NUREG-0002, Vol. 1

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

Health, Safety and Environment

Summary

U.S. Nuclear Regulatory Commission

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NUREG-0002, ES

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HEALTH, SAFETY & ENVIRONMENT

Executive Summary

August 1976

Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission

EXECUTIVE SUMMARY

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1.0 INTRODUCTION, ANALYSES, AND RESULTS

1.1 Introduction

The Nuclear Regulatory Commission is in the process of arriving at a decision as to whether or not the use of mixed oxide fuel (a mixture of recycled plutonium oxide and uranium oxide) in light water reactors should be permitted on a widescale basis, and, if so, under what conditions. This type of fuel has been used for many years in light water reactors on a limited basis. In this document, prepared by the Nuclear Regulatory Commission Staff with significant guidance from the Commissioners as to scope, the health, safety, and environmental impacts of widescale use are examined, and costs and benefits are weighed. Supplementing this study will be an evaluation of the safeguards aspects of the widescale use of mixed oxide fuel, to be published in draft form shortly for public comment. The final safeguards supplement will include the overall cost-benefit balancing, including health, safety, environmental, economic, and safeguards factors. Public hearings will be conducted by a special hearing panel established by the Commission, and will take into account comments received from the public. A Commission decision on whether or not to permit widescale use of mixed oxide fuel will be based on the Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors (including the Final Safeguards Supplement) and the results of the public hearings.

Light water nuclear reactors are currently fueled with slightly enriched uranium. While the reactor operates, some of the uranium is converted to plutonium, which fissions in place, providing about one-third of the reactor's total power output over the useful life of the fuel. Fuel burnup also creates other byproducts, which gradually impede the nuclear reaction, even though substantial quantities of fissile uranium and plutonium still remain in the fuel. When the useful life of the fuel is over, the remaining fissile uranium and plutonium can be separated from the other materials in the spent fuel, converted into uranium and plutonium oxides, and recycled into the reactor as fuel. The process of extracting and reusing the elements in this fashion is known as "uranium and plutonium recycle," and fuel containing recycled plutonium is termed "mixed oxide" fuel.

Current industry plans are to carry out this process in the following steps

- Store the spent fuel to allow some decay of radioactivity
- Separate plutonium and uranium from fission product wastes as nitrate solutions
- Convert the recovered uranium to uranium hexafluoride, which is then enriched to increase the concentration of the fissile isotope uranium-235
- Convert the uranium hexafluoride to uranium dioxide
- Fabricate uranium fuel assemblies

- Convert the plutonium nitrate to plutonium oxide

- Manufacture fuel rods with pellets containing mixed plutonium and uranium oxides

- Fabricate fuel elements containing fuel rods of mixed oxide fuel

- Convert the fission product wastes into forms suitable for long term storage and disposal

- Transport materials as required by the above processing, production, or storage operations

From 1957 through 1972, the Atomic Energy Commission (AEC) carried out extensive research to develop the technology for plutonium recycle. A commercial reprocessing plant operated between 1966 and 1971. Construction began on another, under an AEC permit, in 1970. Several small plants currently have licenses to fabricate mixed oxide fuel. At present 3 of the nation's 57 commercial reactors (Big Rock Point, Quad Cities Unit No. 1, and Dresden Unit No. 1) are licensed to operate with mixed oxide fuel.

On February 12, 1974, the AEC announced that a generic environmental impact statement would be prepared prior to an AEC decision on the widescale use of mixed oxide fuel (39 FR 5356) because of the possible broad impacts of widescale use on the physical and social environment.

In the multi-volume statement, published in draft form in August 1974, as the Generic Environmental Statement on Mixed Oxide Fuel (GESMO), the AEC staff concluded that the widescale use of mixed oxide fuel should be approved. As for safeguarding of the plutonium, the draft did not set forth a detailed cost-benefit analysis of alternative programs for safeguarding plutonium--that is, preventing its illicit use for nuclear explosives or toxic dispersal--but concluded that this problem would not be an unmanageable one.

In January 1975, the Nuclear Regulatory Commission (NRC) succeeded to the licensing and related regulatory functions of the Atomic Energy Commission, and thus assumed the responsibility for deciding the widescale plutonium recycle question.

In a January 20, 1975 letter to the Nuclear Regulatory Commission, the President's Council on Environmental Quality expressed the view that, although the draft environmental statement was well done and reflected a high quality effort, it was incomplete because it failed to present a detailed and comprehensive analysis of the environmental impacts of potential diversion of special nuclear materials and of alternative safeguards programs to protect the public from such a threat. The Council believed that such a presentation should be made by the Nuclear Regulatory Commission before its final decisions on plutonium recycle.

On May 8, 1975, the Commission published its provisional views (40 FR 20142), and on November 14, 1975, its conclusions (40 FR 53056) with respect to the scope and procedures it would follow in the decisional course on widescale use of mixed oxide fuel in light water nuclear power reactors. The Commission took the position that a cost-benefit analysis of alternative safeguards programs should be prepared and set forth in draft and final environmental impact statements before any Commission decision is reached on widescale use of mixed oxide fuels in light water nuclear power reactors. In the same notice, the Commission indicated that it would issue proposed amendments to its regulations relating to widescale use of mixed oxide fuels at about the time relevant portions of the final impact statement are completed.

The Commission also directed the NRC staff to prepare this final environmental impact statement--including a cost-benefit balancing--covering health, safety, and environmental aspects of the widescale use question, utilizing the comments received on the draft GESMO.

The draft Safeguards Supplement, to be issued for public comment later in the year, will include both an analysis of alternative safeguards programs and an overall cost-benefit balancing that takes into account the safeguards factors as well as health, safety, and environmental factors. After consideration of comments received, the Safeguards Supplement will be issued in final form.

1.2 Analyses

In addition to the recovery of uranium and plutonium from spent fuel and their recycle as fuel to light water reactors (referred to in GESMO as the "uranium and plutonium recycle" option), two other major options exist for handling light water reactor spent fuel. In the "uranium recycle" option, only uranium would be recovered from spent fuel and recycled as fuel to LWR's. Plutonium and fission product wastes from the spent fuel would be converted into forms suitable for long term storage and disposal. In the "no recycle" option, considered in GESMO, no fissile materials would be recovered from spent fuel that would be the waste material requiring long term storage and disposal.

This portion of the final GESMO analyzes the health, safety, and environmental impact costs and benefits of implementing any one of the three available options for the light water reactor fuel cycle: uranium and plutonium recycle, uranium recycle, and no recycle. To characterize fully the possible development of these options, five major alternatives have been defined:*

- Alternative 1: prompt fuel reprocessing, prompt uranium recycle, delayed plutonium recycle

*The numbering of the alternatives has been carried over from the draft GESMO. Alternative 4 has been deleted from the final GESMO. See Figure ES-1.

- Alternative 2: delayed fuel reprocessing, followed by uranium and plutonium recycle

- Alternative 3: prompt uranium and plutonium recycle

- Alternative 5: uranium recycle; no plutonium recycle

- Alternative 6: no uranium or plutonium recycle

The alternatives are shown schematically on Figure ES-1; salient characteristics of the alternatives are given in Table ES-1. Alternatives 1 through 3 represent variations of the uranium and plutonium (U + Pu) recycle option; Alternative 5 the uranium (U) recycle option; Alternative 6 the no recycle option.

The analyses of environmental impacts have been based on the 26-year period from 1975 through 2000. The projected nuclear power growth rate was assumed to be independent of the choice of recycle option; the specific nuclear growth projection used as the baseline in the analyses is the Energy Research and Development Administration (ERDA) projection for low growth assuming no breeder reactor. In this growth scenario, approximately 500,000 MW of light water reactor nuclear power is projected to be on line in the year 2000, with about 35 trillion kWh of electrical energy generated from nuclear reactors between 1975 through 2000.

A series of parametric studies of fuel cycle costs was made to determine the effect of nuclear growth rate, delays in start of widescale recycle, fuel cycle unit costs, the period of time covered, and discount rate on the difference in fuel cycle costs attributable to recycle of uranium and plutonium. The transfer of recovered plutonium from use as fuel in light water reactors to the liquid metal fast breeder program was also the subject of analysis. Detailed analyses were made of the fuel cycle costs for the five major fuel cycle alternatives.

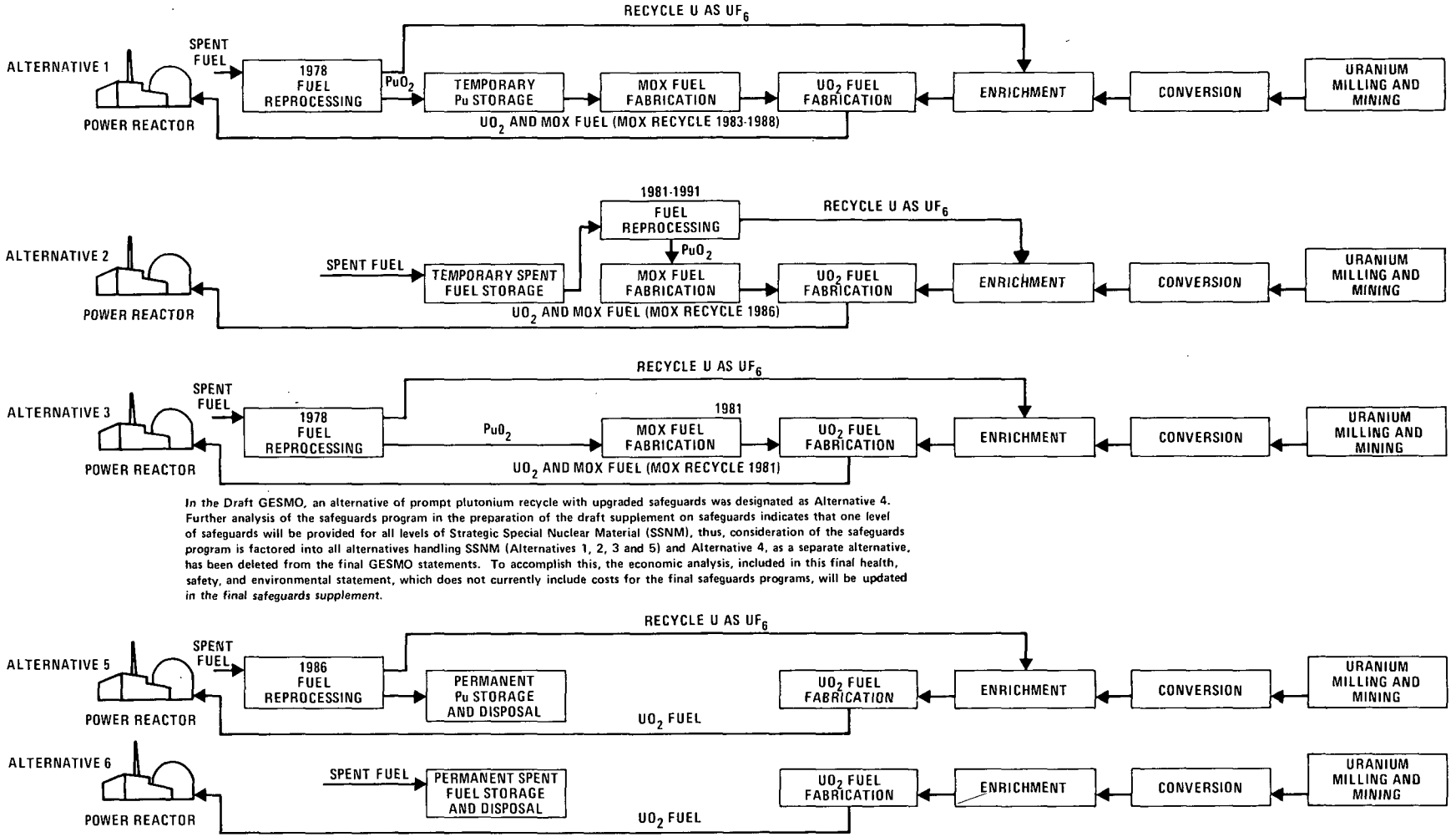
1.3 Results

The effect of the fuel cycle options on the safety of light water reactors and fuel cycle facilities, and on the environmental impact of light water reactors are summarized below. To place a perspective on doses discussed below, the average annual dose in the United States from natural background radiation is 0.1 rem per person. The United States population receives a total dose of about 20 million person-rem annually from natural background radiation.

1.3.1 Safety

1.3.1.1 Reactors

When the amount of plutonium recovered from the spent fuel assemblies removed from a light water reactor is equal to the amount of plutonium in the fuel assemblies initially placed in the core, the reactor is described as an equilibrium self-generation reactor (SGR). In the model used to assess the environmental impact of recycling



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 ES-1 Alternatives for the Disposition of Plutonium

Table ES-1

LWR FUEL CYCLE EVALUATIONS

Option	Alternative	Start of Reprocessing	Start of Pu Recycle	Notes
U + Pu recycle	3	1978	1981	Base case for U + Pu recycle option
	1	1978	1983*	Plutonium recycle delayed 2 years beyond base case
	2	1986*	1986*	Fuel reprocessing delayed 8 years beyond base case
U recycle	5	1986	Never	Base case for U recycle
No recycle	6	Never	Never	Base case for no recycle

*Variations in these dates were used to determine the effect of different delay periods. See paragraph 1.3.3.

plutonium in light water reactors, all of the plutonium produced in LWR's was assumed to be recycled in individual reactor quantities at 115% of the SGR value. Using this model approximately one-half of all light water reactors operating in the year 2000 would be operating with plutonium recycle fuel and the other half with uranium (only) fuel as feed. For the purposes of this statement, a light water reactor is considered to be a 1.15 SGR when the amount of plutonium is 1.8 weight percent of the total heavy metal (plutonium and uranium) that has been charged to the reactor. This value was used as the basis for the environmental calculations because it is judged to characterize adequately industry's plans for recycling and it does not require significant changes to reactor plant systems or engineered safety features systems in presently operating reactors.

The assessment showed that the potential hazards to the public for the model mixed oxide fueled light water reactor remain relatively unchanged by the substitution of mixed oxide fuel assemblies for uranium fuel assemblies for both normal and accident conditions. If widescale use of recycle plutonium as fuel in light water reactors is authorized, the NRC Office of Nuclear Reactor Regulation, in accordance with normal practice, would evaluate each utility application to use mixed oxide fuel assemblies on a case-by-case basis. These evaluations would provide specific assurances that the risks to the health and safety of the public in the vicinity of the nuclear facility will not be affected by the change to mixed oxide fuel. Each core load and reload containing a new type of uranium fuel has been routinely evaluated in the past in the same manner.

1.3.1.2 Mixed Oxide Fuel Fabrication Facilities

Radioactive effluents released by the mixed oxide fuel fabrication plant would result in an estimated maximum bone dose* of about 0.171 rem annually to an individual living at the site boundary. Radioactive effluents released by the mixed oxide fuel fabrication industry through the year 2000 would contribute an estimated bone dose to the population of the United States of about 14,000 person-rem over that period.

The predicted dose to the offsite population of the United States from mixed oxide fuel fabrication plant operation from 1975 through 2000 is about 0.1% of that from the total light water reactor industry, and about 0.002% of the dose from natural background during the 26-year period.

The GESMO analysis indicates that the probability of major accidents occurring at the mixed oxide fuel fabrication plants is quite low. Radiological impacts resulting

*The term "dose" used in the Executive Summary represents the dose commitment received by an individual over a 50-year period following intake of radioactive material.

from postulated accidents have been assessed.* The maximum dose to an individual from a criticality accident at a mixed oxide fuel fabrication plant has been estimated to be 0.360 rem (thyroid); the dose to the United States population would be 4.2 person-rem (thyroid). The impact from a fire in a mixed oxide fuel fabrication plant would have the same impact as an explosion; the dose for either of these accidents is estimated to be less than 0.021 rem (bone) to an individual and to be 0.7 person-rem to the bone of the entire U.S. population.

1.3.1.3 Fuel Reprocessing Plants

In the offsite population, an individual receiving the estimated maximum annual total body from a reprocessing plant would receive about 0.0075 rem. This dose would not be substantially changed whether or not plutonium is recycled. (The maximum dose to an organ is 0.066 rem (thyroid) and is also substantially unaffected by choice of fuel cycle option.) Total body dose to the offsite United States population from reprocessing plant operations through the year 2000 would be 1.1 million person-rem, about 25% of the dose from the total light water reactor industry, and about 0.2% of that from natural background, over the same period.

Plutonium recycle could affect the offsite consequences of an accident, because of the change in transuranic radionuclide concentrations associated with reprocessing mixed oxide fuel. The maximum potential offsite exposure in the event of an accident exists during reprocessing of a fuel lot made up entirely of mixed oxide fuel elements. In the offsite population, an individual receiving the estimated maximum dose would receive about 0.056 rem (thyroid) or about 0.019 rem to the bone. The corresponding doses from a comparable accident with uranium fuel would be 0.056 rem (unchanged) and 0.010 rem.

1.3.1.4 Uranium Fuel Cycle Operations

For individual facilities, neither the impact from normal operations nor the impact of an accident in the uranium fuel cycle operations of mining, milling, uranium hexafluoride conversion, and uranium fuel fabrication would be affected by choice of recycle option. Because fewer uranium fuel cycle facilities are required for the uranium recycle option or the uranium and plutonium recycle option, the overall impacts of the uranium fuel cycle operations would decrease, and fewer accidents would occur.

1.3.1.5 Transportation

Implementation of uranium and plutonium recycle would result in an approximate 6% overall decrease in vehicle-miles (15 million miles) involved in shipment of fuel materials and wastes over the no recycle case.

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*The postulated accidents considered in GESMO are the more serious accidents of the type that either have occurred or realistically can be postulated; the magnitude of the postulated accidents, and the radioactive releases resulting from them, are typical of those that might be reviewed in environmental statements for individual facilities.

The following shipments would be required: spent fuel shipments for all fuel cycle options; plutonium oxide and unirradiated mixed oxide fuel assemblies in the uranium and plutonium recycle option; high level wastes and transuranic wastes in both the uranium recycle and uranium and plutonium recycle options; and plutonium waste from the uranium fuel cycle option.

A range of postulated transportation accidents was considered, including the assumed breach of casks for spent fuel and containers for fresh fuel, and for high level and transuranic wastes. The plutonium oxide shipping vehicles would be designed to withstand unusual efforts of penetration and, accordingly, should be able to withstand extra severe accidents.

Spent Fuel - The characteristics and package used for irradiated fuel are not significantly changed by choice of fuel cycle option. Thus, recycle of fissile materials introduces no new accident types not previously analyzed. In the unlikely event that a cask of irradiated fuel is involved in an accident severe enough to result in a release of radioactivity, the environmental impact should be about the same for any fuel cycle option.

Plutonium - The plutonium oxide containers are doubly sealed and the special vehicle to be used for plutonium oxide transportation is designed to withstand unusual efforts of penetration. Thus the probability that there would be any release of radioactive material from a plutonium oxide shipment following any credible accident is not considered significant. Plutonium waste from the uranium fuel cycle option would be transported in a manner similar to high level wastes and transuranic wastes.

Mixed Oxide Fuel - The impact on the environment from radioactive material being released in a transportation accident involving unirradiated mixed oxide fuel is considered to be negligible. Although material may be released, the particle size of the material would fall predominantly in the non-respirable (greater than 10 micron) range. The area of contamination would be limited to the immediate vicinity of the ruptured package.

High Level Wastes - The structural and containment features of casks for transporting high level wastes are similar to those of casks for irradiated fuel. Furthermore, high level wastes will be packaged in completely sealed steel canisters that are in turn enclosed in the shipping cask so that two levels of containment will be provided.

Plutonium recycle would not have a significant effect on the characteristics of high level waste that are important in the assessment of environmental impact of unusual accident conditions. No significant differences in accident consequences attributable to choice of recycle option have been identified.

Transuranic Wastes - Packages used for waste are so designed and constructed, and the solid form in which the waste is shipped is such that, in the event a shipment of solid waste is involved in an accident, it is unlikely that the radioactive material would be released.

The probability of a transportation accident resulting in the release of radioactivity is small, and is not appreciably affected by choice of recycle option. No transportation considerations have been identified that would preclude the selection of any recycle option.

1.3.1.6 Waste Management

Five major categories of waste are generated by the LWR fuel cycle--chemical (nonradioactive), low level radioactive waste that is not contaminated with substantial amounts of plutonium or other transuranium elements, uranium mill tailings, transuranic wastes, and high level wastes (or, in the case of the no recycle option, spent fuel). Mill tailings, transuranic wastes, and high level or spent fuel are the three categories most affected by the choice of recycle option.

Mill Tailings - The largest volume of waste generated in the fuel cycle is the impounded solid tailings at the uranium mills. These will be stored in the vicinity of the mills which are presently located in remote regions of the western United States. For the no recycle option, the volume of these wastes generated in the years 1975 through 2000 would be about 800 million cubic meters. For the uranium and plutonium recycle option the volume of these wastes will be reduced by about 22%, and for the uranium recycle option by about 11% relative to the no recycle option.

Tailings contain essentially all of the uranium daughters originally present in uranium ore. Emissions of radon, a radioactive gas, from tailings piles will continue for very long periods of time. The doses from radon releases from the mill tailings piles beyond the year 2000 can be placed in perspective by comparing them to the dose from the naturally occurring background radon. The maximum radon concentration at 0.5 mile from stabilized tailings is calculated to be 5 times the average radon background measured at three of four milling sites by the Public Health Service; at 1 mile it is 1.5 times background; at 5 miles it is 0.15 times background; and at 50 miles the radon from the tailings pile would be indistinguishable from background radon.

Transuranic and High Level (or Spent Fuel) Wastes - The presence of plutonium and other radioactive materials in transuranic and high level wastes (or spent fuel in the case of the no recycle option) makes it necessary to isolate these wastes from man and his environment for very long periods of time. GESMO has used a geologic storage concept for isolation of these materials, specifically, placement in bedded salt.

Two waste repositories are required in the year 2000 for all light water reactor fuel cycle options. Approximately 55,000 cubic meters of spent fuel are generated from

the light water reactor no recycle option in the 26-year period from 1975 through 2000. The uranium recycle option and the uranium and plutonium recycle option produce 6,500 cubic meters of high level waste each and 128,000 cubic meters and 148,000 cubic meters of transuranic waste, respectively, over the 26-year period. (The waste plutonium from the uranium recycle option is assumed to be an impure plutonium solid that will be handled in a manner similar to that used for transuranic and solidified high level wastes. Because of the potential for nuclear criticality, the storage of the plutonium will have to include consideration for minimization of the occurrence of criticality.)

Subsurface land requirements for geologic disposal are greatest for the uranium and plutonium recycle option (1,090 acres), and least for the uranium recycle option (915 acres). The no recycle option requires 970 acres of subsurface area for spent fuel storage.

During normal operation of a model bedded salt repository, the release of small amounts of nonradiological pollutants and trace quantities of radionuclides has only negligible effect on the environment. For all fuel cycle options, the maximum annual bone dose to an individual would be about 0.0003 rem, an insignificant fraction of that received from natural background radiation. The overall environmental impact from the operation of a repository is approximately the same for any recycle option.

