81084.	210.	1774.	9258.	4249.	250.	0.
95	73.1	53.4	31.7	9608.	8248.	8248.	87471.	141.	2026.	9411.	4846.	250.	0.
96	76.1	56.5	33.4	10082.	9248.	8248.	89271.	0.	2009.	10152.	5545.	250.	0.
97	76.7	57.0	34.6	10508.	10248.	9248.	94350.	0.	2044.	10470.	6248.	250.	0.
98	77.2	56.8	34.7	10613.	10248.	10248.	110429.	1764.	2288.	10295.	6848.	250.	0.
99	78.9	57.7	35.4	10678.	10248.	10248.	117872.	2493.	2538.	10557.	7548.	250.	0.
0	80.5	59.3	36.1	10842.	10248.	10248.	122798.	2850.	2650.	11224.	8248.	250.	0.
TOT	1241.9	915.5	523.3	163248.	125406.	115158.	1166724.	136547.	25328.	167179.	66918.	10150.	0.

SECTION 2. PROJECTED UNIT COST

ALT I CASE 31 - LOW GROWTH - 70' CF - 1978 REPROCESSING - 1983 RECYCLE - NO FBR

YEAR	U3O8 AS BURNED $/LB	U CONVR $/KG-U	SEP WORK $/SWU	U FAB $/KG-U	SPENT FUEL TRAN $/KG-HM	INCR SPENT FUEL STOR $/KG-HM-YR	REPRO $/KG-HM	PU TRAN $/G-TOT	INCR PU STORAGE $/G-TOT	MOX FAB $/KG-HM	WASTE DISPOSAL $/KG-HM W/O PU	PU VALUE $/G FISS	SPENT FUEL DISP $/KG-HM
75	10.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
76	10.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
77	11.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
78	12.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
79	15.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	18.96	100.0
80	17.8	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	20.47	100.0
81	19.9	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	21.59	100.0
82	21.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	22.18	100.0
83	21.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	22.62	100.0
84	22.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	23.00	100.0
85	23.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	23.51	100.0
86	25.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	24.60	100.0
87	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	26.21	100.0
88	28.5	3.5	75.0	95.0	15.1	5.0	151.0	0.04	2.00	200.0	50.0	26.21	100.0
89	28.5	3.5	75.0	95.0	15.3	5.0	152.7	0.04	2.00	200.0	50.0	26.21	100.0
90	28.5	3.5	75.0	95.0	15.3	5.0	152.9	0.04	2.00	200.0	50.0	26.21	100.0
91	28.5	3.5	75.0	95.0	15.3	5.0	153.1	0.04	2.00	200.0	50.0	26.21	100.0
92	28.5	3.5	75.0	95.0	15.4	5.0	153.6	0.04	2.00	200.0	50.0	26.21	100.0
93	28.5	3.5	75.0	95.0	15.3	5.0	153.2	0.04	2.00	200.0	50.0	26.21	100.0
94	29.9	3.5	75.0	95.0	15.3	5.0	152.7	0.04	2.00	200.0	50.0	26.96	100.0
95	32.5	3.5	75.0	95.0	15.3	5.0	153.4	0.04	2.00	200.0	50.0	28.36	100.0
96	33.0	3.5	75.0	95.0	15.3	5.0	153.5	0.04	2.00	200.0	50.0	28.62	100.0
97	33.0	3.5	75.0	95.0	15.4	5.0	154.1	0.04	2.00	200.0	50.0	28.62	100.0
98	33.0	3.5	75.0	95.0	**15.4**	**5.0**	154.2	0.04	2.00	200.0	50.0	28.62	100.0
99	33.0	3.5	75.0	95.0	**15.4**	**5.0**	**154.4**	0.04	2.00	200.0	50.0	28.62	100.0
0	33.1	3.5	75.0	95.0	**15.5**	**5.0**	**154.7**	0.04	2.00	200.0	50.0	28.66	100.0
WT AVE.	28.1	3.5	75.0	95.0	**15.3**	**5.0**	**153.0**	0.04	2.00	200.0	50.0	23.57	0.0

TABLE XI-28 (CONTINUED)

SECTION 3. PROJECTED COSTS FOR MATERIALS AND SERVICES
(IN MILLIONS OF 1975 DOLLARS)

ALT I CASE 31 - LOW GROWTH - 70% CF - 1978 REPROCESSING - 1983 RECYCLE - NO FBR

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	286.2	36.	359.	127.	0.	0.	0.00	0.00	0.	10.	0.	0.	0.	818.
77	325.2	40.	430.	167.	7.	0.	0.00	0.00	0.	15.	0.	0.	0.	985.
78	401.5	46.	446.	187.	15.	75.	0.00	3.86	0.	13.	16.	0.	0.	1208.
79	601.5	52.	572.	223.	22.	150.	0.00	11.84	0.	19.	31.	-19.	0.	1663.
80	830.2	61.	674.	302.	22.	225.	0.00	29.83	0.	18.	47.	-25.	0.	2185.
81	1045.5	67.	796.	268.	26.	225.	0.00	50.09	0.	18.	47.	-26.	0.	2506.
82	1127.8	71.	856.	395.	30.	262.	0.36	58.04	30.	18.	54.	-22.	0.	2881.
83	1355.6	76.	835.	392.	34.	300.	0.85	47.45	80.	20.	62.	-18.	0.	3184.
84	1671.1	91.	1102.	481.	34.	337.	1.02	32.62	108.	21.	70.	-17.	0.	3932.
85	1817.1	102.	1174.	495.	43.	337.	1.11	17.59	122.	24.	70.	-9.	0.	4193.
86	2161.1	110.	1240.	498.	53.	427.	1.19	5.28	142.	27.	88.	-7.	0.	4746.
87	2708.9	125.	1455.	568.	64.	532.	1.30	0.67	144.	30.	110.	-7.	0.	5733.
88	2944.7	134.	1581.	648.	64.	642.	1.41	0.13	137.	32.	132.	-7.	0.	6309.
89	3159.0	145.	1729.	663.	74.	649.	1.57	0.00	179.	35.	132.	-7.	0.	6759.
90	3340.0	153.	1818.	731.	85.	741.	1.95	0.00	202.	33.	150.	-7.	0.	7254.
91	3518.3	158.	1941.	774.	96.	849.	2.34	0.33	258.	41.	172.	-7.	0.	7805.
92	3711.3	169.	2057.	813.	105.	960.	2.60	0.17	282.	44.	194.	-7.	0.	8330.
93	3876.2	177.	2196.	866.	116.	1049.	2.85	0.29	315.	45.	213.	-7.	0.	8850.
94	4193.8	178.	2284.	900.	126.	1153.	3.24	0.42	355.	46.	234.	-7.	0.	9467.
95	4753.9	187.	2380.	913.	127.	1265.	3.50	0.28	405.	47.	256.	-7.	0.	10331.
96	5020.9	198.	2507.	958.	142.	1266.	3.57	0.00	402.	51.	256.	-7.	0.	10797.
97	5065.1	200.	2592.	998.	158.	1425.	3.77	0.00	409.	52.	287.	-7.	0.	11183.
98	5098.4	199.	2602.	1008.	158.	1581.	4.42	3.53	458.	51.	318.	-7.	0.	11474.
99	5208.8	202.	2656.	1014.	158.	1583.	4.71	4.99	508.	53.	318.	-7.	0.	11703.
0	5325.9	208.	2706.	1030.	159.	1586.	4.91	5.70	530.	55.	318.	-7.	0.	11921.
TOT	69772.8	3204.	39244.	15509.	1917.	17618.	46.67	273.09	5066.	836.	3575.	-239.	0.	156822.

SECTION 4. DISCOUNTED PROCESS COSTS
(IN MILLIONS OF 1975 DOLLARS)

ALT I CASE 31 - LOW GROWTH - 70% CF - 1978 REPROCESSING - 1983 RECYCLE - NO FBR
DISCOUNT RATE =0.100

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	260.2	33.	326.	115.	0.	0.	0.00	0.00	0.	9.	0.	0.	0.	744.
77	268.8	33.	356.	138.	6.	0.	0.00	0.00	0.	12.	0.	0.	0.	814.
78	301.6	34.	335.	141.	11.	56.	0.00	2.90	0.	13.	12.	0.	0.	907.
79	410.8	35.	391.	152.	15.	102.	0.00	8.08	0.	13.	21.	-13.	0.	1136.
80	515.5	38.	418.	188.	14.	140.	0.00	18.52	0.	11.	29.	-15.	0.	1356.
81	590.1	38.	443.	152.	15.	127.	0.00	28.38	0.	10.	26.	-15.	0.	1415.
82	578.8	36.	439.	203.	15.	135.	0.18	29.78	15.	9.	28.	-11.	0.	1479.
83	632.4	35.	389.	183.	16.	140.	0.40	22.14	38.	9.	29.	-8.	0.	1485.
84	708.7	39.	467.	204.	14.	143.	0.43	13.83	46.	9.	30.	-7.	0.	1668.
85	700.6	39.	453.	191.	16.	130.	0.43	6.78	47.	9.	27.	-4.	0.	1617.
86	757.5	38.	434.	174.	19.	150.	0.42	1.85	50.	10.	31.	-3.	0.	1663.
87	863.1	40.	464.	181.	20.	170.	0.41	0.21	46.	10.	35.	-2.	0.	1827.
88	853.0	39.	458.	188.	19.	186.	0.41	0.04	40.	9.	38.	-2.	0.	1828.
89	831.9	38.	455.	175.	19.	171.	0.41	0.00	47.	9.	35.	-2.	0.	1780.
90	799.6	37.	435.	175.	20.	177.	0.47	0.00	48.	9.	36.	-2.	0.	1737.
91	765.7	34.	422.	169.	21.	185.	0.51	0.07	56.	9.	37.	-1.	0.	1699.
92	734.3	33.	407.	161.	21.	190.	0.52	0.03	56.	9.	38.	-1.	0.	1648.
93	697.2	32.	395.	156.	21.	189.	0.51	0.05	59.	8.	38.	-1.	0.	1592.
94	685.7	29.	373.	147.	21.	189.	0.53	0.07	58.	8.	38.	-1.	0.	1548.
95	706.6	28.	354.	136.	19.	188.	0.52	0.04	60.	7.	38.	-1.	0.	1536.
96	678.5	27.	339.	129.	19.	171.	0.48	0.00	54.	7.	35.	-1.	0.	1459.
97	622.2	25.	318.	123.	19.	175.	0.46	0.00	50.	6.	35.	-1.	0.	1374.
98	569.4	22.	291.	113.	18.	177.	0.49	0.39	51.	6.	36.	-1.	0.	1281.
99	528.8	21.	270.	103.	16.	161.	0.48	0.51	52.	5.	32.	-1.	0.	1188.
0	491.6	19.	250.	95.	15.	146.	0.45	0.52	49.	5.	29.	-1.	0.	1100.
TOT	15777.2	845.	9951.	3977.	410.	3596.	8.52	134.11	919.	228.	734.	-94.	0.	36485.

NET GENERATION 35357., BILLIONS KWH
LEVELIZED FUEL CYCLE COST, MILLS/KWH

1.935	0.104	1.220	0.488	0.050	0.441	0.001	0.016	0.113	0.028	0.090	-0.011	0.000	4.474

TABLE XI-29

SECTION 1. PROCESS FLOW

ALT II - CASE 33 - LOW GROWTH - 70% CF - NO FBR - 1986 REPROCESSING

YEAR	MINING MILLING 1000 ST	UF6 CONVR 1000 MTU	ENRICHMNT 1000 MT-SWU	U FUEL FAB MTU	SPENT FUEL TRAN MT-HM	REPROCESS MT-HM	PU TRANS KG-TOT	INCR PU STORAGE KG-TOT	MOX FAB MT-HM	INCR SPENT FUEL STOR MT-HM	WASTE DISPOSAL MT-HM W/O PU	PU SALES KG FISS	SPENT FUEL DISP MT-HM
75	10.5	6.2	3.6	919.	0.	0.	0.	0.	0.	1167.	0.	0.	0.
76	13.4	10.4	4.8	1337.	0.	0.	0.	0.	0.	1962.	0.	0.	0.
77	15.0	11.5	5.7	1758.	0.	0.	0.	0.	0.	2917.	0.	0.	0.
78	17.8	13.5	6.0	1972.	0.	0.	0.	0.	0.	4014.	0.	0.	0.
79	21.8	16.1	7.8	2345.	0.	0.	0.	0.	0.	5236.	0.	0.	0.
80	25.3	19.1	8.9	3181.	0.	0.	0.	0.	0.	6566.	0.	0.	0.
81	29.4	21.3	10.4	2826.	0.	0.	0.	0.	0.	8140.	0.	0.	0.
82	32.2	24.1	12.1	4310.	0.	0.	0.	0.	0.	9930.	0.	0.	0.
83	38.0	27.1	12.7	4532.	0.	0.	0.	0.	0.	12193.	0.	0.	0.
84	44.9	32.6	16.6	5608.	0.	0.	0.	0.	0.	14634.	0.	0.	0.
85	46.2	36.2	17.9	5820.	1348.	0.	0.	0.	0.	17575.	0.	0.	0.
86	46.8	35.7	18.4	5889.	3397.	1348.	5187.	0.	61.	19723.	0.	2200.	0.
87	46.8	36.5	20.0	6280.	5843.	3397.	21408.	0.	424.	20427.	0.	2200.	0.
88	45.8	34.4	20.2	6687.	7245.	5843.	44741.	0.	816.	19192.	0.	1550.	0.
89	46.9	35.1	21.2	6571.	7849.	7245.	61976.	0.	1306.	16874.	0.	700.	0.
90	51.2	37.1	22.5	7243.	8249.	7849.	69344.	0.	1463.	14497.	0.	500.	0.
91	56.0	40.1	25.3	8011.	8241.	8249.	67887.	45.	1433.	12379.	1348.	500.	0.
92	60.2	43.6	26.8	8219.	8248.	8241.	73092.	404.	1745.	10807.	3397.	500.	0.
93	64.3	46.8	28.5	8868.	8248.	8248.	80457.	419.	1823.	9709.	5843.	250.	0.
94	68.2	49.1	29.7	9189.	8248.	8248.	89363.	323.	2054.	9260.	7245.	250.	0.
95	72.4	53.0	31.0	9477.	8248.	8248.	93416.	71.	2157.	9413.	7849.	250.	0.
96	75.9	56.3	32.7	9980.	9248.	8248.	95331.	57.	2111.	10154.	8249.	250.	0.
97	76.7	56.8	34.0	10461.	10248.	9248.	99581.	156.	2092.	10472.	8241.	350.	0.
98	77.1	56.4	34.4	10482.	10248.	10248.	112287.	1613.	2419.	10297.	8248.	250.	0.
99	78.9	57.5	35.3	10642.	10248.	10248.	118658.	2156.	2573.	10559.	8248.	250.	0.
0	80.6	59.6	35.8	10805.	10248.	10248.	124931.	2685.	2687.	11226.	8248.	250.	0.
TOT	1242.2	916.0	522.2	163412.	125404.	115156.	1157655.	7926.	25164.	279323.	66916.	10150.	0.

SECTION 2. PROJECTED UNIT COST

ALT II - CASE 33 - LOW GROWTH - 70% CF - NO FBR - 1986 REPROCESSING

YEAR	U3O8 AS BURNED $/LB	U CONVR $/KG-U	SEP WORK $/SWU	U FAB $/KG-U	SPENT FUEL TRAN $/KG-HM	INCR SPENT FUEL STOR $/KG-HM-YR	REPRO $/KG-HM	PU TRAN $/G-TOT	INCR PU STORAGE $/G-TOT	MOX FAB $/KG-HM	WASTE DISPOSAL $/KG-HM W/O PU	PU VALUE $/G FISS	SPENT FUEL DISP $/KG-HM
75	10.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
76	10.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
77	11.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
78	12.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
79	15.2	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
80	18.2	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
81	20.3	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
82	21.3	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
83	22.2	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
84	22.9	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
85	25.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
86	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	26.18	100.0
87	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	26.21	100.0
88	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	26.21	100.0
89	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	26.21	100.0
90	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	26.21	100.0
91	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	26.21	100.0
92	28.5	3.5	75.0	95.0	15.0	5.0	150.3	0.04	2.00	200.0	50.0	26.21	100.0
93	28.5	3.5	75.0	95.0	15.2	5.0	151.9	0.04	2.00	200.0	50.0	26.21	100.0
94	30.0	3.5	75.0	95.0	15.3	5.0	153.3	0.04	2.00	200.0	50.0	27.00	100.0
95	32.6	3.5	75.0	95.0	15.5	5.0	155.0	0.04	2.00	200.0	50.0	28.39	100.0
96	33.0	3.5	75.0	95.0	15.5	5.0	155.0	0.04	2.00	200.0	50.0	28.62	100.0
97	33.0	3.5	75.0	95.0	15.5	5.0	154.6	0.04	2.00	200.0	50.0	28.62	100.0
98	33.0	3.5	75.0	95.0	15.5	5.0	155.3	0.04	2.00	200.0	50.0	28.62	100.0
99	33.0	3.5	75.0	95.0	15.5	5.0	155.1	0.04	2.00	200.0	50.0	28.62	100.0
0	33.1	3.5	75.0	95.0	15.5	5.0	155.5	0.04	2.00	200.0	50.0	28.66	100.0
WT AVE.	28.1	3.5	75.0	95.0	15.3	5.0	152.9	0.04	2.00	200.0	50.0	26.57	0.0

TABLE XI-29 (CONTINUED)

SECTION 3. PROJECTED COSTS FOR MATERIALS AND SERVICES
(IN MILLIONS OF 1975 DOLLARS)

ALT II - CASE 33 - LOW GROWTH - 70' CF - NO FBR - 1986 REPROCESSING

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	286.2	36.	359.	127.	0.	0.	0.00	0.00	0.	10.	0.	0.	0.	818.
77	330.0	48.	430.	167.	0.	0.	0.00	0.00	0.	15.	0.	0.	0.	982.
78	426.6	47.	447.	187.	0.	0.	0.00	0.00	0.	20.	0.	0.	0.	1128.
79	661.9	56.	585.	223.	0.	0.	0.00	0.00	0.	26.	0.	0.	0.	1552.
80	921.1	67.	670.	302.	0.	0.	0.00	0.00	0.	33.	0.	0.	0.	1993.
81	1195.3	74.	780.	268.	0.	0.	0.00	0.00	0.	41.	0.	0.	0.	2359.
82	1370.2	84.	905.	409.	0.	0.	0.00	0.00	0.	50.	0.	0.	0.	2818.
83	1685.0	95.	954.	431.	0.	0.	0.00	0.00	0.	61.	0.	0.	0.	3226.
84	2055.3	114.	1244.	533.	0.	0.	0.00	0.00	0.	73.	0.	0.	0.	4019.
85	2308.4	127.	1340.	553.	20.	0.	0.00	0.00	0.	88.	0.	0.	0.	4436.
86	2664.0	125.	1378.	559.	51.	202.	0.21	0.00	12.	99.	42.	-58.	0.	5075.
87	2667.8	128.	1503.	597.	88.	510.	0.86	0.00	85.	102.	105.	-58.	0.	5728.
88	2688.9	120.	1519.	635.	109.	876.	1.79	0.00	163.	95.	181.	-41.	0.	6270.
89	2673.0	123.	1588.	624.	118.	1087.	2.48	0.00	261.	84.	225.	-18.	0.	6767.
90	2920.7	130.	1688.	688.	124.	1177.	2.77	0.00	293.	72.	244.	-13.	0.	7326.
91	3193.7	140.	1896.	761.	124.	1237.	2.72	0.09	287.	62.	256.	-13.	0.	7946.
92	3431.9	153.	2011.	781.	124.	1239.	2.92	0.81	349.	54.	256.	-13.	0.	8389.
93	3667.2	164.	2136.	842.	125.	1253.	3.22	0.84	365.	49.	256.	-7.	0.	8855.
94	4087.9	172.	2225.	873.	126.	1264.	3.57	0.64	411.	46.	256.	-7.	0.	9459.
95	4717.1	185.	2329.	900.	128.	1278.	3.74	0.14	431.	47.	256.	-7.	0.	10269.
96	5010.3	197.	2450.	948.	143.	1279.	3.81	0.11	422.	51.	256.	-7.	0.	10753.
97	5060.3	199.	2547.	994.	158.	1429.	3.98	0.31	418.	52.	287.	-7.	0.	11142.
98	5089.9	198.	2583.	996.	159.	1591.	4.49	3.22	484.	51.	318.	-7.	0.	11470.
99	5205.9	201.	2645.	1011.	159.	1590.	4.75	4.31	515.	53.	318.	-7.	0.	11699.
0	5331.0	209.	2685.	1026.	159.	1593.	5.00	5.37	537.	56.	318.	-7.	0.	11918.
TOT	69794.5	3206.	39163.	15524.	1915.	17606.	46.31	15.85	5033.	1397.	3575.	-270.	0.	157005.

SECTION 4. DISCOUNTED PROCESS COSTS
(IN MILLIONS OF 1975 DOLLARS)

ALT II - CASE 33 - LOW GROWTH - 70' CF - NO FBR - 1986 REPROCESSING
DISCOUNT RATE =0.100

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	260.2	33.	326.	115.	0.	0.	0.00	0.00	0.	9.	0.	0.	0.	744.
77	272.7	33.	356.	138.	0.	0.	0.00	0.00	0.	12.	0.	0.	0.	812.
78	320.5	36.	336.	141.	0.	0.	0.00	0.00	0.	15.	0.	0.	0.	848.
79	452.1	38.	399.	152.	0.	0.	0.00	0.00	0.	18.	0.	0.	0.	1060.
80	571.9	42.	416.	188.	0.	0.	0.00	0.00	0.	20.	0.	0.	0.	1237.
81	674.7	42.	440.	152.	0.	0.	0.00	0.00	0.	23.	0.	0.	0.	1332.
82	703.1	43.	464.	210.	0.	0.	0.00	0.00	0.	25.	0.	0.	0.	1446.
83	786.1	44.	445.	201.	0.	0.	0.00	0.00	0.	28.	0.	0.	0.	1505.
84	871.7	48.	528.	226.	0.	0.	0.00	0.00	0.	31.	0.	0.	0.	1705.
85	890.0	49.	517.	213.	8.	0.	0.00	0.00	0.	34.	0.	0.	0.	1710.
86	933.7	44.	483.	196.	18.	71.	0.07	0.00	4.	35.	15.	-20.	0.	1779.
87	850.1	41.	479.	190.	28.	162.	0.27	0.00	27.	33.	54.	-18.	0.	1825.
88	755.7	35.	440.	184.	31.	254.	0.52	0.00	47.	28.	93.	-12.	0.	1816.
89	703.9	32.	418.	164.	31.	286.	0.65	0.00	69.	22.	59.	-5.	0.	1782.
90	699.2	31.	404.	165.	30.	282.	0.66	0.00	70.	17.	58.	-3.	0.	1754.
91	695.0	31.	413.	166.	27.	269.	0.59	0.02	62.	13.	56.	-3.	0.	1729.
92	679.8	30.	398.	154.	25.	245.	0.58	0.16	69.	11.	51.	-3.	0.	1660.
93	659.6	29.	384.	152.	23.	225.	0.58	0.15	66.	9.	46.	-1.	0.	1593.
94	668.4	28.	364.	143.	21.	207.	0.58	0.11	67.	8.	42.	-1.	0.	1547.
95	701.2	28.	346.	134.	19.	190.	0.56	0.02	64.	7.	38.	-1.	0.	1526.
96	677.0	27.	331.	128.	19.	173.	0.52	0.02	57.	7.	35.	-1.	0.	1453.
97	621.6	24.	313.	122.	19.	176.	0.49	0.04	51.	6.	35.	-1.	0.	1369.
98	568.4	22.	288.	111.	18.	178.	0.50	0.36	54.	6.	36.	-1.	0.	1281.
99	528.5	20.	268.	103.	16.	161.	0.48	0.44	52.	5.	32.	-1.	0.	1188.
0	492.0	19.	248.	95.	15.	147.	0.46	0.50	50.	5.	29.	-1.	0.	1100.
TOT	16261.2	872.	10071.	4029.	347.	3026.	7.52	1.80	810.	433.	618.	-71.	0.	36406.
NET GENERATION 35357., BILLIONS KWH														
LEVELIZED FUEL CYCLE COST, MILLS/KWH														
	1.994	0.107	1.235	0.494	0.043	0.371	0.001	0.000	0.099	0.053	0.076	-0.009	0.000	4.465

TABLE XI-30

SECTION 1. PROCESS FLOW

ALT III - CASE 36 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR

YEAR	MINING MILLING 1000 ST	UF6 CONVR 1000 MTU	ENRICHMNT 1000 MT-SWU	U FUEL FAB MTU	SPENT FUEL TRAN MT-HM	REPROCESS MT-HM	PU TRANS KG-TOT	INCR PU STORAGE KG-TOT	MOX FAB MT-HM	INCR SPENT FUEL STOR MT-HM	WASTE DISPOSAL MT-HM W/O PU	PU SALES KG FISS	SPENT FUEL DISP MT-HM
75	10.5	6.2	3.6	919.	0.	0.	0.	0.	0.	1167.	0.	0.	0.
76	13.4	10.4	4.8	1337.	0.	0.	0.	0.	0.	1962.	0.	0.	0.
77	14.8	11.5	5.7	1758.	500.	0.	0.	0.	0.	2917.	0.	0.	0.
78	16.7	13.0	5.9	1972.	999.	500.	0.	1928.	0.	3514.	0.	0.	0.
79	19.6	14.6	7.6	2345.	1499.	999.	0.	5918.	0.	3737.	0.	1000.	0.
80	21.7	16.5	8.6	3106.	1498.	1499.	4665.	10247.	75.	3568.	0.	1200.	0.
81	24.2	17.3	9.5	2570.	1748.	1498.	12930.	7452.	255.	3644.	0.	1200.	0.
82	26.6	19.2	10.5	3896.	1998.	1748.	20406.	0.	413.	3686.	0.	1000.	0.
83	32.2	22.5	11.6	4137.	2249.	1998.	15960.	0.	395.	3951.	500.	800.	0.
84	38.3	27.1	15.3	5230.	2248.	2249.	17996.	0.	378.	4143.	999.	750.	0.
85	39.7	30.2	16.2	5383.	2849.	2248.	20535.	140.	437.	4836.	1499.	400.	0.
86	42.8	32.0	16.9	5347.	3549.	2849.	25527.	222.	602.	5463.	1498.	300.	0.
87	47.6	35.8	19.4	6012.	4249.	3549.	33039.	39.	682.	6035.	1748.	250.	0.
88	51.8	38.3	21.0	6787.	4249.	4249.	36675.	0.	716.	6394.	1998.	250.	0.
89	55.6	41.4	23.1	6991.	4846.	4249.	37983.	0.	886.	7072.	2249.	250.	0.
90	58.6	43.7	24.3	7725.	5545.	4846.	47090.	30.	981.	7658.	2248.	250.	0.
91	61.7	45.1	26.0	8193.	6248.	5545.	56937.	362.	1251.	8284.	2849.	250.	0.
92	65.1	48.2	27.5	8577.	6848.	6248.	64161.	200.	1387.	8705.	3549.	250.	0.
93	68.0	50.6	29.1	9126.	7548.	6848.	71174.	141.	1565.	9007.	4249.	250.	0.
94	70.1	51.0	30.5	9471.	8248.	7548.	80981.	116.	1771.	9258.	4249.	250.	0.
95	73.1	53.4	31.8	9612.	8248.	8248.	87090.	200.	2022.	9411.	4846.	250.	0.
96	76.1	56.5	33.5	10087.	9248.	8248.	88971.	0.	2004.	10152.	5545.	250.	0.
97	76.7	57.0	34.6	10512.	10248.	9248.	94142.	0.	2040.	10470.	6248.	250.	0.
98	77.3	56.8	34.7	10620.	10248.	10248.	110231.	1893.	2281.	10295.	6848.	250.	0.
99	78.9	57.7	35.4	10683.	10248.	10248.	117752.	2640.	2532.	10557.	7548.	250.	0.
0	80.5	59.3	36.1	10846.	10248.	10248.	122637.	2996.	2647.	11224.	8248.	250.	0.
TOT	1241.9	915.5	503.2	163242.	125406.	115158.	1166879.	34520.	25330.	167170.	66918.	10150.	0.

