NUREG-0002, ES

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

Health, Safety and Environment

Executive Summary

U.S. Nuclear Regulatory Commission

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August 1976

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

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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

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*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.

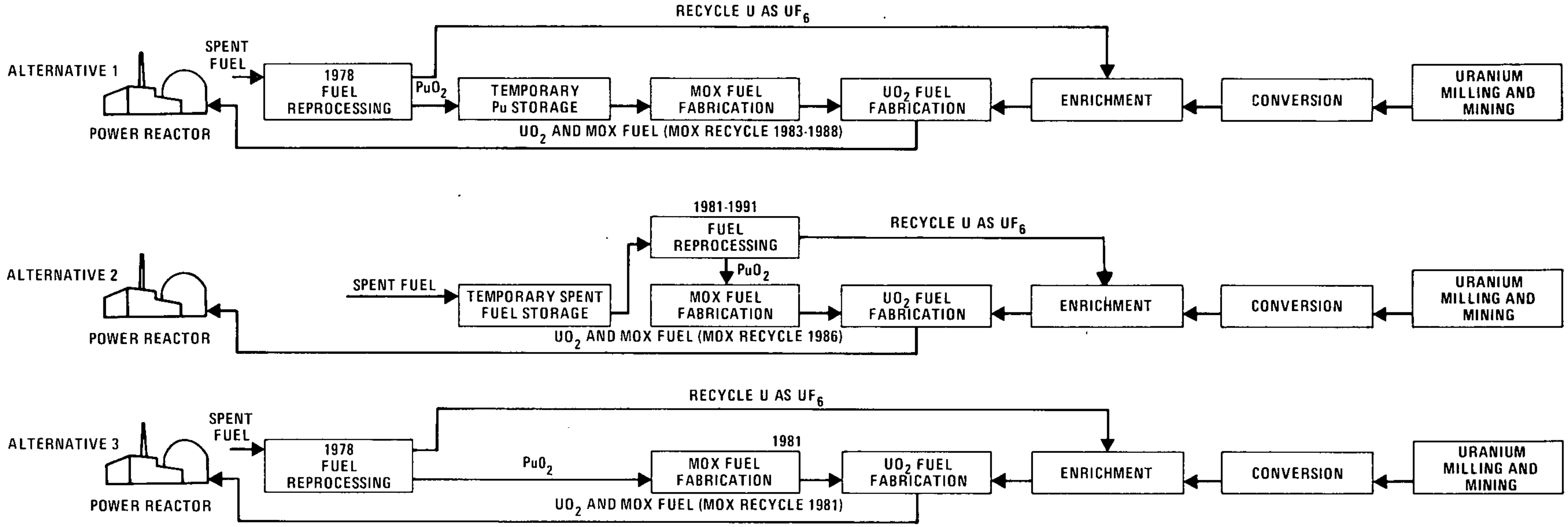
1.3 Results

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.

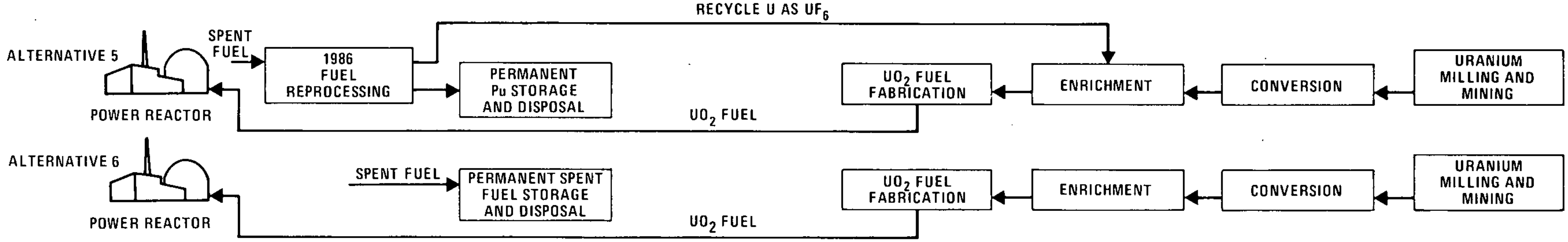


Figure ES-1 Alternatives for the Disposition of Plutonium

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

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*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.

1.15 ?

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	1.1×10^{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}

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*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 ± 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.

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*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:

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