Expectations, based on the operating history of the nuclear industry to date, are that credible accidents in waste management facilities will be of low probability. With the consideration of the type and integrity of the facilities that will be designed for such application, little environmental impact from accidents is projected. The upper level accident at a waste repository involves a rupture of a high level waste canister during handling. Radiation doses from such an accident involving the average mix of solidified high level waste from the uranium and plutonium recycle option (0.0056 rem) is a factor of 2 higher than that resulting from a similar accident involving the high level waste from uranium recycle alone (0.0028 rem). A criticality accident during handling of waste plutonium containers (for the uranium recycle option) would have about the same consequences as a criticality accident at a fuel reprocessing plant. See paragraph 1.3.1.3 above.

The most complete study of geologic containment failure mechanisms and their consequences was made for a waste repository in bedded salt of the Delaware Basin in southeast New Mexico. The main conclusion of that study was that a serious breach of containment of a waste repository, either by natural events or human action, is an extremely remote possibility, one that is a much smaller risk than many others acceptable to society and of such small magnitude to be beyond the limit of human experience. Once the waste has been placed in such a configuration and the mine sealed, only the most extreme of natural events has any potential for release of radioactivity from the disposal zone. Even the surface burst of a large (50 megaton) nuclear weapon could not breach the containment.

The result of this assessment of waste management is that there is no clear preference for a specific fuel cycle option on the basis of waste management considerations. It should be noted, however, that the no recycle option minimizes plutonium handling, that either the uranium or the uranium and plutonium recycle option reduces land committed to long term waste management of mill tailings and high level and transuranic waste, and that the uranium and plutonium recycle option minimizes the quantity of plutonium that ultimately enters waste streams. Recycle of plutonium to light water reactors reduces the plutonium sent to waste management to about 1% of the amount without such recycle.

The assessment shows that no waste management consideration is significant enough to dictate a decision among the three fuel cycle options.

1.3.2 Environmental Impact

An environmental benefit from the uranium recycle or uranium and plutonium recycle options is the conservation of uranium resources. About 10% less uranium mining is required for the uranium recycle option and about 22% less for the uranium and plutonium recycle option than for the no recycle option. Enrichment requirements for the uranium and plutonium recycle option are about 86% of those of the no recycle or uranium recycle options. Added environmental effects from reprocessing operations are partially offset by lowered effects from uranium fuel cycle operations in the uranium recycle option; and the effects from both reprocessing and mixed oxide fuel fabrication are partially offset by lowered effects from uranium fuel cycle operations in the uranium and plutonium recycle option.

The three uranium and plutonium recycle Alternatives 1, 2, and 3, defined in GESMO, have essentially the same environmental impact from plant operations and transportation. The environmental impacts of uranium and plutonium recycle (Alternatives 1, 2, or 3), uranium recycle (Alternative 5), and no recycle (Alternative 6) are listed in Table ES-2.

Table ES-2 shows the major factors influencing the environmental impact of the light water reactor industry. The values result from operation of the light water reactor industry from 1975 through 2000. It can be seen that the resource use of the uranium and plutonium recycle option, Alternatives 1, 2, or 3, is generally the smallest, and that of the no recycle option is greatest, of the three fuel cycle options.

The radionuclides released from LWR industry operations are different with recycle of fissile materials (Alternatives 3 and 5) than without (Alternative 6). The different mixes of radionuclides produce somewhat different doses to workers and offsite individuals. The cumulative total body doses over the 26-year period are:

Table ES-2

SUMMARY OF INTEGRATED ENVIRONMENTAL FACTORS
FROM LIGHT WATER REACTOR INDUSTRY, 1975 THROUGH 2000*

Environmental Factor	Fuel Cycle Option: Prompt Uranium and Plutonium Recycle (Alternatives 1, 2, or 3)	Fuel Cycle Option: Uranium Recycle (Alternative 5)	Fuel Cycle Option: No Recycle (Alternative 6)
Resource Use			
Committed Acres	3.4×10^{4}	4.0×10^{4}	5.0×10^{4}
Water Use (Gallons)	1.2×10^{14}	1.3×10^{14}	1.3×10^{14}
Heat Dissipated (Btu)	2.9×10^{17}	2.9×10^{17}	2.9×10^{17}
Coal Use (Ton)**	8.9×10^{8}	9.0×10^{8}	9.0×10^{8}
Gas Use (Therms)	1.0×10^{10}	1.2×10^{10}	1.3×10^{10}
Fuel Oil (Gallons)	2.0×10^{10}	2.0×10^{10}	1.9×10^{10}
Electricity Use (GWy)	3.8×10^{2}	3.8×10^{2}	3.8×10^{2}
Plant Effluents (Curies)			
Radon-222	2.3×10^{7}	2.5×10^{7}	2.8×10^{7}
Radium-226	1.1×10^{1}	1.3×10^{1}	1.4×10^{1}
Uranium	8.7×10^{2}	1.0×10^{3}	1.1×10^{3}
Thorium-230	3.2×10^{1}	3.6×10^{1}	4.2×10^{10}
Plutonium (Alpha)	4.6	3.0	2.3×10^{-3}
Plutonium-241 (Beta)	1.2×10^{2}	7.4×10^{1}	3.0×10^{-2}
Trans-Plutonium Nuclides	1.1	5.3	9.0×10^{-4}
Tritium	6.5×10^{7}	6.4×10^{7}	4.7×10^{6}
Carbon-14	1.2×10^{5}	1.2×10^{5}	4.3×10^{4}
Krypton-85	1.3×10^{9}	1.3×10^{9}	2.6×10^{6}
Strontium-90	1.8×10^{1}	1.8×10^{1}	2.5×10^{-2}
Technetium-99	4.5×10^{2}	5.3×10^{2}	---
Iodine-129	1.1×10^{2}	1.1×10^{2}	---
Iodine-131	3.4×10^{3}	3.3×10^{3}	6.0×10^{2}
Other Radioactivity	5.3×10^{7}	5.4×10^{7}	5.4×10^{7}
Plant Waste Generated (Cubic Meters)			
Mill Tailings	5.9×10^{8}	6.9×10^{8}	7.8×10^{8}
Transuranium Solids	1.5×10^{5}	1.3×10^{5}	---
High Level Solids	6.5×10^{3}	6.5×10^{3}	5.5×10^{4}
Total Body Dose Commitment, Person-Rem			
Occupational	3.8×10^{6}	4.0×10^{6}	4.1×10^{6}
Nonoccupational			
Offsite United States	4.2×10^{6}	4.6×10^{6}	3.9×10^{6}
Foreign Population	8.8×10^{5}	9.1×10^{5}	2.1×10^{5}

*The impacts include those from mining, milling, uranium hexafluoride conversion, uranium fuel fabrication, mixed oxide fuel fabrication, reactors, fuel reprocessing, transportation, waste management, and spent fuel storage.

**Coal use includes use at fuel cycle plants and at fossil fueled power plants that are assumed to supply two-thirds of power use.

	Millions of person-rem		
	Alternatives (1, 2, 3)	Alternative 5	Alternative 6
U.S. Occupational	3.8	4.0	4.1
Offsite	4.2	4.6	3.9
U.S. Total	8.0	8.6	8.0
Foreign	.9	.9	.2
World (U.S. & Foreign) Total	8.9	9.5	8.2

For perspective, the United States population receives a cumulative total body dose of about 650 million person-rem from natural background radiation during the period from 1975 through 2000. The approximately 10 million person-rem (total body) dose from the light water reactor industry operations adds less than 2% to the natural background dose.

The foreign population dose is higher for Alternatives 3 and 5 than it is for Alternative 6 because of the postulated releases from fuel reprocessing. The dose to the foreign population is less than 1 million person-rem for any option; the value is about .01% of the cumulative dose (10 billion person-rem) from natural background during the same period.

It is possible to estimate health effects (cancer mortality and total genetic defects) attributable to the radiation received by the United States offsite population, occupational workers, and foreign population. Table ES-3 shows the estimated number of cancer mortalities and genetic defects attributable to operation of the light water reactor industry from 1975 through 2000. It can be seen that the estimated number of added cancer mortalities in the United States ranges between 1,100 and 1,300 for the three recycle options. The estimated number of added genetic defects ranges between 2,200 and 2,400.

Table ES-3

ESTIMATED HEALTH EFFECTS ATTRIBUTABLE TO OPERATION OF THE LIGHT WATER REACTOR INDUSTRY, 1975 THROUGH 2000

	Number of Health Effects Fuel Cycle Option		
Health Effects	Uranium & Plutonium Recycle Alternative 3	Uranium Recycle Alternative 5	No Recycle Alternative 6
Cancer Mortality			
U.S. Population	1,100	1,200	1,100
Total World (including U.S.)	1,200	1,300	1,100
Genetic Defects			
U.S. Population	2,100	2,400	2,100
Total World (including U.S.)	2,300	2,600	2,100

The estimated number of health effects results from exposures of very large populations to very small doses. Because of the large population included in the calculations it is possible to estimate large numbers of health effects from any source of radiation. For example, the natural background dose for the U.S. population is estimated as 650 million person-rem for the 26-year period 1975 through 2000. The estimated number of cancers from this natural background dose would be 90,000. The estimated error in the average natural background dose is about 10 percent. The possible error in the estimated cancers from natural background is about $\pm$ 9,000.

The estimated error in health effects from natural background introduces an uncertainty much larger than the estimated health effects from the fuel cycle options. Because of the large uncertainty, the small differences in the estimated health effects are not significant and provide little basis for selection of a fuel cycle option.

1.3.3 Cost-Benefit Analysis*

Overall fuel cycle cost analyses showed that there are minor penalties (on the order of $100 million discounted to 1975 at 10%) to be paid for delaying plutonium recycle for a short time (Alternatives 1 and 2) as compared to the reference case (earliest possible recycle of uranium and plutonium), Alternative 3. If there is no recycle of plutonium (Alternatives 5 and 6), substantial economic penalties--about $3 billion discounted at 10% ($18 billion undiscounted)--will be incurred.

Parametric studies were made to analyze the sensitivity of the results to variations in the growth in electricity demand, to the unit costs of the various fuel cycle steps, to economic assumptions, and to delays in plutonium recycle. The analyses showed that the economic incentive to recycle plutonium

- Increased with increasing nuclear growth rate
- Increased with increasing uranium price and enrichment costs
- Increased with increasing costs of spent fuel disposal
- Decreased with increasing fuel reprocessing and mixed oxide fuel fabrication costs
- Is relatively unaffected by costs of spent fuel transportation, plutonium transportation, and plutonium storage

In the unlikely event that all of the major possible variations in fuel cycle cost components were unfavorable to recycle, plutonium recycle would show a disadvantage relative to the throwaway fuel cycle.

*All dollars are 1975 dollars.

Large changes in the value of discounted fuel cycle costs were caused by variations in the discount rate, with the economic incentive to recycle increasing with decreasing discount rate. Delays of less than 5 years in the start of the recycle were found to have relatively small impacts under the conditions assumed.

Fuel cycle costs of the five major recycle alternatives considered in GESMO are given in Table ES-4. The table lists the total cumulative discounted fuel cycle costs for the period 1975 through 2000 for Alternative 3, and differential costs relative to Alternative 3 for Alternatives 1, 2, 5, and 6.

Alternative 3 is calculated to have a total 1975 present worth fuel cycle cost of $36.3 billion at a 10% discount rate. A summary of the cost-benefit of the other alternatives relative to Alternative 3 shows that:

Alternative 1 (Early Reprocessing, Delayed Plutonium Recycle)

This alternative has a slightly higher demand for uranium than Alternative 3, slightly less mixed oxide fuel fabrication, negligible differences in environmental impact, and a present worth cost penalty of $150 million at a 10% discount rate.

Alternative 2 (Delayed Reprocessing, Followed by Plutonium Recycle)

Compared to Alternative 3 the demand for uranium is higher, fuel storage is increased, mixed oxide fuel fabrication is decreased, the environmental impact is essentially the same, and a present worth cost penalty of $70 million at a 10% discount rate is incurred. Although this alternative is somewhat less attractive than Alternative 3, it represents a potentially more realistic alternative since it appears that commercial reprocessing might not begin until the early 1980's.

Alternative 5 (Delayed Reprocessing, No Plutonium Recycle)

Although this alternative recycles uranium, Alternative 5 has a higher demand for uranium, enrichment services, and spent fuel storage than Alternative 3. It has no demand for mixed oxide fuel fabrication and produces an impure plutonium solid as a waste. Compared to Alternative 3, it has a higher radiological impact and a higher nonradiological environmental impact. It results in a present worth cost increase of $3 billion at a 10% discount rate.

Alternative 6 (No Reprocessing, No Recycle)

Alternative 6, the no recycle option, has a greater demand on uranium resources, enrichment services, and fuel storage than Alternative 3. It requires no reprocessing or mixed oxide fuel fabrication. Compared to Alternative 3, it has a greater nonradiological environmental impact but a lower radiological dose. Its use is projected to result in an increase over Alternative 3 in the present worth fuel cycle cost of $3.2 billion at a 10% discount rate.

Table ES-4

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	15,700	+36	+520	+2,640	+4,670
UF_6 Conversion	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
Pu Sales*	-93	0	+22	+93	+93
TOTAL (Rounded)	36,300	+150	+70	+3,000	+3,200

*The small amount of plutonium leaving the light water fuel cycle for research use is accounted for as a sale or negative cost.

NOTE: This table is the same as Table XI-43.

The principal tradeoff between this Alternative, 6, and Alternative 3 arises from a relatively small decrease in the total radiological dose compared to the $3.2 billion present worth cost penalty.

In an attempt to quantify the value of this radiological impact decrease, a high, or maximum, value for this impact can be assessed by using the upper value for a person-rem suggested in 10 CFR Part 50, Appendix I, at $1,000/person-rem. This value is a very conservative (high) guide for evaluation of the reduction of radiological exposures. By applying this value ($1,000/person-rem) to dose, however, it is possible to approximate a maximum (high) value of reducing to zero the dose from certain facility impacts. It should also be noted that the industry dose commitments are based on a set of assumptions that tend to overstate the actual exposure levels.

The decrease in nonoccupational exposure (U.S. and foreign) of 9.7×10^5 person-rem at $1,000/person-rem, results in a social benefit of $970 million over the time period. Since there is no appropriate mechanism for discounting this benefit to a present worth, it can only be compared to the total undiscounted increase in economic costs of Alternative 6 over Alternative 3, $18 billion. The benefit, $970 million, is less than the undiscounted economic cost, $18 billion.

The world population receives a population dose from natural background radiation in the period from 1975 through 2000 of about 1×10^{10} person-rem, which is over 1,000 times greater than the dose received from the entire LWR industry under any fuel cycle alternative (see Table ES-2) and 10,000 times the difference between any of the various alternatives.

2.0 FINDINGS

The principal staff findings based on evaluations of the health, safety, and environmental (but not safeguards) effects of widescale recycle of plutonium as fuel to light water reactors are as follows

- The safety of reactors and fuel cycle facilities is not affected significantly by recycle of fissile materials.

- Nonradiological environmental impacts resulting from recycle of fissile materials from spent fuel are slightly smaller than those from a fuel cycle that does not reclaim residual fuel values.

- Plutonium recycle extends uranium resources and reduces enrichment requirements, while entailing the need for reprocessing and fuel fabrication of plutonium containing fuels.

- While there are uncertainties, widescale recycle has a likely economic advantage relative to a fuel cycle that does not reclaim residual fuel values.

- Differences in health effects attributable to recycle provide no significant basis for selection of a fuel cycle option.

- No waste management considerations were identified that would bar recycle of uranium and plutonium.

3.0 QUESTIONS AND ANSWERS ON GESMO - HEALTH, ENVIRONMENTAL AND SAFETY

3.1 Why Does Adoption of Rules Governing Widescale Recycle of Plutonium Constitute a Major Federal Action Potentially Affecting the Environment?

Recycle of plutonium as fuel for light water reactors has the potential of affecting all processing steps for uranium and plutonium in the light water reactor fuel cycle. In addition, the toxicity of plutonium is significantly greater than that of natural or slightly enriched uranium. Furthermore, plutonium, unlike the low enriched uranium fuel used in light water reactors, is a strategic special nuclear material capable of being used in a nuclear explosive, and hence requires appropriate safeguarding.

3.2 If Plutonium Were Not Used as Fuel in Light Water Reactors in This Century, Could All of it Be Used?

Current uses of plutonium for neutron sources and for research and development activities are projected to require only a small percentage of the projected 700 metric tons of fissile plutonium available from LWR fuel in this century. The ERDA projection of the plutonium requirement for breeder reactors is 220 metric tons of fissile plutonium between now and the year 2000, or about 30% of the plutonium recovered from light water reactor fuel in this century. Hence most plutonium would remain unused if it is not recycled as fuel to light water reactors.

3.3 What, If Any, Is the Interrelation Between Plutonium Recycle as Fuel to Light Water Reactors and the Liquid Metal Fast Breeder Reactor?

Late in the century, if liquid metal fast breeder reactors (LMFBR's) fulfill the role projected for them by ERDA, plutonium from light water reactors will be used for initial fuel and initial reloads for breeders.

Breeder oxide fuel is chemically similar to light water reactor mixed oxide fuel; therefore, light water reactor mixed oxide fabrication plants would resemble future liquid metal fast breeder reactor fuel plants. Thus recycle of plutonium as fuel to light water reactors provides a base of operating experience with plutonium recovery and fuel fabrication that can be transferred to the liquid metal fast breeder reactor industry.

3.4 Is the Forecasted Number of Light Water Reactors On Line in the Year 2000 Affected by the Choice of the LWR Fuel Cycle Alternatives?

GESMO has assumed that the installed light water reactor generating capacity is independent of the choice of fuel cycle option for several reasons:

(1) Estimates of U_3O_8 resources show them to be adequate to support the 507 LWR's projected to be on line in the year 2000 without recycle of uranium or plutonium.

(2) Virtually every authoritative study available to the Commission utilizes the assumption that the nuclear component of the electrical industry is essentially independent of the mode of fuel management.

(3) Choice of a power plant is primarily based on economic considerations. Fuel cycle costs are a small part of overall nuclear costs, and the type of fuel is only a partial determinant of fuel cycle costs.

3.5 What is the Time Frame Covered by GESMO, and How Was it Chosen?

The draft GESMO assessed the environmental impact of the projected light water reactor industry in a single year, 1990. Considerations of whether a single year could appropriately represent the impact of a growing industry led to the use of a 26-year period, 1975 through 2000, as the base in the final GESMO. Impacts of the LWR industry under the various recycle options were summed over this 26-year period, and differential impacts assessed.

The year 2000 was chosen as a cutoff year for analysis for several reasons:

(1) Breeder reactors may dominate the nuclear power plant market early in the next century, so that the installed base of LWR's may be near its maximum around 2000. Other competitive energy sources may be developed by that time, i.e., fusion, solar, geothermal, etc.

(2) Projections for energy and LWR electrical generating capacity are subject to substantial uncertainty beyond the year 2000.

(3) The use of existing technology and processes to represent the far future industry appears to be unrealistic, since improvements in technology may be expected to occur.

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. Since recycle is economically advantageous in the 1975-2000 period, it will be even more advantageous over its total lifetime.

3.6 What Types of Reactors Have Been Considered in GESMO?

The ERDA 1975 projections show three types of reactors used for power generation in the United States--the light water reactors (LWR's), high-temperature gas-cooled reactors (HTGR's), and liquid metal fast breeder reactors (LMFBR's). GESMO has considered primarily the LWR, and has assumed that essentially all of the nuclear power

generated in the United States between now and 2000 will be generated by LWR's. The rationale behind this assumption is as follows:

(1) The General Atomic Company, sole vendor of HTGR's, announced in October 1975, that it was temporarily withdrawing from offering commercial HTGR's for sale. Hence NRC has assumed that the installed nuclear operating capacity in the period between 1975 and 2000 attributed to HTGR's will be provided by fossil fueled plants.

(2) The LMFBR has been projected by ERDA to supply a small fraction of the nuclear power by year 2000. To focus its analysis on LWR's, NRC has assumed that this small fraction of power will be generated by fossil fueled plants instead of LMFBR's, and therefore the impacts reported account for the impact of recycling all of the plutonium to LWR's. Evaluations have been made of the effect of transfers of plutonium from the LWR fuel cycle to the LMFBR fuel cycle.

3.7 What Level of Plutonium Loading in a Reactor Has Been Used in the GESMO Assessments?

For the purpose of this environmental analysis the quantity of recycle plutonium for a model reactor has been selected at 115% of the equilibrium amount of material that could be self-generated by the reactor. This means that the plutonium would not exceed 1.8% of the total heavy metal content (uranium + plutonium) in the as-charged fuel. Two points should be observed:

- The use of the 1.8 ^{w}/o Pu/ (U + Pu) limitation should not be considered a limitation on the amount of plutonium that could be used in LWR's based on economic, safety, or environmental considerations.

- On an industrywide basis, the impacts of the LWR fuel cycle operations with uranium and plutonium are not affected by the amount of plutonium loaded into any LWR, although the environmental impacts of the reactor might change slightly.

3.8 Are the Potential Hazards to the Public from Reactor Operations Affected by Plutonium Recycle?

The potential hazards to the public remain relatively unchanged by the substitution of mixed oxide fuel assemblies for uranium fuel assemblies. If widescale recycle of plutonium as fuel to light water reactors is authorized, the NRC Office of Nuclear Reactor Regulation, in accordance with normal practice, will evaluate each utility application to use mixed oxide fuel assemblies on a case-by-case basis. These evaluations will provide specific assurances that the risks to the health and safety of the public will not be affected by a change to mixed oxide fuel. Each reactor load and reload of a new type of uranium fuel has been routinely evaluated in the past, in the same manner.

3.9 How Were the Environmental Impacts of the LWR Industry Evaluated?

Each segment of the light water reactor industry, from uranium mining through waste disposal, was represented by model plants. Natural resources use (land, water, energy) and effluents were estimated using existing practice and technology as a basis. The number of facilities of each type required in each year from 1975 through 2000 was estimated using projections of nuclear industry growth. Total industry impacts under the different recycle options were calculated by integrating annual impacts from all required facilities.

3.10 What Pathways to Humans Have Been Evaluated in Assessing Dose Commitments?

Pathways considered in assessing dose commitments include inhalation (including consideration of resuspended materials), plume submersion, ground plane irradiation, dietary intake, and external exposure from waterway recreational uses. (Plume submersion accounts for the external dose commitment received from radioisotopes in the air.)

3.11 What Is the Most Significant Pathway for Plutonium and Other Transuranium Elements?

The inhalation pathway (including the consideration of resuspended materials) is the most significant pathway for plutonium and other transuranium elements.

3.12 What Model Was Used to Assess the Lung Dose Commitment Received from Inhalation of Alpha-Emitting Particles?

An important issue involved in the calculation of radiation dose due to deposited alpha-emitting particles within the lung is the spatial distribution of the particles. Such particles irradiate immediately surrounding tissues intensely, but may leave other more distant tissues unirradiated. Present recommendations of the National Council on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Protection (ICRP), present guidance to Federal agencies issued by the Federal Radiation Council (now incorporated in the Environmental Protection Agency), and present NRC standards are based upon the premise that nonuniform distribution of particles is not more hazardous than uniform distribution. Therefore, dose commitments in GESMO have been calculated assuming that plutonium or other alpha-emitting particles are uniformly distributed in the lung.

3.13 Where Will the Overall Cost-Benefit Balancing for Plutonium Recycle Including Safeguards Considerations Be Published?

The overall cost-benefit balancing will be made in the Safeguards Supplement to the Final Environmental Statement and will include considerations of health, safety and environmental, economic, and safeguards factors.