SECTION 2. PROJECTED UNIT COST

ALT III - CASE 36 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR

YEAR	U3O8 AS BURNED $/LB	U CONVR $/KG-U	SEP WORK $/SWU	U FAB $/KG-U	SPENT FUEL TRAN $/KG-HM	INCR SPENT FUEL STOR $/KG-HM-YR	REPRO $/KG-HM	PU TRAN $/G-TOT	INCR PU STORAGE $/G-TOT	MOX FAB $/KG-HM	WASTE PU VALUE DISPOSAL $/KG-HM W/O PU	$/G FISS	SPENT FUEL DISP $/KG-HM
75	10.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
76	10.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
77	11.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
78	12.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
79	15.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	18.56	100.0
80	17.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	20.42	100.0
81	19.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	21.48	100.0
82	20.8	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	22.10	100.0
83	21.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	22.56	100.0
84	22.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	22.97	100.0
85	23.4	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	23.47	100.0
86	25.5	3.5	75.0	95.0	15.1	5.0	150.7	0.04	2.00	200.0	50.0	24.50	100.0
87	28.5	3.5	75.0	95.0	15.3	5.0	152.7	0.04	2.00	200.0	50.0	26.21	100.0
88	28.5	3.5	75.0	95.0	15.3	5.0	152.9	0.04	2.00	200.0	50.0	26.21	100.0
89	28.5	3.5	75.0	95.0	15.3	5.0	152.6	0.04	2.00	200.0	50.0	26.21	100.0
90	28.5	3.5	75.0	95.0	15.2	5.0	152.0	0.04	2.00	200.0	50.0	26.21	100.0
91	28.5	3.5	75.0	95.0	15.2	5.0	152.3	0.04	2.00	200.0	50.0	26.21	100.0
92	28.5	3.5	75.0	95.0	15.3	5.0	153.0	0.04	2.00	200.0	50.0	26.21	100.0
93	28.5	3.5	75.0	95.0	15.3	5.0	153.1	0.04	2.00	200.0	50.0	26.21	100.0
94	29.9	3.5	75.0	95.0	15.3	5.0	152.9	0.04	2.00	200.0	50.0	26.96	100.0
95	33.2	3.5	75.0	95.0	15.3	5.0	153.4	0.04	2.00	200.0	50.0	28.36	100.0
96	0	3.5	75.0	95.0	15.3	5.0	153.4	0.04	2.00	200.0	50.0	28.62	100.0
97	0	3.5	75.0	95.0	15.4	5.0	154.0	0.04	2.00	200.0	50.0	28.62	100.0
98	0	3.5	75.0	95.0	15.4	5.0	154.2	0.04	2.00	200.0	50.0	28.62	100.0
99	0	3.5	75.0	95.0	15.4	5.0	154.4	0.04	2.00	200.0	50.0	28.62	100.0
0	33.1	3.5	75.0	95.0	15.5	5.0	154.7	0.04	2.00	200.0	50.0	28.66	100.0
WT AVE.	28.1	3.5	75.0	95.0	15.3	5.0	153.0	0.04	2.00	200.0	50.0	23.53	0.0

TABLE XI-30 (CONTINUED)

SECTION 3. PROJECTED COSTS FOR MATERIALS AND SERVICES
(IN MILLIONS OF 1975 DOLLARS)

ALT III - CASE 36 - LOW GROWTH - 70' CF - 1978 REP - 1981 REC - NO FBR

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	286.2	36.	359.	127.	0.	0.	0.00	0.00	0.	10.	0.	0.	0.	818.
77	325.2	40.	430.	167.	7.	0.	0.00	0.00	0.	15.	0.	0.	0.	985.
78	401.5	46.	446.	187.	15.	75.	0.00	3.86	0.	18.	16.	0.	0.	1208.
79	587.5	51.	572.	223.	22.	150.	0.00	11.84	0.	19.	31.	-19.	0.	1648.
80	769.2	58.	646.	295.	22.	225.	0.19	20.49	15.	18.	47.	-25.	0.	2091.
81	954.6	61.	709.	244.	26.	225.	0.52	14.90	51.	18.	47.	-26.	0.	2325.
82	1108.1	67.	789.	370.	30.	262.	0.82	0.00	83.	18.	54.	-22.	0.	2760.
83	1396.7	79.	866.	393.	34.	300.	0.64	0.00	79.	20.	62.	-18.	0.	3211.
84	1723.2	95.	1146.	497.	34.	337.	0.72	0.00	76.	21.	70.	-17.	0.	3981.
85	1859.2	106.	1217.	511.	43.	337.	0.82	0.28	87.	24.	70.	-9.	0.	4246.
86	2180.6	112.	1267.	508.	53.	439.	1.02	0.44	120.	27.	88.	-7.	0.	4781.
87	2716.0	125.	1455.	571.	65.	542.	1.32	0.08	138.	30.	110.	-7.	0.	5748.
88	2955.2	134.	1574.	645.	65.	650.	1.47	0.00	143.	33.	132.	-7.	0.	6324.
89	3167.6	145.	1734.	664.	74.	648.	1.52	0.00	177.	35.	132.	-7.	0.	6773.
90	3343.0	153.	1826.	734.	84.	737.	1.88	0.06	196.	38.	150.	-7.	0.	7257.
91	3518.2	158.	1948.	778.	95.	844.	2.28	0.72	250.	41.	172.	-7.	0.	7802.
92	3709.2	169.	2061.	815.	105.	956.	2.57	0.40	277.	44.	194.	-7.	0.	8326.
93	3875.7	177.	2196.	867.	116.	1048.	2.85	0.28	313.	45.	213.	-7.	0.	8847.
94	4195.6	179.	2284.	900.	126.	1154.	3.24	0.23	354.	46.	234.	-7.	0.	9470.
95	4755.8	187.	2382.	913.	127.	1265.	3.48	0.40	404.	47.	256.	-7.	0.	10334.
96	5021.6	198.	2509.	958.	142.	1265.	3.56	0.00	401.	51.	256.	-7.	0.	10797.
97	5065.4	200.	2593.	999.	158.	1424.	3.77	0.00	408.	52.	287.	-7.	0.	11183.
98	5098.5	199.	2603.	1009.	158.	1580.	4.41	3.79	456.	51.	318.	-7.	0.	11474.
99	5209.2	202.	2656.	1015.	158.	1582.	4.71	5.28	506.	53.	318.	-7.	0.	11703.
0	5326.3	208.	2707.	1030.	159.	1586.	4.91	5.99	529.	56.	318.	-7.	0.	11923.
TOT	69774.0	3204.	39242.	15508.	1918.	17621.	46.68	69.04	5066.	836.	3575.	-239.	0.	156622.

SECTION 4. DISCOUNTED PROCESS COSTS
(IN MILLIONS OF 1975 DOLLARS)

ALT III - CASE 36 - LOW GROWTH - 70' CF - 1978 REP - 1981 REC - NO FBR
DISCOUNT RATE =0.100

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	260.2	33.	326.	115.	0.	0.	0.00	0.00	0.	9.	0.	0.	0.	744.
77	268.8	33.	356.	138.	6.	0.	0.00	0.00	0.	12.	0.	0.	0.	814.
78	301.6	34.	335.	141.	11.	56.	0.00	2.90	0.	13.	12.	0.	0.	907.
79	401.3	35.	391.	152.	15.	102.	0.00	8.08	0.	13.	21.	-15.	0.	1126.
80	477.6	36.	401.	183.	14.	140.	0.12	12.72	9.	11.	29.	-15.	0.	1298.
81	538.9	34.	400.	138.	15.	127.	0.29	8.41	29.	10.	26.	-15.	0.	1312.
82	568.6	35.	485.	190.	15.	135.	0.42	0.00	42.	9.	28.	-11.	0.	1416.
83	651.6	37.	484.	183.	16.	140.	0.30	0.00	37.	9.	29.	-8.	0.	1496.
84	730.8	40.	486.	211.	14.	143.	0.31	0.00	32.	9.	30.	-7.	0.	1689.
85	716.8	41.	469.	197.	16.	130.	0.32	0.11	34.	9.	27.	-4.	0.	1637.
86	764.3	39.	444.	178.	19.	150.	0.36	0.16	42.	10.	31.	-3.	0.	1676.
87	865.4	40.	464.	182.	21.	173.	0.42	0.02	44.	10.	35.	-2.	0.	1831.
88	856.0	39.	456.	187.	19.	168.	0.42	0.00	41.	9.	38.	-2.	0.	1832.
89	834.1	38.	457.	175.	19.	171.	0.48	0.00	47.	9.	35.	-2.	0.	1783.
90	800.3	37.	437.	176.	20.	176.	0.45	0.01	47.	9.	36.	-2.	0.	1737.
91	765.7	34.	424.	169.	21.	184.	0.50	0.16	54.	9.	37.	-1.	0.	1698.
92	733.8	33.	408.	161.	21.	189.	0.51	0.08	55.	9.	38.	-1.	0.	1647.
93	697.1	32.	395.	156.	21.	189.	0.51	0.05	56.	8.	38.	-1.	0.	1591.
94	686.0	29.	373.	147.	21.	189.	0.53	0.04	58.	8.	38.	-1.	0.	1548.
95	706.9	28.	354.	136.	19.	188.	0.52	0.06	60.	7.	38.	-1.	0.	1536.
96	678.6	27.	339.	129.	19.	171.	0.48	0.00	54.	7.	35.	-1.	0.	1459.
97	622.3	25.	319.	123.	19.	175.	0.46	0.00	50.	6.	35.	-1.	0.	1374.
98	569.4	22.	291.	113.	18.	176.	0.49	0.42	51.	6.	36.	-1.	0.	1281.
99	528.9	21.	270.	103.	16.	161.	0.48	0.54	51.	5.	32.	-1.	0.	1188.
0	491.6	19.	250.	95.	15.	146.	0.45	0.55	49.	5.	29.	-1.	0.	1100.
TOT	15741.2	842.	9919.	3966.	410.	3599.	8.73	34.32	944.	228.	734.	-93.	0.	36332.

NET GENERATION 35357., BILLIONS KWH
LEVELIZED FUEL CYCLE COST, MILLS/KWH

1.930	0.103	1.216	0.486	0.050	0.441	0.001	0.004	0.116	0.028	0.090	-0.011	0.000	4.455

TABLE XI-31

SECTION 1. PROCESS FLOW

ALTERNATE V - CASE 39 - LOW GROWTH - 70' CF - NO FBR - 1986 REPROCESSIN DATE: 23-AUG-76 TIME: 10:27:08

YEAR	MINING MILLING 1000 ST	UF6 CONVR 1000 MTU	ENRICHMNT 1000 MT-SWU	U FUEL FAB MTU	SPENT FUEL TRAN MT-HM	REPROCESS MT-HM	PU TRANS KG-TOT	INCR PU STORAGE KG-TOT	MOX FAB MT-HM	INCR SPENT FUEL STOR MT-HM	WASTE DISPOSAL MT-HM W PU	PU SALES KG FISS	SPENT FUEL DISP MT-HM
75	10.5	6.2	3.6	919.	0.	0.	0.	0.	0.	1167.	0.	0.	0.
76	13.4	10.4	4.8	1337.	0.	0.	0.	0.	0.	1962.	0.	0.	0.
77	15.0	11.5	5.7	1758.	0.	0.	0.	0.	0.	2917.	0.	0.	0.
78	17.8	13.5	6.8	1972.	0.	0.	0.	0.	0.	4014.	0.	0.	0.
79	21.8	16.1	7.8	2345.	0.	0.	0.	0.	0.	5236.	0.	0.	0.
80	25.3	19.1	8.9	3181.	0.	0.	0.	0.	0.	6566.	0.	0.	0.
81	29.4	21.3	10.4	2826.	0.	0.	0.	0.	0.	8140.	0.	0.	0.
82	32.2	24.1	12.1	4310.	0.	0.	0.	0.	0.	9930.	0.	0.	0.
83	38.0	27.1	12.7	4532.	0.	0.	0.	0.	0.	12193.	0.	0.	0.
84	44.9	32.6	16.6	5608.	0.	0.	0.	0.	0.	14634.	0.	0.	0.
85	46.7	36.4	17.9	5820.	1348.	0.	0.	0.	0.	17575.	0.	0.	0.
86	49.3	37.5	18.8	5949.	3397.	1348.	0.	0.	0.	19723.	0.	0.	0.
87	52.7	40.6	21.7	6704.	5843.	3397.	0.	0.	0.	20427.	0.	0.	0.
88	55.0	41.9	23.8	7503.	7245.	5843.	0.	0.	0.	19192.	0.	0.	0.
89	58.0	43.9	26.1	7877.	7849.	7245.	0.	0.	0.	16874.	0.	0.	0.
90	62.7	47.2	28.0	8707.	8249.	7849.	0.	0.	0.	14497.	0.	0.	0.
91	67.8	50.9	30.7	9444.	8241.	8249.	0.	0.	0.	12379.	1348.	0.	0.
92	72.8	54.7	32.6	9964.	8248.	8241.	0.	0.	0.	10807.	3397.	0.	0.
93	77.8	59.1	34.8	10692.	8248.	8248.	0.	0.	0.	9709.	5843.	0.	0.
94	82.1	62.2	36.7	11242.	8248.	8248.	0.	0.	0.	9260.	7245.	0.	0.
95	86.2	65.3	38.4	11634.	8248.	8248.	0.	0.	0.	9413.	7849.	0.	0.
96	89.9	68.8	40.2	12091.	9248.	8248.	0.	0.	0.	10154.	8249.	0.	0.
97	92.2	70.5	41.8	12552.	10248.	9248.	0.	0.	0.	10472.	8241.	0.	0.
98	94.3	71.8	43.2	12901.	10248.	10248.	0.	0.	0.	10297.	8248.	0.	0.
99	96.7	73.9	44.5	13216.	10248.	10248.	0.	0.	0.	10559.	8248.	0.	0.
0	98.8	75.5	45.5	13492.	10248.	10248.	0.	0.	0.	11226.	8248.	0.	0.
TOT	1431.1	1082.2	613.4	188576.	125404.	115156.	0.	0.	0.	279323.	66916.	0.	0.

SECTION 2. PROJECTED UNIT COST

ALTERNATE V - CASE 39 - LOW GROWTH - 70' CF - NO FBR - 1986 REPROCESSIN DATE: 23-AUG-76 TIME: 10:27:08

YEAR	U3O8 AS BURNED $/LB	U CONVR $/KG-U	SEP WORK $/SWU	U FAB $/KG-U	SPENT FUEL TRAN $/KG-HM	INCR SPENT FUEL STOR $/KG-HM-YR	REPRO $/KG-HM	PU TRAN $/G-TOT	INCR PU STORAGE $/G-TOT	MOX FAB $/KG-HM	WASTE PU VALUE DISPOSAL $/KG-HM W PU	$/G FISS	SPENT FUEL DISP $/KG-HM
75	10.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
76	10.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
77	11.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
78	12.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
79	15.2	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
80	18.3	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
81	20.3	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
82	21.3	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
83	22.2	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
84	22.9	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
85	25.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
86	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
87	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
88	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
89	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
90	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
91	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
92	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
93	30.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
94	33.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
95	33.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
96	33.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
97	33.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
98	33.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
99	33.9	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
0	34.2	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
WT AVE.	28.9	3.5	75.0	95.0	15.0	5.0	150.0	0.00	0.00	0.0	50.0	0.00	0.0

TABLE XI-31 (CONTINUED)

SECTION 3. PROJECTED COSTS FOR MATERIALS AND SERVICES
(IN MILLIONS OF 1975 DOLLARS)

ALTERNATE V - CASE 39 - LOW GROWTH - 70' CF - NO FBR - 1986 REPROCESSIN DATE: 23-AUG-76 TIME: 10:27:08

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	286.2	36.	359.	127.	0.	0.	0.00	0.00	0.	10.	0.	0.	0.	818.
77	330.0	40.	430.	167.	0.	0.	0.00	0.00	0.	15.	0.	0.	0.	982.
78	426.6	47.	447.	187.	0.	0.	0.00	0.00	0.	20.	0.	0.	0.	1128.
79	661.9	56.	585.	223.	0.	0.	0.00	0.00	0.	26.	0.	0.	0.	1552.
80	921.1	67.	670.	302.	0.	0.	0.00	0.00	0.	33.	0.	0.	0.	1993.
81	1195.3	74.	780.	268.	0.	0.	0.00	0.00	0.	41.	0.	0.	0.	2359.
82	1370.2	84.	905.	409.	0.	0.	0.00	0.00	0.	50.	0.	0.	0.	2818.
83	1685.0	95.	954.	431.	0.	0.	0.00	0.00	0.	61.	0.	0.	0.	3226.
84	2055.3	114.	1244.	533.	0.	0.	0.00	0.00	0.	73.	0.	0.	0.	4019.
85	2334.0	127.	1340.	553.	20.	0.	0.00	0.00	0.	88.	0.	0.	0.	4462.
86	2808.1	131.	1489.	565.	51.	202.	0.00	0.00	0.	99.	42.	0.	0.	5307.
87	3004.3	142.	1631.	637.	88.	510.	0.00	0.00	0.	102.	105.	0.	0.	6219.
88	3133.2	147.	1784.	713.	109.	876.	0.00	0.00	0.	96.	181.	0.	0.	7039.
89	3367.1	154.	1958.	748.	118.	1087.	0.00	0.00	0.	84.	225.	0.	0.	7681.
90	3575.2	165.	2103.	827.	124.	1177.	0.00	0.00	0.	72.	244.	0.	0.	8288.
91	3867.2	178.	2303.	897.	124.	1237.	0.00	0.00	0.	62.	256.	0.	0.	8925.
92	4147.0	192.	2447.	947.	124.	1236.	0.00	0.00	0.	54.	256.	0.	0.	9402.
93	4666.9	207.	2613.	1016.	124.	1237.	0.00	0.00	0.	49.	256.	0.	0.	10168.
94	5415.4	218.	2754.	1068.	124.	1237.	0.00	0.00	0.	46.	256.	0.	0.	11118.
95	5691.6	229.	2883.	1105.	124.	1237.	0.00	0.00	0.	47.	256.	0.	0.	11573.
96	5930.2	241.	3016.	1149.	139.	1237.	0.00	0.00	0.	51.	256.	0.	0.	12019.
97	6086.5	247.	3133.	1192.	154.	1387.	0.00	0.00	0.	902.	287.	0.	0.	12539.
98	6223.9	251.	3240.	1226.	154.	1537.	0.00	0.00	0.	91.	318.	0.	0.	13002.
99	6555.8	259.	3338.	1256.	154.	1537.	0.00	0.00	0.	83.	318.	0.	0.	13469.
0	6756.8	264.	3415.	1282.	154.	1537.	0.00	0.00	0.	56.	218.	0.	0.	13783.
TOT	82659.7	3788.	46007.	17915.	1881.	17273.	0.00	0.00	0.	1397.	3575.	0.	0.	174495.

SECTION 4. DISCOUNTED PROCESS COSTS
(IN MILLIONS OF 1975 DOLLARS)

ALTERNATE V - CASE 39 - LOW GROWTH - 70' CF - NO FBR - 1986 REPROCESSIN DATE: 23-AUG-76 TIME: 10:27:08
DISCOUNT RATE =0.100

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	260.2	33.	326.	115.	0.	0.	0.00	0.00	0.	9.	0.	0.	0.	744.
77	272.7	33.	356.	138.	0.	0.	0.00	0.00	0.	12.	0.	0.	0.	812.
78	320.5	36.	336.	141.	0.	0.	0.00	0.00	0.	15.	0.	0.	0.	848.
79	452.1	38.	399.	152.	0.	0.	0.00	0.00	0.	18.	0.	0.	0.	1060.
80	571.9	42.	416.	188.	0.	0.	0.00	0.00	0.	20.	0.	0.	0.	1237.
81	674.7	42.	440.	152.	0.	0.	0.00	0.00	0.	23.	0.	0.	0.	1332.
82	703.1	43.	464.	210.	0.	0.	0.00	0.00	0.	25.	0.	0.	0.	1446.
83	786.1	44.	445.	201.	0.	0.	0.00	0.00	0.	28.	0.	0.	0.	1505.
84	871.7	48.	528.	226.	0.	0.	0.00	0.00	0.	31.	0.	0.	0.	1705.
85	859.9	49.	517.	213.	8.	0.	0.00	0.00	0.	34.	0.	0.	0.	1720.
86	984.2	46.	494.	198.	18.	71.	0.00	0.00	0.	35.	15.	0.	0.	1860.
87	957.3	45.	520.	203.	28.	162.	0.00	0.00	0.	33.	34.	0.	0.	1981.
88	907.6	43.	517.	206.	31.	254.	0.00	0.00	0.	28.	53.	0.	0.	2039.
89	870.9	40.	516.	197.	31.	286.	0.00	0.00	0.	22.	59.	0.	0.	2023.
90	855.9	40.	503.	198.	30.	282.	0.00	0.00	0.	17.	58.	0.	0.	1984.
91	841.6	39.	501.	195.	27.	269.	0.00	0.00	0.	13.	56.	0.	0.	1942.
92	820.5	38.	484.	187.	24.	245.	0.00	0.00	0.	11.	51.	0.	0.	1860.
93	839.4	37.	470.	183.	22.	223.	0.00	0.00	0.	9.	46.	0.	0.	1829.
94	885.5	36.	450.	175.	20.	202.	0.00	0.00	0.	8.	42.	0.	0.	1818.
95	846.0	34.	429.	164.	18.	184.	0.00	0.00	0.	7.	38.	0.	0.	1720.
96	801.4	33.	408.	155.	19.	167.	0.00	0.00	0.	7.	35.	0.	0.	1624.
97	747.7	30.	385.	146.	19.	170.	0.00	0.00	0.	6.	35.	0.	0.	1540.
98	695.1	28.	362.	137.	17.	172.	0.00	0.00	0.	6.	36.	0.	0.	1452.
99	665.6	26.	339.	127.	16.	156.	0.00	0.00	0.	5.	32.	0.	0.	1367.
0	623.6	24.	315.	118.	14.	142.	0.00	0.00	0.	5.	29.	0.	0.	1272.
TOT	18379.7	969.	11186.	4414.	343.	2985.	0.00	0.00	0.	433.	618.	0.	0.	39327.
NET GENERATION 35357., BILLIONS KWH														
LEVELIZED FUEL CYCLE COST, MILLS/KWH														
	2.254	0.119	1.372	0.541	0.042	0.366	0.000	0.000	0.000	0.053	0.076	0.000	0.000	4.823

TABLE XI-32

SECTION 1. PROCESS FLOW

ALT VI - CASE 40 - LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE

YEAR	MINING MILLING 1000 ST	UF6 CONVR 1000 MTU	ENRICHMNT 1000 MT-SWU	U FUEL FAB MTU	SPENT FUEL TRAN MT-HM	REPROCESS MT-HM	PU TRANS KG-TOT	INCR PU STORAGE KG-TOT	MOX FAB MT-HM	INCR SPENT FUEL STOR MT-HM	WASTE DISPOSAL MT-HM W/O PU	PU SALES KG FISS	SPENT FUEL DISP MT-HM
75	10.5	6.2	3.6	919.	0.	0.	0.	0.	0.	1167.	0.	0.	0.
76	13.4	10.4	4.8	1337.	0.	0.	0.	0.	0.	1962.	0.	0.	0.
77	15.0	11.5	5.7	1758.	0.	0.	0.	0.	0.	2917.	0.	0.	0.
78	17.8	13.5	6.9	1972.	0.	0.	0.	0.	0.	4014.	0.	0.	0.
79	21.8	16.1	7.8	2345.	0.	0.	0.	0.	0.	5236.	0.	0.	0.
80	25.3	19.1	8.9	3181.	0.	0.	0.	0.	0.	6566.	0.	0.	0.
81	29.4	21.3	10.4	2826.	0.	0.	0.	0.	0.	8140.	0.	0.	0.
82	32.2	24.1	12.1	4310.	0.	0.	0.	0.	0.	9930.	0.	0.	0.
83	38.0	27.1	12.7	4532.	0.	0.	0.	0.	0.	12193.	0.	0.	0.
84	44.9	32.6	16.6	5608.	0.	0.	0.	0.	0.	14634.	0.	0.	0.
85	47.1	36.4	17.9	5820.	0.	0.	0.	0.	0.	17575.	0.	0.	0.
86	51.7	38.6	18.7	5949.	3500.	0.	0.	0.	0.	17571.	0.	0.	3500.
87	57.5	44.1	21.8	6704.	3500.	0.	0.	0.	0.	18172.	0.	0.	3500.
88	63.0	47.8	23.5	7503.	3500.	0.	0.	0.	0.	19280.	0.	0.	3500.
89	68.3	51.8	25.8	7877.	3500.	0.	0.	0.	0.	20707.	0.	0.	3500.
90	73.8	55.7	27.7	8707.	3500.	0.	0.	0.	0.	22679.	0.	0.	3500.
91	79.3	59.7	30.2	9444.	3571.	0.	0.	0.	0.	25239.	0.	0.	3571.
92	84.7	64.0	32.2	9964.	4101.	0.	0.	0.	0.	27807.	0.	0.	4101.
93	89.8	68.5	34.5	10692.	4608.	0.	0.	0.	0.	30349.	0.	0.	4608.
94	94.0	71.5	36.3	11242.	4927.	0.	0.	0.	0.	33221.	0.	0.	4927.
95	98.2	74.7	38.0	11634.	5472.	0.	0.	0.	0.	36150.	0.	0.	5472.
96	102.4	78.0	39.8	12091.	6131.	0.	0.	0.	0.	39008.	0.	0.	6131.
97	105.9	80.9	41.4	12552.	6669.	0.	0.	0.	0.	41905.	0.	0.	6669.
98	109.0	83.2	42.8	12901.	7150.	0.	0.	0.	0.	44828.	0.	0.	7150.
99	111.7	85.6	44.0	13216.	7799.	0.	0.	0.	0.	47539.	0.	0.	7799.
0	113.9	87.3	45.0	13492.	8401.	0.	0.	0.	0.	50053.	0.	0.	8401.
TOT	1599.1	1209.8	608.2	188576.	76329.	0.	0.	0.	0.	558842.	0.	0.	76329.

