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

Health, Safety and Environment

U.S. Nuclear Regulatory Commission

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

HEALTH, SAFETY & ENVIRONMENT

Chapter

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August 1976

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

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1.0 BACKGROUND AND PURPOSE OF GESMO

The current generation of light water nuclear power reactors (LWR's) normally uses fuel in which natural uranium is enriched from 0.7 percent readily fissionable uranium-235 (^{235}U) to between 3 and 4 percent ^{235}U. The balance of the uranium fuel consists of relatively nonfissionable uranium-238 (^{238}U).

All nuclear reactors containing ^{238}U in their fuel produce plutonium as a byproduct of the chain reaction. Two of the more plentiful isotopes of plutonium, ^{239}Pu and ^{241}Pu, are readily fissionable and, once formed, contribute to the fission process (chain reaction).

Generally more than half of the plutonium produced in the reactor subsequently fissions in place, thus contributing significantly to the energy produced in the power plant. Just before expended fuel is discharged from the reactor, more than half the fissions occurring in that fuel are fissions of plutonium rather than uranium. Thus, in effect, uranium fueled light water power reactors generate plutonium, some of which is consumed in the reactor without external recycle.

About one-third to one-fourth of a light water reactor's fuel is removed each year and replaced by fresh fuel. Although the used fuel is referred to as "spent fuel," it still contains some reusable ^{235}U, as well as plutonium. The plutonium can be recovered from reprocessed fuel and subsequently used to replace ^{235}U by combining it with recovered or fresh uranium to produce mixed oxide fuel. This recycling of plutonium is a means of augmenting the supply of ^{235}U and of conserving a natural resource.

Currently, three LWR's in the United States are operating with some mixed oxide fuels: Big Rock Point, in Michigan, and Quad Cities Unit No. 1 and Dresden Unit No. 1 in Illinois. Of these the 70 MWe Big Rock Point reactor contains the largest significant loading of mixed oxide fuel, about 1,000 rods or about 11% of the fuel rods in the core containing about 50 kg of plutonium. For comparison, a large modern boiling water reactor (BWR) would be loaded with about 13,000 rods of mixed oxide fuel containing about 2,400 kg plutonium.

Plutonium recycle in light water reactors is defined as the use of plutonium-uranium mixed oxide fuels in which plutonium produced as a byproduct of operating light water reactors (LWR's) replaces some portion of the ^{235}U 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 light water cooled nuclear power reactors 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 which would have the potential to significantly affect 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 Mixed Oxides (GESMO).*

The Council on Environmental Quality (CEQ) Guidelines of August 1, 1973, §1500.1(a), implementing NEPA, require agencies to build into their decision-making process, beginning at the earliest point, an appropriate and careful consideration of environmental aspects of the proposed action so that adverse environmental effects may be avoided or minimized and environmental quality previously lost may be restored. To implement NEPA and the CEQ Guidelines, NRC promulgated Regulation 10 CFR Part 51. Should widescale use of mixed oxide fuels be approved, both Part 50 and Part 51 of the Commission's regulations would require implementing amendments. In accordance with the AEC notice regarding participation in public hearings on this issue (39 FR 43101), copies of proposed amendments to 10 CFR, Parts 50 and 51, were distributed to all parties who received the draft statement or commented on it.

In a Federal Register Notice issued November 14, 1975 (40 FR 53056) the Commission described the scope, procedures and schedule for completing this generic environmental impact statement. That notice set forth the Commission finding that before it can reach a decision on the widescale use of mixed oxide fuel, there must be a full assessment of safeguards issues. Toward that end, the Commission directed the staff to prepare a safeguards supplement to the draft GESMO, which was issued in August 1974. This supplement will include an analysis of the costs and benefits of alternative safeguards programs and a recommendation as to safeguards associated with the widescale use of MOX fuel.

This environmental statement assesses the impacts of the implementation of plutonium recycle in the LWR industry. It is based on assumptions that are intended to reflect conservatively an acceptable level of the application of current technology. It is not intended to be a representation of the "as low as reasonably achievable" (ALARA) philosophy.

The three following fuel cycle options are compared with respect to health, safety, environmental, and economic impact:

The no recycle option--all LWR fuel comes from virgin natural uranium that has been enriched in uranium-235 content by an isotope separation plant.

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

*AEC originally prepared a draft statement.

The uranium and plutonium recycle option--both uranium and plutonium are recovered from LWR spent fuels and subsequently incorporated into replacement fuel as mixed oxides.

The time frame of reference is the period from the year 1975 through the year 2000; impacts are integrated over the entire period in the comparative assessments that are performed.

2.0 LIGHT WATER REACTOR PROJECTIONS AND URANIUM AND PLUTONIUM RECYCLE OPTIONS

Central station generating capacity in the United States has grown steadily to satisfy increasing demands for electricity. It is anticipated that growth will continue in the future. An estimate of the rate of that growth is shown in Figure I-1.* LWR's, as indicated by this chart, are expected to supply an increasing portion of the total future electrical generating capacity. In fact, the LWR should predominate as the nuclear choice for the rest of this century, and may be virtually the only commercial choice during much of the time a widescale recycle industry could be in operation. The growth projections employed for this environmental statement, see Figure I-1, are used as the basis for analytical purposes.

The fuel currently used in LWR's consists of uranium dioxide, UO_2, in the form of chemically and thermally stable ceramic cylinders, encased (clad) in metallic tubing, usually Zircaloy, to form fuel rods. Rods are assembled into square "arrays" with water flow passages between the fuel rods. These fuel bundles, fuel assemblies, or arrays as they are called, are placed into the reactor pressure vessel and--together with other reactor internal parts such as flow guides, support structures, and control rods--constitute the reactor core.

The two types of light water cooled reactors in common use in the United States are the boiling water reactor and the pressurized water reactor (PWR).

- Boiling water reactor--The fission heat from the uranium fuel converts the cooling water directly into steam to drive a turbine which in turn drives a generator to produce electricity.

- Pressurized water reactor--The cooling water is kept from boiling by high system pressures. The heated, high-pressure water subsequently transfers heat to a secondary water system in a large steam generator. The secondary steam is used to drive the turbine generator.

*Estimates are provided by ERDA in its update of WASH-1139 (74) entitled "Total Energy, Electric Energy, and Nuclear Power Projections, United States, February 1975." For further details on that estimate and others, and a comparison of various projections, estimates, and scenarios of future power requirements, nuclear power growth, etc., refer to CHAPTER III, Section 1.0.