3.14 What is the Overall Effect of the Uranium Recycle and Uranium and Plutonium Recycle Options on the Amount of Transplutonium Isotopes Formed in the LWR? The Amount of Plutonium That Must Be Sent to Waste Disposal Facilities? The Amount of Plutonium Released to the Environment?

In comparison to the no recycle option as the datum, the uranium recycle option does not affect the amount of transplutonium isotopes formed in LWR's, the isotopic

composition of the plutonium or the transplutonium isotopes, or the amount of plutonium and transplutonium isotopes that must be sent to waste management.

Recycle of plutonium does result in a change in the isotopic composition of plutonium in spent LWR fuel, and increases the amount of transplutonium isotopes generated in LWR's. Since plutonium is recycled to light water reactors in this option, much less plutonium (about 99% less) and more transplutonium isotopes must be sent to waste disposal under the uranium and plutonium recycle option than under the uranium recycle or no recycle options.

More plutonium and transplutonium isotopes are released to the environment from uranium recycle or the uranium and plutonium recycle options than from the no recycle option. The total emissions of plutonium and transplutonium nuclides from the three options are:

CURIES, 1975 THROUGH 2000

	Uranium and Plutonium Recycle (Alternative 3)	Uranium Recycle (Alternative 5)	No Recycle (Alternative 6)
Pu (alpha)	4.6	3.0	0.0023 Pu
Pu (beta)	120.	74.	0.03
Transplutonium nuclides	11.	5.3	0.0009

3.15 Can the Radiological Effects of the LWR Fuel Cycle Be Put into Perspective?

First, in terms of radiological exposure, naturally occurring cosmic and terrestrial radiation contributes a radiation dose of about 0.1 rem (whole body) annually to the average individual or about 650 million person-rem to the U.S. population over the 26-year period from 1975 through the year 2000. The LWR industry operations over the same period (1975 through 2000), for any fuel cycle option considered in GESMO, would add a total body dose of less than 10 million person-rem to the 650 million person-rem received from natural background, an increase of less than 2%.

Second, in terms of high level wastes, the analyses presented in GESMO show that about 200,000 cubic feet of solidified high level waste would be generated by the light water reactor uranium recycle or uranium and plutonium recycle options by the year 2000. The volume of spent fuel, the waste stream from the no recycle option that is comparable to the high level wastes for the recycle option, is about 2 million cubic feet. The Energy Research and Development Administration estimates that by the year 2000, the volume of high level nuclear wastes from defense activities will total 11 million cubic feet as salt cake.

Third, in terms of plutonium and transplutonium nuclide releases, weapons testing has resulted in the fallout of about 300,000 curies of plutonium-239. The light water

reactor industry would release the equivalent of about 20 curies of plutonium (alpha-emitting plutonium) over the 26-year period.

3.16 How Is NRC Going to Proceed with the Decision Process on Widescale Use of Plutonium in LWR's?

Legislative-type hearings will be conducted before a special hearing panel established by the Commission for the purpose of aiding the Commission in its determination whether or not widescale use of mixed oxide fuel in light water nuclear power reactors should be authorized and, if so, under what conditions and with what implementing regulations. The Commission regards a decision-making process that is both sound and expeditious to be of crucial importance and believes that both considerations can be compatibly accommodated in its public hearing procedure. The legislative-type hearings may be followed by adjudicatory-type hearings on particular issues if the need for further hearings on such issues is demonstrated to the Commission. The Commission intends that hearings commence following issuance of the relevant portion of the final impact statement on widescale use.

The Commission intends to issue proposed amendments to its regulations in 10 CFR Chapter 1 relating to widescale use of mixed oxide fuels in notices of proposed rulemaking to be published in the Federal Register at about the time relevant portions of the impact statement are completed. These proposed amendments will address safety, environmental, and safeguards matters associated with widescale use of mixed oxide fuel. In addition to the usual opportunity for written public comment on these regulations, an opportunity will be afforded for consideration of them during the hearing process. The Commission intends to promulgate appropriate regulations in final form at the time of its final decision. There will be no separate hearing on these proposed rules.

Rules for the conduct of the hearing were published in the Federal Register (41 FR 1133).

The hearing on the health, safety and environmental portion of the final environmental statement is scheduled to begin shortly after its publication. Any person who wishes to be a limited participant in the hearing by filing a written statement may do so by filing such statement with the hearing board at any time prior to the conclusion of the hearing.

Each participant is requested to send two copies of each document which that participant files in this proceeding to each board member, one copy to be sent care of the Secretary of the Nuclear Regulatory Commission, Washington, D.C. 20555, and one copy to the following address:

George Bunn, Law School, University of Wisconsin, Madison, Wisconsin 56706

Albert Carnesale, Program for Science and International Affairs,
Harvard University, 9 Divinity Avenue, Cambridge, Massachusetts 02138

Melvin Carter, Director, Office of Interdisciplinary Programs,
Georgia Institute of Technology, Atlanta, Georgia 30332

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Vanderbilt University, Nashville, Tennessee 37215

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NUREG-0002, VOL. 1

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

HEALTH, SAFETY & ENVIRONMENT

Summary

August 1976

Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission

FOREWORD

This Final Generic Environmental Statement on the Use of Mixed Oxide Fuels in Light Water Cooled Reactors (GESMO) has been prepared to be responsive to the Nuclear Regulatory Commission's responsibilities under the National Environmental Policy Act of 1969 (P.L. 91-190), the Council on Environmental Quality's (CEQ) guidelines of August 1, 1973 (38 FR 20550) and 10 CFR Part 51 of the NRC's regulations. The information in this statement has been gathered from both government and industry sources, and several national laboratory sources have assisted the NRC in preparation of this document.

Due to the comprehensive nature of the material discussed in this document, it is difficult to cover the subject matter in the depth that would permit a member of the public to understand the document without a prior knowledge and understanding of the nuclear industry. Accordingly, the material has been presented in a manner that is judged to be understandable to the reasonably well informed layman who has a reading knowledge of the nuclear industry. As assistance to the reader, a glossary of terms is included as Appendix B to Volume 1. In addition, a listing of references for each chapter or section of the statement is presented immediately following the relevant text material.

The issue being considered is a possible future method of operation of the light water nuclear power industry, including nuclear power plants and their associated fuel cycle facilities and supporting operations. The use of mixed oxide fuels in light water cooled reactors has been proposed by the industry for future widescale practice, and it is not possible to present all information on a purely factual and established basis. Where projections of operations and effects were required, a conservative approach--one that tends to overestimate the health, safety and environmental effects--was employed in making assessments and estimates. The information presented is based either upon actual or planned full scale commercial operations, pilot operations, or extrapolations from established developmental data. It should be noted that both the nuclear industry and its technology are comparatively new and still developing. Thus, it is difficult to select any point or points in time for a review of such a changing situation and be able to cover all variations. Accordingly, parametric analyses and sensitivity analyses have been performed to estimate how much difference it might make if certain changes in technology or economics actually occurred.

The draft statement was prepared in 1974 by the former Atomic Energy Commission (AEC) and the final statement including up-dated projections of the growth of the industry for the rest of this century has been prepared by the Nuclear Regulatory Commission, based on technology currently in use. The draft GESMO published in August 1974 was circulated to obtain comments from a wide variety of people and organizations. Comments were requested from other agencies of the Federal, State and local

governments, and from many segments of the public concerned with various aspects of this issue. In addition to the distribution to these interested groups, many copies of the draft report were provided in response to requests from other individuals and organizations. The comments received by the AEC have been considered by the NRC in the preparation of this final statement. Volume 5 has been included in the final statement, containing both the comments and responses.

VOLUME 1

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1.0 SUMMARY

1.1 Purpose of GESMO

1.1.1 Introduction

Plutonium recycle in light water reactors (LWR's) is defined as the use of plutonium-uranium mixed oxide fuels in which plutonium produced as a byproduct of operating LWR's replaces some portion of the uranium-235 normally used for fueling LWR's. The U.S. Nuclear Regulatory Commission (NRC), and its predecessor, the U.S. Atomic Energy Commission (AEC), determined that widescale recovery and recycle of plutonium fuel in LWR's warranted analysis apart from that given for the licensing of any single recycle facility and that adoption of rules governing such widescale use would constitute a major Federal action that would have the potential to affect significantly the quality of the human environment. Accordingly, pursuant to the National Environmental Policy Act of 1969 (NEPA), Section 102(2)(C), NRC has prepared this final Generic Environmental Statement on the Use of Recycle Plutonium Mixed Oxide Fuel in Light Water Cooled Reactors (GESMO).*

In a Federal Register Notice (40 FR 53056) of November 14, 1975, the Nuclear Regulatory Commission specified the scope and procedures for decisions relating to the widescale use of mixed oxide fuel in LWR's. Highlights of the notice relevant to the environmental statements included

- A Commission determination that the subject of widescale use of mixed oxide fuel in the LWR fuel cycle required a full assessment of safeguards issues before a decision on widescale recycle could be made. Based on that determination, the Commission directed its staff to prepare and to circulate for written comment a safeguards supplement to the draft environmental statement issued by the Atomic Energy Commission staff in August 1974, the supplement to include an analysis of the costs and benefits of alternative safeguards programs and a recommendation as to safeguards associated with widescale use of mixed oxide fuel.

- Proposed rules relating to the possible widescale use of mixed oxide fuel will be published for comment as final portions of the environmental statement are issued. The Commission directed the staff to expedite preparation of all aspects of the final environmental statement, including safety and environmental matters as well as safeguards matters.

*AEC originally prepared a draft statement.

- The public will have the opportunity to participate in the decisional process of the Commission not only by submitting written comments on the draft environmental statement and proposed rules but also by participating in the public hearings to be held on the final statement and on any implementing rules. The legislative-type hearings will be started as soon as practicable after issuance of the nonsafeguards portion of the final statement. These legislative-type hearings may be followed by adjudicatory-type hearings on particular issues if need for further hearings is demonstrated to the Commission.

The final GESMO is being published in two parts--a final evaluation of the health, safety, and environmental impacts of plutonium recycle (including a cost-benefit balancing), and a supplement containing the final evaluation of safeguards (including the final cost-benefit balancing). This document is the health, safety, and environmental portion of the final GESMO. Proposed rules relating to the possible widescale use of mixed oxide fuel will be published at about the same time as final portions of the environmental statement are issued.

1.1.2 Fuel Cycle Options for Light Water Reactors

The fuel currently used in LWR's is low enriched (about 3%) uranium dioxide (UO_2). The heat energy produced during operation of newly fueled LWR's comes basically from the fissioning of the uranium-235 atoms in the fuel. As the reactor operates, atoms of fissile plutonium, Pu_f (i.e., plutonium-239 and plutonium-241), are produced by transmutation of uranium-238 atoms. The fissioning of some plutonium atoms contributes to the energy produced by the reactor.

When fuel can no longer sustain a chain reaction at economic power levels, it is considered to be spent and removed from the reactor. At that point, the fuel still contains fissile isotopes (about 6 grams fissile plutonium and about 8 grams of uranium-235 per kilogram of uranium) and about 98% of the uranium-238 originally charged. These can be recovered from the spent LWR fuel by chemical treatment in a reprocessing plant. It is the potential recovery of fissile isotopes from spent fuel that gives rise to three recycle options for LWR's. If the spent fuel is disposed of without reprocessing, the fuel cycle option is referred to as the "no recycle" option. If spent fuel is reprocessed and the recovered uranium is recycled with plutonium being disposed of as a waste, the fuel cycle option is called "uranium recycle." In the third recycle option, the "uranium and plutonium recycle" option, both uranium and plutonium are recovered by reprocessing and recycled as fuel to LWR's.

Plutonium recovered by reprocessing spent fuel is combined with uranium having a lower uranium-235 content than that of new low enriched uranium fuel to make an equivalent LWR reactor fuel. Thus, a substitution of recovered plutonium is made for some of the uranium-235. Such fuel is called plutonium-uranium mixed oxide or simply mixed oxide (MOX) fuel. The diluent uranium used in mixed oxide fuel has been assumed to be natural uranium throughout GESMO. One special case, that of blending plutonium with low enriched uranium in every fuel rod, called dilute plutonium recycle, has been considered in CHAPTER IV, Section L.

When plutonium produced in LWR's is recovered, recombined with uranium, fabricated into fuel rods, and reinserted into the same LWR core, displacing an equivalent number of enriched uranium fuel rods, the resultant reactor can be described as a self-generation reactor (SGR). The recycle of the equivalent of all of the plutonium that a reactor produces (fissile and non fissile) plus 15% additional plutonium from other LWR's has been chosen as the LWR plutonium recycle model reactor in this study. The mixed oxide content of a reactor operating in that mode increases with time until about 18 years after startup and about 16 years after the first introduction of mixed oxides into the reactor; at this time an equilibrium level is reached wherein about one-third of the fuel rods contain mixed oxides. Refer to CHAPTER IV, Section C, for details of the model reactor.

1.1.3 Environmental Assessments in GESMO

The final GESMO analyzes the environmental impacts, costs, and benefits resulting from the implementation of one of the three possible recycle options for the LWR--no recycle, uranium recycle, and uranium and plutonium recycle.* The characteristics of these options are

- The no recycle option: all reactor fuel comes from newly mined natural uranium, enriched in uranium-235 content in an isotope separation plant.

- The uranium recycle option: only uranium is reused (after enriching the uranium-235 content in an isotope separation plant), to manufacture replacement fuel after recovery from LWR spent fuel.

- The uranium and plutonium recycle option: both uranium and plutonium are recovered from LWR spent fuels and subsequently incorporated into replacement fuels.

The 26-year period 1975 through 2000 has been used as a datum; the baseline growth rate projection used was the ERDA OPA-1975 low nuclear growth rate without the fast breeder reactor. In 1975, there were 37 model (1,000 MWe) reactors; in the year 2000 it is projected that there will be about 500 model 1,000 MWe LWR's. A model plant concept was used to determine the environmental impact of each part of the fuel cycle and a distribution of such plants across the United States to estimate transportation impacts.

In GESMO, the differences in the total environmental effects of the LWR industry have been assessed for the three LWR fuel cycle options. Differences in the environmental impacts among the fuel cycle options might be expected to arise from the following activities

- Change in magnitude of uranium fuel cycle operations

- Addition of fuel reprocessing plants

*In the tables throughout the Summary, the recycle options are indicated as follows: No = no recycle; U = uranium recycle; and U+Pu = uranium and plutonium recycle.

- Addition of mixed oxide fuel fabrication plants

- Changes in several LWR industry operations, such as
  - Reactor operations
  - Spent fuel storage--plutonium storage
  - Transportation
  - Waste management

1.1.4 Organization of GESMO

The body of the environmental statement on the health, safety, and environmental impacts of plutonium recycle as fuel in LWR's is organized, insofar as is appropriate, in accordance with the guidelines of the Council on Environmental Quality (CEQ). This volume, 1, is a summary of the statement.*

The body of the environmental statement, GESMO CHAPTERS I through XI, is contained in Volumes 2 through 4. A brief description of each chapter follows:

CHAPTER I - INTRODUCTION - sets forth the purpose of GESMO and introduces the reader to the LWR fuel cycle options.

CHAPTER II - BACKGROUND AND EXPERIENCE WITH PLUTONIUM - describes the past and current research and development activities.

CHAPTER III - PROJECTED PLUTONIUM RECYCLE INDUSTRY - describes and considers the effects on the LWR industry of the widespread implementation of recycle.

CHAPTER IV - ENVIRONMENTAL IMPACT DUE TO THE IMPLEMENTATION OF PLUTONIUM RECYCLE - constitutes the major portion of this environmental statement. The differential environmental impacts due to widescale implementation of recycle in LWR's are estimated and presented. Environmental impacts from accident conditions as well as from routine operations are addressed.

CHAPTER IV is divided into major sections as follows:

A Summary
B Introduction
C The Light Water Reactor (LWR) with Plutonium Recycle
D Mixed Oxide Fuel Fabrication
E Reprocessing Plant Operations
F Supporting Uranium Fuel Cycle
G Transportation of Radioactive Materials
H Radioactive Waste Management
I Storage of Plutonium
J Radiological Health Assessment
K Extended Spent Fuel Storage
L Blending of Plutonium and Uranium at Reprocessing Plants

*The Summary of necessity omits much of the detail presented in the document. Readers are urged to peruse the document for detailed data.

Section J contains a discussion of the radiological impacts of the overall industry of implementation of plutonium recycle as fuel in light water reactors. General discussions of dose estimation methodology, health effects from radiation, and plutonium in the environment are appended to Section J.

CHAPTER V - SAFEGUARDS REFERENCE - A supplement to the draft GESMO that assesses safeguards issues related to plutonium recycle will be published and a final Safeguards Supplement to such statement will be published after receipt and analysis of public comments.

CHAPTER VI - PROBABLE ADVERSE ENVIRONMENTAL EFFECTS THAT CANNOT BE AVOIDED - summarizes all the adverse environmental effects of implementation of plutonium or uranium recycle as fuels in LWR's in accordance with the guidelines of the Council on Environmental Quality.

CHAPTER VII - MEANS FOR MITIGATING ADVERSE ENVIRONMENTAL EFFECTS - discusses existing and potential future measures for mitigating adverse environmental effects.

CHAPTER VIII - ALTERNATIVE DISPOSITIONS OF PLUTONIUM - identifies and analyzes various alternative dispositions of plutonium produced in LWR's.

CHAPTER IX - RELATIONSHIP BETWEEN LOCAL SHORT TERM USES OF MAN'S ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG TERM PRODUCTIVITY - discusses the extent to which the recycle of plutonium involves tradeoffs between short term and long term environmental gains and losses, and narrows future options.

CHAPTER X - IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES - identifies those resource commitments, resulting from the proposed recycling of plutonium, that would curtail the range of potential uses of the environment or of other resources.

CHAPTER XI - ECONOMIC ANALYSIS AND COST-BENEFIT BALANCING - compares the incremental benefits, costs, and risks associated with alternative dispositions of LWR-produced plutonium.

Volume 5 includes all public comments and NRC responses.

1.2 Background and Experience with Plutonium

1.2.1 General

With the exception of very minute quantities of plutonium-244 fairly recently discovered in nature and minute quantities of plutonium-239 in uranium ore, plutonium is an artificially produced element. Beginning with the wartime research and production activities, the United States has made an intensive study of plutonium. As a result of 30 years of research, development, and production, its properties and characteristics are better known than those of most elements and many commercial materials.

If the use of recycle plutonium as fuel for LWR's is authorized, it will result in the construction and operation of new facilities for the mixed oxide fuel cycle. The new plants would take into account past experience in plutonium processing and would employ advanced technology, new equipment and improved methods to achieve greater safety and protection of employees and the public, as well as to reduce the likelihood that detrimental environmental impacts will occur.

In a typical LWR fuel management scheme the fuel remains in the reactor for about 3 years, until the uranium-235 concentration is about 0.8% and the fissile plutonium concentration is about 0.6%. As soon as plutonium is formed in the fuel, some of its atoms undergo fission and contribute to the production of power. Near the maximum fuel burnup, the plutonium content has increased and the uranium-235 content decreased to the point where plutonium contributes about as much to the production of energy as the uranium-235.

The use of mixed oxide fuel for LWR's does not result in the formation of elements or isotopes that would not otherwise have been present in uranium fuel. However, when plutonium is included in fresh fuel charged to the reactor, the spent fuel contains larger quantities of plutonium, particularly the heavier isotopes of plutonium and transplutonium elements. The initial concentrations of plutonium in mixed oxide fuels is about 2 times the final plutonium content of uranium fuel elements at full burnup (see CHAPTER IV, Section C-4.0). A typical LWR using uranium fuel without plutonium recycle and operating at a power level of 1,000 MWe produces about 280 kilograms of plutonium per year, of which approximately 200 kilograms are the fissile isotopes, plutonium-239 and plutonium-241.

1.2.2 Radiobiological Hazards of Plutonium

Before the world's supply of plutonium was as much as one gram, research on the radiobiological hazards of plutonium had been started. The radiobiological hazards of plutonium have been the subject of continuing research under the Atomic Energy Program and an extensive body of information now exists as the result of 30 years' work by many scientists. Appendix C of Section J, CHAPTER IV, contains a detailed discussion of research findings regarding plutonium in man and the environment.

Recycling of plutonium would have little effect on the exposures to the public due to external radiation from plutonium. Precautions must be taken to avoid inhalation or ingestion of plutonium-bearing materials because plutonium is radiotoxic if taken into the body. The most likely route of intake into the body is deposition in the lung via inhalation and subsequent translocation after absorption from the lung into body fluids. Less likely routes of intake are absorption through the skin or entry through wounds and ingestion and subsequent absorption from the gastrointestinal tract.

The route of plutonium entry into the body has a significant effect on its deposition and distribution in the tissues and bone. CHAPTER IV, Section J, includes a detailed discussion of the radiobiological hazards associated with plutonium, including effects from skin absorption and internal deposition in the bloodstream, lungs, and in other body organs and bone. It is important to note that plutonium is not easily retained in body fluids.

Since the advent of Atomic Energy Commission programs, a number of people working with plutonium have accumulated quantities of the material measurable by urinary excretion. Case histories and data from thorough examinations over periods ranging from 5 to 25 years since exposure are available on 37 individuals who had systemic burdens estimated to be in excess of the maximum permissible level (MPL) established by the National Council of Radiation Protection of 0.04 microcuries of plutonium. Twelve individuals in whom the original plutonium intake occurred 23 and 24 years ago have been kept under surveillance and subjected to periodic thorough examinations. These individuals have experienced no changes in their physical condition not attributable to the natural aging process. Although the number of cases is too few to support reliable extrapolations of the biological consequences of plutonium contamination, these human experiences suggest that the MPL for plutonium is conservative.

A study of indigenous and experimental animals kept for long periods in areas heavily contaminated with plutonium indicates that direct uptake of plutonium is small. Plutonium uptake by plants from soil and growth media has been investigated in both field and laboratory under a variety of conditions. The concentration of plutonium in plants on a dry weight basis was never more than one-thousandth of that contained in the growth medium and only about one ten-thousandth of that in the soil.

Studies at the Nevada Test Site over a period of 10 years following the 1955-1957 series of detonations involving plutonium show that the uptake of plutonium by plants increases over the years. Although the increase in plutonium uptake is measurable, the levels are so low that ingestion of plutonium through consumption of plants does not represent an important pathway to human exposure. This conclusion is based on measurements of the tissues of persons exposed to fallout from past nuclear weapons tests.

At Palomares, Spain, a non-nuclear explosion of a nuclear weapon dispersed a large quantity of plutonium. Follow-up studies after an extensive clean-up campaign have not revealed any consistently measurable plutonium concentration levels in people or produce from the area.

1.2.3 Plutonium Recycle in LWR's

1.2.3.1 Development and Testing of Mixed Oxide Fuels

The initial development of technology for plutonium recycle as fuel in LWR's was sponsored by the United States Atomic Energy Commission, with follow-on programs financed by the utilities and by the nuclear reactor manufacturers; in some cases, programs had joint sponsorship. Development of the technology of plutonium recycle in reactor fuels began with the AEC-sponsored Plutonium Utilization Program (PUP) at Hanford in 1956 and is continuing mainly with mixed oxide fuel performance demonstrations in LWR's. Major industry programs were initiated in 1967 with the Edison Electric Institute support of mixed oxide fuel development and tests conducted by the Westinghouse Electric Corporation and the General Electric Company, followed by the mixed oxide fuel performance demonstration programs in commercial reactors.