SECTION 2. PROJECTED UNIT COST

ALT VI - CASE 40 - LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE

YEAR	U3O8 AS BURNED $/LB	U CONVR $/KG-U	SEP WORK $/SWU	U FAB $/KG-U	SPENT FUEL TRAN $/KG-HM	INCR SPENT FUEL STOR $/KG-HM-YR	REPRO $/KG-HM	PU TRAN $/G-TOT	INCR PU STORAGE $/G-TOT	MOX FAB $/KG-HM	WASTE PU VALUE DISPOSAL $/KG-HM W/O PU	$/G FISS	SPENT FUEL DISP $/KG-HM
75	10.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
76	10.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
77	11.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
78	12.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
79	15.2	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
80	18.2	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
81	20.3	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
82	21.3	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
83	22.2	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
84	22.9	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
85	25.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
86	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
87	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
88	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
89	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
90	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
91	28.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
92	29.6	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
93	32.4	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
94	33.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
95	33.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
96	33.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
97	33.2	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
98	34.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
99	35.8	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
0	37.6	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
WT AVE.	29.8	3.5	75.0	95.0	15.0	5.0	0.0	0.00	0.00	0.0	0.0	0.00	100.0

TABLE XI-32 (CONTINUED)

SECTION 3. PROJECTED COSTS FOR MATERIALS AND SERVICES
(IN MILLIONS OF 1975 DOLLARS)

ALT VI - CASE 40 - LOW GROWTH - 70' CF - NO FBR - NO REPROCESSING OR RECYCLE

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	286.2	36.	359.	127.	0.	0.	0.00	0.00	0.	10.	0.	0.	0.	818.
77	330.0	40.	430.	167.	0.	0.	0.00	0.00	0.	15.	0.	0.	0.	982.
78	426.6	47.	447.	187.	0.	0.	0.00	0.00	0.	20.	0.	0.	0.	1128.
79	661.9	56.	585.	223.	0.	0.	0.00	0.00	0.	26.	0.	0.	0.	1552.
80	921.1	67.	670.	302.	0.	0.	0.00	0.00	0.	33.	0.	0.	0.	1993.
81	1195.3	74.	780.	268.	33.	0.	0.00	0.00	0.	41.	0.	0.	217.	2609.
82	1370.2	84.	905.	409.	33.	0.	0.00	0.00	0.	50.	0.	0.	217.	3068.
83	1685.0	95.	954.	431.	33.	0.	0.00	0.00	0.	61.	0.	0.	217.	3476.
84	2055.3	114.	1244.	533.	33.	0.	0.00	0.00	0.	73.	0.	0.	217.	4269.
85	2359.4	127.	1348.	553.	33.	0.	0.00	0.00	0.	88.	0.	0.	217.	4717.
86	2945.9	135.	1486.	565.	33.	0.	0.00	0.00	0.	88.	0.	0.	252.	5395.
87	3302.9	154.	1634.	637.	38.	0.	0.00	0.00	0.	91.	0.	0.	255.	6112.
88	3593.2	167.	1765.	713.	43.	0.	0.00	0.00	0.	96.	0.	0.	286.	6663.
89	3894.8	181.	1934.	748.	46.	0.	0.00	0.00	0.	104.	0.	0.	306.	7214.
90	4207.9	195.	2081.	827.	51.	0.	0.00	0.00	0.	113.	0.	0.	340.	7815.
91	4522.4	209.	2263.	897.	57.	0.	0.00	0.00	0.	126.	0.	0.	381.	8455.
92	5009.9	224.	2414.	947.	62.	0.	0.00	0.00	0.	139.	0.	0.	414.	9210.
93	5822.3	240.	2584.	1016.	67.	0.	0.00	0.00	0.	152.	0.	0.	444.	10324.
94	6284.5	250.	2723.	1068.	73.	0.	0.00	0.00	0.	166.	0.	0.	484.	10969.
95	6482.3	261.	2852.	1165.	78.	0.	0.00	0.00	0.	181.	0.	0.	522.	11482.
96	6756.5	273.	2987.	1149.	84.	0.	0.00	0.00	0.	195.	0.	0.	558.	12002.
97	7042.2	283.	3109.	1192.	89.	0.	0.00	0.00	0.	210.	0.	0.	594.	12519.
98	7415.0	291.	3207.	1226.	94.	0.	0.00	0.00	0.	224.	0.	0.	625.	13083.
99	7998.5	300.	3301.	1256.	98.	0.	0.00	0.00	0.	238.	0.	0.	653.	13843.
0	8569.8	305.	3378.	1282.	102.	0.	0.00	0.00	0.	250.	0.	0.	678.	14565.
TOT	95283.7	4234.	45619.	17915.	1177.	0.	0.00	0.00	0.	2794.	0.	0.	7847.	174870.

SECTION 4. DISCOUNTED PROCESS COSTS
(IN MILLIONS OF 1975 DOLLARS)

ALT VI - CASE 40 - LOW GROWTH - 70' CF - NO FBR - NO REPROCESSING OR RECYCLE
DISCOUNT RATE =0.100

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	260.2	33.	326.	115.	0.	0.	0.00	0.00	0.	9.	0.	0.	0.	744.
77	272.7	33.	356.	138.	0.	0.	0.00	0.00	0.	12.	0.	0.	0.	812.
78	320.5	36.	336.	141.	0.	0.	0.00	0.00	0.	15.	0.	0.	0.	848.
79	452.1	38.	399.	152.	0.	0.	0.00	0.00	0.	18.	0.	0.	0.	1060.
80	571.9	42.	416.	188.	0.	0.	0.00	0.00	0.	20.	0.	0.	0.	1237.
81	674.7	42.	440.	152.	18.	0.	0.00	0.00	0.	23.	0.	0.	123.	1473.
82	703.1	43.	464.	210.	17.	0.	0.00	0.00	0.	25.	0.	0.	112.	1574.
83	786.1	44.	445.	201.	15.	0.	0.00	0.00	0.	28.	0.	0.	101.	1621.
84	871.7	48.	528.	226.	14.	0.	0.00	0.00	0.	31.	0.	0.	92.	1811.
85	909.6	49.	517.	213.	13.	0.	0.00	0.00	0.	34.	0.	0.	84.	1819.
86	1032.5	47.	493.	198.	12.	0.	0.00	0.00	0.	31.	0.	0.	78.	1891.
87	1052.4	49.	521.	203.	12.	0.	0.00	0.00	0.	29.	0.	0.	81.	1947.
88	1040.8	48.	511.	206.	12.	0.	0.00	0.00	0.	28.	0.	0.	83.	1930.
89	1025.6	48.	509.	197.	12.	0.	0.00	0.00	0.	27.	0.	0.	81.	1900.
90	1007.3	47.	498.	198.	12.	0.	0.00	0.00	0.	27.	0.	0.	81.	1871.
91	984.2	46.	492.	195.	12.	0.	0.00	0.00	0.	27.	0.	0.	83.	1840.
92	991.2	44.	478.	187.	12.	0.	0.00	0.00	0.	28.	0.	0.	82.	1822.
93	1047.2	43.	465.	183.	12.	0.	0.00	0.00	0.	27.	0.	0.	80.	1857.
94	1014.5	41.	445.	175.	12.	0.	0.00	0.00	0.	27.	0.	0.	79.	1793.
95	963.6	39.	424.	164.	12.	0.	0.00	0.00	0.	27.	0.	0.	78.	1707.
96	913.0	37.	404.	155.	11.	0.	0.00	0.00	0.	26.	0.	0.	75.	1622.
97	865.1	35.	382.	146.	11.	0.	0.00	0.00	0.	26.	0.	0.	73.	1538.
98	828.1	33.	358.	137.	10.	0.	0.00	0.00	0.	25.	0.	0.	70.	1461.
99	812.0	30.	335.	127.	10.	0.	0.00	0.00	0.	24.	0.	0.	66.	1405.
0	791.0	28.	312.	118.	9.	0.	0.00	0.00	0.	23.	0.	0.	63.	1344.
TOT	20415.9	1046.	11120.	4414.	250.	0.	0.00	0.00	0.	625.	0.	0.	1664.	39534.

NET GENERATION 35357., BILLIONS KWH
LEVELIZED FUEL CYCLE COST, MILLS/KWH

2.504	0.128	1.364	0.541	0.031	0.000	0.000	0.000	0.000	0.077	0.000	0.000	0.204	4.848

The costs of mining and milling U_3O_8 are the predominant costs in each alternative and increase substantially for the no recycle case (Alternative 6). Enrichment costs are next in importance, followed by UO_2 fuel fabrication. These costs do not exhibit large differences among alternatives. Reprocessing is fourth in importance and, of course, is eliminated entirely in the no recycle alternative. The costs for conversion to UF_6, waste disposal, and spent fuel storage costs are all relatively small. However, waste disposal and spent fuel storage both show some large variations among alternatives. The plutonium transportation, storage, and MOX fabrication components apply only to the recycle alternatives (1, 2, and 3). Together, these last three items account for only 2% or less of the total fuel cycle cost.

The differences between total fuel cycle costs for the three plutonium recycle alternatives (1, 2, and 3) are relatively small. This indicates that, for the industry as a whole over the 26-year period, the exact date in the 1981-1986 period at which plutonium recycle is started has a small impact. However this is not true for the part of the industry that is affected--that is, those plants and facilities operating before 1986. When all of the differences are allocated to those facilities, as would be the case, the impact on them is significant.

For the low-growth scenario and the assumptions used here, elimination of plutonium recycle (Alternative 5) increases the total fuel cycle costs by about 8%. Elimination of all recycle (Alternative 6) increases the total fuel cycle costs by about 9%.

3.0 PARAMETRIC STUDIES

The economic impact of plutonium recycle is affected by many factors. Principal among these are the cost of uranium, the discount rate, and the costs of enrichment services, MOX fabrication, reprocessing, and spent fuel disposal. Other less important factors are the date recycle begins and the form of interim fuel storage. These factors interact and affect the relative economics of recycle and throwaway fuel values in complex ways. The interaction and effect of these factors are described, through parametric analyses, in this section. In this section most of the cost discussions are in terms of discounted constant (1975) dollars. The reader should note that cumulative costs before discounting are usually higher by a factor of 4 to 6 than when discounted at 10%.

3.1 Influence of Growth in Electricity Demand

The subject of power projection has been discussed at some length in CHAPTER III. CHAPTER VIII, Section 5.2, includes the details of the two growth scenarios used in this analysis. An attempt was made to pick two nuclear industry growth projections that most likely bracket the actual growth rate that the country will realize. While the details (shape) of the growth rate curve have some influence on the economic analysis, the most important factor for both economic and environmental impact is the integrated electric power generation in nuclear plants over the time period of study. The two scenarios used indicate an integrated generation of 35 and

50 trillion kWh through the year 2000 for the low- and high-growth projections, respectively. Figure XI-2 illustrates how the economic incentive for plutonium recycle varies with electric power generation in the nuclear plants. The higher projection indicates an economic incentive to recycle of about $6 billion, while the lower projection indicates a benefit of about $3 billion (both discounted at 10%). Whichever projection is used, it is apparent that plutonium and uranium recycle has material economic incentive.

3.2 Effect of Uranium Price

The cost of U_3O_8 is the single largest cost factor in all analyses of total fuel cycle costs. Consequently, the price of U_3O_8 significantly affects the total fuel cycle cost and the economic consequences of the decision to recycle or throw away. The magnitude of this effect can be estimated by comparing the reference case shown in Figure XI-3, at an average of $28/lb U_3O_8, with the case shown in Figure XI-4, with U_3O_8 costs doubled to an average of $56/lb U_3O_8.

In each figure the throwaway cycle is depicted by the horizontal band showing the range of uncertainty of $50 to $150/kg HM for disposal costs. Recycle is depicted by the inclined band showing the range of uncertainty of $150 to $300/kg HM in MOX fuel fabrication cost as a function of reprocessing cost. In Figures XI-3 and XI-4 all other costs are held constant. Recycle is economically attractive for the range of reprocessing costs for which the inclined band is below the horizontal band. The throwaway cycle is more economic when the inclined band is above the horizontal band. The region in which the bands overlap defines the range of reprocessing costs over which the economics of the recycle and throwaway are uncertain. The choice of the economically advantageous cycle in the region representing the overlap range requires more precise knowledge (i.e., a reduction in the uncertainties) of the cost components.

An increase in the price of U_3O_8 increases the incentive to recycle. When reprocessing costs are in the estimated cost range ($110 to $190/kg HM), recycling has an approximately 1 mill/kWh, or an $8 billion present-worth, advantage over the throwaway cycle for doubled U_3O_8 cost of $56/lb (Figure XI-4), whereas the gain from recycle is approximately 0.4 mill/kWh for the reference U_3O_8 cost of $28/lb average (Figure XI-3). Similarly, an increase in the price of U_3O_8 from $28/lb to $56/lb increases the breakeven reprocessing cost from $280/kg to $480/kg.* Doubling the price of U_3O_8 increases the total fuel cycle cost by $20 billion (2.5 mills/kWh) for the throwaway cycle and by $16 billion (1.9 mills/kWh) for plutonium-uranium recycle. Although it is judged highly unlikely that the price of uranium will be significantly reduced, such a case has been analyzed to illustrate the impact. Reducing the average uranium price by one-half to an average of $14/lb U_3O_8 would reduce the present-worth economic incentive to recycle by $2.1 billion to a value of $0.9 billion (0.1 mill/kWh).

*Breakeven reprocessing cost is that cost for reprocessing below which recycle is economically attractive and above which the throwaway fuel cycle is advantageous.

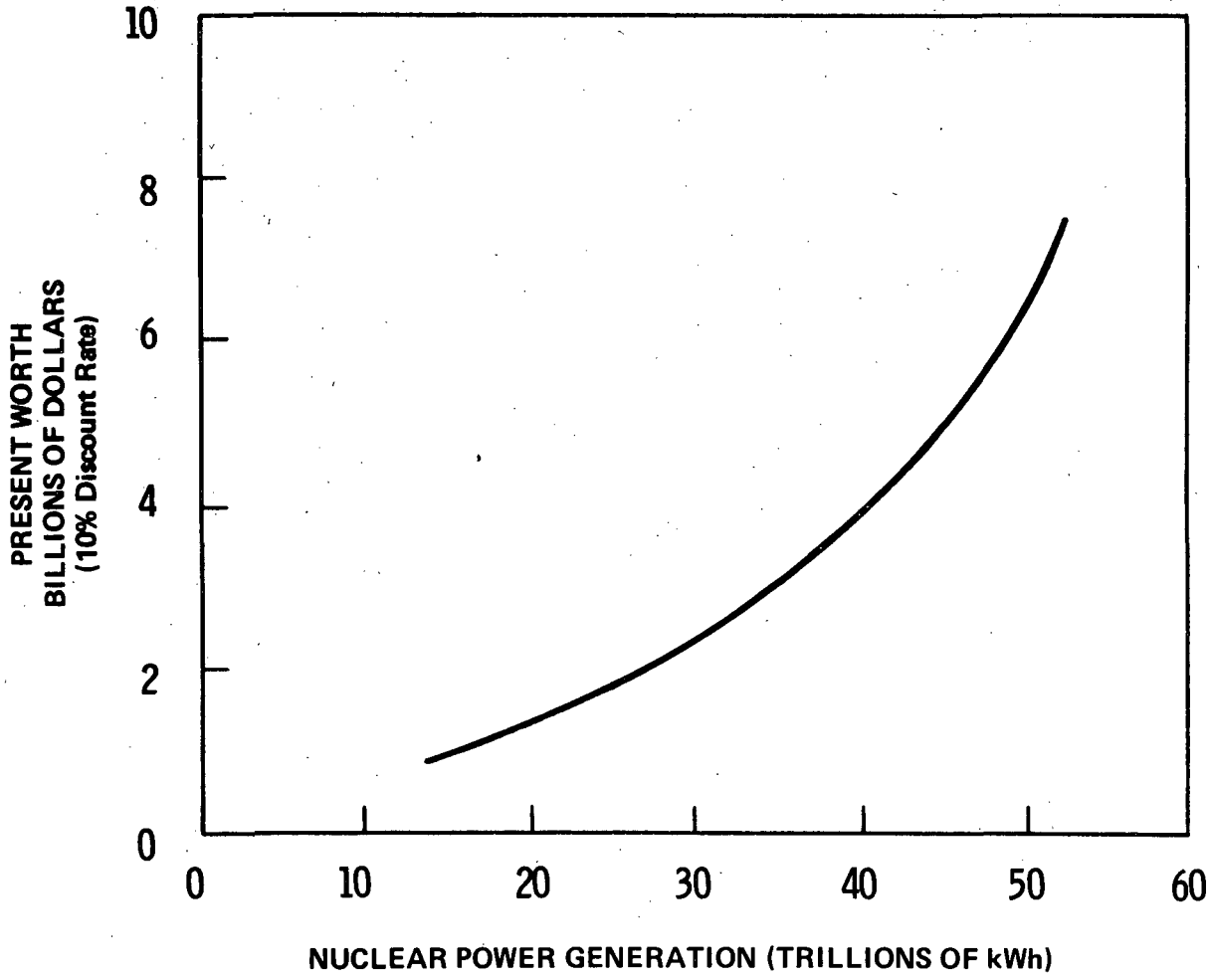


Figure XI-2 Economic Incentive to Recycle as a Function of Total Nuclear Power Generation Through the Year 2000

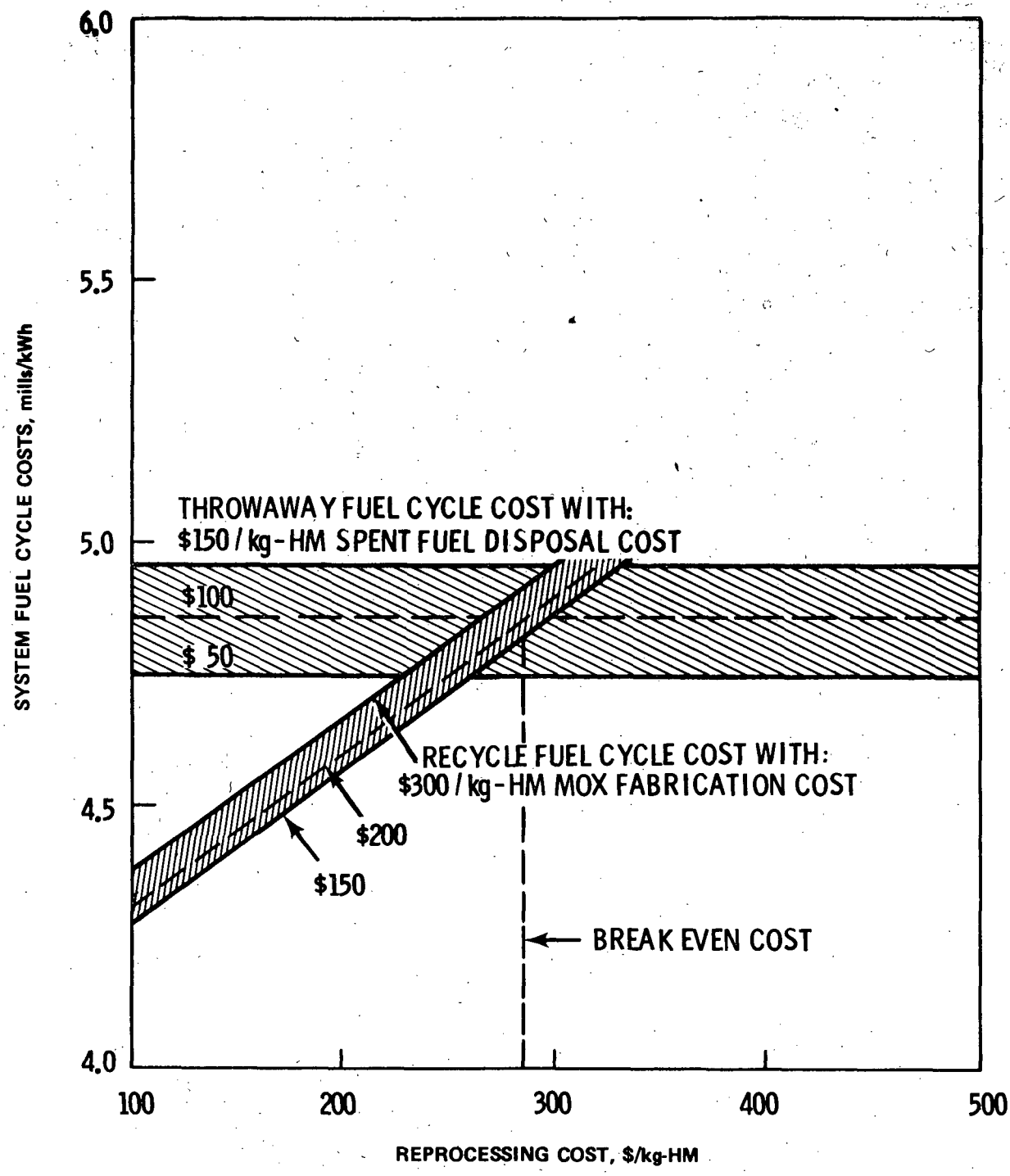


Figure XI-3 Comparative Fuel Cycle Costs for Prompt Recycle and Throwaway With Reference U_3O_8 Cost ($28/lb avg) and Reference Separative Work Costs ($75/kg SWU)

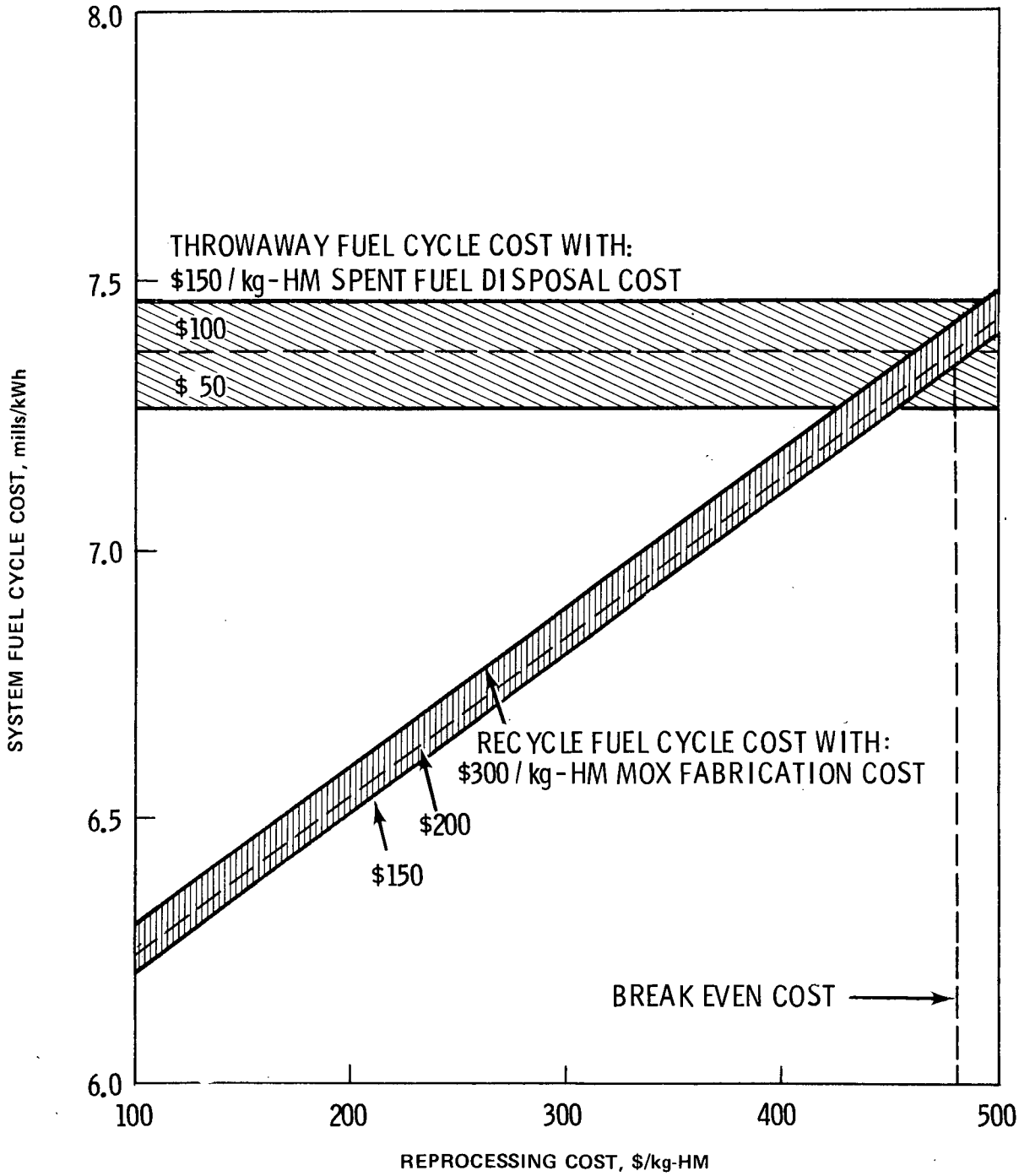


Figure XI-4 Comparative Fuel Cycle Costs for Prompt Recycle and Throwaway With Doubled U_3O_8 Costs ($56/lb avg) and Reference Separative Work Costs ($75/kg SWU)

3.3 Effect of the Price of Separative Work

The price of separative work also has a significant impact on the total fuel cycle cost and on the decision to recycle or throwaway fuel. The effect of price changes for enrichment is similar to that of price changes for uranium. For example, consider the reference price of $75/kg (from Figure XI-3) and a higher price, $110/kg, for separative work (Figure XI-5). The higher separative work price increases the total fuel cycle cost by 0.6 mill/kWh ($5.2 billion) for the throwaway cycle and slightly less, 0.6 mill/kWh ($4.6 billion), for recycle. This increase in the price of separative work, then, raises the incentive to recycle by 0.07 mill/kWh ($0.7 billion). Recycling has an economic advantage over the throwaway cycle of 0.5 mill/kWh ($3.8 billion) for $110 separative work and 0.4 mill/kWh ($3.2 billion) for $75 separative work. Such an increase in price of separative work would increase the breakeven price for reprocessing from $280 to $310/kg HM. As with increases in the price of uranium, an increase in enrichment costs shifts upward the range of reprocessing costs over which recycle is more economic.