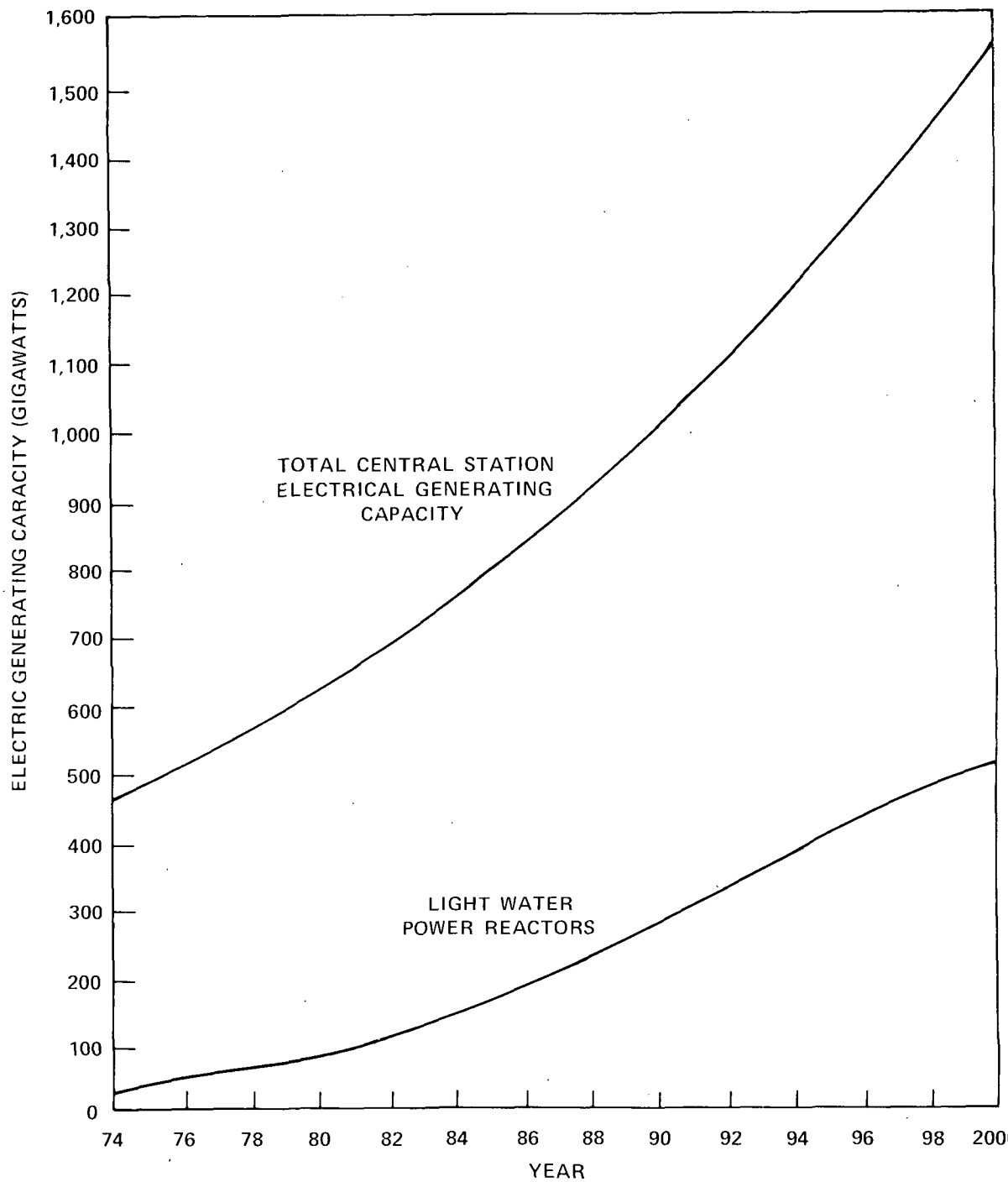

FIGURE I–1 Central Station Electrical Generating Capacity In the United States as Projected by ERDA OPA, 1975 Low Growth

The thermal energy produced by operation of new fuel in LWR's is produced by the fissioning of ^{235}U atoms in the fuel. As the reactor operates and the fuel is progressively used, atoms of fissile plutonium (Pu_f, which is ^{239}Pu and ^{241}Pu) are produced by transmutation of ^{238}U atoms.* Some of these in turn contribute to the nuclear fission reaction and the energy produced by the reactor.

For each megawatt-day, thermal (MWdth) produced by the fission of ^{235}U in LWR fuel, about 1 gram of fissile plutonium (Pu_f) is formed within the fuel. Somewhat more than one-half of that plutonium subsequently fissions prior to removal of the fuel from the reactor, thus contributing significantly (about 35%) to the total energy produced in the nuclear power plant. Just before spent fuel is normally discharged from the reactor, more than half the fissions occurring in that fuel are from plutonium rather than uranium. Thus, in effect, uranium-fueled LWR's are significantly fueled with self-generated plutonium.

Fuel is considered to be "spent" when it can no longer sustain the neutron chain reaction at economic power levels because of the depletion of its contained fissile materials and the accumulation of neutron-absorbing byproducts in the fuel and fuel hardware. At that point, however, the fuel still contains appreciable quantities of fissile isotopes (about 6 grams of Pu_f, about 8 grams of ^{235}U per kilogram of uranium, and about 98% of the ^{238}U originally loaded), which can be recovered from the spent LWR fuel after it is removed from the core by treatment in a reprocessing plant. Recovered uranium can be reenriched in the same manner as natural uranium. The enriched recovered uranium can then be used to replace some of the enriched uranium made from virgin natural uranium in the preparation of new fuel assemblies. This option is called uranium recycle. It is also possible to utilize some of the recovered uranium to prepare recycle fuel without reenrichment by combining the uranium with plutonium. However, this alternative will not utilize all of the recovered uranium because sufficient recovered plutonium does not exist.

Plutonium that is recovered from spent fuel can be combined with uranium having a lower ^{235}U content than that of fresh uranium fuel, which normally contains about 3% ^{235}U, to make an equivalent reactor fuel. Thus, a substitution of recovered plutonium can be made for some of the ^{235}U fissile content of the fuel. Such fuel is called plutonium-uranium mixed oxide or simply mixed oxide fuel; and its use for this purpose is known as plutonium recycle. Further, it is possible to make useful mixed oxide fuels with plutonium in combination with any predominantly ^{238}U uranium, including a low-enriched uranium product from an enrichment plant, recovered uranium from spent fuel, virgin natural uranium, or depleted uranium enrichment plant tails. For the purposes of this environmental statement, it is assumed that natural uranium will be used in the preparation of mixed oxide fuel. This is considered to be an adequate representation because there are no significant differences in safety, environmental or economic impacts related to the type of uranium used for preparation of mixed oxide fuels.**

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*For details of the genesis of plutonium in LWR's, see Appendix A, Part I.

**Special cases, that of blending plutonium with low enriched uranium, called dilute Pu recycle, are discussed in Section L of CHAPTER IV.

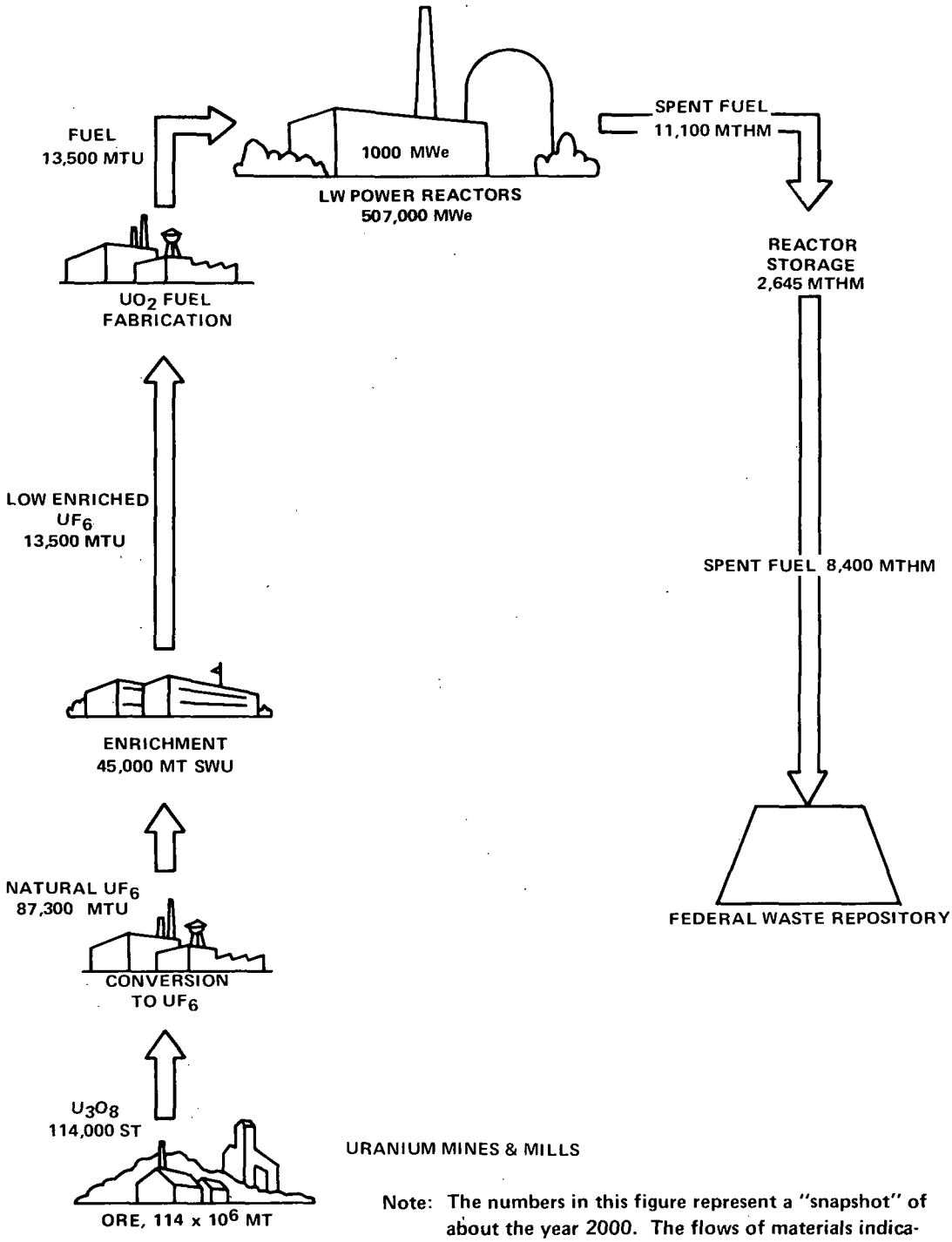
2.1 No Recycle Option

LWR's require many supporting operations. Most of these relate to the supply of fresh fuel and treatment of spent fuel. These operations are usually referred to as the fuel cycle. Fuel cycle operations where neither uranium nor plutonium is recycled include

- Both underground and open pit mining of uranium ores
- Milling to concentrate uranium values from the ores and to produce a semi-refined uranium oxide product called "yellowcake" (assayed as equivalent U_3O_8)
- Refining and converting yellowcake to volatile uranium hexafluoride UF_6 which is the feed for isotopic enrichment facilities
- Enrichment of UF_6 (currently by the gaseous diffusion process) to yield a product enriched in the fissile isotope ^{235}U and a depleted stream (enrichment plant tails)
- Conversion of enriched UF_6 to oxide, fabrication of ceramic fuel cylinders, encapsulation in fuel rods and assembly into fuel elements
- Spent fuel storage
- Permanent disposal of spent fuel

The overall LWR uranium fuel cycle without recycle of either uranium or plutonium is shown in Figure I-2. It should be noted that this option would result in spent fuel being designated as high level waste. The waste management program would have to be modified to accommodate this material. Refer to CHAPTER IV, Section H. The magnitude of each of these operations is expressed in terms of the total quantities of materials processed or handled through the year 2000.