Many other countries have been developing and testing the technology required for recycle of plutonium as fuel in thermal reactors. To date, most national programs have

concentrated on mixed oxide fuel irradiations, demonstration and large reload programs, design studies, critical experiments and economic and environmental assessments. In November 1974, the International Atomic Energy Agency's Panel on Plutonium Utilization in Thermal Reactors met in Karlsruhe, Germany, to review the current status of plans and programs for plutonium utilization in the participating countries. The 1974 status reports with updates from other sources are summarized below for the various countries.

Belgium. Belgium has a well-established plutonium recycle development program. Demonstrations of the behavior of plutonium fuels have been in progress for several years in pressurized water and boiling water reactors. In parallel, a few samples were being irradiated in material testing reactors to assess particular details of the specifications or to investigate the fuel behavior under extreme conditions.

Italy. Extensive research on plutonium recycle as fuel in LWR's has been carried out by Italy. Mixed oxide fuel pins manufactured in Italy have been irradiated in several European reactors and pilot plant reprocessing of mixed oxide fuels has been done. Italy currently plans to use plutonium in fast breeder reactors rather than to recycle plutonium as fuel in light water reactors.

Canada. The plutonium utilization program in Canada is directed towards solving the technical problems of plutonium recycle in natural uranium, heavy water reactors.

Federal Republic of Germany. Up to 1975, work in the Federal Republic of Germany concentrated on the successful demonstration of recycle fuel behavior in thermal power reactors. This included fuel fabrication at prototype scale, testing of elements under irradiation, and the necessary applied software development. Phase I ended in 1974 with the design and initiation of testing of full plutonium reload cores following the self generation concept in both a pressurized water and a boiling water reactor.

France. France has decided to concentrate on the development of fast breeder reactors, and therefore French interest in the recycle of plutonium in thermal reactors is secondary and at a low level.

India. India plans to utilize the plutonium produced in CANDU type reactors as fuel for fast breeders when they become available.

Japan. The Power Reactor and Nuclear Fuel Development Corporation (PNC) is now planning to initiate recycling at an early stage.

The Netherlands. Five prototype plutonium-island elements have been loaded into a boiling water reactor.

United Kingdom. The major research and development effort of the United Kingdom Atomic Energy Authority (UKAEA) is directed toward the exploitation of the sodium-cooled fast reactor. However, adequate expertise and manufacturing capacity are being maintained by both the UKAEA and British Nuclear Fuels Limited (BNFL) for producing plutonium bearing fuels for experimental purposes for either gas- or water-cooled thermal reactors.

Sweden. Demonstration irradiations of plutonium fuel started in the Swedish Agesta reactor in 1966 in cooperation with the UKAEA. The first plutonium fuel to be used in an LWR is represented by three assemblies that have been loaded into the Swedish Oskarhamn I reactor.

As a result of the experience acquired and the technology developed in the various plutonium recycle programs, it has been demonstrated that plutonium recycle is technically feasible. This conclusion is based on successful irradiations of fuel in the Saxton, San Onofre, Big Rock Point, and Dresden Unit No. I reactors in the United States, the Garigliano reactor in Italy, and in the Plutonium Recycle Test Reactor at Hanford. In these irradiations, the mixed oxide fuels were irradiated at specific power levels and to burnups typical of those expected in light water reactors. The irradiations showed no abnormal characteristics with respect to fuel behavior or predicted reactor control and core performance characteristics.

1.2.3.2 Mixed Oxide Fuel Fabrication

Because plutonium is much more radiotoxic than uranium, the incorporation of plutonium into light water reactor fuels requires different fabrication techniques and equipment than required for low enriched uranium fuel fabrication. Engineering designs of equipment and facilities for adequate handling of plutonium have been developed to a high level of sophistication as a result of the wealth of knowledge and experience accumulated under USAEC programs over the past 30 years. Mixed oxide fuels are always fabricated in equipment and facilities specially designed for handling plutonium. In these facilities the plutonium is contained in the process equipment itself to the maximum extent practical. Where transfers from one operation to another are required, plutonium-bearing materials are handled in sealed containers until the fuel is sealed inside the cladding of the fuel rod. After decontamination to remove traces of plutonium from the outside surfaces, the mixed oxide rods are brought into the fuel assembly area and may be handled directly.

There are multiple levels of confinement in a plutonium fabrication facility. Confinement, in this context, means a complete enclosure around the plutonium, where the pressure inside the contained volume is maintained below that in the surrounding area so that any leakage in the enclosure will draw material inward rather than allowing plutonium to escape outward. Confinement systems require complete enclosures with associated ventilation systems.

The first level of confinement is the process vessel or equipment inside the glovebox. The second level of confinement is the glovebox or other equipment enclosure or a totally enclosed transfer device. Additional confinement may be provided by the walls of the process area. A final barrier is provided by the building structure designed as the ultimate barrier to stop the possible release of plutonium into the environment under all conservatively selected design basis conditions. Structures housing new plutonium fabrication facilities must be capable of withstanding the effects of such natural phenomena as tornadoes, hurricanes, earthquakes, and floods.

1.2.3.3 Reprocessing of Fuel

During World War II, one of the Manhattan Project's major objectives was to produce and purify large amounts of plutonium. Radiochemical processing plants were built to separate the plutonium from irradiated natural uranium and fission products.

Large scale separation of plutonium by solvent extraction has been developed into a well-tested industrial technology. In the United States most of the processing to date has been done in government-owned plants, but four privately owned fuel reprocessing plants have been built or are planned to handle fuel from light water reactors. These plants will separate uranium and plutonium from each other and from fission products. One plant operated from 1966 to 1972; the operator has applied for a construction permit to modify the plant for higher throughput. A second plant has been constructed but is not being operated because of technical difficulties encountered in the preoperational tests--difficulties not connected with the solvent extraction section of the plant. The third plant is under construction, with the Separations Facility and the UF_6 Facility nearing completion (see CHAPTER IV, Section E, for details). A fourth plant is planned for completion in the mid 1980's.

Reprocessing of light water reactor fuels after removal from the reactor is performed in a massive concrete structure, subdivided into heavily shielded processing cubicles or cells that contain remotely controlled and operated equipment. Because the standard UO_2 fuel, after being irradiated in the reactor, contains plutonium, all light water reactor fuel reprocessing plants have to date been designed to process, separate, and purify plutonium, whether plutonium recycle comes into practice or not. A decision to permit the widescale use of mixed oxide fuel for LWR's would increase the quantity of plutonium in fuel to be reprocessed. A more detailed discussion is presented in CHAPTER IV, Section E.

1.2.3.4 Criticality

The processing of enriched uranium or plutonium introduces a problem found only in the nuclear industry: a nuclear chain reaction (criticality). There has been a total of six criticality accidents associated with the processing of highly enriched uranium or plutonium. One involving highly enriched uranium occurred in a private commercial facility; none has occurred with the low enriched uranium used in commercial light water reactor fuels. There have been no criticality accidents in fuel cycle plants in the past 12 years.

1.2.3.5 Transportation

Adoption of the uranium and plutonium recycle option would result in greater heat generation in spent fuel than that from the no recycle or uranium recycle option. In addition, high level wastes from the reprocessing of recycle plutonium fuel have higher heat generation rates than comparable wastes from uranium fuel. Casks for shipping these materials (i.e., spent fuel and high level waste) would have to be designed to accommodate higher heat generation rates, or loaded only to the heat rejection capacity of the casks.

1.2.3.6 Waste Management

The quantity of radioactive material involved in the nuclear fuel cycle will not be affected greatly by the implementation of uranium and plutonium recycle in comparison to no recycle. If spent fuel is not recycled, it would be stored with essentially all the radioactive material still contained in the fuel. If spent fuel is reprocessed to recycle the uranium or to recycle both uranium and plutonium, the bulk of the radioactive waste from reprocessing would be solidified and stored as high level waste. The solidified high level waste would contain most of the radioactive material which otherwise would have been stored in the spent fuel, but, with the uranium removed, it will occupy about half the volume.

Some differences in waste composition as a result of recycle of plutonium should be noted. The transuranium elements such as americium and curium will be formed in substantially greater quantities in mixed oxide fuel than in uranium fuel, and these are expected to be completely passed on to the reprocessing wastes. If plutonium is not recycled, it will be disposed of as an impure solid in a manner similar to the high level wastes and transuranic wastes. For a detailed discussion on radioactive waste management, refer to CHAPTER IV, Section H.

1.3 The LWR Industry

1.3.1 Development of the LWR Industry 1975 through 2000

In selecting a forecast of growth of the LWR industry for use, NRC considered projections of growth in the consumption of energy in the United States, of energy resources, and of growth in electrical generating capacity. Several different projections of growth in nuclear generating capacity were developed by other Federal agencies and private organizations. The projections concluded that most of the expansion from the 1974 capacity of about 476,000 MWe to the capacity of 1,550,000 to 1,900,000 MWe forecast for the year 2000 will have come from construction of fossil-fueled plants and LWR's. The capacity of hydroelectric plants, including pumped storage, might be expected to increase by as much as 100,000 MWe. Very little commercial generation of electricity can be expected from breeder reactor or thermonuclear reactor plants. The ERDA research and development program projects a total of 120,000 to 270,000 MWe of geothermal and solar electrical generating capacity by the year 2000. Considering the technology that must be developed and the pilot and demonstration plants that must be operated successfully before commercial plants are built, a combined capacity of 100,000 MWe could be considered an optimistic goal. It appears that, depending on the degree to which conservation is effective, 900,000 to 1,200,000 MWe of new fossil-fueled and LWR nuclear plants will be needed in order to satisfy the projected demand.

Based on assessments of the resource base and projections of the total cost of nuclear power versus the cost from alternative sources, several forecasts have been made of the growth to be expected in nuclear power plant capacity to the year 2000.

Although forecasts may differ in the rate of growth predicted for the nuclear power generation capacity, almost all indicate that the electricity generated by nuclear plants can be expected to increase from the 6% of the total generation in 1974 to 40% to 60% in 2000.

As a result of study of the various forecasts, it was concluded that the ERDA projections for low growth assuming no breeder and moderate high growth with breeder defined reasonable bounds for the range of growth in LWR nuclear power generation capacity that could be expected. The ERDA forecasts for low growth without breeder and moderate high growth with breeder projected installed nuclear capacities of 156,000 and 197,000 MWe, respectively, in 1985 and 507,000 and 893,000 MWe, respectively, in the year 2000. NRC used the ERDA low growth projection as a baseline case. The moderate high case was used for sensitivity analyses.

The cumulative quantity of fissile plutonium recovered from spent LWR fuel through the year 2000 is 689 metric tons (MT) for the uranium recycle option and 790 MT for the uranium and plutonium recycle option.

The LWR fuel cycle for each of the three recycle options is shown in Figures S-1, S-2, and S-3. Table S-1 gives the year 2000 material flows for the overall fuel cycle and Table S-2 lists the size and number of LWR industry facilities in the year 2000 for the three recycle options.

The LWR industry projected for the GESMO analyses is an extrapolation of the present industry. The uranium recycle option and the uranium and plutonium recycle option are based on the assumption that spent LWR fuel will be reprocessed, that liquid high level wastes will be solidified, and that the solidified wastes will be sent to a Federal waste repository and be managed by the Federal government. Plutonium recovered as an impure solid product in the uranium recycle option will be sent to a Federal waste repository. The no recycle option is based on the assumption that spent fuel will be shipped to a Federal waste repository and be managed by the Federal government.

The components of the LWR industry are described in more depth below for each of the three options:

- No recycle
- Recycle of uranium
- Recycle of uranium and plutonium

1.3.2 Reactors

Over 500 reactors (507) of 1,000 MWe generating capacity each are projected to be operating in the year 2000. This number has been assumed to be the same for all options since nuclear penetration of the electric power market is based primarily on economics. Recycle of fissile materials affects only fuel cycle costs, which are

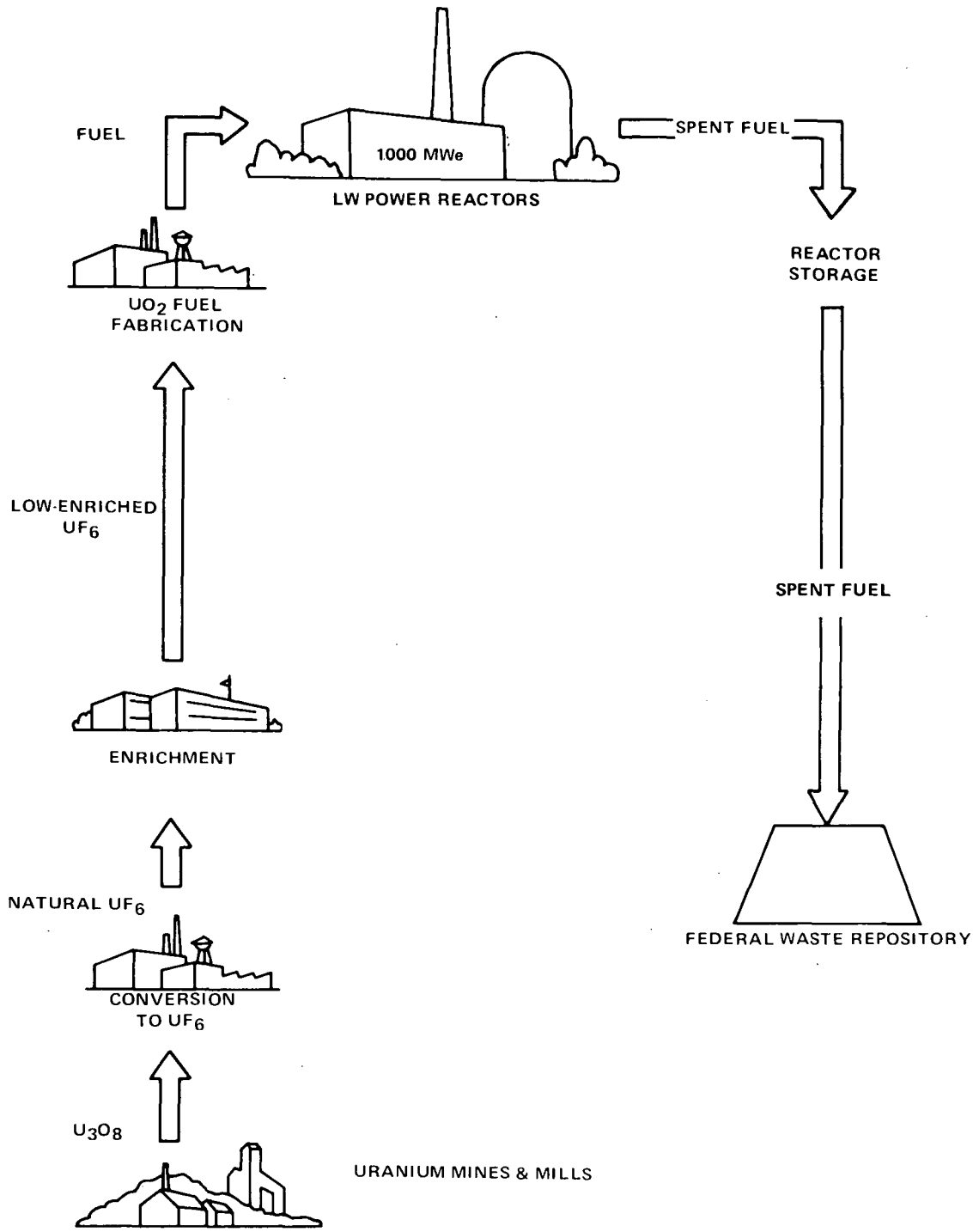

Figure S-1 Light Water Reactor Fuel Cycle – No Uranium or Plutonium Recycle

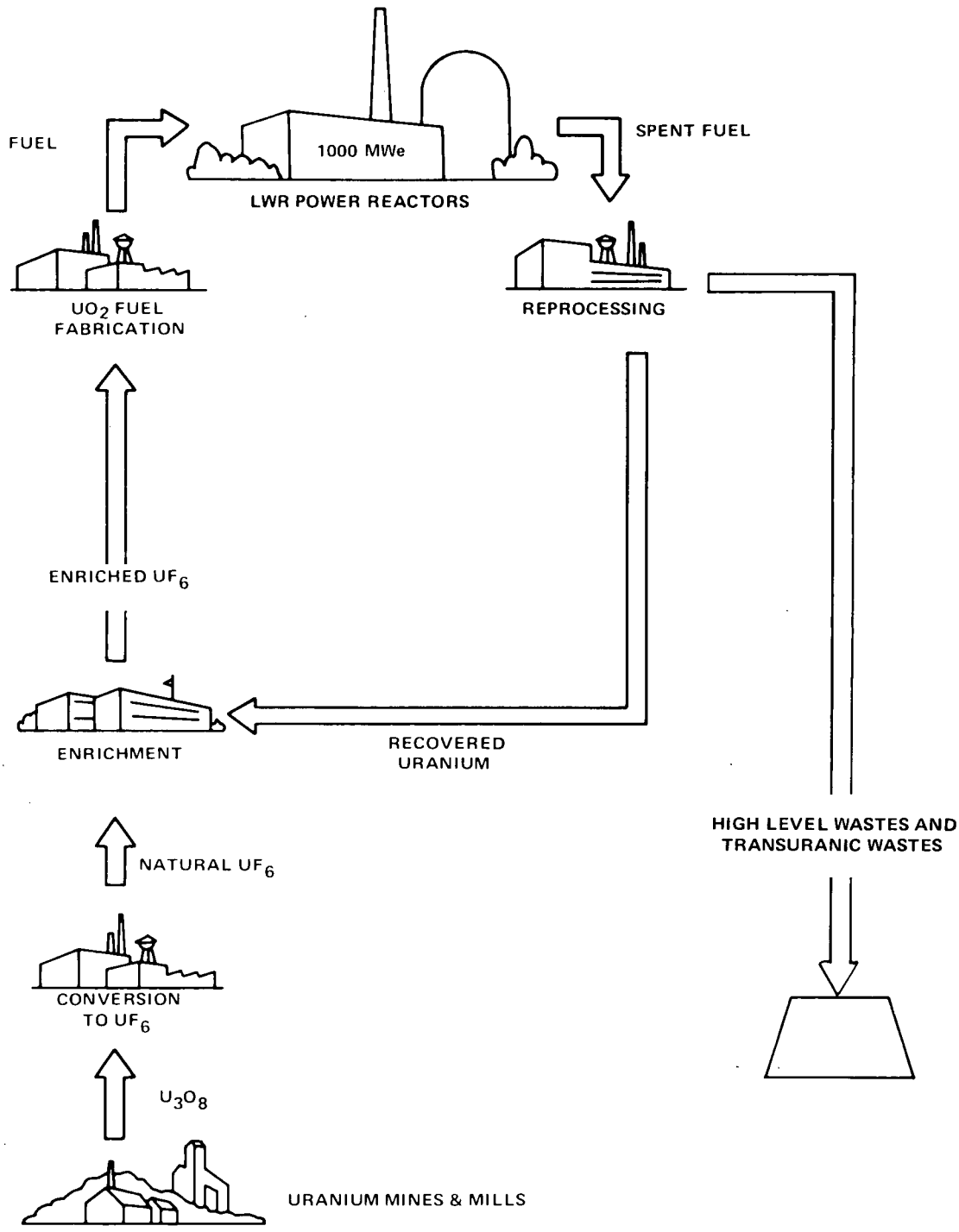

Figure S-2 Light Water Reactor Fuel Cycle — Uranium Recycle Only

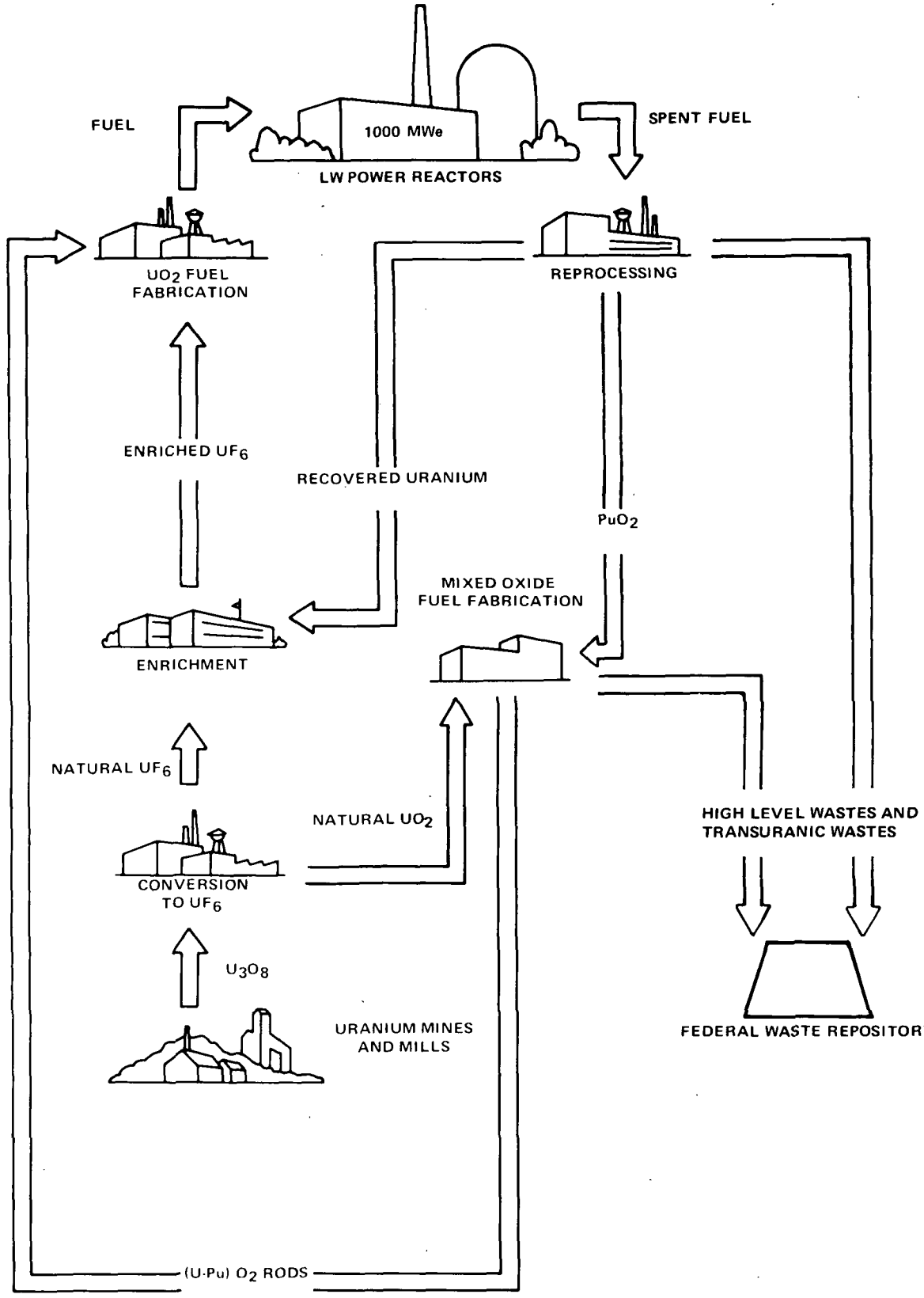

Figure S-3 Light Water Reactor Fuel Cycle – Uranium and Plutonium Recycle

Table S-1

SUMMARY OF MATERIAL FLOWS IN THE OVERALL U.S. LWR FUEL CYCLE IN ABOUT THE YEAR 2000

Fuel Cycle Operation	Option: No Recycle	Option: U Recycle	Option: U + Pu Recycle
Uranium Ore Mined and Milled (MT)	114×10^6	99.1×10^6	80.7×10^6
U_3O_8 Recovered (ST)	113,900	98,800	80,500
Natural Uranium Converted to UF_6 (MTU)	87,300	75,500	59,300
Enrichment of Uranium (MTSWU)	45,000	45,500	36,100
Conversion of UF_6 to UO_2 (MTU)	13,500	13,500	10,850
Plutonium through Reprocessing Plants (kg Pu_f)	None	68,000	82,200
Plutonium in Storage/Inventory or Waste or Spent Fuel (kg Pu_f)*	690,000	690,000	7,000
Mixed Oxide Fuel Fabrication (MTHM)	None	None	2,650

MT - Metric tons

MTU - Metric tons of uranium

MTHM - Metric tons of heavy metal (U + Pu)

MTSWU - Metric ton separative work units

kg Pu_f - Kilograms of fissile plutonium

ST - Short tons

*Total plutonium is about 1.5 times the fissile plutonium

NOTE: Data in this table are the same as those in Table I-2

Table S-2

THE PROJECTED LWR INDUSTRY IN THE YEAR 2000

LWR Industry	Annual Capacity	Number of Facilities		
		No Recycle	U Recycle	U + Pu Recycle
LWR's*		507	507	507
Mines**		5,840	5,064	4,125
Mills	1,050 ST U_3O_8	109	95	77
UF_6 Conversion Plants	15,000 MTU	7	6	5
Uranium Enrichment Plants	8.75×10^6 SWU	6	6	5
UO_2 Fuel Fabrication Plants	1,500 MTU	9	9	7
Reprocessing Plants	2,000 MTHM	0	5	5
MOX Fuel Fabrication Plants	360 MTHM	0	0	8
Federal Repositories for Storage of High Level Waste Transuranic Wastes Spent Fuel Assemblies	360 cu m High level 6,000 cu m Transuranic 15,000 Assemblies	5	5	5
Commercial Burial Grounds	1×10^6 ft^3	11	11	11

*Reactors are assumed to be 1,000 MWe

**Underground mines (capacity of 20,000 short tons annually) constitute over 95% of the total mines; open pit mines (200,000 short tons annual production) constitute remaining 4+%.