3.4 Effect of MOX Fuel Fabrication Price

Mixed oxide fuel fabrication prices are expected to range between $150 and $300/kg HM. This represents an uncertainty in the total fuel cycle cost of 0.1 mill/kWh, or about $0.7 billion. This $150 range in MOX fabrication costs is equivalent to either a change of $30/kg HM in reprocessing costs or a change of $44/kg HM in fuel disposal costs, or an equivalent combination of changes in both reprocessing and disposal costs. Thus the total fuel cycle cost is sensitive to reprocessing, waste disposal, and MOX fabrication costs, respectively, in the ratios 1/30:1/44 = 1/150 or about 5:3.4=1. Of these three factors, reprocessing costs are the most significant driver, followed in order by waste disposal and fabrication.

3.5 Effect of Fuel Disposal Cost

Fuel disposal without reprocessing is estimated to cost between $50 and $150/kg HM. This represents a $1.7 billion (0.20 mill/kWh) uncertainty in the total fuel cycle cost. The effect of this uncertainty on the throwaway or recycle decision is as follows: a $100 range in fuel disposal costs is equivalent to a $70/kg HM range in reprocessing costs. Therefore the breakeven reprocessing cost for plutonium recycle would be $70/kg HM higher for the $150/kg HM disposal cost than for the $50/kg HM disposal cost. This can be seen in Figure XI-3, where the breakeven reprocessing cost is increased from $250 to $320/kg HM (at $200/kg HM MOX fabrication cost) as the disposal cost increases from $50 to $150/kg HM.

3.6 Effect of Discount Rate on Decision to Recycle

Because the benefits or savings in resources and fuel cycle costs that result from plutonium recycle are realized over a period of years, it is necessary to adjust or discount the total cumulative savings for these time differences. The well-established and generally accepted method for making this adjustment is to convert all dollar flows to a present value basis by a time-discounting procedure. However,

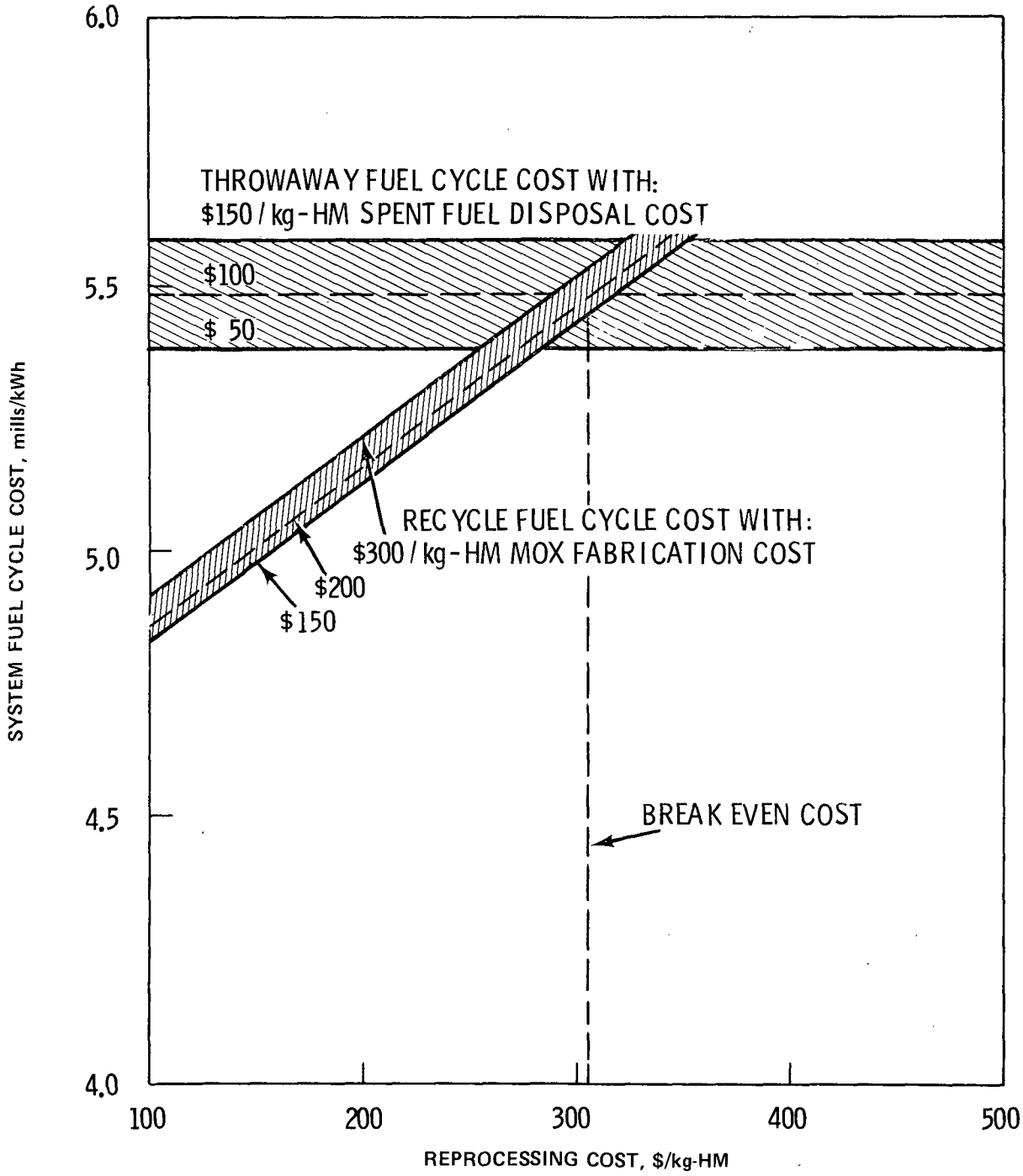


Figure XI-5 Comparative Fuel Cycle Costs for Prompt Recycle and Throwaway With Reference U_3O_8 Cost ($28/lb avg) and High Separative Work Cost ($110/kg SWU)

the selection of an appropriate discount rate has been the subject of considerable debate, particularly regarding the evaluation of public investments.

In considering the selection of a discount rate for this analysis it is essential first of all to identify the party to whom the ultimate benefits accrue since this strongly affects the appropriate discount rate. The system being evaluated includes the entire U.S. nuclear electricity-generating system. Figure XI-6 illustrates schematically the flow of dollars influenced by plutonium recycle alternatives in this system:

(1) Plutonium recycle options alter the fuel cycle costs of nuclear fuel supplied to the utilities by the fuel cycle industry. The fuel cycle industry costs in this study are developed using rates of return appropriate for each segment of the industry. These individual industrial rates of return are considerably higher than the discount rates under discussion here in this section.

(2) Electric utilities are regulated using the equation

$$R = E + Vr$$

where R represents revenues allowed; E represents all expenses, including operation and fuel expenses, depreciation, and taxes; V represents the depreciated rate bases (total assets); and r is the allowed rate of return on the rate base.

Here again, r, the utility rate of return on the rate base, may be considerably higher than the discount rate under consideration here.

(3) Since the utility revenues are the product of electric rates times kilowatt-hour sales, increased or decreased fuel cycle costs are ultimately reflected directly in increased or decreased charges to the electric power users. The amount of electricity generation is assumed to be the same for all alternatives.

(4) The savings or costs of plutonium recycle accrue to the electric power consumers and result in altered consumer spending for goods, services, investments, etc.

Thus the appropriate discount rate for this analysis should represent an appropriate discount rate for the electric power users.

Another essential factor to be considered in developing the discount rate is the constant dollar framework of this analysis. The discount rate must be corrected for inflation effects.

The establishment of an appropriate discount rate reduces to the evaluation of the opportunity cost of the general public who ultimately pay for power and who would benefit from any power cost reduction. Here there is not a question of evaluating the desirability of a transfer of resources from private sector investments. Rather,

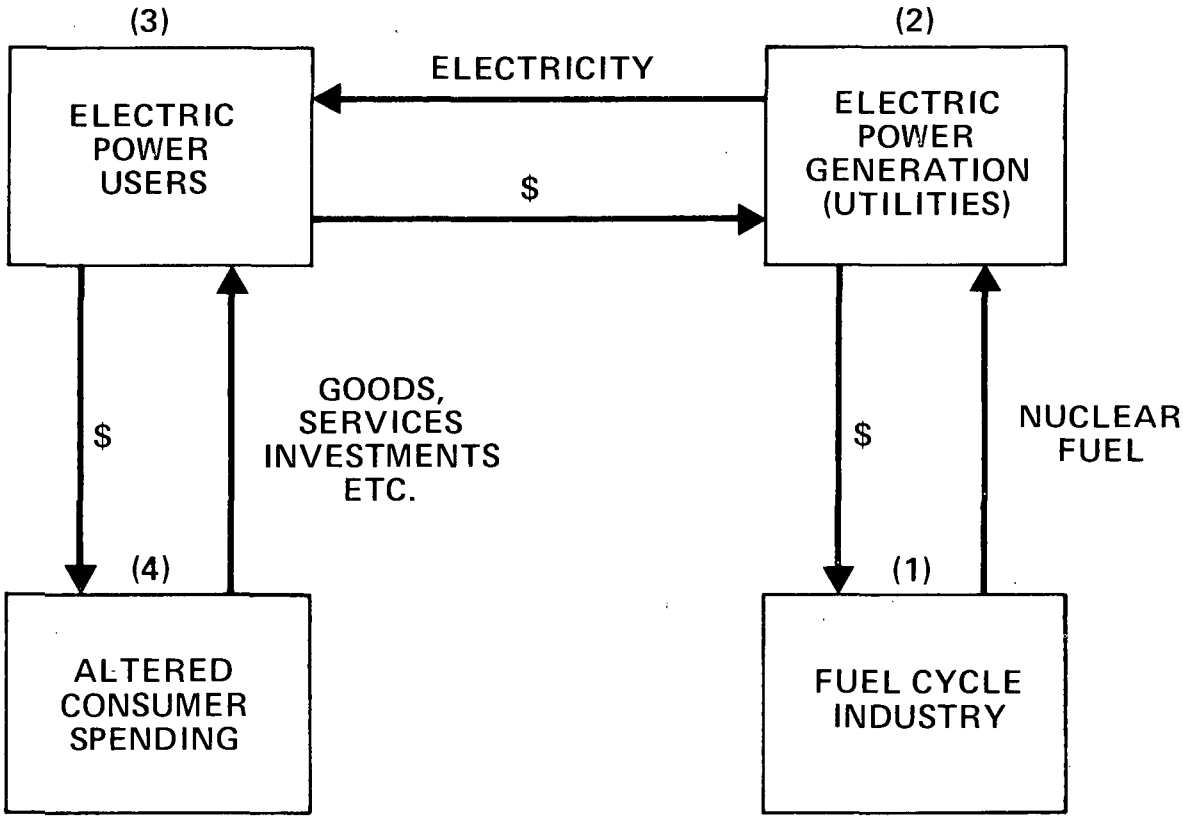


Figure XI-6 Dollar Flows Affected by Plutonium Recycle

it is a matter of evaluating a governmental decision (plutonium recycle) that will alter the cost of electric power and that in turn has the potential to alter the amount of money available for other consumer spending. The fundamental question is the present worth of a future reduction in the cost of electric power.

The cost-benefit analysis for the LMFBR Program Environmental Statement[28] used essentially the same discount rate, except that there it was necessary to justify large governmental research and development expenditures for the program. Their conclusion was that the discount rate should represent the time preference rate of society and should lie between the return on long term government bonds discounted for inflation and the average before-tax return on private capital discounted for inflation. This range was estimated to be 4 to 10%, with an average of 7%. However, the actual rates used in the analysis were 7.5 and 10%.

In another study of LMFBR economics, for the Commonwealth Edison Company, Stauffer et al.,[29] concluded that the appropriate discount rate should be the consumer's discount rate represented by a weighted sum of lending rates and borrowing rates. He noted that opinion regarding the actual value is divided and stated that "the upper bound of opinion was used--6% per year--after correcting for inflation."

Herfindahl and Kneese[30] recently reviewed some of the major positions regarding discount rates for public investments. Their final conclusion was that an average of the government bond rate and the return on private capital is justifiable.

Arrow[31] has argued that an optimal policy for public capital formation is one that equates the marginal productivity of public investment to the natural rate of interest. If this argument is applied, the resulting discount rates are similar to the time preference of society. These can be approximated on the low side by returns on long term government bonds, currently about 8%. On the high side, the rate is analogous to the 11% return on B-rated corporate bonds. Both of these rates need to be corrected for the perceived long term rate of inflation.

Gibson[32] has shown that the short term rates are very sensitive to the current rate of inflation (6%), while long term interest rates tend to discount inflation somewhat. An estimate of the current perception of the future rate of inflation can be derived from the return on long term U.S. Government securities (currently 8%) and the real rate of interest of about 4%. Applying this inflation correction one arrives at a range of 4 to 7% for the appropriate discount rates.

Another basis for the analysis of government investments is that put forth by Baumol[33] and also by Howe.[34] The philosophy of opportunity cost maintains that the appropriate discount rate for evaluating future alternatives is equal to the rates of return available to the individual or group who will be experiencing the future costs and benefits from the proposed alternative projects. If one applies this opportunity cost argument to the analysis, one must determine the opportunity costs of the consumers.

J. A. Stockfisch[35] analyzed data on return on private investments for the period 1949 through 1965. He estimated the rate of return before taxes in the corporate sector (including an estimated 1.5% effective property tax) to be 15% before correcting for inflation. He estimated the rate of return before taxes to the noncorporate sector to be 10% before correcting for inflation. He weighted the estimated return to the corporate and noncorporate sectors by a 40:60 ratio of investment in the corporate and noncorporate sectors, respectively, subtracted a 1.6% inflation adjustment, and concluded that the "real" opportunity rate of return is 10.4%.

A more recent and comprehensive study by Christensen and Jorgenson[36] measuring economic performance in the private sector provides the basis for another estimate of return. Their analysis of return on capital corrects for all the effects of inflation. Their data show a return before all taxes in the corporate sector of 13.7% for the 1950-1969 period. They subdivide the remaining data into three categories: (1) noncorporate, (2) households and institutions, and (3) net claims on governments and the rest of the world. Their data show returns before all taxes for these sectors at 8.0, 3.8, and 3.8%, respectively for the 1950-1969 period. Weighting all four categories 27:19:37:17 (corporate:noncorporate:households and institutions:net claims on governments) based on relative assets in these sectors for the same period produces an estimated return before all taxes, or an estimate of opportunity rate of return of 7.2%.

Thus, using the opportunity cost approach one can derive a range of discount rates from 7 to 10%. If one uses the low end of the time preference range and the high end of the opportunity cost range, one has a 4 to 10% composite. The appropriate discount rate range for this analysis would be 4 to 10%. A midrange rate would be justified. However, to be conservative and avoid any possible overstatement of the benefits of plutonium recycle, a reference rate of 10% has been used. The alternatives are also evaluated at a low discount rate to investigate the sensitivity of this variable. Again, to avoid any criticism of possible over-statement of the value of recycle, 6% was chosen rather than 4%.

Late in the study seven eminent economists met for a one-day workshop, to discuss the appropriate range of discount values to be used. The opinion of the group was that a range of 4.5 to 10% was appropriate, with a reference discount value of 7%. Individual suggestions ranged from 0 to 15%. A summary of the workshop is included as Appendix E. Also tabulated in the appendix are the present worth values calculated for 0 to 15% discount rates. Table XI-33 below shows the effect of discount rates used in GESMO, which are within the panel's selected range.

A change in discount rate from the reference rate of 10 to 6% more than doubles the economic advantage of prompt plutonium recycle (Alternative 3) compared to the throwaway cycle (Alternative 6), showing an increase from $3.2 to $6.5 billion for the lower discount rate.

TABLE XI-33

EFFECT OF DISCOUNT RATE ON THE ECONOMIC ADVANTAGE FOR PLUTONIUM RECYCLE

	Total Fuel Cycle Cost ($ billions)	
	6% Discount Rate	10% Discount Rate
Throwaway Cycle (Alternative 6)	68.1	39.5
Prompt Recycle (Alternative 3)	61.6	36.3
	6.5	3.2

The combined effects of discount rate variations, delay in effecting plutonium recycle, and the method of storing the plutonium (i.e., either as spent fuel or as separated PuO_2) are shown in Figure XI-7. The data plotted here have been normalized by referring to the date MOX fuel fabrication starts. The delays are based on comparison with the earliest possible dates assumed in Alternative 3. From this comparison it is evident that choice of discount factor does not significantly alter the incentive for early recycle for delays of up to 5 to 6 years but becomes increasingly important for longer delays. In addition, in the event that plutonium is to be stored for later use, storage as spent fuel is clearly a better storage alternative than early reprocessing with subsequent storage of separated plutonium.

3.7 Influences of Delays in Plutonium Recycle

Based on this study, plutonium recycle has an economic advantage over other options for the disposal of plutonium, and delays in recycling are likewise economically unfavorable. Increasing delays are increasingly unfavorable. The magnitude of the economic impacts of delayed recycle are also affected by the discount rate, and the form of storage (store spent fuel or store plutonium). The relationship of these factors is illustrated in Figure XI-7. For delay in recycle by storing either spent fuel or plutonium, fuel costs increase. The increased costs exceed $1 billion for the plutonium storage option and exceed $0.3 to $0.4 billion for the spent fuel storage option if recycle is delayed past 1990. The increased costs would continue to increase at an exponential rate with further delays after 1990.

3.7.1 Influence of Discount Rate

As discussed in Section 3.6, increasing the discount rate decreases the economic impact of delaying recycle. However, at any reasonable discount rate, delaying recycle beyond 1990 results in very large cost penalties. The economic impacts of discount rates of 6% and 10% are shown in Figure XI-7.

3.7.2 Influence of Plutonium Storage Options

Two storage options were evaluated: storage as plutonium oxide and storage of

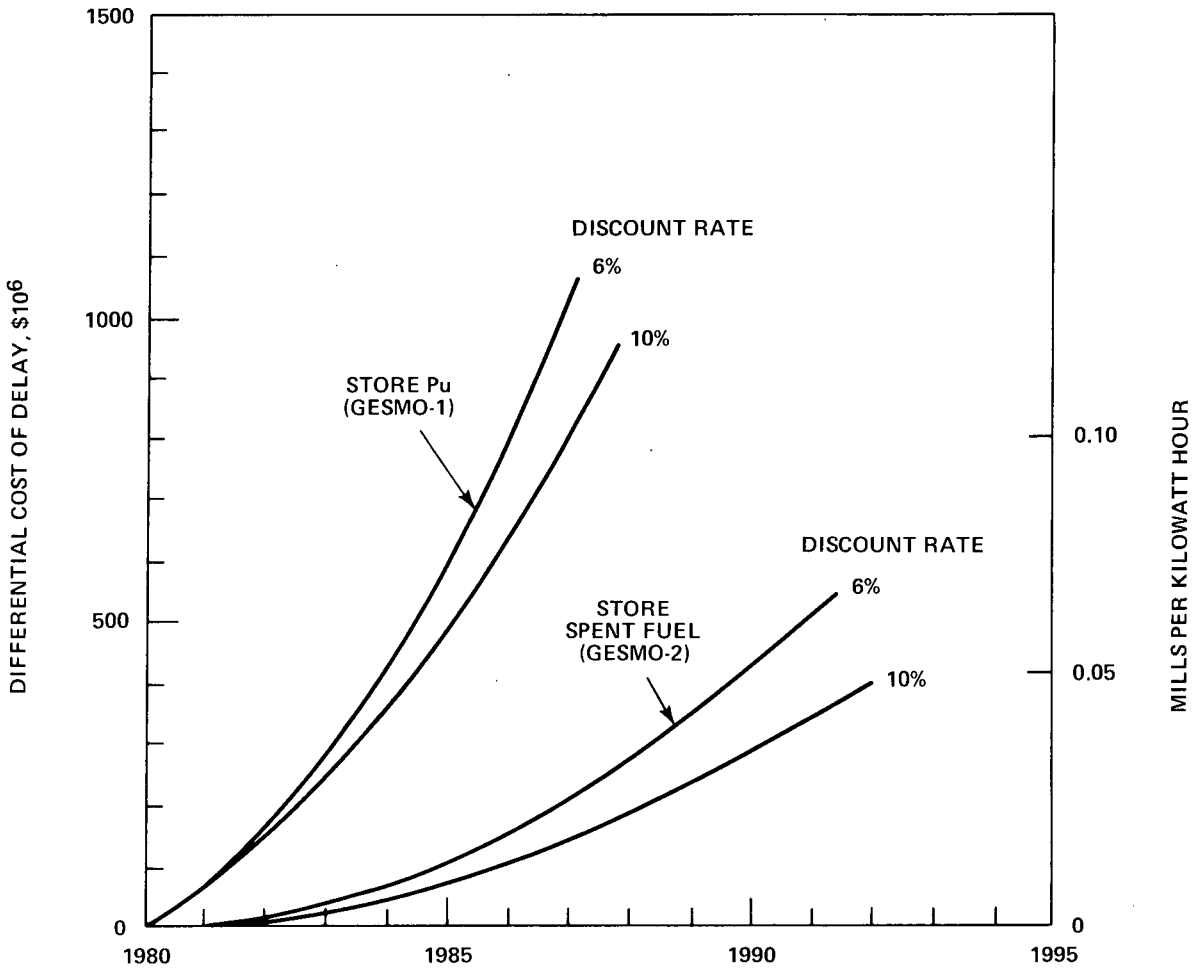


FIGURE XI-7 Effect of Plutonium Recycle Delay as a Function of Plutonium Storage Option and Discount Rate

irradiated fuel elements. Figure XI-7 illustrates the effects of both delays and discount rates. Storage of the plutonium as spent fuel is the best option if recycle delay cannot be avoided.

3.7.2.1 Storage as Plutonium Oxide

In this storage option (Alternative 1), the irradiated fuel is reprocessed in 1978 and the plutonium is stored as oxide until recycle. Since the large reprocessing costs are incurred early, with little immediate economic benefit, this storage option is uneconomic compared to storage as spent fuel. This can be seen in Figure XI-7. Under the plutonium oxide storage option, a delay in plutonium recycle to 1983 results in a present-worth economic penalty of about $150 million (at a 10% discount rate). The present-worth penalty reaches $800 million with an added delay to 1988. Under any recycle delay, plutonium oxide storage is less favorable, economically, than spent fuel storage.

3.7.2.2 Storage as Irradiated Fuel Elements

As can be seen in Figure XI-7, storing spent fuel (Alternative 2) is more attractive than storing plutonium since the large costs incurred for reprocessing are delayed until the benefits of using the plutonium can be realized. In fact the results of this analysis show that if reprocessing is delayed until 1981 and recycle commenced as soon thereafter as possible, the present-worth fuel cycle costs ($36.3 billion) are essentially the same as those for the reference case (Alternative 3) when reprocessing starts in 1978 and plutonium recycle is delayed until 1981. However, an analysis such as this ignores the micro effects (which are real ones) associated with the loss of income from recycle plants already built.