The enrichment process is characterized by the work necessary to accomplish the required separation of isotopes. Such separative work is measured in "separative work units" (SWU) and is expressed in units of kilograms or metric tons. Separative work is a considerable component of the cost of enriched uranium fuel. For example, for the no recycle case for about the year 2000, with projected costs of $37.60 per pound of U_3O_8 for yellowcake and $75.00 per kg SWU (1975 dollars), assuming a tails assay of 0.3%, the value of all the yellowcake projected for fuel for all U.S. reactors is $8.6 billion, and the cost for separative work for enriching that uranium is projected to be $3.4 billion. Separative work requirements and yellowcake requirements to supply initial fuel loadings and reload fuels for the projected needs of U.S. LWR's are shown in Figure I-3.



Note: The numbers in this figure represent a "snapshot" of about the year 2000. The flows of materials indicated are not intended to constitute a material balance. The numbers reflect the production quantities projected for the year 2000 and varying lead times in a growing industry.

Figure I-2 Annual United States Industrywide Fuel Cycle Requirements for Light Water Reactors for About 2000 Without Uranium or Plutonium Recycle, ERDA OPA, 1975 Projection, Low Growth, Without Breeder

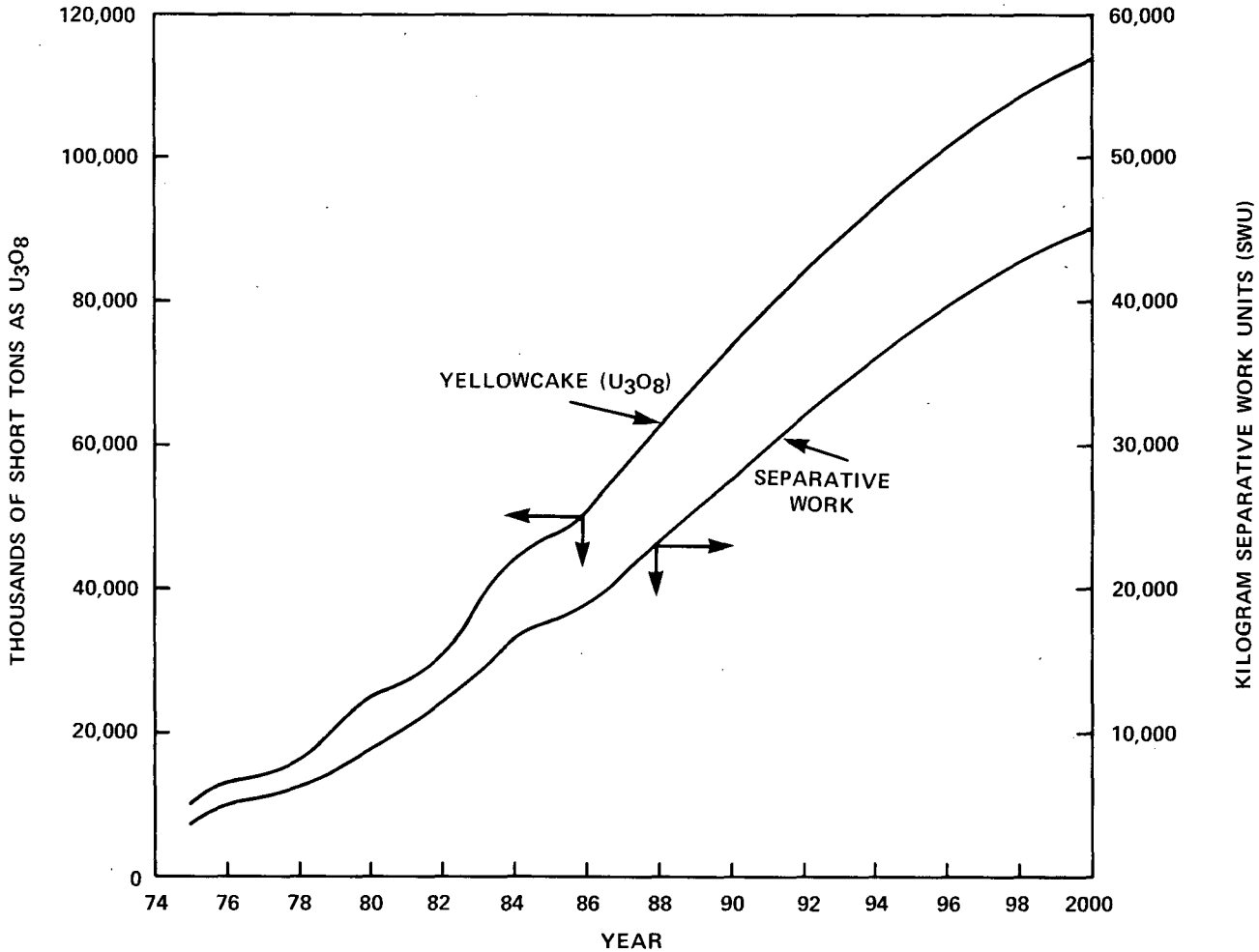


FIGURE I–3 Annual Yellowcake and Enrichment Requirements for United States Light Water Power Reactors as Projected by ERDA OPA, 1975, Low Growth, Without Breeder (Without U of Pu Recycle)

2.2 Uranium Recycle Option

If spent fuels are reprocessed for recovery and recycle of uranium, additional operations are added to the out-of-reactor fuel cycle. The overall cycle then includes

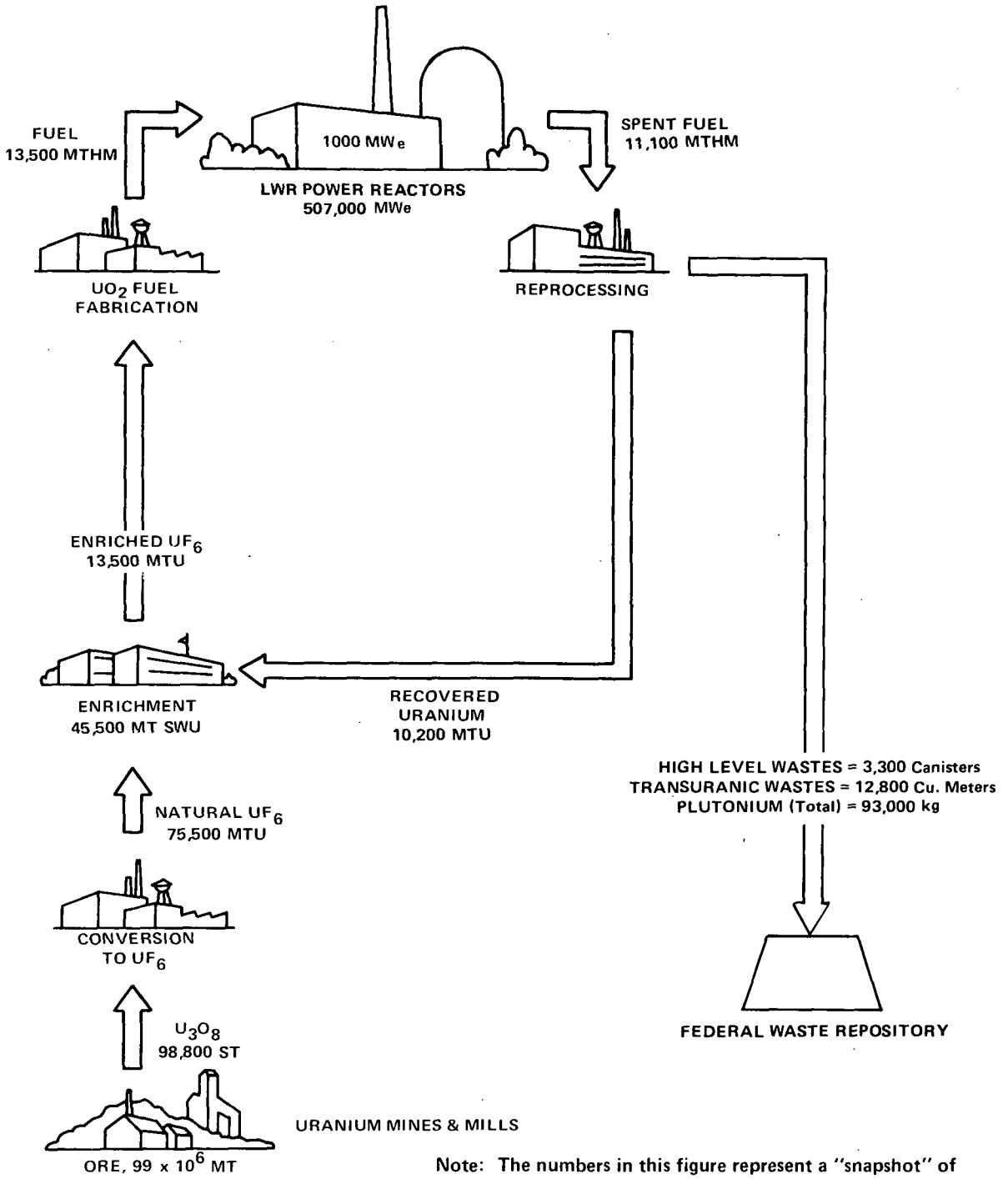
- Both underground and open pit mining of uranium ores
- Milling to concentrate uranium values from the ores and to produce the semirefined uranium oxide product yellowcake (assayed as equivalent U_3O_8)
- Refining and conversion of yellowcake to volatile uranium hexafluoride UF_6 which is the feed for isotopic enrichment facilities
- Enrichment of uranium hexafluoride (currently by the gaseous diffusion process) to yield a product enriched in the fissile isotope ^{235}U and a depleted stream (enrichment plant tails)
- Reprocessing of spent fuels to separate and recover residual uranium from plutonium and radioactive wastes*
- Conversion of the recovered uranium to UF_6*
- Reenrichment of that recovered uranium in the enrichment plant simultaneously with enrichment of virgin natural UF_6 to make a combined enriched product*
- Conversion of enriched UF_6 to oxide, fabrication of ceramic fuel cylinders, encapsulation in fuel rods, and assembly into fuel elements
- Spent fuel storage
- High level waste storage and disposal*
- Transuranic waste storage and disposal*