NOTE: These data come from Tables III-1, III-2, and III-3.

about 20% of total power generating costs. The relatively small differences in fuel cycle costs among the three recycle options are unlikely to affect overall power costs enough to cause major changes in the number of reactors. Small changes in fuel cycle costs can however amount to significant cost savings over a reactor life.

For the no recycle or uranium recycle option, all 507 reactors would be fueled with slightly enriched UO_2. For the uranium and plutonium recycle option that assumes plutonium to be present in reactors at the 1.15 SGR level, about 250 reactors would be using some mixed oxide fuel in the year 2000.

There are some differences in the production of radionuclides in LWR's fueled with mixed oxides and LWR's fueled with uranium only. The most important differences are the following

- The in-reactor inventory of plutonium for the mixed oxide cores at the steady state 1.15 SGR level is about 2-1/2 to 3 times the inventory for uranium fueled LWR's.

- Slightly increased quantities of radioactive iodine, tritium, and xenon are associated with the mixed oxide cores as well as slightly decreased quantities of krypton-85 and carbon-14.

- Increases in the quantities of radioactive americium and curium that are present in mixed oxide cores lead to increased decay heat and increased neutron activity in the spent fuel.

1.3.3 Mixed Oxide Fuel Fabrication

Recycle of plutonium as fuel in light water reactors would require production of 25,000 MT of mixed oxide fuels over the 26-year reference period and 2,700 MT in the year 2000. Year 2000 production is projected to take place in eight model facilities each having a capacity of 360 MT/yr.

The mixed oxide fuel fabrication facility necessary to implement plutonium recycle must be specially designed. The nature of plutonium--particularly its radiotoxicity--is such that many of the fabrication operations cannot be properly performed in a typical uranium fuel fabrication facility. Handling plutonium requires special enclosures and containment since the biological hazard is many times that of slightly enriched uranium.

The net result of recycling plutonium as fuel to LWR's is to increase the size of the mixed oxide fuel fabrication industry from essentially zero to one consisting of about eight model facilities in the year 2000.

1.3.4 Fuel Reprocessing

Fuel reprocessing plants would be required only for the uranium recycle option and the uranium and plutonium recycle option. The anticipated total reprocessing load would be approximately 115,000 MT over the 26-year period and about 10,000 MT in the year 2000. Thus, at the end of this century five model 2,000 MT/yr reprocessing plants would be required for either the uranium or uranium and plutonium recycle options.

1.3.5 The Supporting Uranium Cycle

The total demand for low enriched uranium fuels during the period 1975 through 2000 would be about 188,000 MTU for the no recycle or uranium recycle options and about 163,000 MTU for the uranium and plutonium recycle option. In the year 2000, the total demand for low enriched uranium fuels would be about 13,500 MTU for no recycle or uranium recycle and 10,900 MTU for uranium and plutonium recycle. These reductions would be achieved by substituting about 25,000 MT of mixed oxide fuel for low enriched uranium fuel from 1975 through 2000 and about 2,600 MT in the year 2000. Ninety-five percent of the mixed oxide fuel is uranium dioxide. This study assumes that the uranium present in mixed oxide fuel would be natural uranium.

Most individual components of the supporting uranium fuel cycle would experience a decrease in demand if uranium is recycled and a greater decrease if both uranium and plutonium are recycled. The components of the supporting uranium cycle in the LWR industry are:

- Mining and Milling
- UF_6 Conversion
- Uranium Enrichment
- Uranium Fuel Fabrication

1.4 Environmental Impacts Due to the Implementation of the Uranium or Uranium and Plutonium Recycle Options

1.4.1 Introduction

To determine the environmental impact of implementing plutonium recycle, the total LWR industry impacts have been evaluated for the three recycle options described earlier. Environmental factors for the 26-year period for the three options are tabulated in Appendix A of this Summary.

The environmental factors for the uranium recycle option are based on the assumption that reprocessing is begun in 1986; the factors for the uranium and plutonium recycle option are based on the assumption that fuel reprocessing is begun in 1978, and plutonium recycle in 1981. The uranium and plutonium recycle option is the prompt uranium and plutonium recycle alternative. See paragraph 1.8.

1.4.2 Effect of Recycle Options on Impacts of the LWR Fuel Cycle

The dominant effect of the uranium or uranium and plutonium recycle options is a reduction in the amount of newly mined uranium required by the no recycle option.

Enrichment requirements for the uranium and plutonium recycle option are reduced from the level of such services for the no recycle and uranium recycle option. Incremental changes in health, safety, and environmental impacts arise as the result of substituting impacts from reprocessing (for both the uranium and uranium and plutonium recycle options) and mixed oxide fuel fabrication (for the uranium and plutonium recycle option) for a fraction of the impacts from the uranium fuel cycle operations of mining, milling, UF_6 conversion, and enrichment.

1.4.2.1 Health Effects

Assessments of radiological effects have been performed principally with respect to humans, on the basis that other biota will not be injured if human exposure is maintained below promulgated standards. Exposures to radionuclides via the four principal pathways (submersion, inhalation including resuspension of deposited particulates, dietary intake, and irradiation from deposited material in the environs) have been taken into account. Appendix A of Section J, CHAPTER IV explains the methodology used in estimating population dose commitments to various organs from the amounts of radioactive materials discharged to the environs by the respective model plants.

Use of the uranium recycle option or the uranium and plutonium recycle option results in the release of radioactive krypton, tritium, carbon (^{14}C), iodine, fission products, and actinides to the environment. These materials are released predominantly from the fuel reprocessing plants. Offsetting the release of these materials is a reduction in the amount of uranium and its daughters, especially radon, from uranium operations. Table S-3 shows the total body dose commitments for the no recycle option and the changes attributable to the uranium recycle and uranium and plutonium recycle options. The following facts can be deduced from the data presented in Table S-3.

- The increase in occupational exposure of personnel at reprocessing and mixed oxide fuel fabrication plants for the uranium recycle and uranium and plutonium recycle options is offset by reductions in occupational exposure from uranium operations relative to the no recycle option.

- The increase in population exposure from reprocessing plant operations for the uranium recycle and uranium and plutonium recycle options is partially offset by reductions in exposure from uranium operations.

- Mixed oxide fuel fabrication plants do not contribute significant increases to nonoccupational exposures.

Total worldwide total body dose commitment for the no recycle option is 8.2 million person-rem. Use of the uranium recycle option increases that dose commitment by 1.3 million person-rem; use of the uranium and plutonium recycle option increases the worldwide total body dose commitment by 0.68 million person-rem.

Table S-4 shows the dose commitments by organ to workers, United States population, and world population (excluding United States) for the three options. It can be seen

Table S-3

EFFECT OF RECYCLE OPTION ON CUMULATIVE TOTAL BODY DOSE COMMITMENTS FROM THE LWR INDUSTRY, 1975-2000*

Operations	Cumulative Dose Commitment, Millions of Person-Rem, No Recycle Option			Change in Cumulative Dose Commitments, Millions of Person-Rem, U Recycle Option			Change in Cumulative Dose Commitments, Millions of Person-Rem, U + Pu Recycle Option		
	Occupational	U.S. Nonoccupational	Foreign	Occupational	U.S. Nonoccupational	Foreign	Occupational	U.S. Nonoccupational	Foreign
Uranium Operations**	1.8	3.6	0	-0.19	-0.38	0	-0.40	-0.81	0
Fuel Reprocessing	0	0	0	+0.072	+1.1	+0.70	+0.078	+1.1	+0.67
MOX Fabrication	0	0	0	0	0	0	+0.025	+0.0003	0
Other***	2.3	0.31	.21	-0.005	+0.004	0	+0.068	+0.046	0
TOTAL (Rounded)	4.1	3.91	.21	-0.1	+0.7	+0.7	-0.2	+0.3	+0.7

*Exposed populations are: Occupational = occupational exposure of U.S. LWR industry worker; U.S. Nonoccupational = nonoccupational exposure of United States population; Foreign = nonoccupational exposure of world population, excluding U.S. population.

**Mining, Milling, UF_6 Conversion, Enrichment, and UO_2 Fuel Fabrication

***Reactors, Transportation, Waste Management, and Fuel Storage

Table S-4

CUMULATIVE DOSE COMMITMENTS FROM UNITED STATES LWR INDUSTRY, 1975-2000

Dose Commitment, Millions of Person-Rem*

Organ	Occupational			U.S. Population			Foreign			Option Total		
	No	U	U + Pu	No	U	U + Pu	No	U	U + Pu	No	U	U + Pu
Total Body	4.1	4.0	3.8	3.9	4.6	4.2	0.21	0.91	0.88	8.2	9.5	8.9
GI Tract	3.8	3.7	3.5	0.45	2.0	2.1	0.21	0.91	0.88	4.5	6.6	6.5
Bone	6.5	6.1	5.6	13.	14.	13.	1.0	3.3	3.2	21.	23.	22.
Liver	3.8	3.7	3.5	3.2	4.0	3.6	0.21	0.91	0.88	7.2	8.6	8.0
Kidney	4.4	4.2	4.0	14.	13.	12.	0.21	0.91	0.88	19.	18.	17.
Thyroid	3.8	3.7	3.5	0.49	2.4	2.4	0.21	0.91	0.88	4.5	7.0	6.8
Lung	16.	15.	13.	1.4	2.4	2.3	0.21	1.3	1.2	18.	19.	17.
Skin	3.8	3.7	3.6	0.33	6.9	6.7	0.26	26.	25.	4.4	37.	35.
Natural Background	- -			650			10,000			10,000		

*Exposed populations are indicated as follows: Occupational = occupational exposure of U.S. LWR industry worker; U.S. population = nonoccupational exposure of United States population; Foreign = nonoccupational exposure of world population, excluding U.S.

that dose commitments are greatest for the uranium recycle option and smallest for the no recycle option. For any fuel cycle option, total occupational and nonoccupational dose commitments received by the U.S. population are less than 18 million person-rem to any organ. Natural background gives a dose commitment of about 650 million person-rem. The LWR industry dose commitment to any organ would be less than 3% of that from background.

Health risks to U.S. LWR industry workers, U.S. general public, and foreign public have been conservatively estimated using risk estimators given in WASH-1400, Reactor Safety Study, and are given in Table S-5. It can be seen that the estimated number of added cancer mortalities in the United States ranges between 1,100 and 1,300 for the three recycle options. The estimated number of added genetic defects ranges between 2,200 and 2,400.

The estimated number of health effects results from exposures of very large populations to very small doses. Because of the large populations included in the calculations it is possible to estimate large numbers of health effects from any source of radiation. For example, the natural background dose for the U.S. population is estimated as 650 million person-rem for the 26-year period 1975 through 2000. The estimated number of cancers from this natural background dose would be 90,000. The estimated error in the average natural background dose is about 10 percent. The possible error in the estimated cancers from natural background is about $\pm$ 9,000.

The estimated error in health effects from natural background introduces an uncertainty much larger than the estimated health effects from the fuel cycle options. Because of the large uncertainty, the small differences in the estimated health effects provide little basis for selection of a fuel cycle option.

1.4.2.2 Radiological Impact on Closest Theoretical Resident

Annual dose commitments have been computed for hypothetical individuals residing near the respective LWR industry plants. These individuals are assumed to be adults living continuously in the vicinity of such plants and eating normal diets derived from food produced at the residence and, consequently, the adult who would receive the maximum dose commitment from the plant. These individuals have been referred to as "closest theoretical resident."

Dose commitments to the closest theoretical resident from reactors operating with mixed oxide fuel are not significantly different from dose commitments received from reactors operating with uranium fuel. Variations of 1% in dose commitments from one type of fuel to the other may occur.

For the enrichment and transportation steps, steps that contribute insignificant annual doses of about 0.001 and 0.00005 rem respectively, the increase in the closest

Table S-5

ESTIMATED HEALTH EFFECTS FROM U.S. LWR INDUSTRY 1975-2000*

Type of Health Effect	Option: No Recycle				Option: U Recycle				Option: U + Pu Recycle			
	Occ.	U.S. Non Occ.	Foreign	Option Total	Occ.	U.S. Non Occ.	Foreign	Option Total	Occ.	U.S. Non Occ.	Foreign	Option Total
Bone Cancer Deaths	45	90	6.9	140	42	97	23	160	39	90	22	150
Benign and Malignant Thyroid Nodules	1,300	160	69	1,500	1,230	800	300	2,300	1,200	800	300	2,300
Thyroid Cancer Deaths	51	6.6	2.8	60	50	32	12	94	48	32	12	92
Lung Cancer Deaths	360	31	4.7	390	330	53	29	420	290	51	27	370
Total Cancer Deaths	550	530	28	1,100	540	620	120	1,300	530	570	120	1,200
Specific Genetic Defects	650	620	33	1,300	630	730	140	1,500	620	660	140	1,400
Defects with Complex Etiology	410	390	21	820	400	460	91	950	390	420	89	900
Total Genetic Defects	1,100	1,000	54	2,100	1,000	1,400	170	2,400	1,000	1,100	230	2,300

*Exposed populations are indicated as follows: Occ. = occupational exposure of U.S. LWR industry worker; U.S. Nonocc. = nonoccupational exposure of United States population; Foreign = nonoccupational exposure of world population, excluding U.S..

Note: The data in this table are derived from Table IV J-14.

theoretical resident's total body dose commitment is approximately 40% above the no recycle option for either the uranium recycle option or the uranium and plutonium recycle option. Recycling uranium in either the uranium recycle option or the uranium and plutonium recycle option causes an increase of less than 4% in dose commitments to neighbors of UO_2 fuel fabrication plants, LWR's and irradiated fuel storage facilities. For these operations, the theoretical nearest neighbor doses are an order of magnitude or more below the unrestricted area limit of 10 CFR Part 20.

For reprocessing plant operations, use of the uranium and plutonium recycle options results in a small increase, from 1% to 10%, in the dose commitments to the closest theoretical resident over their value for the uranium recycle operation. The annual dose commitments range from 0.0075 rem (total body) to .040 rem (gastrointestinal tract) for the uranium recycle option.

The annual dose commitment, 0.0003 rem, to the closest theoretical resident of the Federal waste management repository is the same for all fuel cycle options considered in GESMO.

For uranium milling, the consideration of the dose to the closest theoretical resident is not projected to change with the implementation of uranium or uranium and plutonium recycle, but the number of neighbors in this range of exposure will be decreased, since recycle decreases the required number of mills. The number of households adjacent to the respective plants is likely to be low because of the sparsely populated nature of the geographical locations where milling is expected to take place. The mixed oxide fuel fabrication plants, present only in the uranium and plutonium recycle option, contribute an annual dose of 0.177 rem to the bone of the closest theoretical resident.

The risk to closest theoretical resident for the several fuel recycling options is too small to be detectable or to provide a clearly defined basis for making a selection of a fuel recycle option purely on the basis of radiological exposure of persons living adjacent to fuel cycle plants.

1.4.3 Safety

1.4.3.1 Reactor Safety Aspects

LWR's utilizing uranium fuels produce plutonium during all normal operations. Once plutonium is formed in the fuel, it contributes to the fission reaction. Approximately one-third of the total heat output from the LWR's has been contributed from fissions of plutonium bred in the uranium fuel. Mixed oxide fuels do not include or produce any isotopes not otherwise present in LWR fuel.

Many of the nuclear properties of mixed oxide fuels differ from UO_2 nuclear properties. The most notable of these differences is the increased neutron cross section of the plutonium isotopes and the corresponding decrease in control rod worth. The altered nuclear properties can be largely accommodated by using various rod placement and enrichment schemes such that it is feasible to design fuel assemblies that are interchangeable with the spent uranium fuel assemblies they are to replace.

The materials properties and performance of mixed oxide fuels are in many cases indistinguishable from the corresponding UO_2 cases, and in all cases the differences are small. The inhomogeneity of fissile material in physically blended mixed oxide fuel pellets could cause a change in fuel performance, but the degree of homogeniety can be controlled during fabrication and evaluation of any changes will be required.

The performance of a mixed oxide core will be similar to a uranium core under the normal steady-state and load-following conditions. Changes in the nuclear and physical properties of mixed oxide cores will somewhat alter their behavior during transients and accidents. The steam-line-break accident consequences with a pressurized water reactor mixed oxide core, for example, may require more reactivity control. The loss of coolant accident (LOCA), on the other hand, is generally less severe when compared with uranium core LOCA consequences. However, none of the postulated accidents will change enough to increase the public risk significantly.

Offsite radiological effects of reactors are based on the inventory of radioactive elements in the core used to derive source terms for radioactive releases during normal and accident conditions. An analysis of the halogen and noble gas fission product inventory in LWR's with mixed oxide fuel at the SGR level and uranium fuel showed that, at worst, some SGR fuels exhibit as much as a 14% increase in the iodine thyroid dose source term. More typically, dose source terms decrease, except for the thyroid dose source term, which typically shows a 3% increase. The total actinide inventory in the core is essentially the same for the 1.15 SGR case at equilibrium and the uranium fuel case. However, the 1.15 SGR equilibrium core contains about three times the amount of plutonium and 30 times the amount of transplutonium elements contained in a uranium fueled LWR. Although the total weight of fission products in the core is about the same whether mixed oxide fuel or uranium fuel is used, the total amount of radioactivity is slightly higher in the mixed oxide fueled reactor.

The overall assessment of the accident behavior of LWR's with mixed oxide loadings at the 1.15 SGR level shows that the hazards to the public remain relatively the same as those from LWR's with uranium cores.

1.4.3.2 Radiological Impact of Accidents at Fuel Cycle Facilities*

The radiological consequences of postulated accidents have been estimated for the respective model plants in the fuel cycle. The nearest neighbor dose commitments for any accident are predicted to be less than the 10 CFR Part 20 limit for a year's exposure to an individual in an "unrestricted area." Since the frequency of serious radiological accidents in the industry is expected to be far less than one per year, it is considered that the conservative estimates (overassessment of releases and

*The postulated accidents at fuel cycle facilities are the more serious accidents of the type that either have occurred or realistically can be postulated; the magnitude of the accidents, and the radioactive releases resulting from them, are typical of those that might be reviewed in environmental statements for individual facilities.

effects) used to account for normal releases from the model fuel cycle plants have sufficient margin to encompass, over the period of the study, the impacts of accidental releases.

In the uranium supply steps of the fuel cycle, the consequences of an accident at any plant would not be significantly different with the implementation of uranium or plutonium recycle, but there would be fewer model plants. Therefore, the potential for accidents would be decreased.

The additional steps required by recycling, reprocessing of irradiated fuel and the fabrication of mixed oxide fuel, would have comparably low radiological impacts per accident, as indicated in Table S-6, as well as low accident expectancy.

Accidents in waste management facilities are expected to be low probability, based on the operating history of the nuclear industry to date. Considering the type and integrity of the facilities that will be designed for such application, little environmental impact from accidents is projected. The hypothetical maximum credible accident at a waste repository involves a rupture of a high level waste canister during handling. Radiation doses from such an accident involving the average mix of solidified high level waste from uranium and plutonium recycle option (5.6 mrem) is a factor of 2 higher than that resulting from a similar accident involving the high level waste from uranium recycle alone (2.8 mrem).

A criticality accident during the handling of waste plutonium canisters (for the uranium recycle option) in the waste receiving portion of the repository would have approximately the same consequences as a criticality accident at a fuel reprocessing plant (See Table S-6).

Table S-6

ESTIMATED RADIOLOGICAL DOSE COMMITMENTS FROM MODEL PLANT ACCIDENTS

	Reprocessing		Fabrication
	UO_2 Fuel	MOX Fuel	MOX Fuel
Accident Characterization	Dose to Closest Theoretical Resident (rem)		
Criticality	0.056	0.056	0.360
Fire	0.002	0.014	0.027
Explosion	0.011	0.019	0.027
	Dose to Public (person-rem)		
Criticality	629	629	4.2
Fire	18	152	0.8
Explosion	123	213	0.8

Note: The data in this table are the same as Table IV A-5

1.4.3.3 Transportation

Spent fuel, plutonium containing materials and high level waste shipments were reviewed to determine whether choice of fuel cycle option would significantly affect the risk to the public from transportation accidents.

The following shipments would be required: spent fuel shipments for all fuel cycle options; plutonium oxide and unirradiated mixed oxide fuel assemblies in the uranium and plutonium recycle option; high level wastes and transuranic wastes in both the uranium recycle and uranium and plutonium recycle options; and plutonium waste from the uranium fuel cycle option.

A range of postulated transportation accidents was considered, including the assumed breach of casks for spent containers for fresh fuel, and for high level and transuranic wastes. The plutonium oxide shipping vehicle would be designed to withstand unusual acts of penetration and, accordingly, should be able to withstand extra severe accidents.

Spent Fuel - The characteristics and package used for irradiated fuel are not significantly changed by choice of fuel cycle option. Thus, recycle of fissile materials introduces no new accident types not previously analyzed. In the unlikely event that a cask of irradiated fuel is involved in an accident severe enough to result in a release of radioactivity, the environmental impact should be about the same for any fuel cycle option.