Under this storage option, a further delay of 5 years in plutonium recycle to 1986 results in a present-worth economic penalty of about $74 million. However, a delay in recycle to 1991 results in a present-worth economic penalty somewhat in excess of $300 million (at 10% discount rate). The economic penalties increase more rapidly for longer delays.

3.8 Effects of ^{242}Pu and ^{236}U

Corrections have been made to the NUFUEL program for the effects of ^{242}Pu and ^{236}U. See Section 5.2 of CHAPTER VIII. It has been estimated from NUCOST calculations that the undiscounted cost of the ^{242}Pu effect is about $1.2 billion for the reference case. The corresponding penalty for the ^{236}U effect is about $2.8 billion.

3.9 Effect of Constrained Reprocessing Buildup

A basic assumption in all of the comparisons discussed up to this point has been that reprocessing capability would catch up by the end of the century, the year 2000, so that the total quantity of fuel reprocessed would be equal in all comparisons. This type of growth of reprocessing capacity is considered normal since the demand will be guaranteed with a 1-year backlog in sight. This requires a more rapid

buildup of reprocessing capacity in cases where start of reprocessing is delayed. In order to test the sensitivity of the results of the above assumption, two pairs of cases were run with delayed reprocessing startup dates and with the subsequent growth rate of reprocessing capacity constrained to the same as that of the reference case (1978 startup) in one of each pair of cases.

As expected, the constrained reprocessing cases were more costly. However, when credit is taken for the discounted net values of the unreprocessed spent fuel, the difference in cost is substantially reduced. This is shown in Table XI-34.

Table XI-34

EFFECT OF CONSTRAINED REPROCESSING CAPACITY

	Discounted Total Fuel Cycle Cost ($ millions)	
Reprocessing Date	1981	1986
Constrained Reprocessing	36,660	37,310
Credit for Discounted Net Value in Unreprocessed Fuel	280	460
Net Cost with Constrained Reprocessing	36,380	36,850
Normal Reprocessing	36,310	36,410
Net Disadvantage	70	440

The net value of the unreprocessed spent fuel is defined in the following relationship:

Net value = U value + Pu value - reprocessing cost - waste disposal cost - fuel storage cost.

Calculation of the net value present-worth was based on year of recovery. The uranium and plutonium values were based on the unit values in the year 2000.

Thus the net disadvantage of delayed reprocessing for a constrained reprocessing case would add to the differential cost, shown in Figure XI-7. This would result in a much steeper slope in the curve representing the effect of delayed recycle based on the spent fuel storage option, which would then tend to fall near the curve for plutonium storage.

3.10 Effect of the Fast Breeder Reactor (FBR)

As discussed in CHAPTER VIII, paragraph 5.2, the NUFUEL program was used to calculate material flows for this analysis. The ERDA forecast encompassed by NUFUEL includes the advent of a commercial FBR in 1993. Since the FBR needs the plutonium generated in LWR's for startup, this transfer of material from one fuel cycle to another can cause some analytical complications. In order to ensure that there was

no cross impact between the two technologies, NUFUEL was rerun with all FBR additions removed. The low growth scenario without FBR, then, is the basis for most of the analyses in this report.

The reference alternative (prompt recycle) was analyzed by NUCOST, both without the FBR and with the FBR, cases* 36 and 46, respectively. The results of these analyses are illustrated in Tables XI-35 and XI-36. If all of the flow and cost corrections have been properly entered, there should be no difference between the total cost of the two cases. As can be seen from the total discounted process costs, there is only a slight difference between the two answers: $36,334 million for case 46 vs $36,332 million for case 36. This result is to be expected, for the plutonium transfers to the FBR were made at the "indifference" value (the plutonium price that makes no difference to the total system costs; the method by which this price was derived is discussed in detail in paragraph 6.4 of Chapter VIII).

As is to be expected, when the LWR industry recycles all of its own plutonium (case 36) as compared to transferring part of it to the FBR (case 46), a reduction in the demand for U_3O_8 is realized. This reduction of 64,000 short tons amounts to a total cost saving of about $4.4 billion. Discounted at 10%, this is $0.55 billion. Likewise, a saving of 29,000 MT of separative work is realized. The reduced enrichment costs amount to a total of about $2.1 billion, or $0.262 billion discounted. The sales of plutonium to the FBR make up for these differences. The total sales in case 46 are over $6.2 billion as compared to the $0.2 billion sales to research reactors in case 36. This $6 billion difference in total plutonium credits amounts to about $0.73 billion discounted at 10%.

The analysis of the incentive to recycle plutonium as fuel in LWR's uses a value of plutonium as burned in an LWR. It can be argued that plutonium is neutronically more attractive for FBR use and hence should be worth more. Although it is reasonably certain that the FBR's (which need plutonium for their startup loads) will, if necessary, bid up the price of plutonium in the market place to ensure their supply of this fuel, it is not sound economics to assume that they will pay large premiums to purchase the plutonium. If some arbitrarily high value of plutonium is used for these calculations, it, in essence, gives the LWR industry credit for plutonium recycle in an entirely different technology in which the value of plutonium is yet to be determined. Hence the results are both economically and technologically deficient when such assumptions are used.

3.11 Effect of Study Time Period

As has been discussed earlier, the selection of an appropriate time period for an analysis of this sort requires certain tradeoffs. If the time period is too short, the industry does not have time to mature; in such cases delayed program costs or benefits may not be properly reflected in the analysis. Likewise, a short time

*The combination of scenarios and alternatives is handled by a "case" number. Prompt recycle (Alternative 3) under the low growth, no-FBR scenario is designated "case 36." Under the low growth with FBR scenario it is designated "case 46."

TABLE XI-35

SECTION 1. PROCESS FLOW

ALT III - CASE 36 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR

YEAR	MINING MILLING 1000 ST	UF6 CONVR 1000 MTU	ENRICHMNT 1000 MT-SWU	U FUEL FAB MTU	SPENT FUEL TRAN MT-HM	REPROCESS MT-HM	PU TRANS KG-TOT	INCR PU STORAGE KG-TOT	MOX FAB MT-HM	INCR SPENT FUEL STOR MT-HM	WASTE DISPOSAL MT-HM W/O PU	PU SALES KG FISS	SPENT FUEL DISP MT-HM
75	10.5	6.2	3.6	919.	0.	0.	0.	0.	0.	1167.	0.	0.	0.
76	13.4	10.4	4.8	1337.	0.	0.	0.	0.	0.	1962.	0.	0.	0.
77	14.8	11.5	5.7	1758.	500.	0.	0.	0.	0.	2917.	0.	0.	0.
78	16.7	13.0	5.9	1972.	999.	500.	0.	1928.	0.	3514.	0.	0.	0.
79	19.6	14.6	7.6	2345.	1499.	999.	0.	5918.	0.	3737.	0.	1000.	0.
80	21.7	16.5	8.6	3106.	1498.	1499.	4665.	10247.	75.	3568.	0.	1200.	0.
81	24.2	17.3	9.5	2570.	1748.	1498.	12930.	7452.	255.	3644.	0.	1200.	0.
82	26.6	19.2	10.5	3896.	1998.	1748.	20486.	0.	413.	3686.	0.	1000.	0.
83	32.9	22.5	11.6	4137.	2249.	1998.	15960.	0.	395.	3951.	500.	800.	0.
84	38.3	27.1	15.3	5230.	2248.	2249.	17996.	0.	378.	4143.	999.	750.	0.
85	39.7	30.2	16.2	5383.	2849.	2248.	20535.	140.	437.	4836.	1499.	400.	0.
86	42.8	32.0	16.9	5347.	3549.	2849.	25527.	232.	602.	5463.	1498.	300.	0.
87	47.6	35.8	19.4	6012.	4249.	3549.	33039.	39.	692.	6035.	1748.	250.	0.
88	51.8	38.3	21.0	6787.	4249.	4249.	36675.	0.	716.	6394.	1998.	250.	0.
89	55.6	41.4	23.1	6931.	4846.	4249.	37983.	0.	886.	7072.	2249.	250.	0.
90	58.6	43.7	24.3	7725.	5545.	4846.	47090.	30.	981.	7659.	2249.	250.	0.
91	61.7	45.1	26.0	8193.	6248.	5545.	56927.	362.	1251.	8284.	2849.	250.	0.
92	65.1	48.2	27.5	8577.	6848.	6248.	64161.	200.	1387.	8705.	3549.	250.	0.
93	68.0	50.6	29.3	9126.	7548.	6848.	71174.	141.	1565.	9007.	4249.	250.	0.
94	70.1	51.0	30.5	9471.	8248.	7548.	80981.	116.	1771.	9258.	4249.	250.	0.
95	73.1	53.4	31.8	9612.	8248.	8248.	87050.	200.	2022.	9411.	4846.	250.	0.
96	76.1	56.5	33.5	10087.	9248.	8248.	88971.	0.	2004.	10152.	5545.	250.	0.
97	76.7	57.0	34.6	10512.	10248.	9248.	94142.	0.	2040.	10470.	6248.	250.	0.
98	77.3	56.8	34.7	10620.	10248.	10248.	110231.	1893.	2281.	10295.	6848.	250.	0.
99	78.9	57.7	35.4	10683.	10248.	10248.	117752.	2640.	2532.	10557.	7548.	250.	0.
0	80.5	59.3	36.1	10846.	10248.	10248.	122637.	2996.	2647.	11224.	8248.	250.	0.
TOT	1241.9	915.5	523.2	163242.	125406.	115158.	1166879.	34520.	25330.	167170.	66918.	10150.	0.

SECTION 2. PROJECTED UNIT COST

ALT III - CASE 36 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR

YEAR	U3O8 AS BURNED $/LB	U CONVR $/KG-U	SEP WORK $/SWU	U FAB $/KG-U	SPENT FUEL TRAN $/KG-HM	INCR SPENT FUEL STOR $/KG-HM-YR	REPRO $/KG-HM	PU TRAN $/G-TOT	INCR PU STORAGE $/G-TOT	MOX FAB $/KG-HM	WASTE DISPOSAL $/KG-HM W/O PU	PU VALUE $/G FISS	SPENT FUEL DISP $/KG-HM
75	10.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
76	10.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
77	11.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
78	12.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
79	15.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	18.56	100.0
80	17.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	20.42	100.0
81	19.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	21.48	100.0
82	20.8	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	22.10	100.0
83	21.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	22.56	100.0
84	22.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	22.97	100.0
85	23.4	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	23.47	100.0
86	25.5	3.5	75.0	95.0	15.1	5.0	150.7	0.04	2.00	200.0	50.0	24.58	100.0
87	28.5	3.5	75.0	95.0	15.3	5.0	152.7	0.04	2.00	200.0	50.0	26.21	100.0
88	28.5	3.5	75.0	95.0	15.3	5.0	152.9	0.04	2.00	200.0	50.0	26.21	100.0
89	28.5	3.5	75.0	95.0	15.3	5.0	152.6	0.04	2.00	200.0	50.0	26.21	100.0
90	28.5	3.5	75.0	95.0	15.2	5.0	152.0	0.04	2.00	200.0	50.0	26.21	100.0
91	28.5	3.5	75.0	95.0	15.2	5.0	152.3	0.04	2.00	200.0	50.0	26.21	100.0
92	28.5	3.5	75.0	95.0	15.3	5.0	153.0	0.04	2.00	200.0	50.0	26.21	100.0
93	28.5	3.5	75.0	95.0	15.3	5.0	153.1	0.04	2.00	200.0	50.0	26.21	100.0
94	29.9	3.5	75.0	95.0	15.3	5.0	152.9	0.04	2.00	200.0	50.0	26.96	100.0
95	32.5	3.5	75.0	95.0	15.3	5.0	153.4	0.04	2.00	200.0	50.0	28.36	100.0
96	33.0	3.5	75.0	95.0	15.3	5.0	153.4	0.04	2.00	200.0	50.0	28.62	100.0
97	33.0	3.5	75.0	95.0	15.4	5.0	154.0	0.04	2.00	200.0	50.0	28.62	100.0
98	33.0	3.5	75.0	95.0	15.4	5.0	154.2	0.04	2.00	200.0	50.0	28.62	100.0
99	33.0	3.5	75.0	95.0	15.4	5.0	154.4	0.04	2.00	200.0	50.0	28.62	100.0
0	33.1	3.5	75.0	95.0	15.5	5.0	154.7	0.04	2.00	200.0	50.0	28.66	100.0
WT AVE.	28.1	3.5	75.0	95.0	15.3	5.0	153.0	0.04	2.00	200.0	50.0	23.53	0.0

TABLE XI-35 (CONTINUED)

SECTION 3. PROJECTED COSTS FOR MATERIALS AND SERVICES
(IN MILLIONS OF 1975 DOLLARS)

ALT III - CASE 36 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	286.2	36.	359.	127.	0.	0.	0.00	0.00	0.	10.	0.	0.	0.	818.
77	325.2	40.	430.	167.	7.	0.	0.00	0.00	0.	15.	0.	0.	0.	985.
78	401.5	46.	446.	187.	15.	75.	0.00	3.86	0.	18.	16.	0.	0.	1208.
79	507.5	51.	572.	223.	22.	150.	0.00	11.84	0.	19.	31.	-19.	0.	1648.
80	769.2	58.	646.	295.	22.	225.	0.19	20.49	15.	18.	47.	-25.	0.	2091.
81	954.6	61.	709.	244.	26.	225.	0.52	14.90	51.	18.	47.	-26.	0.	2325.
82	1100.1	67.	789.	370.	30.	262.	0.82	0.00	83.	18.	54.	-22.	0.	2760.
83	1396.7	79.	866.	393.	34.	300.	0.64	0.00	79.	20.	62.	-18.	0.	3211.
84	1723.2	95.	1146.	497.	34.	337.	0.72	0.00	76.	21.	70.	-17.	0.	3981.
85	1859.2	106.	1217.	511.	43.	337.	0.82	0.28	87.	24.	70.	-9.	0.	4246.
86	2180.6	112.	1267.	508.	53.	429.	1.02	0.44	120.	27.	88.	-7.	0.	4781.
87	2716.0	125.	1455.	571.	65.	542.	1.32	0.08	138.	30.	110.	-7.	0.	5748.
88	2955.2	134.	1574.	645.	65.	650.	1.47	0.00	143.	33.	132.	-7.	0.	6324.
89	3167.6	145.	1734.	664.	74.	648.	1.52	0.00	177.	36.	132.	-7.	0.	6773.
90	3343.0	153.	1826.	734.	84.	737.	1.88	0.06	196.	39.	150.	-7.	0.	7257.
91	3518.2	158.	1948.	778.	95.	844.	2.20	0.72	250.	41.	172.	-7.	0.	7802.
92	3709.2	169.	2061.	815.	105.	956.	2.57	0.40	277.	44.	194.	-7.	0.	8326.
93	3875.7	177.	2196.	867.	116.	1048.	2.85	0.28	313.	45.	213.	-7.	0.	8847.
94	4195.6	179.	2284.	900.	126.	1154.	3.24	0.23	354.	46.	234.	-7.	0.	9470.
95	4755.8	187.	2382.	913.	127.	1265.	3.48	0.40	404.	47.	256.	-7.	0.	10334.
96	5021.6	198.	2509.	958.	142.	1265.	3.56	0.00	401.	51.	256.	-7.	0.	10797.
97	5065.4	200.	2593.	999.	158.	1424.	3.77	0.00	408.	52.	287.	-7.	0.	11183.
98	5098.5	199.	2603.	1009.	158.	1580.	4.41	3.79	456.	51.	318.	-7.	0.	11474.
99	5209.2	202.	2656.	1015.	158.	1582.	4.71	5.20	506.	53.	318.	-7.	0.	11703.
0	5326.3	208.	2707.	1030.	159.	1586.	4.91	5.99	529.	56.	318.	-7.	0.	11923.
TOT	69774.0	3204.	39242.	15508.	1918.	17621.	46.68	69.04	5066.	836.	3575.	-239.	0.	156622.

SECTION 4. DISCOUNTED PROCESS COSTS
(IN MILLIONS OF 1975 DOLLARS)

ALT III - CASE 36 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR
DISCOUNT RATE =0.100

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	260.2	33.	326.	115.	0.	0.	0.00	0.00	0.	9.	0.	0.	0.	744.
77	268.8	33.	356.	138.	6.	0.	0.00	0.00	0.	13.	0.	0.	0.	814.
78	301.6	34.	335.	141.	11.	56.	0.00	2.90	0.	13.	12.	0.	0.	907.
79	401.3	35.	391.	152.	15.	102.	0.00	8.08	0.	13.	21.	-13.	0.	1126.
80	477.6	36.	401.	103.	14.	140.	0.12	12.72	9.	11.	29.	-15.	0.	1298.
81	538.9	34.	400.	138.	15.	127.	0.29	8.41	29.	10.	26.	-15.	0.	1312.
82	568.6	35.	405.	190.	15.	135.	0.42	0.00	42.	9.	28.	-11.	0.	1416.
83	651.6	37.	404.	183.	16.	140.	0.30	0.00	37.	9.	29.	-8.	0.	1498.
84	730.8	40.	486.	211.	14.	143.	0.31	0.00	32.	9.	30.	-7.	0.	1689.
85	716.8	41.	469.	197.	16.	130.	0.32	0.11	34.	9.	27.	-4.	0.	1637.
86	764.3	39.	444.	178.	19.	150.	0.36	0.16	42.	10.	31.	-3.	0.	1676.
87	865.4	40.	464.	182.	21.	173.	0.42	0.02	44.	10.	35.	-2.	0.	1831.
88	856.0	39.	456.	187.	19.	188.	0.42	0.00	41.	9.	38.	-2.	0.	1832.
89	834.1	38.	457.	175.	19.	171.	0.40	0.00	47.	9.	35.	-2.	0.	1783.
90	800.3	37.	437.	176.	20.	176.	0.45	0.01	47.	9.	36.	-2.	0.	1737.
91	765.7	34.	424.	169.	21.	184.	0.50	0.16	54.	9.	37.	-1.	0.	1698.
92	733.8	33.	408.	161.	21.	189.	0.51	0.08	55.	9.	38.	-1.	0.	1647.
93	697.1	32.	395.	156.	21.	189.	0.51	0.05	56.	8.	38.	-1.	0.	1591.
94	686.0	29.	373.	147.	21.	189.	0.53	0.04	58.	8.	38.	-1.	0.	1548.
95	706.9	28.	354.	136.	19.	188.	0.52	0.06	60.	7.	38.	-1.	0.	1536.
96	678.6	27.	339.	129.	19.	171.	0.48	0.00	54.	7.	35.	-1.	0.	1459.
97	622.3	25.	319.	123.	19.	175.	0.46	0.00	50.	6.	35.	-1.	0.	1374.
98	569.4	22.	291.	113.	18.	176.	0.49	0.42	51.	6.	36.	-1.	0.	1281.
99	528.9	21.	270.	103.	16.	161.	0.48	0.54	51.	5.	32.	-1.	0.	1188.
0	491.6	19.	250.	95.	15.	146.	0.45	0.55	49.	5.	29.	-1.	0.	1100.
TOT	15741.2	842.	9919.	3966.	410.	3599.	8.73	34.32	944.	228.	734.	-93.	0.	36332.

NET GENERATION 35357., BILLIONS KWH
LEVELIZED FUEL CYCLE COST, MILLS/KWH

1.930	0.103	1.216	0.486	0.050	0.441	0.001	0.004	0.116	0.023	0.090	-0.011	0.000	4.455

TABLE XI-36

SECTION 1. PROCESS FLOW

ALT III - CASE 46 - LOW GROWTH - 70% CF - 1978 REPROCESSING - 1981 REC

YEAR	MINING MILLING 1000 ST	UF6 CONVR 1000 MTU	ENRICHMNT 1000 MT-SWU	U FUEL FAB MTU	SPENT FUEL TRAN MT-HM	REPROCESS MT-HM	PU TRANS KG-TOT	INCR PU STORAGE KG-TOT	MOX FAB MT-HM	INCR SPENT FUEL STOR MT-HM	WASTE DISPOSAL MT-HM W/O PU	PU SALES KG FISS	SPENT FUEL DISP MT-HM
75	10.5	6.2	3.6	919.	0.	0.	0.	0.	0.	1167.	0.	0.	0.
76	13.4	10.4	4.8	1337.	0.	0.	0.	0.	0.	1962.	0.	0.	0.
77	14.8	11.5	5.7	1758.	500.	0.	0.	0.	0.	2917.	0.	0.	0.
78	16.7	13.0	5.9	1972.	999.	500.	0.	1928.	0.	3514.	0.	0.	0.
79	19.6	14.6	7.6	2345.	1499.	999.	0.	5918.	0.	5737.	0.	1000.	0.
80	21.7	16.5	8.6	3106.	1498.	1499.	4665.	10247.	75.	5568.	0.	1200.	0.
81	24.2	17.3	9.5	2570.	1748.	1498.	12930.	7452.	255.	5644.	0.	1200.	0.
82	26.6	19.2	10.5	3896.	1998.	1749.	20406.	0.	413.	5686.	0.	1000.	0.
83	32.2	22.5	11.6	4137.	2249.	1998.	15960.	0.	395.	3951.	500.	800.	0.
84	38.3	27.1	15.3	5230.	2248.	2249.	17996.	0.	378.	4143.	999.	750.	0.
85	39.7	30.2	16.2	5383.	2849.	2248.	20535.	140.	437.	4836.	1499.	400.	0.
86	42.9	32.0	16.9	5347.	3549.	2849.	25527.	222.	602.	5483.	1498.	300.	0.
87	47.8	35.9	19.4	6021.	4249.	3549.	32474.	42.	683.	6035.	1748.	250.	0.
88	52.0	38.4	21.1	6813.	4249.	4249.	35055.	0.	690.	6394.	1998.	1752.	0.
89	55.8	41.6	23.1	7009.	4846.	4249.	37616.	0.	868.	7072.	2249.	250.	0.
90	59.2	44.0	24.5	7759.	5545.	4846.	45252.	30.	947.	7698.	2248.	1159.	0.
91	62.6	46.0	26.3	8276.	6248.	5545.	52827.	576.	1169.	8284.	2849.	2315.	0.
92	66.5	48.9	27.9	8694.	6848.	6248.	58509.	434.	1270.	8705.	3549.	3485.	0.
93	70.7	52.7	30.1	9343.	7548.	6848.	60812.	399.	1349.	9007.	4249.	5370.	0.
94	74.5	54.6	32.1	9894.	8248.	7548.	60326.	632.	1349.	9258.	4249.	12036.	0.
95	79.2	58.3	34.1	10296.	8248.	8248.	57017.	1061.	1338.	9411.	4846.	17314.	0.
96	84.0	63.0	36.7	10997.	9248.	8248.	47457.	483.	1094.	10152.	5545.	25270.	0.
97	86.2	65.3	38.8	11619.	10248.	9248.	41561.	0.	933.	10470.	6248.	31988.	0.
98	87.2	65.5	39.5	11866.	10248.	10248.	49883.	0.	1035.	10295.	6848.	38644.	0.
99	89.3	66.8	40.3	12016.	10248.	10248.	56840.	0.	1199.	10557.	7548.	36326.	0.
0	90.7	68.4	41.4	13264.	10248.	10248.	55716.	0.	1228.	11224.	8248.	37978.	0.
TOT	1386.4	970.1	551.6	170867.	125406.	115158.	809360.	29561.	17707.	167170.	66918.	220787.	0.