The overall industrywide fuel cycle for light water reactors where uranium, but not plutonium, is recycled is shown in Figure I-4. Impure plutonium is disposed of in a manner similar to the high level wastes. An alternative scheme would store the separated plutonium in a special repository. Comparison with the "no recycle" fuel cycle shown in Figure I-2 indicates that implementation of uranium recycle reduces virgin U_3O_8 requirements by about 13% in the year 2000.

2.3 Plutonium Recycle Option

A considerable amount of plutonium is produced in LWR's. In fact, the quantity is sufficiently large that even if ERDA projections prove to be accurate regarding

*Operation added to the out-of-reactor fuel cycle when spent fuels are reprocessed for recovery and recycle of uranium.



Note: The numbers in this figure represent a "snapshot" of about the year 2000. The flows of materials indicated are not intended to constitute a material balance. The numbers reflect the production quantities projected for the year 2000 and varying lead times in a growing industry.

Figure I-4 Annual United States Industrywide Fuel Cycle Requirements for Light Water Reactors for About 2000 With Uranium Recycle Only, ERDA OPA, 1975 Projection, Low Growth, Without Breeder

penetration of the electric power industry by the breeder reactor in the early 1990's, there will be a substantial quantity of plutonium in excess of breeder program requirements. The fundamental safety, environmental, and safeguards issues concerning plutonium recycle in LWR's are not contingent upon the breeder. Figure I-5 charts projected electric generating capacity for the LWR and the breeder reactors to the year 2000; Figure I-6 shows the generation and utilization of plutonium.

With plutonium recycle, two new operations--plutonium conversion and mixed oxide fuel manufacture--are added to the fuel cycle, and the reprocessing step modified somewhat from that of the uranium only recycle; the out-of-reactor portions of the fuel cycle then become

- Underground and open pit mining of uranium ores
- Milling to concentrate uranium values from the ores and to produce a semi-refined uranium oxide product, yellowcake (assayed as equivalent U_3O_8)
- Refining and converting yellowcake to volatile uranium hexafluoride UF_6 which is the feed for isotopic enrichment facilities
- Enrichment of UF_6 (currently by gaseous diffusion process) to yield a product enriched in the fissile isotope ^{235}U and a depleted stream (enrichment plant tails)
- Reprocessing of spent fuels to separate and recover uranium and plutonium from radioactive wastes and from one another
- Conversion of recovered uranium to UF_6
- Reenrichment of that recovered uranium in the enrichment plant simultaneously with enrichment of virgin natural UF_6 to make a combined enriched product
- Conversion of enriched UF_6 to oxide, fabrication of ceramic fuel cylinders, encapsulation in fuel rods and assembly into fuel elements
- Conversion of recovered plutonium into a solid form*
- Combination of recovered plutonium with uranium to make mixed oxide, fabrication of ceramic fuel cylinders, encapsulation in fuel rods and assembly into fuel elements*
- Spent fuel storage
- High level waste storage and disposal

*Operation added to the fuel cycle with plutonium recycle.

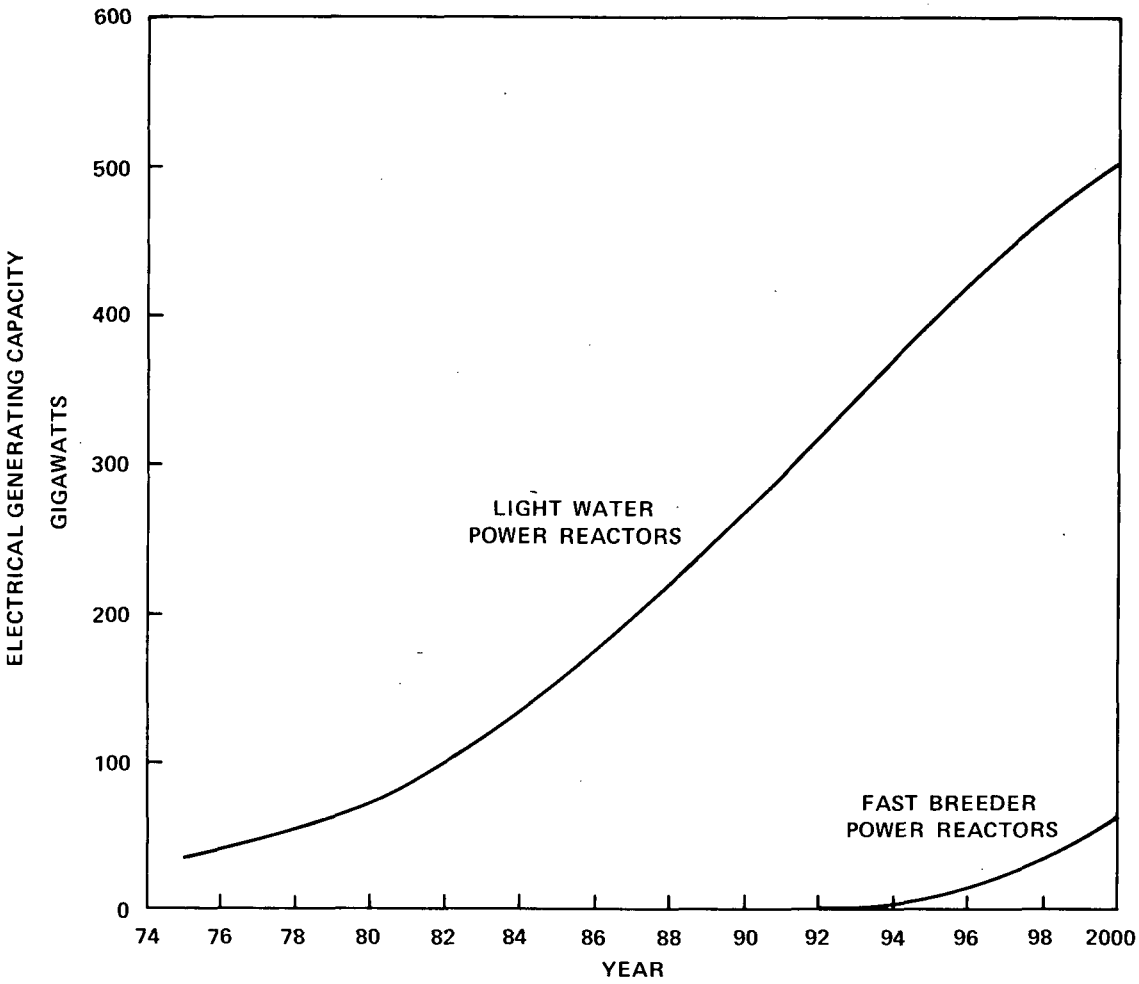


FIGURE I–5 Central Station Generating Capacity in the United States by Reactor Type as Projected by ERDA OPA, 1975, Low Growth