Plutonium - The plutonium oxide containers are doubly sealed and the special vehicle to be used for plutonium oxide transportation is designed to withstand unusual efforts of penetration. Thus the probability that there would be any release of radioactive material from a plutonium oxide shipment following any credible accident is not considered significant. Plutonium waste from the uranium fuel cycle option would be transported in a manner similar to high level wastes and transuranic wastes.

Mixed Oxide Fuel - The impact on the environment from radioactive material being released in a transportation accident involving unirradiated mixed oxide fuel is considered to be negligible. Although material may be released, the particle size of the material would fall predominantly in the non-respirable (greater than 10 micron) range. The area of contamination would be limited to the immediate vicinity of the ruptured package.

High Level Wastes - The structural and containment features of casks for transporting high level wastes are similar to those of casks for irradiated fuel. Furthermore, high level wastes will be packaged in completely sealed steel canisters that are in turn enclosed in the shipping cask so that two levels of containment will be provided.

Plutonium recycle would not have a significant effect on the characteristics of high level waste that are important to possible environmental impact under unusual

accident conditions. No significant difference in accident consequences attributable to choice of recycle option has been identified.

Transuranic Wastes - Packages used for waste are so designed and constructed, and the solid form in which the waste is shipped is such that, in the event a shipment of solid waste is involved in an accident, it is unlikely that the radioactive material would be released.

The probability of a transportation accident resulting in the release of radioactivity is small, and is not appreciably affected by choice of recycle option. No transportation considerations have been identified that would preclude the selection of any recycle option.

1.4.4 Waste Management

Although five major categories of waste are generated by the LWR fuel cycle--chemical (nonradioactive); low level radioactive waste that is not contaminated with substantial amounts of plutonium or other transuranium elements; uranium mill tailings; transuranic wastes; and high level wastes (or, in the case of the no recycle option, spent fuel)--mill tailings, transuranic wastes and high level (or spent fuel) are the three categories most affected by the choice of recycle option.

The amounts of low level radioactive wastes are controlled by the waste generated at reactors; the amount of these wastes is not changed by the choice of recycle option.

Mill Tailings. The largest volume of waste generated in the fuel cycle is the impounded solid tailings at the uranium mills. These will be stored in the vicinity of the mills which are presently located in remote regions of the western United States. For the no recycle option, the volume of these wastes generated in the years 1975 through 2000 would be about 800 million cubic meters. For the uranium and plutonium recycle option the volume of these wastes will be reduced by about 22%, and for the uranium recycle option, by about 10%.

Mill tailings are a source of radon gas not only during mill operation but also after the mill has been shut down (decommissioned). In GESMO, it is assumed that when the mills are decommissioned, the mill tailings are stabilized against erosion by wind and water. The tailings piles are graded to provide gradual slopes and to eliminate depressions which might collect water, and then covered by earth topped with crushed rock in arid regions or with vegetation in regions with sufficient rainfall. Tailings generated in the years 1975 through 2000 would, after stabilization, release about 400,000 curies of ^{222}Rn per year if no recycle were practiced. Use of the uranium recycle option or the uranium and plutonium recycle option would reduce the radon release by 10% and 22% respectively. The release rate of 400,000 curies would not be realized until long after the year 2000; in the year 2000, most of the tailings would occur at active mill sites and the radon release rate would be considerably lower.

The radon release rate, 400,000 curies, is less than 0.2% of the radon released annually from the soil of the United States. The radiological effect of radon from the tailings piles on the U.S. population is very small compared with the effect of natural background radon. The doses from the mill tailings piles beyond the year 2000 can be placed in perspective by comparing them to the dose from the naturally occurring background radon. The maximum radon concentration at 0.5 mile from stabilized tailings is calculated to be 5 times an average radon background of 0.41 picocuries/liter measured at three of four milling sites by the Public Health Service; at 1 mile it is 1.5 times background; at 5 miles it is 0.15 times background; and at 50 miles the radon from the tailings pile would be indistinguishable from background radon.

Transuranic and High Level (or Spent Fuel) Wastes. The presence of plutonium and other biologically hazardous radioactive materials in transuranic and high level wastes (or spent fuel in the case of the no recycle option) makes it necessary to isolate these wastes from man and his environment for very long periods of time. NRC has used a geologic storage concept for isolation of these materials, specifically, placement in bedded salt.

Two waste repositories are required in the year 2000 for all LWR fuel cycle options. Approximately 55,000 cubic meters of spent fuel are generated from the LWR no recycle option in the 26-year period from 1975 through 2000. The uranium recycle option and the uranium and plutonium recycle option produce 6,500 cubic meters of high level waste each, and 128,000 cubic meters and 148,000 cubic meters of transuranic wastes respectively over the 26-year period.

Subsurface land requirements for geologic disposal are greatest for the uranium and plutonium recycle option (1,090 acres), and least for the uranium recycle option (915 acres). The no recycle option requires 970 acres of subsurface land for spent fuel storage.

The most complete study of geologic containment failure mechanisms and their consequences was made for a waste repository in bedded salt of the Delaware Basin in southeast New Mexico. The main conclusion of that study was that a serious breach of containment of a waste repository either by natural events or human action is an extremely remote possibility, one that is a much smaller risk than many others acceptable to society and of such small magnitude to be beyond the limit of human experience. Once the waste has been placed in such a configuration and the mine sealed, only the most extreme of natural events have any potential for release of radioactivity from the disposal zone. Even the surface burst of a large (50 megaton) nuclear weapon could not breach the containment.

The result of this assessment of waste management is that there is no clear preference for a specific fuel cycle option on the basis of waste management considerations. It should be noted, however, that the no recycle option minimizes plutonium production and handling, that either the uranium or the uranium and plutonium

recycle option reduces committed land and radiological releases, and that the uranium and recycle option minimizes the quantity of plutonium that ultimately enters waste streams. The plutonium that enters the waste streams from the uranium and plutonium recycle option is about 1% of the plutonium sent to waste management from the no recycle or uranium recycle options. The major findings of the assessment is that no waste management consideration is significant enough to dictate a decision among the three fuel cycle options.

1.4.5 Nonradiological Environmental Impacts

The environmental impacts of each generic type of LWR industry facility have been assessed in detail in CHAPTER IV. Environmental factors from each industry component have been integrated for each option. An analysis of the integrated data in Tables S(A)-1, -2, and -3* shows that the nonradioactive impacts of the LWR industry are generally slightly reduced by recycle of fissionable materials. The no recycle option generally shows the greatest nonradiological environmental impacts, and the uranium and plutonium recycle option the smallest.

A more detailed analysis of the integrated data is presented below.

1.4.5.1 Land Use

Land use requirements for the LWR industry are dominated by the mining and milling segments, with permanent land commitments controlled by mining, milling, reactors and waste management. Reactor and waste management requirements are relatively unaffected by the choice of recycle option. The amount of land required by the LWR industry is decreased by the uranium recycle option relative to the no recycle option; an additional decrease results from use of the uranium and plutonium recycle option. The land requirement for the uranium recycle option is about 90% (26 million acre years) and the uranium and plutonium recycle option is about 80% (23 million acre years) of the no recycle option requirement (28 million acre years) over the 26-year period. The land area of the continental United States is about 2 billion acres; land use available from that land area over the 26-year period amounts to about 60 billion acre years.

Permanent land commitments of the uranium recycle and uranium and plutonium recycle options are 80% and 70% respectively of that (50,000 acres) of the no recycle option.

1.4.5.2 Water

Water requirements for the LWR industry are largely unaffected by the choice of fuel cycle option since the total water requirement is dominated by reactors. The data on water use show no significant differences among options.

1.4.5.3 Heat Dissipation

Heat dissipation from the LWR industry is dominated by that from reactors. The 26-year total, 2.9×10^{17} Btu, is unaffected by the choice of recycle options.

*See the appendix of this volume.

1.4.5.4 Energy Consumed

The amount of energy consumed by the LWR industry has been measured by calculating the electrical energy, coal (consumed directly), natural gas, and fuel oil consumed.

Total electrical energy consumed (380 GWy) by the LWR industry is dominated by that required by reactors and enrichment plants, and is substantially unaffected by the choice of recycle option. Electrical consumption by fuel cycle operations other than reactors and enrichment may be affected by recycle, but the changes approximately offset one another so that the total is largely unaffected. (The amount of fuel required to generate the electricity is unaffected by the choice of recycle option.)

The amount of natural gas used is smallest, 10 billion therms, for the uranium and plutonium recycle option, and greatest, 13 billion therms, for the no recycle option. The uranium recycle option requires 12 billion therms. The reduction in natural gas usage results from reduction in uranium milling requirements, the principal user of gas.

Changes in quantities of materials transported and distances traversed for the uranium and plutonium recycle option result in an increase in the amount of fuel oil consumed over the 26-year period increasing from 19 billion gallons for the no recycle option to 20 billion gallons for uranium recycle and the uranium and plutonium recycle option, a 15% increase.

1.4.5.5 Nonradioactive Effluents to the Atmosphere

Nonradioactive effluents released to the atmosphere from the LWR industry include oxides of sulfur (SO_x) and nitrogen (NO_x), carbon monoxide (CO), particulates, and hydrocarbons, predominantly from combustion of fossil fuels; ammonia and fluorides from reagent use; and aldehydes, and organic acids from combustion of fuel used in transportation.

The use of electricity by the LWR industry produces atmospheric pollutants from coal-fired power stations that supply some part of the electricity. It has been assumed for this GESMO that about two-thirds of the power has been produced by coal-fired power plants. With this assumption, the SO_x, NO_x, and particulates from the power stations dominate the amounts of these effluents directly attributable to the LWR industry. The process plant and power plant effluents for the three options are summarized as follows:

	Quantity Released, MT		
Effluent	No recycle	U recycle	U + Pu recycle
SO_x	1.1×10^7	1.1×10^7	1.1×10^7
NO_x	8.6×10^6	8.8×10^6	8.6×10^6
CO	1.8×10^5	1.8×10^5	1.8×10^5
Particulates	6.1×10^5	6.1×10^5	6.0×10^5
Hydrocarbons	1.3×10^5	1.3×10^5	1.3×10^5

It can be seen that none of these emissions is increased substantially by choice of recycle option.

Transportation related effluents, hydrocarbons, aldehydes, and organic acids, decrease somewhat with recycle.

Ammonia effluents are predominantly associated with UF_6 conversion and enrichment operations. Fluorides are released from UF_6 conversion, enrichment and reprocessing operations. Ammonia effluents are reduced by about 7% by the uranium recycle option and 18% by the uranium and plutonium recycle option from the 470 MT released from the no recycle option. Fluoride releases are increased 30% by the uranium recycle option, and 21% by the uranium and plutonium recycle option, from the 450 MT released by the no recycle option.

The amount of the nonradioactive materials discharged to the atmosphere is controlled at the source. Effluents from power plants are controlled to meet limiting standards. Effluents from fuel cycle facilities are calculated to result in annual average concentrations at site boundaries that are a fraction of 1% of applicable standards (or occupational limits in the absence of standards). None of the nonradioactive effluents released to the atmosphere result in applicable standards being exceeded.

1.4.5.6 Plant Effluents to Water Bodies

The LWR industry facilities release chemical materials to water bodies. Chemical effluents may result from release of water treatment chemicals (e.g., from reactors, enrichment plants) or from release of chemical reagents.

All chemical releases--sulfate, nitrate, chloride, fluoride, sodium, calcium, ammonia, and iron--are either unchanged by choice of recycle option or reduced by the uranium recycle or uranium and plutonium recycle option. Generally, sulfate and chloride emissions are dominated by releases from reactors and are unaffected by choice of recycle option. The amounts of other species listed are reduced by the uranium recycle and uranium and plutonium recycle options relative to their value for the no recycle option.

1.4.5.7 Wastes

Wastes from the LWR industry include chemical compounds from the uranium operations of conversion, enrichment, and uranium fuel fabrication; mill tailings; solids contaminated with transuranium elements; high level waste or spent fuel; and low level radioactive solid wastes from conversion enrichment and reactor operations.

Chemical wastes for the uranium fuel cycle option are 5% higher for the uranium recycle option and 10% lower for the uranium and plutonium recycle option than those for the no recycle option. Mill tailings are reduced from their level for the no recycle option by about 10% and 22% for the uranium recycle option and uranium and plutonium recycle option respectively.

Transuranic wastes are not generated by the no recycle option; the volume of transuranic wastes, 150 thousand cubic meters, generated by the uranium and plutonium recycle option is about 15% higher than that generated by the uranium recycle option. High level waste volumes for the uranium recycle and uranium and plutonium recycle options are unaffected by choice of option; the volume of high level wastes under these options is smaller than the volume of spent fuel generated under the no recycle option. The differences in transuranic and high level waste or spent fuel volumes among the three options do affect the number of waste shipments; they do not affect the type or number of waste repositories.

The amount of other radioactive wastes, about 1.5 million cubic meters, is unaffected by the choice of recycle option.

1.4.5.8 Summary of Nonradiological Environmental Impacts

The analysis presented above shows that there are relatively small differences in nonradiological impact among the three LWR recycle options, although the plutonium recycle option generally shows the smallest impacts.

It is important in assessing the environmental impact of any LWR fuel cycle option to recognize that environmental impacts generally are local in nature. For example, the heat release from a facility has generally its greatest effect near the facility, and the impact of the heat release must be evaluated by considering the specific location and size of the facility. All LWR industry facilities--excluding all mines, mills, and low level waste burial grounds in Agreement States, and the ERDA enrichment facilities--are required to be licensed by NRC. Both 10 CFR Part 51 and the Energy Reorganization Act of 1974 specify that such licensed facilities be the subject of environmental reviews, prior to construction or expansion. The impacts of both conventional and radioactive effluents are evaluated to determine that the levels of these effluents are controlled to environmentally acceptable levels. The total impact of the LWR industry over the period 1975-2000 is the sum of the impacts of individual facilities over the same time period, the individual facilities having been the subject of detailed environmental evaluation.

1.4.6 Environmental Effects per Annual Fuel Requirement

10 CFR Part 51 requires that Environmental Reports for LWR's contain the environmental effects of the fuel cycles including transportation. Any rules that may be published regarding the widescale recycle of plutonium will contain tables of environmental effects of the LWR fuel cycle and transportation. These effects calculated from the integrated effects calculated in GESMO are listed in Tables S-7 and S-8; the effects given have been maximized over the three recycle options evaluated in GESMO. The effects have been normalized to the effects per annual fuel requirement (AFR) of a 1,000 MWe LWR (0.8 GWy of energy produced). An analysis of the environmental effects of the LWR fuel cycle follows.

Table S-7

ENVIRONMENTAL IMPACTS OF THE LWR FUEL CYCLE
PER ANNUAL FUEL REQUIREMENT

Basis: 1,000 MWe Reactor

Environmental Factor	Quantity per Annual Reactor Reload
Acre Years Occupied	4,200
Disturbed Acres	13
Committed Acres	4.1
Water (Millions of Gallons)	
Discharged to Air	380
Discharged to Water	9,800
Discharged to Ground	510
Total Discharged	11,000
Heat Dissipated (10^{12} Btu)	1.2
Coal (Tons)	650
Gas (Millions of Therms)	2.3
Fuel Oil (Millions of Gallons)	0.21
Electricity (MW-yr)*	26
Coal Equivalent of Electricity Used:*	
Coal Burned (thousands tons)	61
Sludge (thousands tons)	8.4
SO_x to Atmosphere (MT)	690
NO_x to Atmosphere (MT)	550
CO to Atmosphere (MT)	11
Part. to Atmosphere (MT)	32
Hydrocarbons to Atmosphere (MT)	5.5
Plant Effluents to Atmosphere (Metric Tons)	
SO_x	32
NO_x	57
CO	1.4
Particulates	10
NH_3	.08
Fluorides	.12

*In order to account for effluents from power plants supplying electricity for the fuel cycle plants, the amount of power supplied by coal-fired plants over the time period 1975 through 2000 has been assumed to be about 2/3 of total.

Table S-7 (Cont'd)

ENVIRONMENTAL IMPACTS OF THE LWR FUEL CYCLE
PER ANNUAL FUEL REQUIREMENT

Basis: 1,000 MWe Reactor

Environmental Factor	Quantity per Annual Reactor Reload
Plant Effluents to Atmosphere (Metric Tons) (Cont'd)	
Hydrocarbons	5.3
Aldehydes	0.02
Organic Acids	0.02
Plant Effluents to Atmosphere (Curies)	
^{222}Rn	4,800
^{226}Ra	0.0022
Uranium	0.0092
Pu(Alpha)	0.0011
^{241}Pu (Beta)	0.029
Trans-Pu Nuclides	0.0029
^{3}H	15,900
^{14}C	21
^{85}Kr	352,000
^{90}Sr	0.005
^{99}Tc	0.0066
^{129}I	0.03
^{131}I	0.73
Other radioactivity	0.3
Plant Effluents to Water Bodies (Metric Tons)	
$SO_4^{=}$	10
NO_3^{-}	1.9
Cl^{-}	3.1
Fluorides	0.21
Na^{+}	9.0
Ca^{++}	0.69
NH_3	3.0
Fe	0.04

Table S-7 (Cont'd)

ENVIRONMENTAL IMPACTS OF THE LWR FUEL CYCLE
PER ANNUAL FUEL REQUIREMENT

Basis: 1,000 MWe Reactor

Environmental Factor	Quantity per Annual Reactor Reload
Plant Effluents to Water Bodies (Curies)	
Trans-Pu Nuclides	0.0000008
Pu (Alpha)	0.000019
Uranium	0.10
^{230}Th	0.0074
^{226}Ra	0.00025
^{99}Tc	0.085
Other radioactivity	0.0014
Plant Waste Generated (Cubic Meters)	
Chemical Compounds	70
Mill Tailings	180,000
Trans-U Solids	40
High Level Solids	4
Other Rad Solids	100
Dose Commitment Occupational (Person-rem)	
Total Body	320
G.I. Tract	260
Bone	720
Liver	260
Kidney	350
Thyroid	260
Lung	2,300
Skin	260
Dose Commitment Offsite U.S. Population (Person-rem)	
Total Body	860
G.I. Tract	460
Bone	250
Liver	750
Kidney	240

Table S-7 (Cont'd)

ENVIRONMENTAL IMPACTS OF THE LWR FUEL CYCLE
PER ANNUAL FUEL REQUIREMENT

Basis: 1,000 MWe Reactor

Environmental Factor	Quantity per Annual Reactor Reload
Dose Commitment Offsite U.S. Population (Person-rem) (Cont'd)	
Thyroid	520
Lung	490
Skin	1,800
Dose Commitment to Foreign Population from U.S. Industry (Person-rem)	
Total Body	190
G.I. Tract	190
Bone	620
Liver	190
Kidney	190
Thyroid	190
Lung	300
Skin	700

Table S-8

ENVIRONMENTAL IMPACT OF TRANSPORTATION OF FUEL AND WASTE
TO AND FROM ONE LIGHT WATER COOLED NUCLEAR POWER REACTOR*

Normal Conditions of Transport			
			Environmental Impact
Heat (per irradiated fuel cask in transit)			400,000 Btu/hr
Weight (governed by Federal or State restrictions)			73,000 lbs. per truck; 100 tons per cask per rail car or barge
Traffic density			
Truck			less than 1 per day
Rail or Barge			less than 3 per month
Exposed Population	Estimated Number of Persons Exposed	Range of Doses to Exposed Individuals** (per reactor year)	Cumulative Dose to Exposed Population (per reactor year)***
Transportation workers	200	0.0 to 300 millirem	4 person-rem
General public			
Onlookers	1,100	0.003 to 1.3 millirem)	3 person-rem
Along Route	600,000	0.0001 to 0.06 millirem)	

Accidents in Transport	
	Environmental Risk
Radiological effects	Small†
Common (nonradiological) causes	1 fatal injury in 100 reactor years; 1 non-fatal injury in 10 reactor years; $475 property damage per reactor year.

*Data in this table are derived from data in CHAPTER IV, Section G, GESMO, the "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants", WASH-1238, and Supplement I and II to WASH-1238.

**The Federal Radiation Council has recommended that the radiation doses from all sources of radiation other than natural background and medical exposures should be limited to 5,000 millirem per year for individuals as a result of occupational exposure and should be limited to 500 millirem per year for individuals in the general population. The dose to individuals due to average natural background radiation is about 130 millirem per year.

***Person-rem is an expression for the summation of whole body doses to individuals in a group. Thus, if each member of a population group of 1,000 people were to receive a dose of 0.001 rem (1 millirem), or if 2 people were to receive a dose of 0.5 rem (500 millirem) each, the total of person-rem dose in each case would be 1. person-rem.

†Although the environment risk of radiological effects stemming from transportation accidents is currently incapable of being numerically quantified, the risk remains small regardless of whether it is being applied to a single reactor or a multi-reactor site.

1.4.6.1 Land Use

Approximately 13 acres of land are disturbed, and of that amount about 4 acres are permanently committed, per LWR annual fuel requirement (AFR). Over a 40-year reactor life, approximately 160 acres, or about 0.25 sq. mi., of land must be permanently committed at fuel cycle plants. Open pit mining of coal would disturb much more land than the LWR fuel cycle operations.

1.4.6.2 Water

The fuel cycle water requirement, 10,700 million gal./AFR, is dominated by the water requirements of the enrichment facilities.

1.4.6.3 Heat Dissipation

The total heat released from the fuel cycle facilities, 1.2 million Btu/AFR is about 6% of that discharged from the reactor.

1.4.6.4 Electricity and Fossil Fuel Requirements

About 26 MWe-yr/AFR of energy are consumed by the LWR fuel cycle. This consumption is about 4% of the reactor output.

Coal is used in fuel cycle operations and in generating some portion of the electricity consumed, and gas and fuel oil are used in processing and transportation operations. About 61,000 tons of coal, 2.3 million therms of gas, and 2.0 million gallons of fuel oil are used per AFR.

1.4.6.5 Plant Effluents Released to the Atmosphere

The amounts of oxides of sulfur (SO_x) and nitrogen (NO_x) released from the fuel cycle are dominated by those released from coal-burning plants supplying energy to the various facilities. Both the SO_x emission, about 720 MT/AFR, and the NO_x emission, about 600 MT/AFR, are about equivalent to those emitted annually from a 20 MWe coal-fired station.

Carbon monoxide, particulates, hydrocarbons, aldehydes, and organic acids released from fuel cycle facilities result from the use of fossil fuels. Carbon monoxide emissions, 12 MT/AFR, are equivalent to the annual emissions from a 20 MWe coal-fired station; particulate emissions, 42 MT/AFR, are equivalent to those emitted annually from a 30 MWe coal-fired station.

Hydrocarbons, aldehydes, and organic acids arise predominantly from the transportation component of the fuel cycle. The total fuel oil consumed amounts to about 20 gal./MT of ore mined. The fuel oil, about 0.2 million gal./AFR, amounts to less than 1% of the daily United States production in 1970. Hence, the hydrocarbons, aldehydes, and organic acids emitted from fuel cycle transportation operations are an extremely small fraction of such total emissions from United States transportation.

Radiological materials released from the fuel cycle include natural uranium, radon, and radium; plutonium and transplutonium nuclides; and fission and activation products. It can be seen from Table S-7 that ^{85}Kr, ^{3}H, ^{222}Rn, and ^{14}C dominate the releases.