SECTION 2. PROJECTED UNIT COST

ALT III - CASE 46 - LOW GROWTH - 70% CF - 1978 REPROCESSING - 1981 REC

YEAR	U3O8 AS BURNED $/LB	U CONVR $/KG-U	SEP WORK $/SWU	U FAB $/KG-U	SPENT FUEL TRAN $/KG-HM	INCR SPENT FUEL STOR $/KG-HM-YR	REPRO $/KG-HM	PU TRAN $/G-TOT	INCR PU STORAGE $/G-TOT	MOX FAB $/KG-HM	WASTE DISPOSAL $/KG-HM W/O PU	PU VALUE $/G FISS	SPENT FUEL DISP $/KG-HM
75	10.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
76	10.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
77	11.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
78	12.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	0.00	100.0
79	15.0	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	18.96	100.0
80	17.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	20.42	100.0
81	19.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	21.48	100.0
82	20.8	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	22.10	100.0
83	21.7	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	22.56	100.0
84	22.5	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	22.97	100.0
85	23.4	3.5	75.0	95.0	15.0	5.0	150.0	0.04	2.00	200.0	50.0	23.47	100.0
86	25.5	3.5	75.0	95.0	15.1	5.0	150.7	0.04	2.00	200.0	50.0	24.58	100.0
87	28.5	3.5	75.0	95.0	15.3	5.0	152.7	0.04	2.00	200.0	50.0	26.21	100.0
88	28.5	3.5	75.0	95.0	15.3	5.0	152.9	0.04	2.00	200.0	50.0	26.21	100.0
89	28.5	3.5	75.0	95.0	15.3	5.0	152.6	0.04	2.00	200.0	50.0	26.21	100.0
90	28.5	3.5	75.0	95.0	15.2	5.0	152.0	0.04	2.00	200.0	50.0	26.21	100.0
91	28.5	3.5	75.0	95.0	15.2	5.0	152.3	0.04	2.00	200.0	50.0	26.21	100.0
92	28.5	3.5	75.0	95.0	15.3	5.0	153.0	0.04	2.00	200.0	50.0	26.21	100.0
93	28.5	3.5	75.0	95.0	15.3	5.0	153.1	0.04	2.00	200.0	50.0	26.23	100.0
94	30.0	3.5	75.0	95.0	15.3	5.0	152.8	0.04	2.00	200.0	50.0	27.01	100.0
95	32.9	3.5	75.0	95.0	15.3	5.0	153.3	0.04	2.00	200.0	50.0	28.59	100.0
96	33.0	3.5	75.0	95.0	15.3	5.0	153.3	0.04	2.00	200.0	50.0	28.62	100.0
97	33.0	3.5	75.0	95.0	15.4	5.0	153.7	0.04	2.00	200.0	50.0	28.62	100.0
98	33.0	3.5	75.0	95.0	15.4	5.0	153.8	0.04	2.00	200.0	50.0	28.62	100.0
99	33.0	3.5	75.0	95.0	15.4	5.0	153.8	0.04	2.00	200.0	50.0	28.62	100.0
0	33.7	3.5	75.0	95.0	15.4	5.0	153.6	0.04	2.00	200.0	50.0	29.00	100.0
WT AVE.	28.4	3.5	75.0	95.0	15.3	5.0	152.8	0.04	2.00	200.0	50.0	28.22	0.0

TABLE XI-36 (CONTINUED)

SECTION 3. PROJECTED COSTS FOR MATERIALS AND SERVICES
(IN MILLIONS OF 1975 DOLLARS)

ALT III - CASE 46 - LOW GROWTH - 70% CF - 1978 REPROCESSING - 1981 REC

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	286.2	36.	359.	127.	0.	0.	0.00	0.00	0.	10.	0.	0.	0.	818.
77	325.2	40.	430.	167.	7.	0.	0.00	0.00	0.	15.	0.	0.	0.	985.
78	401.5	46.	446.	187.	15.	75.	0.00	3.86	0.	18.	16.	0.	0.	1208.
79	587.5	51.	572.	223.	22.	150.	0.00	11.84	0.	19.	31.	-19.	0.	1648.
80	769.2	58.	646.	295.	22.	225.	0.19	20.49	15.	18.	47.	-25.	0.	2091.
81	954.6	61.	709.	244.	26.	225.	0.52	14.90	51.	18.	47.	-26.	0.	2325.
82	1108.1	67.	789.	370.	30.	262.	0.82	0.00	83.	18.	54.	-22.	0.	2760.
83	1396.7	79.	866.	393.	34.	300.	0.64	0.00	79.	20.	62.	-18.	0.	3211.
84	1723.2	95.	1146.	497.	34.	337.	0.72	0.00	76.	21.	70.	-17.	0.	3981.
85	1859.2	106.	1217.	511.	43.	337.	0.82	0.28	87.	24.	70.	-9.	0.	4246.
86	2183.7	112.	1267.	508.	53.	429.	1.02	0.44	120.	27.	88.	-7.	0.	4784.
87	2727.3	126.	1458.	572.	65.	542.	1.30	0.08	137.	30.	110.	-7.	0.	5762.
88	2963.7	135.	1584.	647.	65.	650.	1.40	0.00	138.	32.	132.	-46.	0.	6301.
89	3179.3	146.	1736.	666.	74.	648.	1.50	0.00	174.	35.	132.	-7.	0.	6785.
90	3373.4	154.	1837.	737.	84.	737.	1.81	0.06	189.	38.	150.	-30.	0.	7272.
91	3566.1	161.	1973.	786.	95.	844.	2.11	1.15	234.	41.	172.	-61.	0.	7816.
92	3789.8	171.	2095.	826.	105.	956.	2.34	0.87	254.	44.	194.	-91.	0.	8346.
93	4037.4	184.	2257.	888.	116.	1048.	2.43	0.80	270.	45.	213.	-141.	0.	8919.
94	4470.7	191.	2406.	940.	126.	1153.	2.41	1.26	270.	46.	234.	-325.	0.	9516.
95	5222.1	204.	2559.	978.	136.	1264.	2.28	2.12	268.	47.	256.	-495.	0.	10434.
96	5545.5	221.	2754.	1045.	142.	1264.	1.90	0.97	219.	51.	256.	-723.	0.	10776.
97	5686.4	228.	2907.	1104.	158.	1422.	1.66	0.00	187.	52.	287.	-916.	0.	11117.
98	5753.7	229.	2964.	1127.	158.	1576.	2.00	0.00	207.	51.	318.	-1106.	0.	11280.
99	5892.7	234.	3020.	1142.	158.	1576.	2.27	0.00	240.	53.	318.	-1040.	0.	11595.
0	6113.3	239.	3106.	1165.	157.	1574.	2.23	0.00	246.	56.	318.	-1101.	0.	11876.
TOT	74141.1	3395.	41369.	16232.	1915.	17595.	32.37	59.12	3541.	836.	3575.	-6232.	0.	156461.

SECTION 4. DISCOUNTED PROCESS COSTS
(IN MILLIONS OF 1975 DOLLARS)

ALT III - CASE 46 - LOW GROWTH - 70% CF - 1978 REPROCESSING - 1981 REC
DISCOUNT RATE =0.100

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	260.2	33.	326.	115.	0.	0.	0.00	0.00	0.	9.	0.	0.	0.	744.
77	268.8	33.	356.	138.	6.	0.	0.00	0.00	0.	12.	0.	0.	0.	814.
78	301.6	34.	335.	141.	11.	56.	0.00	2.90	0.	13.	12.	0.	0.	907.
79	401.3	35.	391.	152.	15.	102.	0.00	8.08	0.	13.	21.	-13.	0.	1126.
80	477.6	36.	401.	183.	14.	140.	0.12	12.72	9.	11.	29.	-15.	0.	1298.
81	538.9	34.	400.	138.	15.	127.	0.29	8.41	29.	10.	26.	-15.	0.	1312.
82	568.6	35.	405.	190.	15.	135.	0.42	0.00	42.	9.	28.	-11.	0.	1416.
83	651.6	37.	404.	183.	16.	140.	0.30	0.00	37.	9.	29.	-8.	0.	1498.
84	730.8	40.	486.	211.	14.	143.	0.31	0.00	32.	9.	30.	-7.	0.	1689.
85	716.8	41.	469.	197.	16.	130.	0.32	0.11	34.	9.	27.	-4.	0.	1637.
86	765.4	39.	444.	178.	19.	150.	0.36	0.16	42.	10.	31.	-3.	0.	1677.
87	869.0	40.	465.	182.	21.	173.	0.41	0.03	44.	10.	35.	-2.	0.	1836.
88	858.5	39.	459.	187.	19.	188.	0.41	0.00	40.	9.	38.	-13.	0.	1825.
89	837.2	38.	457.	175.	19.	171.	0.40	0.00	46.	9.	35.	-2.	0.	1787.
90	807.6	37.	440.	176.	20.	176.	0.43	0.01	45.	9.	36.	-7.	0.	1741.
91	776.1	35.	429.	171.	21.	184.	0.46	0.25	51.	9.	37.	-13.	0.	1701.
92	749.8	34.	414.	163.	21.	189.	0.46	0.17	50.	9.	38.	-18.	0.	1651.
93	726.2	33.	406.	160.	21.	189.	0.44	0.14	49.	8.	38.	-25.	0.	1604.
94	731.0	31.	393.	154.	21.	189.	0.39	0.21	44.	8.	38.	-53.	0.	1556.
95	776.2	30.	380.	145.	19.	188.	0.34	0.32	40.	7.	38.	-74.	0.	1551.
96	749.4	30.	372.	141.	19.	171.	0.26	0.13	30.	7.	35.	-98.	0.	1456.
97	698.5	28.	357.	136.	19.	175.	0.20	0.00	23.	6.	35.	-112.	0.	1366.
98	642.6	26.	331.	126.	18.	176.	0.22	0.00	23.	6.	36.	-124.	0.	1260.
99	598.3	24.	307.	116.	16.	160.	0.23	0.00	24.	5.	32.	-106.	0.	1177.
0	564.2	22.	287.	108.	15.	145.	0.21	0.00	23.	5.	29.	-102.	0.	1096.
TOT	16290.8	866.	10181.	4055.	410.	3596.	6.97	33.64	756.	228.	734.	-825.	0.	36332.

NET GENERATION 35357., BILLIONS KWH
LEVELIZED FUEL CYCLE COST, MILLS/KWH

1.998	0.106	1.249	0.497	0.050	0.441	0.001	0.004	0.093	0.028	0.090	-0.101	0.000	4.455

period does not allow a realistic analysis of alternatives that entail a significant time displacement. For example, if this study period were to be shortened to 15 years (1975-1990), alternatives (such as Alternatives 2 and 5) that delay reprocessing to 1986 would be distorted in the analysis inasmuch as they are operable only over a 4-year time span.

The inverse of this tradeoff is a time period so long that it exceeds the ability to predict technological developments with a reasonable degree of confidence. Although an extended time period (say 50 years) would allow considerable flexibility for studying alternatives, it would project the industry so far into the future as to seriously strain confidence in the forecasts. For example, it could be conjectured that laser enrichment would be fully operable by the year 2000. This would have the effect of reducing the demand for uranium and would materially increase the projected span of LWR's in the economy. The discovery of vast new uranium resources or a new extraction technology could have a similar impact. On the other hand, an efficient fusion generator could reduce LWR's to a peaking role as their useful lives were run out.

Inclusion of costs and benefits accruing so far in the future could, rightfully, be challenged. A 1975-2000 time period was used in this analysis as appropriate for the study. However, it should be noted that with the industry still expanding in the year 2000, even with discounting at 10%, there are still significant benefits accruing at the end of the time period. This can be seen in Table XI-37.

Table XI-37

PERIOD-END RECYCLE INCENTIVES

Year	Total Annual* Incentive ($ millions)	10% Discounted* Annual Incentive ($ millions)
1995	1,150	171
1996	1,210	163
1997	1,340	164
1998	1,610	180
1990	2,140	217
2000	2,640	244

*Alternative 6 minus Alternative 3.

The additional benefit of recycling in the year 2000 is $2.64 billion, an increase of 23% over the 1999 benefit of $2.14 billion. One effect of discounting is the reduction of the relative importance of such distant entries; the discounted contributions increase only 12% from 1999 to 2000. In spite of the muting effect of discounting, there is still a large and significant contribution that can be expected from years beyond 2000. Since recycle is economically advantageous in the 1975-2000 period, it will be even more advantageous over its total lifetime.

3.12 Effect of Uncertainties in Fuel Cycle Costs

Plutonium recycle will save about $3.2 billion over spent fuel disposal. The projected savings and distribution of fuel cycle costs for these alternatives are summarized in Table XI-38. Uncertainties in each of the cost components could either increase or reduce the savings. The reference values and the range of uncertainties were discussed in Sections 2.1 through 2.10 for each of the fuel cycle cost components and are summarized in Table XI-39. The effects of these uncertainties on the incentive to recycle for the reference case (low growth rate nuclear industry) are shown in Table XI-40. If all of the adverse uncertainties tend toward their maximum values, then the throwaway cycle could attain an economic advantage of about $2.4 billion. Conversely, if the uncertainties all turn favorable to recycle to the maximum extent, recycle would attain an economic advantage of over $11 billion.

Table XI-38

FUEL CYCLE COST COMPARISON BETWEEN SPENT FUEL DISPOSAL AND THE REFERENCE CASE

(Millions of Dollars)

	Cost (Discounted at 10%)		
Item	Reference Case (Alt. 3, Case 36)	Spent Fuel Disposal (Alt. 6, Case 40)	Difference
Mining and Milling (U_3O_8)	15,740	20,420	+4,680
Conversion to UF_6	840	1,040	+200
Uranium Enrichment	9,920	11,120	+1,200
UO_2 Fuel Fabrication	3,970	4,410	+440
Increased Spent Fuel Storage	230	630	+400
Spent Fuel Disposal	--	1,660	+1,660
Spent Fuel Transportation	410	250	-160
Fuel Reprocessing	3,600	--	-3,600
Waste Disposal	730	--	-730
MOX Fuel Fabrication	940	--	-940
Increased Pu Storage	30	--	-30
Plutonium Transportation	10	--	-10
Plutonium Sales	90	--	+90
Total	36,330	39,530	--
Net Incentive to Recycle	--	--	+3,200

Table XI-39

MATERIAL AND SERVICE UNIT COSTS, 1975 DOLLARS

Parameter	Low	Reference	High
Mining and Milling, average $/lb U_3O_8*	14	28	56
Conversion to UF_6, $/kg U	3	3.5	4
Uranium Enrichment, $/SWU	60	75	110
UO_2 Fabrication, $/kg HM	85	95	105
MOX Fabrication, $/kg HM**	150	200	300
Spent Fuel Transportation, $/kg HM	5	15	30
Spent Fuel Storage, $/kg HM-yr	2	5	10
Reprocessing, $/kg HM***	110	150	190
Waste Disposal, $/kg HM†	30	50	70
Plutonium Transportation, $/g	0.02	0.04	0.06
Plutonium Storage, $/g-yr	1	2	3
Spent Fuel Disposal, $/kg††	50	100	150

*Use-weighted average cost (1975-2000), varies with consumption.

**Includes MOX shipping to reactor.

***Includes waste solidification.

†Includes waste shipment to Federal repository.

††Five years' spent fuel storage costs and shipping to repository are incurred in addition to disposal cost.

Table XI-40

POTENTIAL ECONOMIC IMPACT OF UNCERTAINTIES ON THE INCENTIVE TO RECYCLE FOR LOW-GROWTH INDUSTRY

Incentive to Recycle ($ Billions)

Total Through Year 2000 18.2

Present Worth at 10% 3.2

Parameter	Reference Value	Uncertainty	Impact Through Year 2000 on Present Worth*** Incentive, $ Billions Decrease	Increase
Mining and Milling (U_3O_8)	Avg $28/lb	+100%		+4.7
		-50%	-2.4	
Separative Work	$75/kg	+$35		+0.6
		-$15	-0.2	
Reprocessing	$150/kg	+$40	-1.0	
		-$40		+1.0
MOX Fabrication	$200/kg	+$100	-0.5	
		-$50		+0.2
Waste Disposal	$50/kg	+$20	-0.3	
		-$20		+0.3
Spent Fuel Disposal	$100/kg	+$50		+0.8
		-$50	-0.8	
Other Costs That Decrease Incentive**		Maximum		+0.5
		Minimum	-0.2	
Other Costs That Decrease Incentive**		Maximum	-0.2	
		Minimum		+0.1
	Total Change		-5.6	+8.2
	Reference Incentive to Recycle		+3.2	+3.2
	Maximum Range of Incentive to Recycle		-2.4	+11.4

*Summation of UF_6 conversion, U fuel fabrication, and spent fuel storage.

**Summation of spent fuel transportation, plutonium transportation, and plutonium storage.

***Costs discounted at 10%.

The cost of uranium is the single most important uncertainty; increases in the cost of uranium, which is the predominant trend that will tend to accelerate with increased demand, favor recycle. No realistic decrease in the cost of uranium, on the other hand, could be sufficient by itself to offset the economic advantages of recycle. The cost of reprocessing is the next most important uncertainty, followed closely by spent fuel disposal. Increases in the cost of reprocessing reduce the incentive to recycle, whereas increases in the cost of spent fuel disposal increase the incentive to recycle. The uncertainty in these three costs--uranium supply, spent fuel reprocessing, and spent fuel disposal--amounts to 75% of both the positive and negative uncertainties.

The range of values reported by ERDA in their draft report on LWR fuel recycle (see paragraph 2.6 of this chapter) for the sum of "chemical processing and waste disposal" is from $212/kg to $333/kg (in 1975 dollars) and is $33/kg higher than comparable NRC values. Ignoring any offsetting factors included in the ERDA report, these high range cost estimates would tend to decrease the incentives for Pu recycle. The highest value of $333/kg is comparable to an increase in the range of uncertainties from $80/kg to $110/kg in the sum of the ranges for the reprocessing, waste disposal, and "Other Costs that Decrease Incentive" items of Table XI-40. This is comparable to an overall decrease of $2.3 billion in the incentive to recycle, and would be $0.8 billion more than the value ($1.5 billion) that would be obtained from this table. Such a variation would have the effect of adding a like amount to the "Total Change" resulting in a value of minus $6.4 billion. In the highly unlikely event that all uncertainties occurred on the negative side, this would increase the negative incentive to recycle plutonium to minus $3.2 billion.

4.0 EFFECTS OF ALTERNATIVES ON ENVIRONMENTAL AND ECONOMIC FACTORS

4.1 Methodology

The nuclear projections described in CHAPTER VIII, paragraph 5.2, were prepared as input to the NUFUEL program. The spent fuel reprocessing and plutonium recycle assumptions representing the alternatives were incorporated into the program input. The output from NUFUEL provided the annual U_3O_8 and fuel cycle service requirements for the period 1975 through 2000. These data were used as input to the NUCOST program (described in CHAPTER VIII, paragraph 5.4). The unit costs for U_3O_8 and fuel cycle services (derived as described in this chapter, paragraph 2.2 through 2.11) were also provided to NUCOST. The annual cost for U_3O_8 and each fuel cycle service was computed and summed to obtain the total direct fuel cycle cost for each year in constant 1975 dollars. Each column was summed to obtain the total direct cost of U_3O_8, each service, and the fuel cycle. The present worth of each cost in each year was then computed and summed to obtain the total discounted direct costs. Environmental effects were calculated with the NUEN program, as described in Section 5.4 of CHAPTER VIII.

4.2 Comparison of Alternatives

Alternative 3 is taken as the reference case. This choice is somewhat arbitrary and is made for the purpose of comparing alternatives, one to the other. Alternative 3

has the lowest economic cost, and hence all cost comparisons are positive. In this section values are given for Alternative 3 and variations from it are noted for the other alternatives.

4.2.1 Materials Processed

The complete list of materials processed at each step of the fuel cycle for each year and each alternative is given in Section 2.0 of this chapter. The 26-year totals for each process step in the alternatives are compared in Table XI-41. The quantity of material processed in Alternative 3 is given in column 2 for each process step. The quantities processed for Alternative 1 minus the quantities processed for Alternative 3 are given in column 3 to serve as direct comparison. Alternatives 2, 5, and 6 are treated similarly. The delay cases (Alternatives 1 and 2) cause relatively minor increases in the uranium portion of the fuel cycle. Significant increases in storage requirements for spent fuel are seen in the long-delay (Alternative 2) case. Likewise, there are minor decreases in the plutonium recycle portion of the fuel cycle.

The plutonium disposal case (Alternative 5) sees about a 15% increase in the uranium portion of the fuel cycle, a significant increase in spent fuel storage requirements, and elimination of plutonium recycle. The plutonium is assumed to be buried in this case.

The throwaway case (Alternative 6) results in a 29% increase in U_3O_8 and UF_6 requirements, a 16% increase in separative work, a 15% increase in UO_2 fabrication, and more than twice the spent fuel storage capacity. The reprocessing and plutonium recycle portions of the fuel cycle are eliminated, and the waste disposal facilities are replaced by final spent fuel storage facilities. The decrease in spent fuel transportation of 49,000 MT results from the spent fuel's being stored for 5 years before shipping to the fuel element disposal site.

4.2.2 Environmental Considerations

The environmental effects for each step of the fuel cycle for each alternative are given in Appendix A of CHAPTER VIII. The environmental effects are compared in Table XI-42. Total values are reported for Alternative 3, the reference case, and incremental changes in each environmental effect are reported for Alternatives 5 and 6 relative to Alternative 3.

Alternatives 1 and 2 have environmental effects that are essentially identical with those of Alternative 3 and hence are not included. Note that for Alternative 5 the environmental effects generally increase except for certain gaseous releases. The dose commitments for the industry and the world's general population increase slightly. In comparing Alternative 5 to Alternative 3, the environmental effects that increase are more important than those that decrease; hence there is an environmental advantage in recycling plutonium and uranium as opposed to recycling uranium only.

Table XI-41

COMPARISON OF MATERIALS PROCESSED*

Process	Total Flow, Alternative 3	Incremental Flow Relative to Alternative 3			
		Alternative 1	Alternative 2	Alternative 5	Alternative 6
Mining and Milling, Short Tons U_3O_8	1,240,000	0	+300	+189,000	+357,000
Conversion to UF_6, MTU	916,000	0	+500	+167,000	+294,000
Enrichment, MTSWU	523,000	+100	-1,000	+90,000	+85,000
UO_2 Fabrication, MT U	163,000	+6	+170	+25,000	+25,000
MOX Fabrication, MT U+Pu	25,300	-2	-170	-25,000	-25,000
Spent Fuel Transportation, MT	125,000	0	-2	-2	-49,000
Reprocessing, MT	115,000	0	-2	-2	-115,000
Plutonium Transportation, MT	1,170	0	-9	-1,170	-1,170
Maximum Plutonium Storage, MT	10	+29	-10	-10	-10
Spent Fuel Storage, MT-years	167,000	0	+112,000	+112,000	+392,000
Waste Disposal, MT	66,900	0	-2	-2*	+12,300**

*Cumulative 1975-2000.

**The waste from Alternative 5 includes all the plutonium. From Alternative 6 it contains the plutonium and uranium.

Table XI-42

COMPARISON OF INTEGRATED ENVIRONMENTAL FACTORS, 1975-2000

Environmental Factor	Total Environmental Effect for Alternative 3 (Earliest Reprocessing and Recycle)	Incremental Environmental Effects	
		Alternative 5 (Delayed Reprocessing, No Pu Recycle)	Alternative 6 (No Reprocessing, No Recycle)
Resource Use:			
Occupied, (acre-yrs)	2.3×10^{7}	3.0×10^{6}	6.0×10^{6}
Disturbed (acres)	3.0×10^{5}	6.0×10^{4}	1.1×10^{5}
Committed (acres)	3.4×10^{4}	6.0×10^{3}	1.6×10^{4}
Water (gallons):			
Discharged to Air	3.5×10^{13}	0	0
Discharged to Water	8.6×10^{13}	3.0×10^{12}	2.0×10^{12}
Discharged to Ground	2.3×10^{12}	4.0×10^{11}	7.0×10^{11}
Total Discharged	1.2×10^{14}	1.0×10^{12}	1.0×10^{13}
Heat Dissipated (Btu):	2.9×10^{17}	0	0
Coal (tons)	3.1×10^{6}	6.0×10^{5}	6.0×10^{5}
Gas, (therms)	1.0×10^{10}	2.0×10^{9}	3.0×10^{9}
Fuel Oil, (gallons)	2.0×10^{10}	0	-1.0×10^{9}
Electricity (GWy)	3.8×10^{2}	0	0

Table XI-42 (continued)

Environmental Factor	Total Environmental Effect for Alternative 3 (Earliest Reprocessing and Recycle)	Incremental Environmental Effects	
		Alternative 5 (Delayed Reprocessing, No Pu Recycle)	Alternative 6 (No Reprocessing, No Recycle)
Coal Equivalent of 2/3 GWy Electricity Used:			
Coal Burned (tons)	8.9×10^8	1.0×10^7	1.0×10^7
Sludge, (tons)	1.2×10^8	0	0
SO_x to Atmosphere (MT)	1.0×10^7	0	0
NO_x to Atmosphere (MT)	8.1×10^6	1.0×10^5	0
CO to Atmosphere (MT)	1.6×10^5	0	0
Particulates to Atmosphere (MT)	4.9×10^5	0	0
Hydrocarbons, (MT)	8.1×10^4	1.0×10^3	0
Plant Effluents to Atmosphere (metric tons):			
SO_x	6.3×10^5	2.0×10^4	2.0×10^4
NO_x	5.4×10^5	3.0×10^4	-2.0×10^4
CO	2.5×10^4	0	-2.0×10^3
Particulates	1.1×10^5	1.0×10^4	1.0×10^4
NH_3	3.6×10^2	80	1.1×10^2
Fluoride	5.3×10^2	40	-80
Hydrocarbons	4.6×10^4	3.0×10^3	5.0×10^3
Aldehydes	72	-2	3
Organic Acids	90	-4	6

Table XI-42 (continued)

Environmental Factor	Total Environmental Effect for Alternative 3 (Earliest Reprocessing and Recycle)	Incremental Environmental Effects	
		Alternative 5 (Delayed Reprocessing, No Pu Recycle)	Alternative 6 (No Reprocessing, No Recycle)
Plant Effluents to Atmosphere (curies):			
^{222}Rn	2.2×10^{7}	2.0×10^{6}	5.0×10^{6}
^{226}Ra	10	2	3
Uranium	4.2×10^{2}	60	1.2×10^{2}
Pu (alpha)	4.5	-1.5	-4.5
^{241}Pu (beta)	1.2×10^{2}	-50	-1.2×10^{2}
Trans-Pu Nuclides	11	-6	-11
^{3}H	6.4×10^{7}	-1.0×10^{6}	-6.0×10^{7}
^{14}C	1.2×10^{5}	0	-7.7×10^{4}
^{85}Kr	1.3×10^{9}	0	-1.3×10^{9}
^{90}Sr	18	0	-18
^{99}Tc	32	6	-32
^{129}I	1.1×10^{2}	0	-1.1×10^{2}
^{131}I	3.4×10^{3}	-1.0×10^{2}	-2.8×10^{3}
Other Radioactivity	5.3×10^{7}	1.0×10^{6}	-1.0×10^{6}
Plant Effluents to Water Bodies (metric tons):			
SO_4	1.4×10^{7}	0	0
NO_3	8.7×10^{3}	2.3×10^{3}	2.3×10^{3}

Table XI-42 (continued)

Environmental Factor	Total Environmental Effect for Alternative 3 (Earliest Reprocessing and Recycle)	Incremental Environmental Effects	
		Alternative 5 (Delayed Reprocessing, No Pu Recycle)	Alternative 6 (No Reprocessing, No Recycle)
Plant Effluents to Water Bodies (metric tons) (continued):			
Cl	1.2×10^6	0	0
Fluorides	9.0×10^2	2.0×10^2	3.0×10^2
Na+	3.9×10^4	8.0×10^3	1.1×10^4
Ca++	2.9×10^3	3.0×10^2	1.0×10^3
NH_3	1.3×10^4	3.0×10^3	4.0×10^3
Fe	1.8×10^2	30	50
Plant Effluents to Water Bodies (curies):			
Trans-Pu Nuclides	5.1×10^3	-5.1×10^3	-5.1×10^3
Pu (Alpha)	0.12	-0.12	-0.12
Uranium	4.5×10^2	80	1.0×10^2
^{230}Th	32	4	10
^{226}Ra	1.1	0.2	0.3
^{129}I	0	0	0
^{99}Tc	4.2×10^2	70	-4.2×10^2
^{90}Sr	0	0	0
^{14}C	0	0	0
^{3}H	9.5×10^5	-7.0×10^4	-7.0×10^4

Table XI-42 (continued)

Environmental Factor	Total Environmental Effect for Alternative 3 (Earliest Reprocessing and Recycle)	Incremental Environmental Effects	
		Alternative 5 (Delayed Reprocessing, No Pu Recycle)	Alternative 6 (No Reprocessing, No Recycle)
Plant Effluents to Water Bodies (curies) (continued)			
Other Radioactivity	1.2×10^{3}	0	-1.0×10^{2}
Plant Waste Generated (cubic meters):			
Chemical Compounds	3.0×10^{5}	3.0×10^{4}	2.0×10^{4}
Mill Tailings	5.9×10^{9}	1.0×10^{8}	1.9×10^{9}
Trans-U Solids	1.5×10^{5}	-2.0×10^{4}	-1.5×10^{5}
High Level Solids	6.5×10^{3}	0	4.8×10^{4}
Other Radioactive Solids	3.9×10^{6}	0	1.0×10^{5}
Occupational Dose Commitment (person-rem) Total Body	3.8×10^{6}	2.0×10^{5}	3.0×10^{5}
Offsite U.S. Population Dose Commitment (person-rem), Total Body	4.2×10^{6}	4.0×10^{5}	-3.0×10^{5}
Dose Commitment (person-rem) to Foreign Population From U.S. Industry, Total Body	8.8×10^{5}	3.0×10^{4}	-6.7×10^{5}

For Alternative 6 relative to Alternative 3, there is a more significant decrease in gaseous releases than in Alternative 5. The total dose commitment (occupational plus general United States population) is unchanged. The acres of land committed increase by almost 50%. Likewise gas consumption goes up by 30%. In comparing Alternative 6 to Alternative 3, it is more difficult to determine whether the environmental effects that increase are more important than those that decrease. Since the other alternatives (1, 2 and 5) have both economic and environmental impacts greater than those of the reference case, the comparison is simple. In the case of Alternative 6, though, a more delicate balancing of environmental and economic effects is required. See Section XI-4.3 for such a balancing.