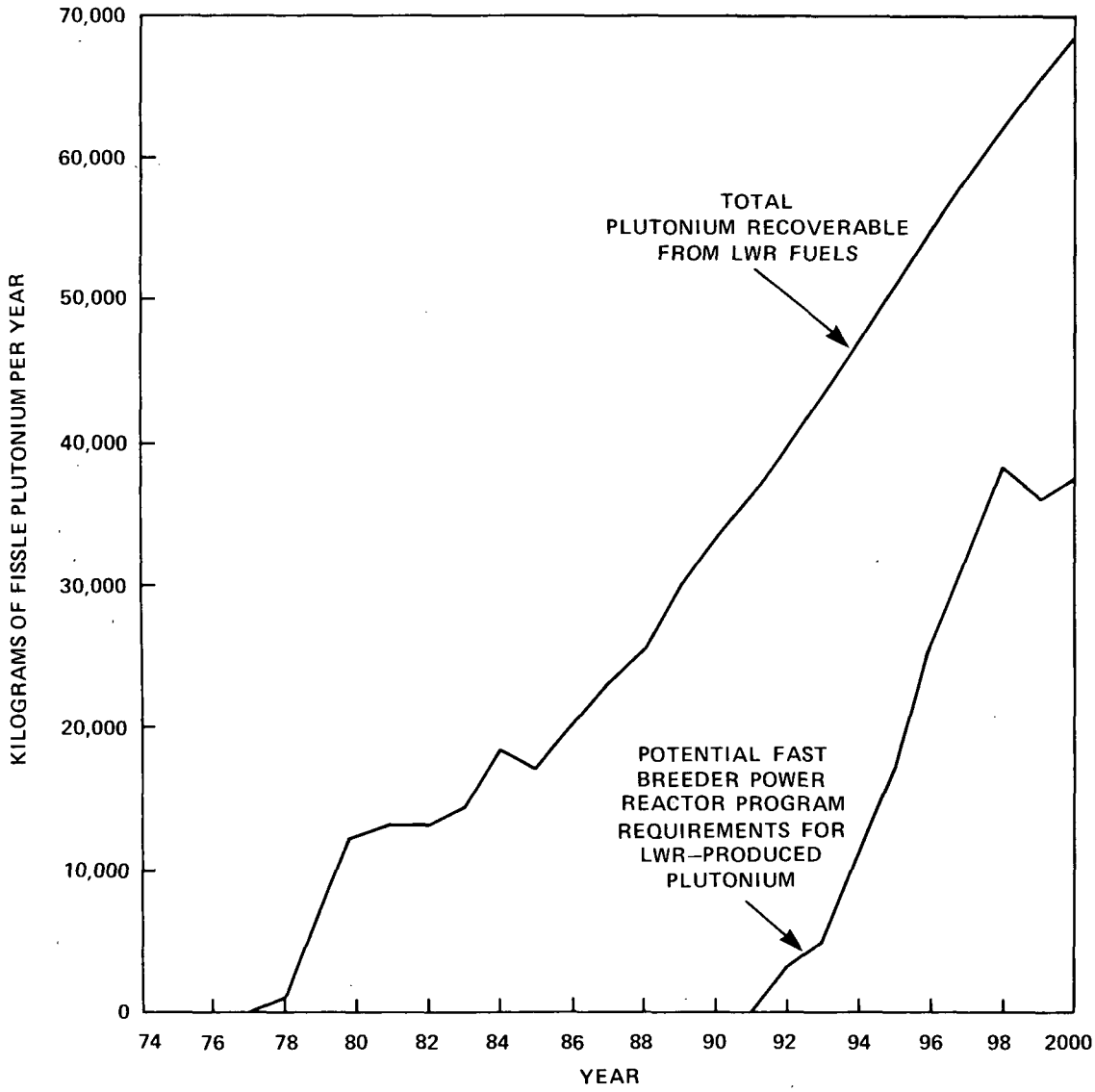


FIGURE I–6 Annual Production and Utilization of Plutonium in Power Reactors in the United States as Projected by ERDA OPA, 1975, Low Growth (Without Pu Recycle in LWR's)

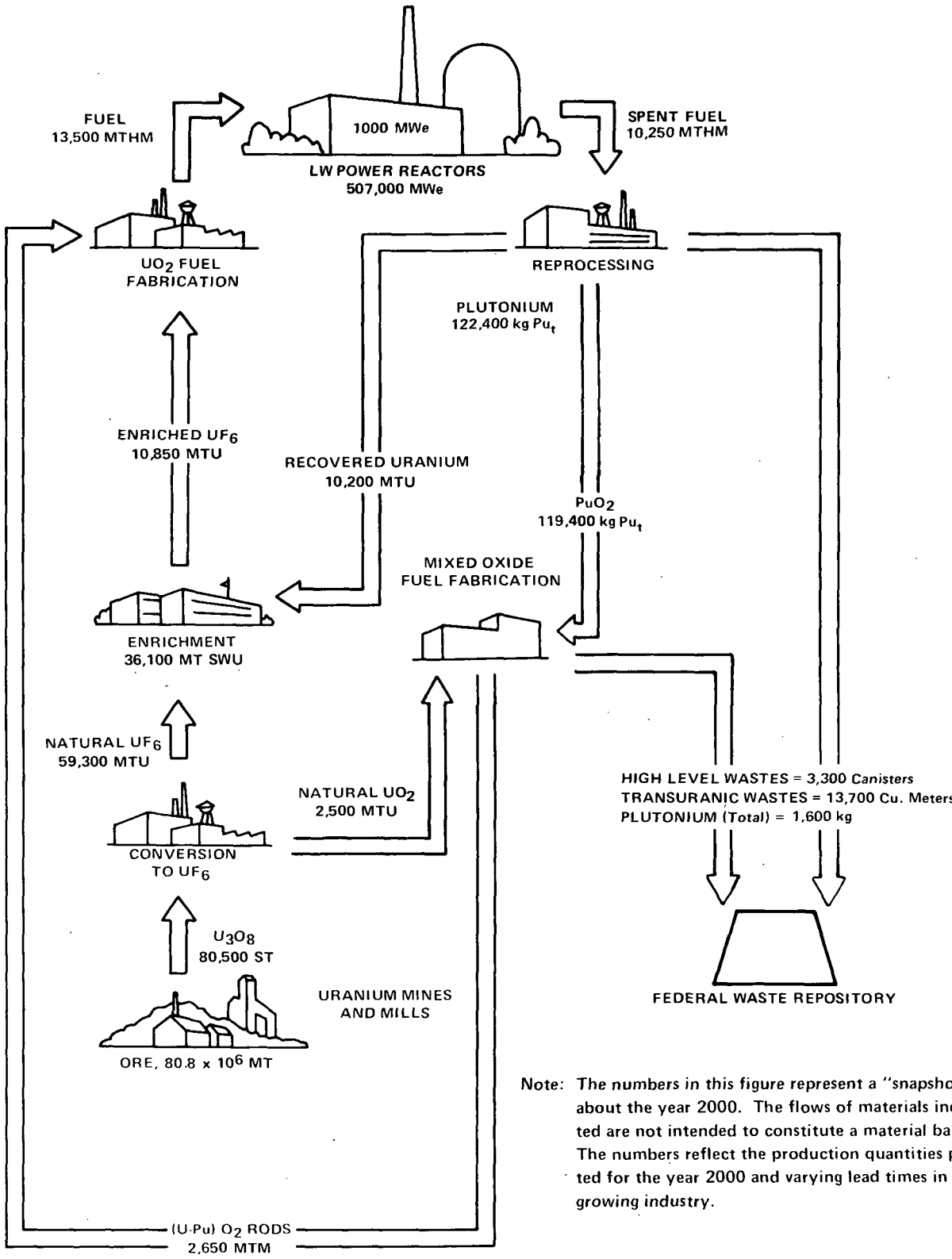
- Transuranic waste storage and disposal

If recovered uranium and plutonium are recycled to LWR's, the separative work and yellowcake requirements for sustaining the LWR economy are substantially reduced. However, there will not be enough plutonium to make mixed oxide fuel for all LWR requirements, and there will be a continuing need for the present type of slightly enriched UO_2 fuel. Over the period 1975-2000, it is projected that 87% of the LWR fuel will be the standard UO_2 fuel, whereas 13% will be mixed oxide. At the end of the period, it is forecast that the quantity of plutonium being recycled will be such that 20% of the LWR fuel will be mixed oxide.

The LWR fuel cycle projected for the year 2000 is presented in Figure I-7. It is assumed that the recovered uranium is reenriched for fabrication into uranium-only fuel and that newly mined uranium will be used with the recycled plutonium to make mixed oxide fuel for LWR's. Comparison of the LWR fuel cycle when both plutonium and uranium are recycled (Figure I-7) with the no recycle option (Figure I-2) and with the uranium only recycle option (Figure I-4) shows the following major effects for the year 2000: (1) when both plutonium and uranium are recycled, enriched uranium supply operations* are reduced by about 20% compared to the uranium only recycle option; U_3O_8 and natural UF_6 requirements are reduced by about 30% compared with the no recycle option; and uranium enrichment supply operations are reduced by about 20%; (2) the recycle of plutonium and uranium introduces a commercial traffic in purified plutonium and this creates new environmental effects that are shown by detailed analyses to be far below the permissible limits; and (3) when plutonium is recycled promptly the quantity of plutonium in inventory or in nuclear fuel wastes is about 1-2% of what it would be without recycle.