1.4.6.6 Plant Effluents to Water Bodies

Nonradiological plant effluents released to water bodies include sulfates, nitrates, chlorides, fluorides, sodium, calcium, ammonia, and iron. The impact of these effluents must be determined on a facility-by-facility review. No permit or license will be issued by NRC with respect to an activity for which a certification is required by Section 401 of the Federal Water Pollution Control Act unless such certification has been obtained.

Radioactive materials released to water bodies are a small fraction of those released to the atmosphere. At a minimum, plant liquid effluent must meet 10 CFR Part 20 limits.

1.4.6.7 Radiological Dose Commitments

Radiological dose commitments to workers in fuel cycle operations total about 315 person-rem/AFR (whole body). Organ doses to workers range from about 250 (liver) to 2,300 (lung) person-rem/AFR. The U.S. population receives 860 person-rem/AFR. Organ doses, except to the skin are bounded by the total body dose; the skin dose is 1,800 person-rem/AFR. Foreign population dose commitments are lower than dose commitments received by the U.S. population.

1.4.6.8 Overall Environmental Impact per Annual Fuel Requirement

The overall maximum environmental impacts from fuel cycle operations can be summarized as follows:

- Land: permanent land commitments are about 0.25 square mi/AFR.
- Water, Heat: Water requirements and heat dissipation are each about 7% of those of the reactor itself.
- Electricity: the fuel cycle consumes about 4% of the electrical energy output of the reactor.
- Fossil fuel: coal, oil, and gas are consumed.
- Nonradiological emissions: With the exception of fluorides and ammonia, airborne effluents from the fuel cycle process operations are those that might be emitted from a 20-30 MWe coal-fired power station or diesel-fueled trucking operation. Carbon monoxide, hydrocarbons, aldehydes and organic acids emitted from fuel cycle transportation operations are a very small fraction of total emissions of such chemicals in the United States.

Fluoride and ammonia emissions to the atmosphere, and chemical emissions to water bodies are evaluated on a case by case basis. Licensing requires that these effluents be minimized, based on cost-effective considerations.

- Radiological Emissions: Conservative calculations estimate that the United States population would receive a dose commitment of about 1200 person-rem/AFR.

1.5 Safeguards

No detailed evaluation of safeguards is included in this GESMO document. A Safeguards Supplement to the draft GESMO is being published, and a final Safeguards Supplement will be published.

1.6 Probable Adverse Environmental Effects that Cannot be Avoided

1.6.1 Introduction

The LWR industry produces unavoidable adverse environmental effects due to the construction and operation of reactors and the supporting fuel cycle. Unavoidable environmental effects of the construction and operation of the supporting fuel cycle facilities are somewhat different for the three recycle options.

Differences in environmental impact among the three recycle options result from changes in the type and capacity of the fuel cycle operation required. Table S-9 quantifies the cumulative material requirements for the fuel cycle operations, and Table S-10 shows the total number of facilities required in 1980, 1990, and 2000 for the various options. The cumulative impacts of each operation of the fuel cycle are given in Table S(A)-1 for the no recycle option; Table S(A)-2 for the uranium recycle option and Table S(A)-3 for the uranium and plutonium recycle option.

Evaluation of the effects of the three LWR recycle options leads to the conclusion that the unavoidable adverse environmental impacts of any LWR recycle option is small and that the differences among the three options is small. Detailed data on the environmental impact of LWR's and the supporting fuel cycle facilities are presented in CHAPTER IV; a summary of these data has been presented in paragraph 1.4 above.

1.6.2 Reactors

Since the number of LWR's projected to be built between 1975 through 2000 is considered to be independent of the fuel cycle option--uranium recycle or plutonium recycle or no recycle--the environmental effects of constructing the reactors would not be altered by the recycle option chosen. In addition, essentially all of the environmental effects of power station operation including heat rejection, releases of water-treatment chemicals, and radiological dose commitments are substantially unaffected by the choice of recycle option.

Choice of one recycle option over another would cause essentially insignificant changes in the environmental impact of LWR's. Substantially all fission products are

Table S-9

CUMULATIVE MATERIALS PROCESSED

1975-2000

Process	No Recycle	U Recycle	U + Pu Recycle
Mining and Milling, Short tons U_3O_8	1,597,000	1,429,000	1,240,000
Uranium Hexafluoride Conversion, MTU	1,210,000	1,083,000	916,000
Enrichment, MTSWU	608,000	613,000	523,000
Uranium Fuel Fabrication, MTU	188,000	188,000	163,000
Mixed Oxide Fuel Fabrication, MT (U+Pu)	0	0	25,300
Spent Fuel Transportation, MT	176,000	125,000	125,000
Reprocessing, MT	0	115,000	115,000

MT - metric tons
MTU - metric tons of uranium
MTSWU - metric ton separative work units
MT (U+Pu) - metric tons of uranium + plutonium

Note: The data in this table are derived from those given in Table XI-41. See also Table S-10 for the numbers of plants and annual capacity.

Table S-10

THE PROJECTED LWR INDUSTRY, 1980-2000*

LWR Industry Components	Annual Capacity	Number of Facilities								
		1980			1990			2000		
		No	U	U + Pu	No	U	U + Pu	No	U	U + Pu
LWR's*		71	71	71	269	269	269	507	507	507
Mines**		488	488	416	2,337	1,984	1,856	584	5,064	4,125
Mills	1,050 ST U_3O_8	25	25	21	71	60	56	109	95	77
UF_6 Conversion Plants	15,000 MTU	2	2	2	5	4	4	7	6	5
Uranium Enrichment Plants	8.75×10^6 SWU	3	3	3	4	4	3	6	6	5
UO_2 Fuel Fabrication Plants	1,500 MTU	6	6	6	6	6	6	9	9	7
Reprocessing Plants	2,000 MTHM	0	1	1	0	4	3	0	5	5
MOX Plants	360 MTHM	0	0	1	0	0	3	0	0	8
Federal Repositories for Storage High Level Waste Transuranic Waste Spent Fuel Assemblies	360 m^3 High Level 6,000 m^3 Transuranic 15,000 Assemblies	0	0	0	1	2	2	2	2	2
Commercial Burial Grounds	1×10^6 ft^3	6	6	6	6	6	6	11	11	11

*LWR's are 1,000 MWe plant

**Underground mines (capacity of 20,000 short tons of ore annually) constitute over 95% of the total mines; open pit mines (200,000 short tons ore annual production) constitute remaining 4+%.

Note: These data are the same as those in Tables III-1, III-2, and III-3.

normally retained within sealed fuel rods. Based on experience with uranium fuel rods, however, it can be expected that some clad 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. Under both normal operations and accident conditions, the effects of fuel type (mixed oxide or uranium fuel) are not significantly different in terms of radiological impacts.

Other nonradiological, probable adverse impacts of reactors are unaffected by choice of recycle option.

1.6.3 Other Fuel Cycle Facilities

The unavoidable adverse environmental impacts associated with any type of fuel cycle facility are relatively unaffected by the mode of recycle selected. Industry impact, however, changes as the number of each type of facility is changed by the recycle option chosen. Detailed evaluations of environmental impacts of the LWR fuel cycle facilities are presented in CHAPTER IV. Almost all nonradiological environmental factors are decreased by the use of the uranium recycle or uranium and plutonium option relative to the no recycle option. Since discharges from plants are limited so that concentrations are below permissible limits at the appropriate locations, the use of the no recycle option, although it may impose nonradioactive impacts that could be reduced by the use of the uranium recycle or uranium and plutonium recycle option, would not result in environmentally acceptable criteria being exceeded.

The total body occupational exposure is approximately the same for all recycle options. Over the 26-year period, the total body nonoccupational dose commitment for the U.S. public is about 4.0 million person-rem for the entire LWR industry (including reactors). Natural background radiation over the same period results in a dose of about 650 million person-rem. Although the exposure of the public is increased by recycle of uranium and plutonium, the exposure of the public should be considered in the context of the natural background received by that group. The LWR industry increases nonoccupational total body exposure by less than 1% of natural background over the 26-year period for any fuel cycle option.

As a part of the nuclear fuel cycle, the impacts of commitments for decommissioning and permanent care must be considered. Construction of fuel reprocessing and 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

- 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 approach to be followed will depend on a technical analysis and a cost-benefit study of a particular plant and site.

1.7 Means for Mitigating Adverse Environmental Impacts

1.7.1 Present Measures and Controls to Limit Adverse Impacts

The mitigation of adverse environmental effects of activities licensed by the NRC is an objective in all NRC licensing actions. Through its licensing and inspection and enforcement functions, NRC seeks to ensure that licensees provide effective means to limit the adverse environmental impacts from the operation of their facilities and activities.

A person or organization carrying out activities (e.g., possession, use, processing, or transfer) involving special nuclear materials (including enriched uranium and plutonium) must possess a Special Nuclear Materials (SNM) license issued by NRC, specifically authorizing the activity. In all States except Agreement States, persons or organizations carrying out activities with source material (including natural uranium) must possess a uranium source material license from the NRC.* The NRC regulations require that, where appropriate, applicants for licenses provide the 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 evaluation, and a criticality analysis. This description provides NRC with 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 the protection of health and safety are adequate, and whether strategic special nuclear material (SSNM) in his possession is adequately safeguarded.

In conjunction with the application for such licenses, the applicant must also submit a detailed environmental report.** The staff independently assesses the potential environmental impact of the proposed activity, including the construction and operation of any facility in which activities involving licensed material will be carried out, and prepares and circulates draft and final environmental statements.

*Persons in an Agreement State must have a license from the State, the license being compatible with NRC requirements.

**Persons having licenses to handle small quantities of SNM are exempt from this requirement.

In addition to preparing the environmental statements, before authorizing any activities involving special nuclear material or source material, the NRC evaluates the safety and environmental (as well as materials and plant protection, as applicable) considerations involved. Specific factors limiting any adverse effects 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. These factors are discussed in CHAPTER VII, Means for Mitigating Adverse Environmental Effects. The draft Safeguards Supplement describes the means for mitigating adverse environmental effects resulting from safeguards related considerations.

The existing means used to mitigate adverse environmental effects for all three recycle options--uranium and plutonium recycle, uranium recycle, and no recycle--are similar for similar types of facilities. Differences in the adverse environmental effects of the three options arise only because of a different mix of facilities and a difference in the amount of fission products and transuranium elements occurring under the three options.

1.7.2 Potential Measures to Further Mitigate Adverse Impacts

The nuclear industry today is the product of nearly 30 years of development. In order to be responsive to the public interest and exploit recent advances, a technology as complex as this must continually undergo refinement and development. Additional measures to limit further any adverse effects of the three recycle options may be possible. As measures are proved, they will be considered and added to the conditions for licensing where their use is shown to be in accord with the cost-benefit balancing.

Additional measures may be developed under all of the existing factors used to limit adverse effects. These include site selection, design basis, construction activities, monitoring procedures, transportation, and waste management. The potential additional measures available under these factors are discussed in CHAPTER VII, Section 3.0. (See the draft Safeguards Supplement for information on safeguards.)

Potential additional measures to mitigate adverse environmental impacts of particular fuel cycle facilities could amplify or reduce the differential environmental effects among the three options. For example, future installation of processes to reduce effluents from reprocessing plants would reduce the adverse environmental impact of the uranium and plutonium recycle options without affecting the environmental effects of the no recycle option and, hence, reduce the incremental radiological impacts of the uranium recycle and uranium and plutonium recycle options relative to the no recycle option. Development of techniques to reduce the impacts of mining, milling, or enrichment would reduce the impact of all options. The difference in impact between the uranium recycle and uranium and plutonium recycle options and the no recycle option may be increased, however.

1.8 Alternative Dispositions of Plutonium

Current uses for neutron sources and for research and development activities projected primarily in the fast breeder program require only a small fraction of the approximately 700 MT of plutonium potentially available from LWR fuel through the year 2000. The net plutonium requirement projected for the commercial breeder program between now and the turn of the century, 200 metric tons, is about 30% of the plutonium available from LWR's. The major potential use of plutonium in the remainder of this century is recycle fuel for the LWR.

Several cases of the uranium and plutonium recycle option were evaluated in the draft GESMO, together with the no recycle and uranium recycle options. These, together with a definition of their treatment in the final GESMO, are as follows:

- Prompt reprocessing of spent fuel, recycle of recovered uranium, and recycle of plutonium after some storage. For the final GESMO, delays in plutonium of 2 to 7 years were considered with only the 2-year delay evaluated in detail. The case of 2-year delay is Alternative 1.

- Storage of spent fuel for later reprocessing, recovery, and recycle of uranium and plutonium. In the final GESMO, delays of 3 to 13 years in reprocessing were considered. The delay period used for the detailed evaluations in GESMO was an 8-year delay, and is Alternative 2. Although Alternative 2 is not the reference case, it may represent a realistic commercial alternative, if slippage occurs in reprocessing plant startup.

- Prompt reprocessing of spent fuel with prompt recycle of uranium (1978) and plutonium (1981) as fuel in LWR's. This case is the reference case for this final GESMO, Alternative 3.

- In the draft GESMO, Alternative 4 was defined to be prompt reprocessing of spent fuel with prompt recycle of uranium (1978) and plutonium (1981), i.e., the same as Alternative 3, with upgraded safeguards. Since safeguards for all alternatives must be based on a consistent level of performance, Alternative 4 no longer has specific meaning in the final GESMO. Accordingly, only Alternatives 1, 2, 3, 5, and 6 will be assessed for their economics. Based on the findings of the final Safeguards Supplement, the final cost-benefit balancing of the alternatives will be derived in that document.

- Reprocessing of spent fuel (in 1986) for the recovery of uranium; plutonium is disposed of as a waste. This case represents the uranium recycle option, Alternative 5.

- Storage of spent fuel for ultimate disposal without consideration for later reprocessing and recovery of either uranium or plutonium. This case represents the no recycle option, Alternative 6.

The numbering of alternatives in draft GESMO has been retained in the final GESMO. The health, safety, environmental, and nonsafeguards economic aspects of Alternatives 1, 2, 3, 5, and 6 have been addressed in detail in this document. The final analysis of all alternatives, including health, safety, environmental, economic, and safeguards aspects, will be presented in the final Safeguards Supplement.

An evaluation of the environmental impacts including radiological dose commitments of Alternatives 1, 2, and 3 (the uranium and plutonium recycle options) shows these alternatives to be essentially indistinguishable from one another. These three alternatives do have different cumulative fuel cycle costs. As noted earlier, the nonradioactive environmental impacts of Alternative 5, uranium recycle, and Alternative 6, no recycle, are generally greater than those of Alternative 3, the uranium and plutonium recycle option. The radiological impacts of Alternatives 3, 5, and 6 differ from one another.

1.8.1 Cases Evaluated

NRC evaluated different cases of fuel cycle options. These cases are permutations of the uranium and plutonium recycle option using different delay times for start of fuel reprocessing and plutonium recycle. Table S-11 provides data on the salient features of the cases investigated. (See footnote to Table S-11 for a definition of case numbers.) Cases 31 and 32 represent variations of prompt reprocessing and delayed plutonium recycle. In case 31, reprocessing is delayed 2 years beyond 1981, the earliest plutonium recycle date; in case 32, the plutonium recycle date is delayed 7 years beyond 1981. Case 31 is the base case for Alternative 1, with case 32 being used to estimate the change in fuel cycle costs with long delayed plutonium recycle.

Delayed fuel reprocessing was the subject of five case studies. The base case (Alternative 2), case 33, assumed reprocessing and recycle to begin in 1986. Two sensitivity studies, cases 34 and 35, evaluated the impact of reprocessing and recycle starting 5 years earlier (1981) and 5 years later (1991) than case 34. In cases 33, 34 and 35, spent fuel accumulated during the delay period was worked off before the year 2000. Two additional sensitivity analyses, cases 37 and 37A, evaluated the effect on fuel cycle costs if accumulations of spent fuel were not worked off by 2000.

The base case for Alternative 3, prompt reprocessing and prompt recycle was case 36. The uranium recycle option was represented by case 39, and the no recycle option by case 40.

Only the cases representative of the five alternatives have been discussed in detail in the final GESMO, i.e., the additional cases, 32, 34, 35, 37, and 37A were used for sensitivity analyses.

1.8.2 Environmental Impacts

Environmental impacts of Alternatives 1, 2, and 3 showed essentially no difference in impacts. Therefore, the impacts of Alternative 3 were used as representative of

Table S-11

LWR FUEL CYCLE CASES

Option	Alternative	Case No.*	Start of Reprocessing	Start of Pu Recycle	Notes
Cases used to Define Alternatives					
U + Pu recycle	3*	36	1978	1981	Base case for U + Pu recycle option
	1	31	1978	1983	Plutonium recycle delayed 2 years beyond case 36
	2	33	1986	1986	Fuel reprocessing delayed 8 years beyond case 36
U recycle	5*	39	1986	Never	Base case for U recycle
No Recycle	6*	40	Never	Never	Base case for no recycle
Variations used for Sensitivity Analyses					
U + Pu recycle	No alternative	32	1978	1988	Pu recycle delayed 7 years beyond case 36
	numbers	34	1981	1981	Fuel reprocessing delayed 3 years beyond case 36
	associated	35	1991	1991	Fuel reprocessing delayed 13 years beyond case 36
	with these	37	1981	1984	Fuel reprocessing not caught up by 2000
	runs.	37A	1986	1986	Fuel reprocessing not caught up by 2000

*The case numbers refer to computer runs by Battelle Pacific Northwest Laboratories. In addition to the 30 series tabulated above, other cases for different nuclear growth rates were made. Cases No. 1-29 were trial runs; cases 41-50 repeat the time delays of the 30 series for the ERDA low growth (with breeder) projection; cases 51-60 repeat the calculations for the ERDA moderate (high) scenario without breeder; and cases 61-70 repeat the 50 series with the breeder. Runs 41-70 were considered in sensitivity analyses reported in CHAPTER XI.

the uranium and plutonium recycle option. The three recycle options were discussed in detail in Summary paragraph S-1.4 and CHAPTER IV. Impacts from Alternatives 1, 2, 3, 5, and 6 are given in CHAPTERS VIII and XI.

1.8.3 Fuel Cycle Costs

Table S-12 shows the fuel cycle costs associated with each of the alternatives evaluated. Unit costs of materials and services used in developing fuel cycle costs are given in Table S-13. It can be seen that all alternatives representing the uranium and plutonium recycle option had lower fuel cycle costs than the uranium recycle or no recycle options. Alternative 3, covering the prompt recycle of uranium and plutonium, showed the lowest fuel cycle cost, 4,455 mill/kWh. Alternative 2, with reprocessing delayed 3 years beyond 1978, the earliest startup projected, showed a small cost disadvantage of 0.01 mill/kWh relative to case 36. The fuel cycle costs for Alternative 2 do not, however, include the costs to the owner of not operating plants that may be operable.

Table S-12

DIFFERENTIAL PRESENT VALUE

Alternative	Fuel Cycle Costs Mill/kWh	Disadvantage versus Case 36, Case - Case 36
3	4.455	0
1	4.474	0.019
2	4.465	0.01
5	4.824	0.369
6	4.848	0.393

The no recycle option showed the highest fuel cycle costs, 4.848 mill/kWh, about 9% higher than Alternative 3. The fuel cycle costs of the uranium recycle option are 4.848 mill/kWh, almost as high as those of the no recycle option, and about 8% higher than those of the prompt uranium and plutonium recycle option.

1.8.4 Material and Plant Protection

Plutonium is produced as a pure plutonium compound in all alternatives with plutonium recycle (i.e., Alternatives 1, 2, and 3). Shipping of plutonium oxide and mixed oxide fuel between sites occurs under each of these alternatives. Plutonium would be separated as an impure solid at reprocessing plants under the uranium recycle option, Alternative 5, and shipped to a Federal repository. Under Alternative 6, there is no fuel reprocessing, so that no plutonium values are recovered from the spent fuel assemblies. The detailed evaluation of safeguards requirements for the LWR industry has been included in the draft Safeguards Supplement and, after public comment, will be addressed in the final Safeguards Supplement.

1.9 Relationship Between Local Short Term Use of Man's Environment and the Maintenance and Enchancement of Long Term Productivity

The major differences among the three recycle options arise from the substitution of reprocessing in both the uranium recycle and uranium and plutonium recycle options

Table S-13

MATERIAL AND SERVICE UNIT COSTS, 1975 DOLLARS

Activity	Cost		
	Low	Reference	High
Mining and Milling, Avg $/lb U_3O_8*	15	28	56
UF_6 Conversion, $/kgU	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

*Weighted average cost (1975 through 2000), varies with consumption.

**Includes MOX shipping to reactor.

***Includes waste solidification.

†Includes waste shipment to Federal repository.

Note: The data in this table are the same as those in Table VIII-5.

and, in the case of uranium and plutonium recycle option, mixed oxide fuel fabrication, for some fraction of the uranium mining, milling, UF_6 production, enrichment, and UO_2 fuel fabrication. The net nonradiological environmental impacts of the LWR industry are generally smallest for the uranium and plutonium recycle and largest for no recycle. Radiological dose commitments, occupational, U.S. general public, and foreign, are largest for the uranium recycle option and smallest for the no recycle option.

The fundamental tradeoff associated with the uranium recycle and uranium and plutonium recycle relative to no recycle is the substitution of the environmental impacts from reprocessing (uranium recycle and uranium and plutonium recycle options) and MOX fabrication (uranium and plutonium recycle options) for impacts from uranium operation (mining, milling, conversion of UF_6, enrichment, uranium fabrication). In addition, uranium resources are conserved by use of the uranium or uranium and plutonium recycle. Prompt recycle of plutonium conserves the plutonium-241 isotope, one that would otherwise be lost via radioactive decay.

Construction activities required for the LWR industry are affected somewhat by the choice of recycle option. Fewer mines, mills, UF_6, and uranium fuel fabrication facilities are required for either the uranium recycle or uranium and plutonium recycle option relative to the no recycle case. In addition, fewer power plants, either

fossil or nuclear, are required to supply the enrichment services required for the uranium and plutonium recycle case. The reduction in these facilities is offset by the requirement to construct reprocessing plants for the uranium recycle and the uranium and plutonium recycle options, and mixed oxide fuel fabrication plants for the uranium and plutonium recycle option.

Temporary land commitments required for the LWR industry are least for the uranium and plutonium recycle option and greatest for the no recycle option, with the uranium recycle option falling between the two extremes. Long term land commitments for Federal repositories for high level waste (or spent fuel) and transuranic waste are not affected by the choice of recycle option; land commitments for uranium mill tailings are smallest for the uranium and plutonium recycle option and greatest for the no recycle option.

1.10 Irreversible and Irretrievable Commitments of Resources

The use of nuclear power implies an irreversible commitment of fissile materials. In the case of the LWR fuel cycles considered in GESMO, these fissile materials are uranium-235 and plutonium. Neither material has application for other purposes over the time frame of this statement that would be precluded by use for LWR fissile material. Plutonium can effectively substitute for uranium-235 as the fissile material in LWR's. The consumption of uranium ore is greatest for the no recycle option, and least for the uranium and plutonium recycle option. Hence, both the no recycle and uranium recycle options represent an incremental commitment of uranium resources relative to the plutonium recycle option for the production of nuclear power. If plutonium recycle is delayed, fissile plutonium-241 will be irreversibly lost by radioactive decay.