4.2.3 Economic Considerations

Direct costs as computed by the NUCOST program for each process step in the fuel cycle, for each year, for each alternative are presented in Section 2.0. In this section the alternatives will be compared using the costs discounted to 1975 since these costs are reasonable estimates of the present value to the consumer of direct fuel cycle costs. The reader may wish to make similar comparisons using the tables of total cost, but the conclusions will be the same. The cost comparison is presented in Table XI-43. The total cost for U_3O_8 and each fuel cycle service is listed for Alternative 3; for ease of comparison the cost differentials between each of the other alternatives and Alternative 3 are also tabulated.

The unit costs represent a direct cost to the utility (and a passthrough cost to the consumer), but to the service industry they represent all costs including capital recovery and profit. Other costs of electricity production to the utility are not included in the comparison since they are constant with all alternatives.

A 2-year delay in plutonium recycle (Alternative 1 compared to Alternative 3) is estimated to cost the consumer, consisting of the bulk of the U.S. population, an extra $153 million. Two-thirds of this cost is caused by the plutonium storage requirements and the remainder by the increased costs in the uranium portion of the fuel cycle.

A delay in reprocessing (Alternative 2 compared to Alternative 3) is estimated to have an additional cost to the consumer of $74 million. Essentially all of this cost may be construed to be caused by the increased spent fuel storage costs since the increased costs of the uranium portion of the fuel cycle are offset by the savings in reprocessing and plutonium recycle. This calculation is based on the assumption that the industry can delay reprocessing until 1986 and make up the delay by 1996. If this catchup is not realized, the additional costs will be about $1 billion. The $570 million saving in the reprocessing industry is potentially misleading since some plants are in place with substantial investment already made. The reprocessors may not be willing to absorb the loss and may attempt to recover most of it through increased unit charges. This is a fault common to most macro analyses such as this; they usually fail to consider losses of income from investments already in place.

Table XI-43

COMPARISON OF DISCOUNTED PROCESS COSTS

(Discounted to 1975 at 10% in Millions of 1975 Dollars)

Process	Total Costs, Alternative 3	Differential Costs			
		Alternative 1	Alternative 2	Alternative 5	Alternative 6
Mining and Milling (U_3O_8)	15,700	+36	+520	+2,640	+4,670
Conversion to UF_6	842	+3	+30	+127	+204
Enrichment	9,920	+32	+152	+1,270	+1,200
UO_2 Fabrication	3,970	+11	+63	+448	+448
MOX Fabrication	944	-25	-134	-944	-944
Spent Fuel Transportation	410	0	-63	-67	-160
Reprocessing	3,600	-3	-573	-614	-3,600
Plutonium Transportation	9	0	-1	-9	-9
Plutonium Storage	34	+100	-33	-34	-34
Spent Fuel Storage	228	0	+205	+205	+397
Waste Disposal	734	0	-116	-116	+930
Plutonium Sales*	-93	0	+22	+93	+93
TOTAL	36,000	+153	+74	+3,000	+3,200

*Pu leaving the light water fuel cycle for research use is accounted for as a sale or negative cost.

An 8-year delay in reprocessing followed by plutonium disposal rather than recycle (Alternative 5 compared to Alternative 3) is estimated to have an extra cost to the consumer of $3 billion. Most of this increase is caused by the substantial increase in the uranium portion of the fuel cycle industry. All of the economic and environmental costs of reprocessing must be borne with the only benefit realized being the uranium values.

The spent fuel disposal case (Alternative 6 compared to Alternative 3) is estimated to have an extra cost to the consumer of $3.2 billion. Most of this increase is caused by the substantial increase in the uranium portion of the fuel cycle industry--an increase that is only partially offset by savings due to the elimination of reprocessing and plutonium recycle costs. The remaining increase is caused by substantial increases in spent fuel storage costs and the higher cost of spent fuel disposal relative to high level waste disposal.

4.2.4 Safeguards

The costs and environmental effects of the proposed safeguards system will be analyzed in the final Safeguards Supplement.

4.3 Conclusions

The physical, environmental, and economic factors for each alternative have been summarized in the preceding sections. On the basis of these results the following conclusions can be reached.

Alternative 1 (Early Reprocessing, Delayed Plutonium Recycle)

This alternative has a slightly higher demand for uranium than the reference case, slightly less MOX fabrication demand, negligible difference in environmental impact, and a $153 million cost penalty, discounted at 10%. This alternative is less attractive than the reference case, Alternative 3.

Alternative 2 (Delayed Reprocessing, Followed by Plutonium Recycle)

Compared to the reference case, the demand for uranium is higher, fuel storage is increased, MOX fabrication is decreased, the integrated environmental impact is essentially the same, and a cost penalty of $74 million, discounted at 10%, is incurred. This alternative is also less attractive than the reference, Alternative 3.

Alternative 4

As explained in Section 2.0 of this chapter, Alternative 4 of the Draft Statement will not be analyzed as a distinct alternative.

Alternative 5 (Delayed Reprocessing, No Plutonium Recycle)

Alternative 5 has a much higher demand on uranium, enrichment services and spent fuel storage than does the reference case. It has no demand for MOX fabrication. It has, compared to Alternative 3, a 7% higher radiological impact and higher environmental

impact in water, land, and most combustion products. It results in a cost increase of $3 billion. Alternative 5 appears much less attractive than any of the previously discussed alternatives.

Alternative 6 (No Reprocessing, No Recycle)

Alternative 6, the throwaway fuel cycle, has a much greater demand on uranium resources, enrichment, and fuel storage. It requires no reprocessing or MOX fabrication. Compared to the reference it has a greater land, water, and energy consumption, but about the same radiological dose commitment. It has an increase in fuel cycle cost of $3.2 billion.

The principal tradeoff between this alternative and Alternative 3 arises from the reduction in the worldwide dose commitment compared to the $3.2 billion cost penalty. The value of the reduction in dose commitment is difficult to analyze rigorously. There is always a potential error involved in comparing economic benefits with environmental costs, because they are usually evaluated on different bases. There is even some question as to the appropriate components of dose commitment to include in the balancing. Should the occupational dose be included? Should the dose commitment to the general population outside the United States be included? In the calculations that follow only the dose commitment to the general worldwide population is used; this amounts to a reduction of 9.7×10^5 person-rem. This exclusion of the occupational dose overstates the benefit of the throwaway cycle because it ignores the fact that the workers in the mining and milling industry incur an increase in dose of 3×10^5 person-rem under this alternative. When environmental and economic costs are mathematically compared, the imprecisions are often compounded. Nonetheless, the National Environmental Policy Act charges those analyzing programs to balance costs against benefits. In this instance one might do so as follows.

An upper value for a person-rem has been suggested as $1,000.[37] The use of this number should be very carefully scrutinized, for it is designed as a guide for evaluating the practicability of reducing radiologic exposures to levels below standard. The standards are set at levels deemed safe for the population, and no facilities are permitted to operate unless they meet these standards. By applying this value of $1,000 per person-rem to an integrated dose commitment one is, in effect, analyzing the value of reducing to zero the dose from certain facilities. The values themselves have considerable individual conservatism: $1,000 per person-rem is the highest in a range of numbers; the dose commitments as calculated here are based on a set of assumptions that tend to overstate the actual exposure levels.

Notwithstanding these caveats, it is necessary to evaluate the cost-versus-dose tradeoff in a quantitative manner. The integrated saving of 9.7×10^5 person-rem at $1,000 per person-rem gives a calculated value of $970 million over the time period. This should properly be discounted to a present worth, which presents both social and mechanical difficulties. An alternative approach is to compare the total undiscounted economic costs with the above undiscounted savings. When the undiscounted costs of Alternative 6 over Alternative 3 (see Table XI-28 and Table XI-32) are compared, a

$18.2 billion extra cost can be seen. One must weigh the benefit, $970 million, of reducing dose commitment against the $18.2 billion cost of this reduction. This displays a risk-benefit/cost ratio of 0.05. Or, conversely, the economic benefits of plutonium recycle outweigh the radiologic costs by a ratio of 19 to 1.

It can thus be concluded that the value of reducing the radiologic dose commitment does not overbalance the economic and other environmental disadvantages of Alternative 6 as compared to Alternative 3.

In summary, the most important economic variables in the analysis of plutonium recycle alternatives are uranium prices and discount rates. These are closely followed by reprocessing, enrichment, and spent fuel disposal costs. Prompt recycle has both economic and environmental advantages over all other alternatives except the throwaway fuel cycle. The latter has the environmental advantage of a decreased dose commitment when compared to prompt recycle, but has a large economic penalty. On balance, the economic advantages outweigh the environmental disadvantages, making prompt recycle the preferred alternative.

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CHAPTER XI

Appendix A

URANIUM PRICING

Statements about the extent of uranium resources such as "there is sufficient uranium to totally meet world demand through 1995" and "the United States alone has uranium resources equal to four times the world's needs through 1995" are heard from time to time. These statements are correct but misleading. Pertinent terms are defined in this appendix to place such statements in proper perspective.

The above statements would be correct if the cost of uranium were not a limiting factor; domestic U_3O_8 resources recoverable at $100 per pound or less (forward cost) are estimated at 17.4 million tons of U_3O_8.[1] These resources are more than adequate to satisfy world needs (about 4 million tons through 1995),[2] and other countries also have extensive uranium resources.

However, uranium recovered at such high cost is not really of interest. This leads to a discussion of uranium in terms of reserves and other less well-defined resources. The term "reserves" refers to the quantity of uranium in known deposits that estimates indicate can be economically produced within a stated cost. For such material, the quantity, grade, and physical characteristics have been established with reasonable certainty by detailed sampling, surface drilling, and support of underground drilling and sampling.[3]

This definition of reserves is roughly synonymous with "reasonably assured resources" used by the Working Party on Uranium Resources sponsored by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development and the International Atomic Energy Agency. "Reasonably assured resources" is defined as uranium that occurs in known ore deposits of such great quantity and configuration that it can, within a given price range, be profitably recovered with currently proved mining and processing technology. Estimates of tonnage and grade are based on specific sampling data and measurements of the deposits and knowledge of ore body habit.

For the purposes of this analysis, four categories of resources are defined:

- Reserves--see above
- "Probable" potential resources--those estimated to occur in known uranium districts and further postulated to be
    a. Extensions of known deposits
    b. New deposits within trends or areas of mineralization that have been identified by exploration

- "Possible" potential resources--those estimated to occur in new deposits in formations or geologic settings productive elsewhere:

  a. Within the same geologic province or subprovince under similar geologic conditions

  b. Within the same geologic province or subprovince under different geologic conditions

- "Speculative" potential resources--those estimated to occur in new deposits:

  a. In formations or geologic settings not previously productive within a productive geologic province or subprovince

  b. Within a geologic province or subprovince not previously productive

Moreover, for the purposes of this analysis, the "forward cost" concept is replaced by an "estimated cost of recovery." This is done to replace the marginal cost concept based only on new exploration cost, mine development costs, mill costs, and a return on investment. The more usual forward cost categories of ERDA were revised upward to more nearly reflect the current cost of mining and milling facilities. The price index of such equipment has risen over 50% since 1972; other price indices have risen similarly. Also, since ore grade has continued to decline, the current output is very nearly equal to the mills' capacities. New mines/mills will be needed, and the higher costs will be reflected in U_3O_8 prices. Table XI(A)-1 shows the resources and the cost categories when adjusted in this manner.

Table XI(A)-1

ESTIMATED U.S. URANIUM RESERVES AND POTENTIAL RESOURCES*

(1975 Dollars)

Estimated Recovery Cost ($/lb U_3O_8)	Thousands of Tons U_3O_8				
		Potential Resources			
	Reserves	Probable	Possible	Speculative	Total
<35	270	440	420	145	1,275
35-50	160	215	255	145	775
50-80	210	405	595	300	1,510
Byproduct 1975-2000	140	-	-	-	140
TOTAL	780	1,060	1,270	590	3,700

*Based on Ref. 4.

Based on the projected forward costs, the cost of money, profits, sunk costs, exploration, mine development costs, and mill construction costs, it is estimated that the recovery cost would be nearly twice the forward cost. However, the cost of exploration can be expected to vary for various classes of resources. Since the cost of recovery is very sensitive to exploration costs, the more speculative resurces will be higher cost. The factors used to estimate the recovery cost of uranium are shown below:

Estimated Forward Cost ($/lb U_3O_8)	Factor Used to Estimate Recovery Cost			
		Potential Resources		
	Reserves	Probable	Possible	Speculative
15	1.6	1.9	2.2	2.5
20	1.7	1.9	2.1	2.3
35	1.7	2.0	2.1	2.3

Considering the time required to put new mine/mill complexes into operation, the mining industry operates with about an 8-year reserve. Such a reserve now exists. The assumption is then made that many of the potential resources will be converted into reserves in time to supply the market. Although the resources are represented as blocks, they very evidently are not; they only represent an average based on several technical factors, such as ore grade, deposit size, etc. In the potential resources the graphic representation is more appropriate.

In a mature market there would be a smooth transition in prices as the low-cost reserves are mined and the higher cost reserves come into the market. As a potential buyer (utility) sees that the lower cost reserves are depleted or under contract, he must bid for higher cost resources or accept the risk that no more lower cost resources will develop. As in any commodity, the marketplace is constantly discounting the effect of future supplies. Likewise, the seller, in attempting to obtain the best price, will develop his resources as needed to supply the market. A producer holding the few remaining low-cost reserves will attempt to obtain some of the difference between them and the higher cost future supplies.

It would be hopeless to try to anticipate the short-term fluctuations in market prices. In these studies only a longer view is taken. While at any given time many factors may affect the "spot" market prices (such as news releases concerning supply and demand), long-term contracts historically produce the more stable market that we have attempted to represent here. Most of the requirements by utilities appear to be contracted for through 1982 at prices under $16/lb, but the deliverability at those prices is in doubt. The current market is somewhat chaotic as these contracts are renegotiated. Long-term purchases are being made for delivery 5 years and late into the future.

Expectations based on the forward cost concept as opposed to the cost of recovery lead to misconceptions about uranium prices. The cost of recovery was adopted herein to help alleviate the problems caused by these conceptual differences. Differences between the "estimated cost of recovery" and the market price will always exist.

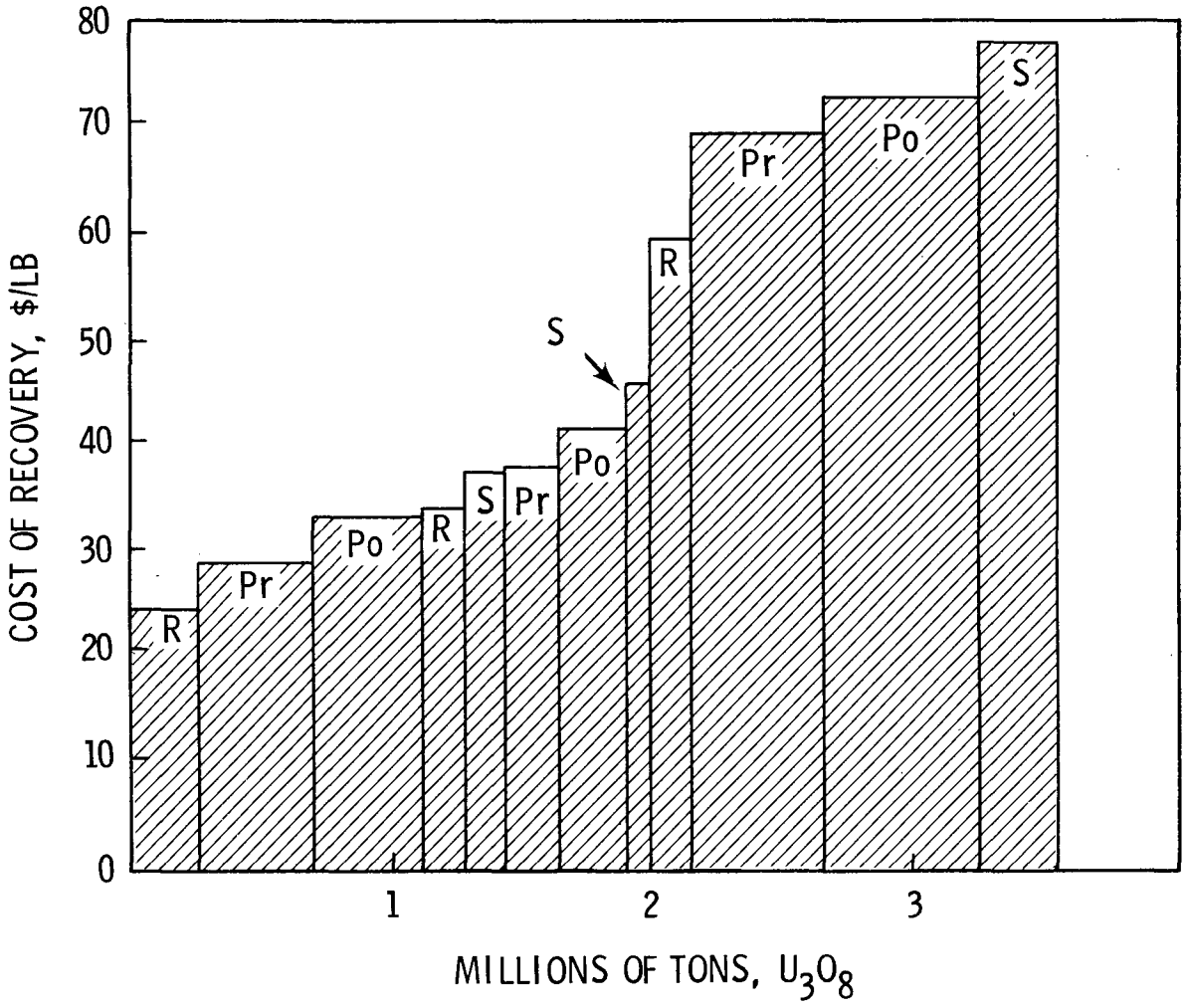

Figure XI (A)-1 Uranium Resources

To handle this situation, an approximation to a market strategy is made. It is assumed that the purchaser will attempt to find a breakeven strategy; that is, he will try to evaluate the worth of early purchase (and attendant costs) versus a delay of purchase. It is assumed that a discount rate of 10% is an appropriate weighting factor representing the opportunity cost of money. (There is nothing magic about 10%; each separate situation would require its own analysis, but the 10% number is representative.) With the assumption of the discount rate, the cost of the next effective block is discounted back for each year for which the requirement is foreseen, or until the discounted price of the next block is less than the estimated recovery cost.

To illustrate the method, the data for the base case are shown in Figure XI(A)-2. In the years before the $28.50 per pound resources are exhausted, the selling price will probably be influenced by the discounted $33 per pound resource as follows:

$33 discounted 1 year = 33/1.1, or $30
$33 discounted 2 years = $33/(1.1^2)$, or $27.30

The latter figure's being less than $28.50 does not influence the calculated price.

The boundary of the resource does not match perfectly since there is a correction for an amount of byproduct uranium available in limited quantities and sold at the prevailing market price.

The prices shown prior to 1980 are contracted prices, which essentially satisfy demand. After that time there is a mixture of existing contract prices and current resource price until about 1985, when the existing contracts become a small fraction of the total. The lowest price reserve is then exhausted, and the price stabilizes until the influence of the next higher price resource is felt.

Technically, the difference between the estimated cost of recovery and the expected price is an unallocated economic rent, and the actual selling price will most likely be at or above the estimated cost of recovery. It should be assumed that, in the absence of any large changes in the situation, the resources will be developed in approximately the order shown in Figure XI(A)-1.

The price steps were computed with the use rate determined for Alternative 5. The steps thus determined are shown in Figure XI(A)-2. The same price versus consumption relationship was then used for all cases. Shown also in the figure is the time scale. The prices for the various cases are shown in Table XI(A)-2.

Uranium demand in any one year does not by itself indicate monies and effort that must be expended up to that year for uranium exploration and development effort. For such estimates, the industry has accepted the 8-year forward concept.[5] Because of the lead time required for reserve development, planning new mines and mills, and also to support forward sales commitments, it is the industry consensus that at any time at least an 8-year forward reserve of reasonably assured resources should be available.

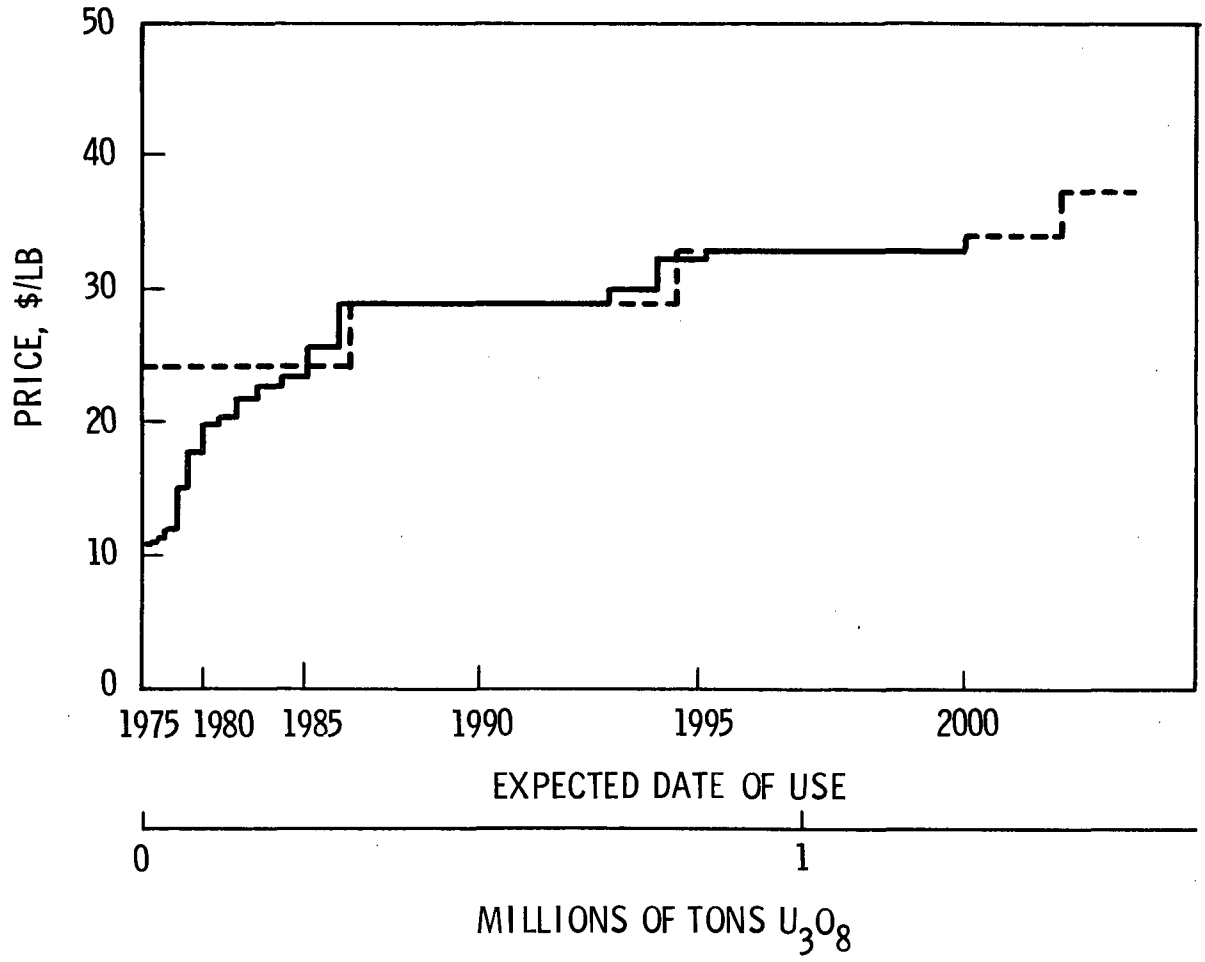

Figure XI (A)-2 Expected Uranium Price Versus Year of Delivery and Resource Use

Table XI (A)-2

EXPECTED URANIUM PRICES FOR VARIOUS OPTIONS

(Dollars per Pound, U_3O_8)

Year	Alternative				
	1	2	3	5	6
1975	10.7	10.7	10.7	10.7	10.7
1980	17.8	18.2	17.7	18.2	18.2
1985	23.5	25.0	23.4	25.0	25.0
1990	28.5	28.5	28.5	28.5	28.5
1995	32.5	32.6	32.5	33.0	33.0
2000	33.1	33.1	33.1	34.2	37.6

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CHAPTER XI

Appendix B

URANIUM ENRICHMENT SUPPLEMENT

Currently, except for small quantities produced in pilot-scale facilities, the U.S. supplies all noncommunist world requirements for separative work. It is planned to supplement the current capability of the ERDA three-plant complex through cascade improvement and upgrading programs (CIP/CUP) so that ultimate capacity will be 27.7 million SWU/yr. At this capacity, the complex could support an LWR nuclear power base of from 275,000 to 382,000 MWe, depending on the extent of plutonium and uranium recycle.