Recycling plutonium in LWR fuel requires the construction of specially designed mixed oxide fuel manufacturing facilities which otherwise would not be needed. The nature of plutonium--particularly its radiotoxicity--is such that most of the mixed oxide fuel manufacturing operations cannot be properly performed in a typical UO_2 fuel fabrication facility. Handling plutonium requires special enclosures and containment because the biological hazard is many times that of slightly enriched uranium. Although uranium and plutonium are both radioactive and are both primarily alpha emitters, plutonium isotopes exhibit much higher specific activities than do the uranium isotopes contained in slightly enriched uranium. For example, 1 gram of fissile ^{239}Pu emits 2.26 billion alpha particles per second, whereas 1 gram of its fissile cousin, ^{235}U, emits only 79,000 alpha particles per second. Alpha particles are intensely ionizing but have almost no penetrating power; thus, alpha emitters present little biological hazard unless they are in intimate contact with body tissues as is the case with internally deposited alpha emitters. Alpha particles emitted inside the body have the potential to damage body tissues immediately surrounding their points of origin.

*Mining, milling, UF_6 conversion, enrichment of the ^{235}U isotope.



Note: The numbers in this figure represent a "snapshot" of about the year 2000. The flows of materials indicated are not intended to constitute a material balance. The numbers reflect the production quantities projected for the year 2000 and varying lead times in a growing industry.

Figure I-7 Annual United States Industrywide Fuel Cycle Requirements for Light Water Reactors for About 2000 With Uranium and Plutonium Recycle, ERDA OPA, 1975 Projection, Low Growth, Without Breeder

Although the body assimilates roughly the same fraction of inhaled airborne plutonium as it does inhaled uranium--inhalation is the major exposure pathway to employees in plants manufacturing nuclear fuel--the biochemistry is such that assimilated plutonium is distributed differently within the body and is eliminated much more slowly than uranium. These factors, combined with the very much higher specific activity of plutonium, make the biological hazard of plutonium markedly greater than that of uranium. A useful measure of the relative biological hazard of plutonium and uranium isotopes is the maximum permissible concentration in air for occupational exposure (MPC_a) set by Federal regulation (10 CFR Part 20, Appendix B, Table 1, Column 1), as expressed in activity concentration units, microcuries per milliliter ($\mu Ci/ml$), and transformed for this purpose to mass concentration units, grams per cubic meter (g/m^3). See Table I-1.

The lowest MPC_a for uranium is that of the relatively high specific activity isotope ^{234}U. Because slightly enriched uranium contains only very small quantities of high specific activity ^{234}U, about 0.04%, it can be handled safely where confinement (and thus protection from inhalation) is provided only by process equipment and by manufacturing area ventilation and housekeeping practices consistent with safe and established practices for handling of nonradioactive, but toxic, compounds of heavy metals such as lead or cadmium. In contrast, plutonium manufacturing facilities are characterized by elaborate confinement structures (process enclosures), which usually completely surround all process equipment and all materials transfer operations. Largely because of the gamma radiation and neutron emissions associated with such activities, routine manufacturing operations are mechanized to the maximum extent practicable. Hand operations are minimized but when necessary, are performed through long gauntleted gloves that are sealed to ports in the process enclosure. Elaborate supplemental confinement systems and structures are integral parts of the process confinement concept. These include such items as high integrity ventilation systems equipped with multiple stages of high efficiency particulate air (HEPA) or equivalent filters (capable of $\geq$99.9% removal of Pu aerosols per stage) and high integrity natural phenomena-resistant building structures to provide essentially complete isolation of plutonium from the mixed oxide fuel fabrication plant workers and the plant environs.*

Plutonium-handling plants are considerably more expensive to build, maintain, and operate than those used for the manufacture of low enriched uranium fuels. Thus, it has been generally considered to be uneconomic to distribute recycle plutonium uniformly throughout all the fuel pellets.* To do so would require that all reload fuels for all LWR's be manufactured only in plants with the special features required for plutonium handling. Inherent in the materials flow quantities of Figure I-7 are assumptions about the disposition of recycled plutonium within LWR fuels. The basic assumption, proposed by industry and accepted by NRC for this statement, is that any one fuel rod

*Another view concerning the matter of the relative toxicity of uranium and plutonium and the necessary degrees of containment for manufacturing processes and disposition of Pu in LWR fuel has also been proposed, cf., "The Case for Low Concentration Plutonium Recycle," by K. H. Puechl, in International Nuclear Engineering, p. 687, September 1975.

Table I-1

MAXIMUM PERMISSIBLE AIRBORNE CONCENTRATIONS (MASS/VOLUME) OF URANIUM AND PLUTONIUM NUCLIDES, OCCUPATIONAL EXPOSURE*

Isotope	Form	MPC_a grams per cubic meter
^{234}U	S	9.58×10^{-8}
	I	1.60×10^{-8}
^{235}U	S	2.31×10^{-4}
	I	4.63×10^{-5}
^{238}U	S	2.08×10^{-3}
	I	2.98×10^{-4}
^{238}Pu	S	1.16×10^{-13}
	I	1.75×10^{-12}
^{239}Pu	S	3.26×10^{-11}
	I	6.52×10^{-10}
^{240}Pu	S	8.78×10^{-12}
	I	1.76×10^{-10}
^{241}Pu	S	9.10×10^{-13}
	I	4.04×10^{-10}
^{242}Pu	S	5.24×10^{-10}
	I	1.05×10^{-8}

S = Soluble
I = Insoluble

*Because of its relatively short effective half-life in the body, the uranium MPC's reported in Table I-1 are correct for both long and short exposure periods whereas the corresponding MPC's for long biological half-life plutonium presume exposure for 50 years. Thus, whereas Table I-1 presents a useful illustration of levels of confinement necessary for long periods of exposure such as occur in occupational exposures, it greatly overstates the hazard of plutonium relative to uranium for short exposure periods.

will contain either enriched uranium only, or mixed oxide fuel only. Additionally assumed, as discussed earlier, is that mixed oxide fuels contain only natural uranium. Average fissile Pu contents of mixed oxide fuel assemblies are expected to be less than 5% of the total uranium and plutonium.

When plutonium produced in a light water reactor is recovered, recombined with uranium, fabricated into fuel rods, and reinserted into the same LWR core displacing an equivalent number of ^{235}U-enriched fuel rods, the resulting reactor can be described as a self-generation reactor (SGR). The SGR recycles all of the plutonium that it produces (fissile and nonfissile). The mixed oxide content increases with time until an equilibrium level is reached wherein about one-third of the fuel rods contain mixed oxide. In that state, a reactor is described as an equilibrium self-generation reactor. See CHAPTER IV, Section C for detailed discussion of the SGR.

The SGR concept of plutonium recycle is an example of many possibilities that utilize less or more plutonium than is produced within the core. For example, by utilizing plutonium from other reactors in addition to its own, a standard LWR can be operated with all of its enriched uranium fuel rods replaced by PuO_2-UO_2 mixed oxide rods, eliminating dependence on enrichment facilities for that reactor. However, the SGR mode of operation, or its near equivalent, is assumed to represent the industry-wide norm. In the near equivalent mode, the plutonium from any one reactor may be pooled with that from other reactors and then recycled to individual LWR's in quantities such that the mixed oxide contents of their cores do not greatly exceed the mixed oxide contents of equilibrium self-generation reactors. An excess of 15% above self-generation levels is believed to be a justifiable extension of present reactor technology. Accordingly, an LWR operating with recycle plutonium in the amount of 115% of the equilibrium self-generating quantity has been selected as the model reactor in this study. It is referred to as a 1.15 SGR. Typically it would contain mixed oxide in about 40% of the fuel rods with the remainder of the rods containing only enriched uranium fuel. See CHAPTER IV, Section C, paragraph 4.1.1.

Introduction of mixed oxide fuel produces only minor effects on reactor operation. Nuclear properties of mixed oxide fueled reactors differ somewhat from UO_2 fueled reactors, but differences can be accommodated by suitable core management. Characteristics of the reactor design, however, such as fuel assembly geometry, coolant flow patterns, and mechanical properties of cladding and structural members, are unchanged by the use of mixed oxide fuels. Analytical results and reactor experience indicate that the performance of mixed oxide cores will be similar to UO_2 cores under steady state and load following conditions; core behavior during transients and accidents will be only slightly altered.

There are some differences in the production of fission product radionuclides in mixed oxide fueled LWR's as compared with uranium only fueled LWR's. However, no safety or environmental problems have been identified as result of these differences.

The most important differences are as follows:

- The in-reactor inventory of plutonium for the mixed oxide cores is about 2-1/2 to 3 times the plutonium inventory of UO_2 fueled LWR's.

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

- The quantities of radioactive americium and curium are increased in the spent fuel of mixed oxide cores, leading to increased decay heat and increased neutron activity.*

Resource and processing requirements for the recycle of uranium and plutonium, which are shown in Figures I-2, I-4, and I-7, are summarized in Table I-2.