Plutonium recycle has an irreversible effect in that it results in the production of a slightly different mixture of radioactive fission products and an increased amount of transuranium elements, over and above those produced from a reactor whose fuel is uranium. The increase in transuranium elements causes the high level radioactive wastes to release more heat and to remain highly radioactive for a longer period. These differences can be accommodated without causing appreciable increases in environmental impacts.

Recycle of plutonium is expected to result in a decrease in manpower requirements, resulting from decreased employment in mining and milling and increased employment in reprocessing plants and mixed oxide fuel fabrication plants. Although there is a savings in manpower resources, it is not considered significant in the total United States employment picture.

The three recycle options involve permanent land commitments either for the disposal of high level and transuranic wastes or spent fuel or mining and milling wastes. These land commitments are greatest for the no recycle option and least for the uranium and plutonium recycle option. Hence, the no recycle and uranium recycle options imply an incremental commitment of land relative to the uranium and plutonium recycle option.

1.11 Economic Analysis and Cost-Benefit Balancing

1.11.1 Economic Analysis

Each of the fuel cycle cost elements was analyzed for its economic impact on alternative dispositions of plutonium. All analyses used 1975 dollars. Little, if any, difference was found in fuel cycle requirements among Alternatives 1, 2, and 3. Uranium recycle only, Alternative 5, puts a higher demand on most of the head end services, particularly mining and milling. 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 head end services than does Alternative 5. With no reprocessing required for Alternative 6, most of the planned back end services are no longer needed and are replaced by spent fuel disposal. Spent fuel elements are lower in density than the concentrated wastes from reprocessing and hence cost more for disposal. An overall fuel cycle analysis indicated that the failure to recycle plutonium (Alternatives 5 and 6) results in substantial economic penalties relative to prompt plutonium recycle. There are minor penalties to be paid for delaying plutonium recycle for a short time (Alternatives 1 and 2) as compared to the prompt recycle alternative. Table S-14 shows the cumulative discounted costs of each of the fuel cycle elements for each of the alternatives for the period 1975 through 2000. Total discounted fuel cycle costs are also given for each case studied. It can be seen that the increase of the no recycle option over the prompt uranium and plutonium recycle option is on the order of $3.2 billion. (It should be noted that with the industry still expanding in the year 2000, even with discounting at 10%, there would still be significant benefits accruing at the end of the time period. Because recycle is economically advantageous in the 1975-2000 period, it would be even more advantageous over its total lifetime.) Major fuel cycle cost contributors are mining, milling, enrichment, and reprocessing when it is a part of the fuel cycle. Mining and milling at 43% and enrichment costs at 27% total about 70% of the fuel cycle costs for prompt uranium and plutonium recycle. For the no recycle option (Alternative 6), mining and milling costs are about 50% of the total fuel cycle cost, with enrichment being about 27% of the total.

A review of the data in Table S-14 shows that:

- The incentive to recycle plutonium increases with increasing

  mining and milling costs
  enrichment costs
  uranium fuel fabrication costs
  waste management costs and

- The incentive to recycle Pu decreases with increasing

  reprocessing costs
  mixed oxide fuel fabrication costs.

Table S-14

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	15,700	+36	+520	+2,640	+4,670
UF_6 Conversion	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
Pu Sales *	-93	0	+22	+93	+93
TOTAL (Rounded)	36,300	+150	+70	+3,000	+3,200

*The small amount of plutonium leaving the light water fuel cycle for research use is accounted for as a sale or negative cost.

NOTE: The data in this table are derived from those in Table XI-43.

1.11.2 Parametric Studies

The economic impact of uranium and plutonium recycle on fuel cycle costs is affected by many factors. Principal among these are the growth rate of nuclear power, costs of uranium, enrichment services, mixed oxide fabrication, reprocessing, and spent fuel disposal. Other factors are the discount rate, the date recycle begins, and the form of interim fuel storage. These factors interact and bear on the decision to recycle or throw fuel values away. In the economic analysis, efforts were made to develop the fuel cycle costs for the bounding projections for each key variable.

1.11.2.1 Influence of Growth Rate in Electrical Demand

Two scenarios for growth in nuclear power over the 1975-2000 period were examined. The higher projection, 50 trillion indicates an economic incentive to recycle of about $6 billion discounted to 1975 at a 10% discount rate. The lower growth projection, 35 trillion indicates a benefit of about $3 billion, also discounted, to 1975 at a 10% discount rate. Whichever projection is used, there is no change in the conclusion that plutonium and uranium recycle has material economic incentive.

1.11.2.2 Effect of Uranium Price

The cost of mining and milling (U_3O_8 cost) is significant in all alternatives considered. The price of U_3O_8 has a significant effect on the total fuel cycle cost and on the economic consequences of the decision to recycle spent fuel values or throw them away. The magnitude of this effect can be estimated by comparing the reference case for a nominal cost of $28 per pound of U_3O_8, with a maximum projected unit price of $56 per pound of U_3O_8.

An increase in the price of U_3O_8 increases the incentive to recycle. Recycling has an $8 billion (present worth) advantage over the throwaway cycle for $56/lb U_3O_8, whereas the gain from recycle is $3.2 billion (present worth) for $28/lb U_3O_8. An increase in the price of U_3O_8 from $28 to $56 per pound increases the breakeven reprocessing cost from $300 to $475/kg HM.* An increase in the price of U_3O_8 from $28 to $56 per pound increases the total discounted fuel cycle cost by $20 billion (2.5 mill/kWh) for the no recycle option and by $16 billion (1.9 mill/kWh) for the uranium and plutonium recycle option. A decrease in the average uranium price to $14 per pound of U_3O_8 would reduce the economic incentive (discounted) to recycle by $2.1 billion to a value of $0.9 billion.

1.11.2.3 Effect of the Price of Enrichment

Recycle of plutonium decreases enrichment requirements by 14% from the level required by the no recycle option. Hence the incentive to recycle increases with increasing enrichment cost. The effect of price changes in enrichment is similar to that of price changes in uranium. An increase in the cost of separative work from $75 to $110 per kgSWU increases the total discounted fuel cycle cost by $5.2 billion for the no recycle option and slightly less, $4.6 billion, for the uranium and plutonium recycle option. This increase in the price of separative work, then, raises

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

the discounted incentive to recycle by $0.7 billion. Recycling has an economic advantage over the no recycle option of $3.8 billion (discounted) for $110 separative work and $3.2 billion (discounted) for $75 separative work. This increase in the price of separative work increases the breakeven price for reprocessing from $280 to $310 per kilogram of heavy metal. 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.

1.11.2.4 Effect of Mixed Oxide Fuel Fabrication

Mixed oxide fuel fabrication prices are expected to range between $150 and $300 per kilogram of heavy metal. This results in an uncertainty in the total fuel cycle cost of 0.1 mill/kWh or about $0.7 billion (discounted). This $150 range in mixed oxide fuel fabrication costs is equivalent to either a change of $30 per kilogram of heavy metal in reprocessing costs, or a change of $44 per kilogram of heavy metal in fuel disposal cost, or an equivalent combination of changes in both reprocessing and disposal costs. Of these three factors, reprocessing costs are the most significant driver, followed in order by waste disposal and fabrication. At the margin, these interactions affect the economic choices and uncertainties between the uranium and plutonium recycle option and no recycle option.

1.11.2.5 Effect of Discount Rate on Decision to Recycle

The choice of discount rate would not change the decision, based on economics, to recycle or throwaway. The choice of the discount rate affects the magnitude of the economic incentive. For discount rates from 6 to 10%, the advantage of prompt recycle over a throwaway fuel cycle varies from $6.5 billion to $3.2 billion. Lower discount rates increase the economic advantage of prompt recycle.

1.11.2.6 Influences of Delays in Plutonium Recycle

If economic factors favor plutonium recycle, then delays in recycling are economically unfavorable. Increasing delays are increasingly unfavorable.

1.11.2.7 Effects of Uncertainties

Uranium and plutonium recycle will save about $3 billion (discounted) over the no recycle option. The projected savings and distribution of fuel cycle costs for each alternative have been summarized in Table S-14. Uncertainties in each of the cost components could increase or reduce the savings as shown in Table S-15. If all of the uncertainties turn adverse to recycle to the maximum extent, then the no recycle option would attain an economic advantage of about $2 billion, discounted, relative to the uranium and plutonium recycle option. Conversely, if the uncertainties all turn favorable to recycle to the maximum, the uranium and plutonium recycle option would attain an economic advantage of over $11 billion (discounted). The price of uranium is the single most important uncertainty; increases in the price of uranium favor the uranium and plutonium recycle option. A decrease in the price of uranium, on the other hand, could not be sufficient by itself to offset the economic advantages of the uranium and plutonium recycle option.

Table S-15

POTENTIAL ECONOMIC IMPACT OF UNCERTAINTIES
ON THE INCENTIVE TO RECYCLE

Incentive to Recycle ($ Billions)

Total Through Year 2000 18

Present Worth at 10% 3.2

Parameter	Reference Value	Uncertainty	Impact Through Year 2000 on Present Worth Incentive ($ Billions) Decrease	Increase
U_3O_8	Avg $28/lb	+$28		+4.7
		-$14	-2.4	
Separative Work	$75/kg	+$35		+0.6
		-$15	-0.2	
Reprocessing	$150/kg	+$40	-1.0	
		-$40		+1.0
MOX Fuel 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 Increase 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

*UF_6 conversion, U fuel fabrication, and spent fuel storage.

**Spent fuel transportation, plutonium transportation, and plutonium storage.

NOTE: This table is the same as Table XI-40.

1.11.3 Environmental Impacts of Recycle Options

Twenty-six year totals of the material processed in each of the five alternatives are compared in Table S-16. The quantity of material processed is given in column 2 for the prompt uranium and plutonium recycle option, Alternative 3. 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) for the uranium and plutonium recycle option have larger requirements for plutonium storage or spent fuel storage than Alternative 3. Their environmental impacts are essentially indistinguishable from Alternative 3; therefore Alternatives 1 and 2 have not been discussed in this summary. See CHAPTER VIII and CHAPTER XI for more detailed data.

A detailed comparison of environmental impacts of the three recycle options--no recycle (Alternative 6), uranium recycle (Alternative 5), and prompt uranium and plutonium recycle (Alternative 3)--has been presented in paragraph 1.4. The data show that both the prompt uranium and plutonium recycle option and the uranium recycle option have generally smaller nonradiological impacts than the no recycle option, and generally larger radiological impacts. The uranium and plutonium recycle option has generally lower nonradiological and radiological impacts than the uranium recycle option. No environmental impacts, either nonradiological or radiological, have been found that would bar the selection of any fuel cycle option.

1.11.4 Cost-Benefit Analysis

Alternative 3 is calculated to have a total 1975 present worth fuel cycle cost of $36.3 billion at a 10% discount rate. A summary of the cost-benefit of the other alternatives relative to Alternative 3 shows that:

Alternative 1 (Early Reprocessing, Delayed Plutonium Recycle)

This alternative has a slightly higher demand for uranium than Alternative 3, a slightly lower demand for mixed oxide fuel fabrication, negligible difference in environmental impact, and a present worth cost penalty of $150 million at a 10% discount rate.

Alternative 2 (Delayed Reprocessing, Followed by Plutonium Recycle)

Compared to Alternative 3 the demand for uranium is higher, fuel storage is increased, mixed oxide fuel fabrication is decreased, the integrated environmental impact is essentially the same, and a present worth cost penalty of $70 million at a 10% discount rate is incurred. Although this alternative is somewhat less attractive than Alternative 3, it represents a potentially more realistic commercial alternative, based on potential slippage in the startup of commercial reprocessing.

Alternative 5 (Delayed Reprocessing, No Plutonium Recycle)

Although this alternative recycles uranium, Alternative 5 has a higher demand for uranium, enrichment services, and spent fuel storage than Alternative 3. It has no demand for mixed oxide fuel fabrication and produces an impure plutonium solid as a

Table S-16

COMPARISON OF MATERIALS PROCESSED

Process	Total Flow Alternative 3	Incremental Flow Relative to Alternative 3			
		Alternative 1	Alternative 2	Alternative 5	Alternative 6
Milling, Short tons, U_3O_8	1,240,000	0	+300	+189,000	+357,000
UF_6 Conversion, MTU	916,000	0	+500	+167,000	+294,000
Enrichment, MTSWU	523,000	+100	-1000	+90,000	+85,000
UO_2 Fabrication, MTU	163,000	+6	+170	+25,000	+25,000
MOX Fabrication, MT (U+Pu)	25,300	-2	-170	-25,000	-25,000
Reprocessing, MT	115,000	0	-2	-2	-115,000

NOTE: The data in this table came from Table XI-41.

waste. Compared to Alternative 3, it has a higher radiological impact and higher nonradiological environmental impact. It results in a present worth cost increase of $3 billion at a 10% discount rate.

Alternative 6 (No Reprocessing, No Recycle)

Alternative 6, the no recycle option, has a greater demand on uranium resources, enrichment, and fuel storage than Alternative 3. It requires no reprocessing or mixed oxide fuel fabrication. Compared to the reference case, it has greater nonradiological environmental impact but a lower radiological dose commitment. It has an increase over Alternative 3 in present worth fuel cycle cost of $3.2 billion at a 10% discount rate.

The principal tradeoff between this Alaternative 6, and Alternative 3 arises from a relatively small decrease in the radiological dose commitment compared to the $3.2 billion present worth cost penalty.

In an attempt to quantify the value of this radiological impact decrease, a high, or maximum, value for this impact can be assessed by using the upper value for a person-rem suggested in 10 CFR Part 50, Appendix I, at $1,000/person-rem. This value is a very conservative (high) guide for evaluation of the reduction of radiological exposures. By applying this value ($1,000/person-rem) to dose, however, it is possible to approximate a maximum (high) value of reducing to zero the dose from certain facility impacts. It should also be noted that the industry dose commitments are based on a set of assumptions that tend to overstate the actual exposure levels.

The decrease in nonoccupational total body exposure (U.S. and foreign) of 9.7×10^5 person-rem at $1,000/person-rem, results in a social benefit of $970 million over the time period. Since there is no appropriate mechanism for discounting this benefit to a present worth, it can only be compared to the total undiscounted increase in economic costs of Alternative 6 over Alternative 3, $18 billion. The benefit, $970 million, is less than the undiscounted economic cost, $18 billion.

The world population receives a population dose from natural background radiation in the period 1975-2000 of about 1×10^{10} person-rem, which is over 1,000 times greater than the dose received from the entire LWR industry under any fuel cycle alternative (see Table S-4) and 10,000 times the difference between any of the various fuel cycle alternatives.

2.0 FINDINGS

Principal staff findings based on evaluations of the health, safety and environmental (but not safeguards) effects of widescale recycle of plutonium as fuel to light water reactors are as follows

> The safety of reactors and fuel cycle facilities is not affected significantly by recycle of fissile materials.

- Nonradiological environmental impacts resulting from recycle of fissile materials from spent fuel are slightly smaller than those from a fuel cycle that does not reclaim residual fuel values.

- Plutonium recycle extends uranium resources and reduces enrichment requirements while entailing the need for reprocessing and fuel fabrication of plutonium containing fuels.

- While there are uncertainties, widescale recycle has a likely economic advantage relative to a fuel cycle that does not reclaim residual fuel values.

- Differences in health effects attributable to recycle provide no significant basis for selection of a fuel cycle option.

- No waste managment considerations were identified that would bar recycle of uranium and plutonium.

SUMMARY

APPENDIX A

INTEGRATED ENVIRONMENTAL FACTORS

FOR THE LIGHT WATER REACTOR INDUSTRY, 1975 THROUGH 2000

Values of integrated environmental factors for the light water reactor industry, 1975 through 2000, are listed in Tables S(A)-1, S(A)-2, and S(A)-3. Table S(A)-1 lists the factors for the no recycle option, Alternative 6; S(A)-2 lists factors for the uranium recycle option, Alternative 5; and S(A)-3 lists factors for the prompt uranium and plutonium recycle option, Alternative 3. Three facts should be noted:

- The environmental factors for Alternative 1 and 2 are essentially equal to those of Alternative 3, and hence have not been included in the Summary and Conclusions.

- Appendix VIII A contains tables of environmental factors for all alternatives. The Tables S(A)-1, -2, and -3 are reproductions of the tables for Alternatives 6, 5, and 3 (respectively) in Appendix VIII A.

- The tables have been reproduced from computer output; note, for example 2.5E+02 is 2.5×10^{2} or 250 and 4.0E-02 is 4.0×10^{-2} or 0.04.

Table S(A)-1
INTEGRATED ENVIRONMENTAL FACTORS FOR THE LWR INDUSTRY, 1975 THROUGH 2000

NO RECYCLE OPTION

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 S(A)-1 (cont'd)
INTEGRATED ENVIRONMENTAL FACTORS FOR THE LWR INDUSTRY, 1975 THROUGH 2000

NO RECYCLE OPTION

ENVIRONMENTAL FACTORS FOR ALTERNATIVE 6

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	2.4E+07	4.4E+06	3.4E-02	- -	- -	0.0	- -	0.0	- -	2.0E+01	- -	2.8E+07
RA-226	- -	1.3E+01	1.9E-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	0.7E+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 S(A)-1 (cont'd)
INTEGRATED ENVIRONMENTAL FACTORS FOR THE LWR INDUSTRY, 1975 THROUGH 2000

NO RECYCLE OPTION

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

Table S(A)-2
INTEGRATED ENVIRONMENTAL FACTORS FOR THE LWR INDUSTRY, 1975 THROUGH 2000

URANIUM RECYCLE OPTION

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVERSION	ENRICHMENT	UO2 FUEL FABRICATION	MOX FUEL FABRICATION	REACTOR	REPROCESSING	TRANSPORTATION	WASTE MANAGEMENT	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 S(A)-2 (cont'd)
INTEGRATED ENVIRONMENTAL FACTORS FOR THE LWR INDUSTRY, 1975 THROUGH 2000

URANIUM RECYCLE OPTION

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	2.1E+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-00	- -	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)	- -	- -	- -	5.6E-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 S(A)-2 (cont'd)
INTEGRATED ENVIRONMENAL FACTORS FOR THE LWR INDUSTRY, 1975 THROUGH 2000

URANIUM RECYCLE OPTION

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 S(A)-3
INTEGRATED ENVIRONMENTAL FACTORS FOR THE LWR INDUSTRY, 1975 THROUGH 2000

URANIUM AND PLUTONIUM RECYCLE OPTION

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVERSION	ENRICHMENT	UO2 FUEL FABRICATION	MOX FUEL FABRICATION	REACTOR	REPROCESSING	TRANSPORTATION	WASTE MANAGEMENT	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 S(A)-3 (cont'd)
INTEGRATED ENVIRONMENTAL FACTORS FOR THE LWR INDUSTRY, 1975 THROUGH 2000

URANIUM AND PLUTONIUM RECYCLE OPTION

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	- -	5.8E+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 S(A)-3 (cont'd)
INTEGRATED ENVIRONMENTAL FACTORS FOR THE LWR INDUSTRY, 1975 THROUGH 2000

URANIUM AND PLUTONIUM RECYCLE OPTION

ENVIRONMENTAL FACTORS	MINING	MILLING	CONVERSION	ENRICHMENT	UO2 FUEL FABRICATION	MOX FUEL FABRICATION	REACTOR	REPROCESSING	TRANSPORTATION	WASTE MANAGEMENT	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	4.6E+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	- -	- -	- -	- -	- -	- -	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	- -	- -	8.3E+01	1.2E+06
SKIN	- -	- -	- -	- -	- -	- -	2.4E+05	2.5E+07	- -	- -	3.2E+03	2.5E+07

SUMMARY

APPENDIX B

GLOSSARY OF ACRONYMS AND TERMS

AEC	U.S. Atomic Energy Commission
ALARA	As low as reasonably achievable (applied to radiation exposures and environmental releases of radioactivity)
ANL	Argonne National Laboratory
ASLB	Atomic Safety and Licensing Board
BEIR	Advisory Committee on the Biological Effects of Ionizing Radiation
BNFP	Barnwell Nuclear Fuel Plant
BWR	Boiling Water Reactor
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
DBE	Design Basis Earthquake
EEI	Edison Electric Institute
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
FBR	Fast Breeder Reactor
FR	Federal Register
FRC	Federal Radiation Council
Fuel Cycle	The complete sequence of operations, from mining of uranium raw material to disposal of radioactive wastes, involved in providing fuel for nuclear power plants
No recycle	The fuel cycle in which spent fuel is stored rather than being reprocessed to recover uranium and plutonium
U Only recycle	The fuel cycle in which only uranium is recovered by reprocessing the spent fuel, plutonium being stored with the reprocessing wastes
Pu recycle	The fuel cycle in which both uranium and plutonium are recovered in reprocessing and are reused in making new fuel for LWR's
GESMO	Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors
Draft GESMO	First edition published in 1974 for public review and comment
Final GESMO	Second edition published in 1976 with changes in response to comments received on the draft
Safeguards Supplement	A separate report to be issued in draft form for public comment and then in final form to cover the special Safeguards aspects of plutonium recycle

GWy	Gigawatt-year
HEPA Filter	High Efficiency Particulate Air Filter
HLW	High Level Waste
HTGR	High Temperature Gas Cooled Reactor
IAEA	International Atomic Energy Agency
ICRP	International Committee on Radiological Protection
ICV	Integrated Container-Vehicle
kWh	Kilowatt hour
LASL	Los Alamos Scientific Laboratory
LMFBR	Liquid Metal Fast Breeder Reactor
LOCA	Loss of Coolant Accident
LWR	Light Water Reactor
MeV	Million Electron Volts
MOX	Mixed Oxide (UO_2 and PuO_2, as used in LWR fuel)
MPC	Maximum Permissible Concentration
mrem	Millirem
MT	Metric Ton
MTHM	Metric Tons of Heavy Metal (uranium and plutonium)
MTU	Metric Tons of Uranium
MUF	Material Unaccounted For
MWe	Megawatts electric
MWd	Megawatt-days
NEPA	National Environmental Policy Act
NFS	Nuclear Fuel Services
NRC	Nuclear Regulatory Commission
ORGDP	Oak Ridge Gaseous Diffusion Plant
ORNL	Oak Ridge National Laboratory
person-rem	(Population rem) Sum of rem doses in a defined population or sum of doses to specific organs in a defined population
PNL	Pacific Northwest Laboratories
ppb	Parts per billion
ppm	Parts per million
Pu recycle	The use of LWR produced plutonium to replace some portion of the fissile ^{235}U normally required in LWR fuels
Pu_f	Fissile Plutonium (^{239}Pu and ^{241}Pu)

Pu_t	Total Plutonium (fissile and nonfissile)
PuO_2	Plutonium Dioxide
PUP	Plutonium Utilization Program
PWR	Pressurized Water Reactor
rem	Dose of any radiation supposedly having a biological effect equivalent to one roentgen
Recycle Pu	LWR produced Pu recovered from spent fuel subsequently used to replace some portion of ^{235}U normally required in LWR fuel
RSSF	Retrievable Surface Storage Facility (for radioactive wastes)
SGR	Self Generation Reactor
SNM	Special Nuclear Material
SSNM	Strategic Special Nuclear Material
SPERT	Special Power Excursion Reactor Tests
ST	Standard Ton (2000 pounds, also called "Short Ton." A "Long Ton" is the same as a Metric Ton, which is 1000 kilograms or 2200 pounds).
SWU	Separative Work Units (a measure of enrichment output)
UO_2	Uranium Oxide

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