If the CIP/CUP additions are made as contemplated, and if power is available to allow preproduction as currently contemplated, the ERDA complex will be capable of satisfying all noncommunist world separative work requirements until the early 1980's,[1] more precisely, with full plutonium and uranium recycle (Alternatives 3 and 4) to about 1984.[2] However, it is becoming clear that the anticipated preproduction may not come about. CIP may be delayed by a year, with a subsequent loss of production of 2.0 million SWU. Also, a significant portion of the power required to meet contemplated preproduction is not under firm contract.

This situation is somewhat alleviated by the pressure of other countries to become involved in enrichment. Current foreign plans for entering the enrichment arena are presented in Table XI(B)-1. However, it must be pointed out that these are, in fact, plans and not reality. If these plans should materialize, foreign production capacity would exceed foreign requirements in 1982. If this should occur, the projected capacity of the U.S. three-plant complex would be sufficient to satisfy domestic requirements through 1992 under the full recycle case and through mid-1990 with no plutonium recycle, even if no credit is taken for any preproduction stockpile. If the foreign plants are delayed, and/or if U.S. contemplated preproduction becomes greatly deficient, the U.S. three-plant complex could become unable to satisfy world requirements as early as 1981.

The enrichment situation is further complicated in the United States because no one knows who will build the next additions to capacity. Two concepts are under consideration: (a) capacity provided by industry and (b) additions through the establishment of a Government corporation. Under the former concept, a number of U.S. corporations have applied for access to enrichment technology as allowed under 10 CFR 25.

Table XI(B)-1

SUMMARY OF PLANNED NON-USA ENRICHMENT CAPACITY

(MT SW/yr)

Year	EURODIF	URENCO	South Africa	BRINCO	Japan	Total
1974	-	0.09	-	-	-	0.09
1975	-	0.09	-	-	-	0.09
1976	-	0.19	-	-	-	0.19
1977	-	0.39	-	-	-	0.39
1978	-	0.74	-	-	-	0.74
1979	-	1.24	-	-	-	1.24
1980	4.5	2.0	-	-	-	6.5
1981	6.7	3.0	-	-	-	9.7
1982	9.0	4.5	2.0	3.0	-	18.5
1983	9.0	6.0	4.0	5.0	-	24.0
1984	9.0	8.0	6.0	8.0	-	31.0
1985	9.0	10.0	8.0	8.0	1.0	36.0

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CHAPTER XI

Appendix C

WORKSHOP ON DISCOUNT RATES

As has been discussed in Section 3.6 of this chapter, the appropriate discount rate to be used in the GESMO analysis is not a clearcut proposition. There is ample reference in the literature to the question of analysis of government projects. There is, though, little or no consideration in the literature of the discount rate to be used for the analysis of a Federal regulatory decision as it affects industry. To help clarify some of the thinking on this subject, a workshop of eminent economists was organized for a one-day discussion of this matter. The participants had been provided in advance a copy of the material, essentially that in Section 3.6, used in the derivation of the 6 and 10% discount rates used in the analysis. At the meeting they were briefed in greater detail on the methods used for the economic and environmental analyses.

Attendees of the workshop are listed below:

Prof. W. Z. Hirsch
Economics Department, UCLA

Dr. George W. McKinney
Senior Vice President
Irving Trust Company

Prof. Robert Merton
Sloan School of Management, MIT

Prof. Edwin S. Mills
Economics Department, Princeton

Prof. Jerome Rothenberg
Economics Department, MIT

Prof. Joseph Stiglitz
Economics Department, Stanford

Dr. Kenneth M. Wright
Vice President
American Life Insurance Association

After a discussion of the general approach to the analysis, it was concluded by the panel that the risks which should be considered were not the entrepreneurial risks of the nuclear fuel cycle industry but those risks that must be borne by society as a whole. Three risks of this type were identified by the panel:

(1) The pass-through of profits. If it is assumed that the nuclear fuel cycle industry will be highly monopolistic and unregulated, one can assume that few or none of the profits from the recycle of plutonium will be passed through to the consumer but will be held by the industry.

(2) Savings will not develop as calculated. If the calculated prices for the nuclear fuel cycle services are not realized in practice and if the costs of these higher prices for services are passed through to the consumer, the calculated economic benefits of recycle will not be realized.

(3) Cyclical nature of the industry. If one assumes that the recycle industry is highly procyclical and that the expected benefits will vary directly with the overall health of the economy, then one tends to assign a higher risk to the venture than one would to less cyclical investments. If, on the other hand, it is judged that the industry is countercyclical, one tends to assign to it lower than average discount rates.

The question was raised, "Why worry about discount rates for this analysis? If the conclusions do not change as the analysis is run at various discount rates, then the selection of a specific rate is of academic importance." It was pointed out that even though it takes a discount rate of 53% to make the economic incentive to recycle negative, the magnitude of the present worth of recycle is highly sensitive to the specific discount rate. Proponents of recycle are going to tend to seize on large present values as a strong argument. Likewise opponents of plutonium recycle will use small present values as an argument against future risks even though the environmental risks have not been discounted.

The panel pointed out a possible shortcoming of the manner in which the benefits of plutonium recycle are calculated. In the analysis only the reduced cost of power is used to measure the value of the various recycle alternatives. Some of the panel members felt that this is a serious understatement of the benefits inasmuch as it ignores the profits realized by the industry. Taxes on these profits and returns to shareholders are clearly both benefits to society. Other panel members disagreed on the basis that the same investments made in other similar industries would yield the same returns.

With this background material the panel attacked the question of low, high, and reference discount rates applicable to this analysis. The mechanics of this endeavor were as follows. The panel members each made a secret vote of their selections for a low discount rate that he thought appropriate. This datum was then plotted, a statistical analysis run, and the results displayed for discussion. Each panel member was called on to present the logic that went into his selection. After these presentations were made and debated, the panel was asked to respond again in secret ballot to the question. These results were again plotted, statistically analyzed, and presented to the panel. No further iteration was attempted. The second vote was accepted as the panel's opinion. The panel pointed out that there is no right number for any one of the three rates that were to be identified. They pointed out that there would always be a divergence of opinion and there was an element of subjectivity in the selection of a given number. The respondent is forced to factor in his assessment of the various elements discussed above and to what degree each applies to the industry.

The results of the first vote on the applicable low discount rate were as follows: 0%, 1%, 4%, 5.5%, 6%, and 7%; the median number was 5, the range was 7, the mean was 4.1, and the standard deviation was 2.62. The median was chosen as the statistic to summarize the individual estimates. There is little loss of precision in using the median (compared to the mean) as a measure of central tendency in this situation and the median is less responsive to outlier estimates than is the mean. This is particularly important with the small sample sizes and highly skewed distribution of sample values observed in two of the three sets of values reported here.

The individuals defended their selection of the rate. The arguments are briefly summarized below:

0% - A completely risk-free societal situation is assumed in which all of the benefits are passed through and any cost overruns are absorbed by industry. The rationale starts with an assumption that the real rate of return on a riskless basis is about 1%. To this number is added a negative number that reflects the insurance nature of plutonium recycle. Any increases in the cost of alternative energy forms or failure to find expected quantities of uranium will all tend to drive up the cost of power. These will be reflected in increased benefits from the use of plutonium recycle; hence the regulatory decicion to allow plutonium recycle is a form of insurance and should be discounted accordingly. The net of these considerations is a zero discount rate. This rate can also be defended in an argument on the intertemporal distribution of income. A zero rate can be argued on the basis that future generations should have the same consideration as present ones, and hence no discounting of economics should be used.

1% - This again is derived on the assumption that the risks to society are nil. The value is derived from reviewing many years of real rates of return on Treasury bills, both long and short term. The latter demonstrated an historical real rate of return of about 0.1%, whereas the former have shown a real rate of about 1%.

4% - This is based on a real rate of return of about 3% on a risk-free basis. This number is also derived from consideration of the real rate of growth of gross national product. Added to this is about a 1% premium that reflects the panelist's evaluation of the degree of economic risk that will be passed on to the consumers.

5% - This number is influenced somewhat by the investments of the private sector. It assumes that society accepts a certain amount of these risks.

5.5% - This is considered a low-risk number but not entirely risk-free. It assumes that many of the price failures would be passed on to the consumers.

6% - This reflects a number of uncertainties in the nuclear business. These include public acceptance, regulatory uncertainties, and technical uncertainties. The number also reflects a judgment on the amount of benefits that would flow through from the industry to the consumers.

7% - This number is derived from an assumed 3.5% to 4% real rate of return to society on a riskless basis. Risk factors--political, regulatory, and technical--are added to bring the number to 5%. The panelist was sceptical of the pass-through of benefits and added 2% to reflect this scepticism.

The results of the second vote on the low discount rate were as follows: 0%, 1.5%, 4%, 4.5%, 5%, 5%, and 6%; the median number was 4.5, the range was 6, the mean was 3.7, and the standard deviation was 2.16. A summary of the group's opinion on appropriate low discount rate is captured by the median value of 4.5%.

The Delphi process described above was repeated to capture the panel's opinion on the appropriate high-side discount rate. The results of their first vote were as follows: 9%, 10%, 10%, 10%, 10.5%, 15% and 15%; the median was 10, the range was 6, the mean was 11.4, and the standard deviation was 2.53. The arguments for each of these individual selections are briefly as follows:

9% - This rate is considered consistent with the panelist's selection of 5% on the low side. This reflects a larger degree of risk for the consumers, but the respondent is conscious of double counting risks and wants to avoid them.

10% - Consistent with 6% on the low side; assumes less pass-through of benefits and higher risks to the consumer.

10% - Perception of range consistent with the low value chosen. Reflects a change in the level of risks and distribution of benefits.

10% - Panelist could not conceive of any set of conditions of pass-through benefits that would make a rate higher than 10% justifiable.

10.5% - Essentially the same logic as the 10% votes.

15% - No relation to the assumption the same panelist made on the low side (1%). Assumes that consumers are all the same class and are also investors. If the nuclear fuel cycle industry as a whole is realizing 15% after tax, then the consumers are assumed to bear the same level of risk as the equity holders and to have the same opportunity costs. If the after-tax return is, in truth, some other number, that number should be used.

15% - If the capital market is not perfect, then borrowing rates for individuals may be as high as 18%; industry has to depend to some extent on retained earnings for investments. On this basis one should look at the opportunity cost of capital to the industry as a guide to the high range rate.

On the second vote the following results were obtained: 10%, 10%, 10%, 10%, 10%, 14%, and 15%; the median was 10, the range was 5, the mean was 11.3, and the standard deviation was 2.21. The median value of 10 captures the summary of the panel's opinion on this high value.

The panel then selected a reference or most likely interest rate. Their first vote was 4%, 6%, 7%, 7%, 7.5%, and 9%; the median was 7, the range was 5, the mean was 6.9, and the standard deviation was 1.55. A summary of the arguments and defense of the selections is as follows:

4% - The panelist perceives a degree of negative covariance between plutonium recycle and the rest of the economy; hence the plutonium recycle industry can be seen as a form of insurance. It has a diversifying influence as a substitute energy form which can be characterized by a lower than average discount rate.

6%-7.5% - There was no specific defense of the middle rates; they were all considered to be essentially the same and represented the discount rate appropriate to the analysis.

9% - This is derived from a long-run estimate of the expected investment return of the economy as a whole.

The second vote of the panel on the best estimate or reference discount rate was as follows: 5%, 6%, 7%, 7%, 7%, 7.5%, and 8.5%; the median was 7, the range was 3.5, the mean was 6.9, and the standard deviation was 1.11.

In summary, the panel's opinion of the appropriate discount rates was 4.5% to 10%, with a reference value of 7%.

The economic incentive for plutonium recycle will, obviously, be sensitive to the rate of discounting used. This is illustrated in Table XI(C)-1.

Table XI(C)-1

ECONOMIC INCENTIVE TO RECYCLE

(Billions of Dollars)

	Discount Rate				
	0%	4.5%	7.0%	10%	15%
Incentive (Case 40 minus 36)	18.2	8.1	5.2	3.2	1.5

In the total range of discount values suggested, the incentive varies from $18.2 billion to $1.4 billion.

CHAPTER XI

APPENDIX D

AN INDUSTRY ASSESSMENT OF URANIUM RESOURCES

Introduction

The cost/benefit analyses presented in the body of this chapter were based primarily on uranium reserves and resource data prepared by the ERDA. While these ERDA estimates are the result of comprehensive assessment and analysis, the question arises whether the industry believes these estimates sufficiently to take consistent appropriate action. Uranium exploration will not be undertaken unless producers are convinced that uranium can be found; utilities will not order nuclear power plants unless they are convinced that uranium will be available at reasonable price over the entire life of the power plants. Accordingly, a representative sample of the industry (producers, agents, reactor vendors, utilities, and Government agencies) was contacted to ascertain the current status of sentiment relative to uranium supply and price. Discussions were held with a total of 28 organizations, which constitutes a large sampling of the suppliers and the utilities most heavily engaged in nuclear activities.

Comments Relative to Uranium Resources

It must be understood that the assessment of potential uranium resources is largely a matter of extrapolation based on limited specific data. Consequently, one would anticipate a wide variability of opinion. A starting point for the discussions was the latest ERDA resource projection [Table XI(D)-1].

Relative to the reserves figures, industry comments were generally of two varieties:

- Actual proved reserves (without byproduct production) without any extrapolation are probably in the 400,000- to 450,000-ton range rather than the 640,000 tons indicated; however,

- Allowing for the reasonable extrapolation included in the ERDA estimates, the ERDA figures are probably low because recent significant finds have not yet been reported to ERDA (because evaluations have not been completed or because commercial considerations dictate confidentiality).

Industry generally considers prudent extrapolation from known ore bodies to be valid. Accordingly, many producers would not hesitate to characterize the ERDA reserves plus probable categories as "proved." Producers who have made independent assessment of this combined category indicate that their results are at least as high as those presented in Table XI(D)-1, extending up to about 2,000,000 tons.

Table XI(D)-1

ERDA ESTIMATES[7]
OF U.S. URANIUM RESOURCES

(Tons U_3O_8, as of January 1, 1976)

$/lb U_3O_8 Cutoff Cost	Proved Reserves	Potential Resources			Total
		Probable	Possible	Speculative	
$10	270,000	440,000	420,000	145,000	1,275,000
$10-15 Increment	160,000	215,000	255,000	145,000	775,000
$15	430,000	655,000	675,000	290,000	2,050,000
$15-30 Increment	210,000	405,000	595,000	300,000	1,510,000
$30	640,000	1,060,000	1,270,000	590,000	3,560,000
Byproduct, 1975-2000*	140,000	--	--	--	140,000
	780,000	1,060,000	1,270,000	590,000	3,700,000

*Byproduct of phosphate and copper production.

When questioning extends beyond this range of resources where extrapolation becomes more tenuous, the variability of assessments increases. However, predominantly, the opinions are optimistic. The following is a list of pertinent (at times contradictory) comments that were made.

1. We have X million pounds of proved reserves at relatively high grade and would be surprised if the potential reserves, including lower but now apparently economic grades were not at least an order of magnitude greater.

2. In the light of the immaturity of the industry, one must expect the unproved potential to be much higher than the proved reserves; after 70 years of activity in the petroleum industry, only about half the economically recoverable oil has been found.

3. The ERDA estimates are based on prudent extrapolation and give zero credit for potential in land areas that have not yet been explored; this is prudent but decidedly conservative.

4. Over 90% of the ERDA estimates are for sandstone recovery. In other parts of the world, other types of deposits predominate. It is highly probable that large deposits of somewhat lower grade ore, such as the Rossing deposit, exist in the United States.

5. One would expect that the potential resources per unit grade increment would increase with lower grade.

6. It is reasonable to assume that Alaskan deposits, not included in the ERDA tabulation, will be comparable to those anticipated for the contiguous United States ratioed as to land area.

7. Uranium is leached out of the upper layers of soil by normal weathering; hence radiometric exploration is of limited value unless the region shows outcropping.

8. Since uranium is radioactive, exploration is relatively simple, and much of this has been done; accordingly, one should not expect to find much more than the reserves that already have been proved.

9. Much of the lower grade material previously discarded is not amenable to economic recovery.

10. The ERDA figures grossly underestimate the potential byproduct recovery, especially from copper operations.

11. A resource base of 3,000,000 tons would require discovery of many deposits of size equivalent to those already found; finding of such major new deposits is unrealistic.

12. Probably only a few large new deposits will be found, but there are many small deposits. The question is not whether the material exists but rather whether the small deposits can be aggregated for economic milling.

13. The discovery rate per foot of drilling has not been dropping off as cursory examination of the data would indicate. The discovery rate of less than $15/lb material per foot of drilling during recent years has been no less than the discovery rate of less than $8/lb material in the 1960's. Taking inflation into account, one must conclude that the discovery rate per foot of drilling has not decreased significantly.

14. The increased amount of drilling contemplated by the supply industry is indicative of the fact that they believe economically recoverable material will be found. The planned drilling rate is a measure of the optimism that exists in the industry relative to potential resources.

On the basis of these comments and associated quantitative information, an attempt was made to prepare a resource table [comparable to Table XI(D)-1] as it might appear when more geological information becomes available. The results are presented in Table XI(D)-2. Simply, this table shows an additional increment in the $30 to $50 forward-cost category; the current ERDA-designated speculative resources increased by a factor of about 3; and the inclusion of Alaskan potential as being 20% of that for the contiguous 48 states. Most geologists would not argue with the rationale for including these three additions; however, they would not be willing to go out on the limb to suggest that the total domestic resources might approach 9 million tons.

This comes about because extrapolation is such a tenuous undertaking. In any single locale, economically recoverable resources may or may not exist. Speculation cannot provide the answer; drilling is required. To add up all potentials on the basis of generalized considerations can result in gross overestimates; accordingly, some potential areas should be given value to account for possible shortfalls. In this context, it appears prudent to omit Alaska--keeping its potential in your back pocket, so to speak, and pulling it out only when needed because of adverse experience elsewhere. On this basis, the total (reserves plus potential) resources (recoverable at less than $50/lb forward cost) are estimated to be about 7.3 million tons. Further, since essentially no evaluation has been made in the $30 to $50/lb forward cost category, one might consider that the 1 million tons shown as speculative in this category is a compounding of speculation, and hence should not be included in a prudent estimate. Eliminating the 1 million tons would reduce the overall estimate to 6.3 million tons. Based on the composite of all the discussions, it is concluded that the median resource estimate by the industry is in the range of 6.3 to 7.3 million tons. The bottom tenth percentile is at about 2 million tons, and the top tenth percentile at about 10 million tons.

Table XI(D)-2

U.S. URANIUM RESOURCE PICTURE
ANTICIPATED WITH ADDITIONAL GEOLOGICAL DATA

(Tons U_3O_8)

$/lb U_3O_8 Cutoff Cost	Proved Reserves	Potential Resources			Total Contiguous U.S.
		Probable	Possible	Speculative	
$10	270,000	440,000	420,000	500,000	1,630,000
$10-15	160,000	215,000	255,000	500,000	1,130,000
$15-30	210,000	405,000	595,000	1,000,000	2,210,000
$30-50	200,000	400,000	600,000	1,000,000	2,200,000
Totals	840,000	1,460,000	1,870,000	3,000,000	7,170,000
Byproduct	140,000	--	--	--	140,000
				Total, Contiguous U.S.	7,310,000
				Alaska	1,400,000
				Total Domestic	8,710,000

Recent literature also gives indication that this is a median estimate. On the low side is a recent assessment published in Science.[1]

On the high side is a study[2] by the Electric Power Research Institute, which indicates that the median resource estimate of material recoverable at a price of less than $100/lb (1974 dollars) is about 13.2 million tons. The recent Edison Electric Institute report[3] recognizes the uncertainties associated with extrapolation from a base of limited data and indicates the possible consequences of the extreme situations; in general, this report tends to be somewhat less optimistic than the assessment presented herein.

In general, this assessment, which contemplates significantly greater resource potential than indicated by the ERDA data, is consistent with experience with other mineral resources. A quotation from an ERDA publication[4] is appropriate:

> "History does not treat kindly estimates of mineral resources. Invariably estimates have been conservative. Man, as a rule, underestimates the endowment of metal in sub-economic grades and the ability of technology to transform resources into reserves."

Having reached such an optimistic conclusion, a word of caution is warranted. One must never forget that uranium resource estimates made on the basis of present exploratory data are little more than educated guesses. A wealth of exploration is required before such resources can be proved or disproved. While there is reason for optimism, we cannot ignore the consequences of a possible considerable shortfall.

Comments Relative to Near-Term Availability

While the industry apparently has few doubts about uranium that is in the ground, it does foresee potential problems with regard to making the material available. Developing mines and constructing mills takes time, and the time required is increasing significantly due to licensing requirements and environmental evaluations. Also, the supply of skilled miners is limited. Further, the current uncertainties relative to nuclear power generation tend to raise doubts relative to the prudence of increased investments. This is aggravated by the fact that sizeable capital is required to expand the supply industry at the rate that is deemed necessary.

1975 production was estimated to be about 12,500 tons U_3O_8; 1976 production is estimated to be about 15,000 tons. With the addition of currently planned expansions and new capacity, this production rate is expected to increase to about 23,000 tons in 1980. A further production increase to about 30,000 tons is anticipated by 1982. These increases are barely capable of satisfying expected requirements. Substantial new capacity is required to meet requirements in the mid-1980's. In particular, mine/mill capacity may not be adequate to meet supply at that time if plutonium recycle is not undertaken and/or if the tails assay must be increased because of insufficient enriching capacity.

The supply situation can be further aggravated by an adverse price/production relationship since mill production output is dependent on ore grade. Specifically, when demand is high, one can expect high prices to prevail. Such high prices will make economic recovery of relatively low-grade ore practical. Consequently, when such low-grade ore is processed, mill production will decrease and the demand/supply relationship will be further imbalanced. In periods of relatively low demand, the converse is true. Low demand implies relatively low price, which forces working with relatively high-grade ore. This increases mill capacity, again causing further imbalance of the supply/demand. This adverse economic coupling of mill operation to the prevailing market price will always tend to produce more violent price fluctuations than would casually be anticipated.

Comments Relative to Price

Three factors are expected to influence the price of uranium:

- Production and related exploration cost
- Market demand
- Price of alternative fuels

At the average grade of ore that is currently being mined, a price in the range of \$25 to \$30/lb U_3O_8 is adequate to provide incentive to the supply industry. As increased production is required from ore that contains significantly less than 0.1% U_3O_8, the cost-related market price can be expected to rise, perhaps to \$50/lb U_3O_8 (1976 dollars) by the end of the century.

In the near term, prevailing prices can be expected to be significantly higher than the cost-related price because of the uncertainty of supply. This uncertainty results in overpurchase and therefore in excessive demand and premium price.

While the majority of industry opinion is that the price of yellowcake will be determined primarily by production cost, a significant segment of the industry believes that the price will be coupled to that of alternative fuels, primarily coal. Among those that are of this opinion, there is a wide disparity as to what the coal-equivalent price will be. While some few suppliers estimate that the market can bear a uranium price of up to \$100/lb U_3O_8 and therefore that such will prevail, most suppliers and most utilities believe that the competitive breakeven price is much lower because of the "headaches" associated with nuclear power projects. This major segment of the industry does not foresee a price much higher than the cost-related figures indicated above.

Summary and Conclusions

Relative to our findings, the industry assessment of the uranium resource picture is summed up in a paper presented by H. Weed at the Atomic Industrial Forum Fuels Conference in 1976:

"Present indications are that there are enough uranium resources minable at reasonable costs to last well into the next century."

Industry believes that adequate conventional resources exist so that near-term consideration need not be given to recovery from Chattanooga shale or seawater. The ERDA National Uranium Resource Evaluation (NURE) program together with substantial industrial drilling planned should provide a solidly reliable picture within about 5 years.

A price of less than \$50/lb U_3O_8 (but not less than \$25/lb) should provide adequate inducement for the necessary exploration and required production. This is not to say that the price will go no higher; it might if uncertainty continues to exist relative to adequacy of supply or if there is economic coupling to fossil fuel prices. The uncertainty relative to supply can be alleviated only by stabilization of the entire nuclear industry so that demand can be forecast with sufficient reliability to attract the necessary capital. Because of the current uncertainty, supply will be tight (and the price will be at a premium) in the near term. This situation will be either further aggravated or alleviated in the mid-1980's, depending on overall industry developments.

While the industry conclusion relative to the size of the domestic resource base is optimistic, one cannot lose sight of the fact that this conclusion is based largely on supposition without adequate hard data. Until such data become available, it is prudent to plan on a more conservative basis than is indicated.

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