3.0 ENVIRONMENTAL EFFECTS OF RECYCLE IN LIGHT WATER REACTORS

Moving from the present mode of LWR operation with only virgin UO_2 to uranium only or uranium and plutonium recycle is anticipated to result in some decreases and some increases in environmental effects for each part of the fuel cycle. The net environmental effect of these changes for the total fuel cycle is expected to be small.

Decreases in environmental effects of the fuel cycle arise from reductions in uranium mining, milling, UF_6 conversion, enrichment and UO_2 fuel fabrication activities due to the partial satisfaction of ^{235}U requirements with recovered uranium or recovered uranium and plutonium.

The decreases in environmental effects due to recycle of the uranium and plutonium occur because of decreased land committed to mining and milling, small decreases of radioactivity released to the environment, and decreases of energy requirements for enrichment.

Somewhat offsetting these decreases due to use of recycle uranium or uranium and plutonium, are the increased environmental effects produced by reprocessing plant operations for recovery of recycle fuel materials, either uranium or plutonium. Increased transportation related impacts may also accrue from reprocessing operations. Plutonium recycle introduces the mixed oxide fuel fabrication plant into the fuel cycle, along with the necessity of shipping plutonium and unirradiated mixed oxide fuels. These added operations are accompanied by potential environmental effects

*For details of generation of transplutonium actinides, see Appendix A, Part 2.

Table I-2

SUMMARY OF EFFECTS OF PLUTONIUM RECYCLE IN THE OVERALL U.S. LWR FUEL CYCLE IN ABOUT THE YEAR 2000

Fuel Cycle Parameter	No Recycle	U Recycle	U & Pu Recycle
1. Uranium Ore Mined and Milled (MT)	114×10^6	99.1×10^6	80.7×10^6
2. U_3O_8 Recovered (ST)	113,900	98,800	80,500
3. Natural Uranium Converted to UF_6 (MTU)	87,300	75,500	59,300
4. Enrichment of Uranium (MT SWU)	45,000	45,500	36,100
5. Conversion of UF_6 to UO_2 (MTU)	13,500	13,500	10,850
6. Plutonium through Reprocessing Plants (kg Pu_f)	None	68,000	82,200
7. Plutonium in Storage/Inventory or Waste or Spent Fuel (kg Pu_f)	690,000	690,000	7,000
8. 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)

MT SWU - Metric Ton Separative Work Units

kg Pu_f - Kilograms of fissile plutonium

ST - Short Tons

associated with the toxicity of plutonium or its possible use as a nuclear explosive and from the potential for its releases to the environment from normal operations, from an accident, or as a result of theft or sabotage. Generation of additional quantitites of low level transuranic wastes results from reprocessing operations for the uranium recycle option, and is increased with the plutonium recycle option through increased plutonium handling and waste generation in MOX fabrication operations.

In addition to the direct impacts of increased plutonium handling throughout much of the fuel cycle, plutonium recycle in LWR's leads to added potential environmental effects on the fuel cycle. Those include

- Potential effects (not necessarily adverse) on the operational safety of the reactor from increased quantities and different distributions of plutonium in the reactor core due to changes in the core physics, and fission product and transuranium nuclide inventories in the operating reactor

- Slightly different fission product contents and increased quantities of transplutonium nuclides in spent fuels and their impacts upon shipping, reprocessing, and storage or disposal of high level wastes

4.0 APPROACH TO ASSESSMENT OF ENVIRONMENTAL IMPACTS OF RECYCLE IN LIGHT WATER REACTORS

The approach to assessing the environmental impact of implementation of recycle in the light water reactor industry involves the following steps:

- Environmental impacts are evaluated and compared for each element of the LWR fuel cycle, with no recycle, with uranium recycle, and with plutonium recycle, considering the effects associated with construction, the normal operation, and postulated accidents for model plants of each type, with the attendant radioactive waste management and transportation activities.

- The industrywide environmental impacts for each option are then assessed for the period 1975 through 2000. The integrated economic impacts for the period 1975 through 2000 are similarly developed for use in the cost-benefit analyses.

- Based upon analyses of the first two steps, the unavoidable adverse environmental impacts of implementation of plutonium recycle in LWR's are determined.

- Alternatives are studied for mitigating adverse environmental impacts of the LWR-Pu recycle, based either upon currently feasible methods or potential future developments.

- Potential relationships between short term environmental benefits and long term environmental costs brought on by implementation of plutonium recycle are investigated.

- The irreversible and irretrievable commitments of resources resulting from implementation of plutonium recycle are determined.

- A cost-benefit analysis is made of alternative fuel recycle schemes considering also the timing of implementation of plutonium recycle.

5.0 SCOPE OF GESMO

The body of this generic environmental impact statement on the use of mixed oxides in LWR's is organized, insofar as is appropriate, in accordance with the guidelines of the Council on Environmental Quality.

5.1 Volume 1 - SUMMARY AND CONCLUSIONS

This section presents a summary of the evaluations and analyses described in the various chapters of GESMO and it includes the conclusions concerning the relative adverse and beneficial impacts of implementation of Pu recycle in LWR's.

5.2 Volume 2

CHAPTER I - INTRODUCTION--sets forth the purpose of GESMO, introduces the reader to the no recycle, the uranium only recycle, and the uranium plus plutonium recycle fuel management options; describes the origin of environmental impacts that occur because of the widespread application of plutonium recycle; the methodology of assessment of such impacts; and introduces the reader to the body of this environmental impact statement.

CHAPTER II - BACKGROUND AND EXPERIENCE WITH PLUTONIUM--outlines past and current research and development activities that have brought plutonium recycle to the threshold of possible widespread commercial application. It also describes the industrial context in which plutonium recycle would occur--the structure and status of the U.S. nuclear power industry.

CHAPTER III - PROJECTED PLUTONIUM RECYCLE INDUSTRY--describes and considers the effects on the light water reactor industry of widespread implementation of recycle. It describes the industry which is the subject of this environmental impact statement: the overall LWR industry as it is projected to exist between the present time and about the year 2000, with and without recycle in LWR's. Specifically addressed are differences effected in the LWR industry by the introduction of plutonium recycle.

5.3 Volume 3

CHAPTER IV - ENVIRONMENTAL IMPACT DUE TO THE IMPLEMENTATION OF PLUTONIUM RECYCLE--this chapter constitutes the major portion of this environmental impact statement. The environmental impacts resulting from widescale implementation of recycle in LWR's are estimated and presented. Environmental impacts from accident conditions as well as from routine operations are addressed. Also presented, as appropriate for background information and perspective, are estimates of the environmental effects of the LWR industry without recycle, with uranium recycle, and with plutonium recycle.

CHAPTER IV describes in detail the individual model plants and other elements of the LWR fuel cycles. These, in the aggregate, constitute the projected light water reactor industry for the period 1975-2000 with no recycle, uranium recycle, and plutonium recycle.

Because of the comprehensive discussions, CHAPTER IV is divided into the following major sections:

Section IV A - Summary--summarizes the industrywide environmental impacts of the implementation of plutonium recycle in light water reactors and describes the overall light water reactor industry for the period 1975-2000.

Section IV B - Introduction--introduces various elements of the light water reactor industry, discussed in greater detail in the remaining sections of CHAPTER IV.

Section IV C - The Light Water Reactor (LWR) With Plutonium Recycle--describes typical light water reactors and assesses the operational and safety effects of implementation of plutonium recycle in such reactors. Analyzes at some length those aspects of fuel and reactor core performances that differ or that could differ from those of uranium-fueled reactors. Incremental impacts of implementation of plutonium recycle upon reactor safety are addressed. Radiological impacts are assessed by developing source terms for potential releases related both to accident and normal conditions, with and without plutonium recycle (there are essentially no differences in reactor operation with no recycle and with uranium only recycle) and translating these to equivalent exposures to the environment.

Section IV D - Mixed Oxide Fuel Fabrication--describes a model mixed oxide fuel fabrication plant, its processes, and projected effluents. Resultant environmental impacts due to both normal operations and accident conditions are estimated and described.

Section IV E - Reprocessing Plant Operations--describes a model reprocessing plant, both with recycle of uranium and with recycle of uranium and plutonium; establishes the incremental changes in effluents and radiological source terms. The corresponding incremental environmental impacts are estimated for both normal operating and accident conditions.

Section IV F - Supporting Uranium Fuel Cycle--this section describes those portions of the light water reactor industry that constitute the uranium fuel supply segment and assesses their environmental impacts. Those operations are mining, milling, UF_6 conversion, enrichment, and UO_2 fuel manufacture. The most significant cumulative industrywide decreases in the environmental impact for the supporting uranium fuel cycle resulting from recycling uranium or both uranium and plutonium in LWR's are summarized.

Section IV G - Transportation of Radioactive Material--discusses transportation of radioactive materials within the light water reactor industry and the changes effected in the transportation requirements by uranium recycle and by uranium and plutonium recycle. The corresponding environmental impacts are assessed. Also discussed are means of minimizing the probabilities and limiting the consequences of transportation accidents.

Section IV H - Radioactive Waste Management--describes primarily the means for assuring the long term isolation of radioisotopes from the environment. Storage concepts are described for high level and other-than-high level wastes containing transuranium elements, and for disposal of other wastes by burial. The environmental impacts associated with long term waste management, with no recycle, uranium recycle, and uranium and plutonium recycle, and under normal and accident conditions, are estimated and described. Environmental impacts of management of fuel cycle wastes are reviewed and analyzed.

Section IV I - Storage of Plutonium--addresses the need for plutonium storage and potential environmental impacts with and without plutonium recycle. The increased requirement for storage of plutonium if plutonium is not recycled and the concomitant facility requirements are discussed. The loss by beta decay of fissile ^{241}Pu, if LWR Pu is not promptly recycled, is also discussed.

Section IV J - Radiological Health Assessment--includes a discussion of radiological impacts for the overall industry of implementation of plutonium recycle in light water reactors. General discussions of dose estimation methodology, health risks from radiation, and plutonium in the environment are appended.

Section IV K - Extended Spent Fuel Storage--describes temporary storage of spent fuel as a necessary component of the fuel cycle under each fuel management option. Environmental impact assessments are made.

Section IV L - Blending of Plutonium and Uranium at Reprocessing Plants--discusses blending and analyzes some concentrations of blends that have been considered for use in the fuel cycle plants. Describes environmental impacts related to blending and the use of blends in the fuel cycle.

5.4 Volume 4

CHAPTER V - SAFEGUARDS CONSIDERATIONS--refers to the supplement that assesses safeguards issues related to Pu recycle.

CHAPTER VI - PROBABLE ADVERSE ENVIRONMENTAL EFFECTS THAT CANNOT BE AVOIDED--In accordance with the guidelines of the Council on Environmental Quality, this chapter gathers and summarizes all the adverse environmental effects of implementation of uranium only or uranium and plutonium recycle in light water reactors.

CHAPTER VII - MEANS FOR MITIGATING ADVERSE ENVIRONMENTAL EFFECTS--the NRC has established siting, design, and operating criteria, and established review processes designed to assure that releases from fuel cycle facilities are very small, as low as reasonably achievable and that environmental impacts are minimized. Chronic releases are mitigated by engineered confinement systems. Acute releases that may result from accident or natural phenomena are mitigated by engineered safety systems. Also discussed are potential future measures for mitigating adverse environmental effects.

CHAPTER VIII - ALTERNATIVE DISPOSITIONS OF PLUTONIUM--identifies and describes in detail the various alternative dispositions of plutonium produced in light water reactors. Environmental and economic considerations are discussed for alternatives consisting of the no recycle option, uranium only recycle option, and the plutonium recycle option with various implementation dates. This chapter provides the basis for the comparative evaluations of the incremental benefits, costs, and risks associated with each alternative disposition of plutonium, which are developed in the cost-benefit analysis in CHAPTER XI.

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. Short term effects are those associated with the fuel cycle operations through the year 2000. Long term effects are those associated with conservation of uranium ore reserves and long term confinement of radioactive materials.

CHAPTER X - IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES--identifies those resource commitments, resulting from the proposed recycling of plutonium, which would curtail the range of potential uses of the environment or of other resources. Resources discussed are fissile materials, manpower, and permanent land commitments.

CHAPTER XI - ECONOMIC ANALYSIS AND COST-BENEFIT BALANCING--makes comparisons of the incremental benefits, costs, and risks associated with alternative dispositions of LWR-produced plutonium. The impact of each alternative upon individual components of the fuel cycle is evaluated, and the results are combined into assessments of the overall cost-benefits of each alternative.

5.5 Volume 5

All public comments received are included in this volume, as are NRC responses.

APPENDIX A

Part I

THE GENESIS OF PLUTONIUM

On the average, fissioning ^{235}U atoms in LWR fuel emit about 2.4 neutrons each (2.9 for ^{239}Pu), one of which must subsequently initiate fission in another fissionable atom in order to sustain the fission chain reaction. Those neutrons not entering into fission reactions can cause nuclear transmutations when absorbed in the fuel or in surrounding materials. When an atom of ^{238}U absorbs a neutron not sufficiently energetic to cause its fission, it is transformed into ^{239}U, which decays rapidly by beta emission to ^{239}Np; ^{239}Np then decays, fairly rapidly and by beta emission, to ^{239}Pu. (See the third reaction to be listed.) The isotope ^{239}Pu, by comparison with its precursors, is relatively stable, having a half-life of about 24,000 years. These reactions are

$$^{238}U + n \rightarrow {}^{239}U + \gamma$$

$$^{239}U \rightarrow {}^{239}Np + e^- \qquad t_{1/2} = 23.5 \text{ minutes}$$

$$^{239}Np \rightarrow {}^{239}Pu + e^- \qquad t_{1/2} = 2.35 \text{ days}$$

Occasionally an atom of ^{235}U does not fission upon absorbing a neutron, but instead is transformed into heavier isotopes of uranium and, thence, into transuranium nuclides by a series of successive neutron absorptions and beta decays:

$$^{235}U + n \rightarrow {}^{236}U + \gamma$$

$$^{236}U + n \rightarrow {}^{237}U + \gamma$$

$$^{237}U \rightarrow {}^{237}Np + e^- \qquad t_{1/2} = 6.75 \text{ days}$$

$$^{237}Np + n \rightarrow {}^{238}Np + \gamma$$

$$^{238}Np \rightarrow {}^{238}Pu + e^- \qquad t_{1/2} = 2.12 \text{ days}$$

Similarly, some of the atoms of ^{239}Pu will, instead of fissioning, undergo radiative capture of a neutron:

$$^{239}Pu + n \rightarrow {}^{240}Pu + \gamma$$

^{240}Pu is nonfissile, but readily absorbs neutrons to form the fissile isotope ^{241}Pu:

$$^{240}Pu + n \rightarrow {}^{241}Pu + \gamma$$

Once again, however, some of the fissile ^{241}Pu will absorb neutrons without fissioning:

$$^{241}Pu + n \rightarrow {}^{242}Pu + \gamma$$

leading to the formation of nonfissile ^{242}Pu. Although similar processes leading to even heavier isotopes of plutonium occur in the fuel, the quantities formed are not significant. The net result of all the higher order nuclear reactions previously described, as well as others of lesser effect, is that the product of the first order or main reaction of neutron irradiation of ^{238}U, viz, ^{239}Pu, is inevitably mixed with other plutonium isotopes. A plutonium product mixture typical of spent fuel from an LWR initially fueled with slightly enriched uranium is approximately

Pu Isotope	Percent Composition
^{238}Pu	2
^{239}Pu	61
^{240}Pu	24
^{241}Pu	10
^{242}Pu	3

The amounts of the two fissile isotopes, ^{239}Pu and ^{241}Pu, are often added and their sum referred to as fissile plutonium, Pu_f, content. Thus, the plutonium mixture described above could be characterized as 71% Pu_f.

APPENDIX A

Part II

THE GENERATION OF TRANSPLUTONIUM ACTINIDES

In addition to fission products, various transplutonium (actinide) radionuclides are created in the cores of LWR's. The more important of these and their predominant source reactions are described as follows:

$$^{241}Pu \rightarrow {}^{241}Am + e^- \qquad t_{1/2} = 13.2 \text{ years}$$

$$^{241}Am + n \rightarrow {}^{242}Am + \gamma$$

$$^{242}Am \rightarrow {}^{242}Cm + e^- \qquad t_{1/2} = 16.0 \text{ hours}$$

$$^{242}Pu + n \rightarrow {}^{243}Pu + \gamma$$

$$^{243}Pu \rightarrow {}^{243}Am + e^- \qquad t_{1/2} = 5.0 \text{ hours}$$

$$^{243}Am + n \rightarrow {}^{244}Am + \gamma$$

$$^{244}Am \rightarrow {}^{244}Cm + e^- \qquad t_{1/2} = 10.1 \text{ hours}$$

^{241}Am, ^{243}Am, ^{242}Cm, and ^{244}Cm are present in significant quantities in spent reactor fuel. Even heavier transplutonium isotopes are produced, but not in substantial quantities. Because ^{241}Pu and ^{242}Pu are the precursors of the transplutonium radionuclides ^{241}Am, ^{243}Am, ^{242}Cm, and ^{244}Cm, the increased average in-reactor inventories of ^{241}Pu and ^{242}Pu typically present in mixed oxide fuels lead to much higher inventories of transplutonium isotopes in spent mixed oxide fuels.

GESMO

CHAPTER II

BACKGROUND AND EXPERIENCE WITH PLUTONIUM

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BACKGROUND AND EXPERIENCE WITH PLUTONIUM

1.0 INTRODUCTION

This generic environmental statement discusses the anticipated effects of recycling plutonium in light water nuclear power reactors. It is based on about 30 years of experience with the element in the context of a projected light water nuclear power industry that is already substantial. This chapter provides a background perspective on plutonium, its safety, and its recycling as a reactor fuel.

Section 2.0 deals with general information about plutonium, developed since its discovery more than three decades ago: how it is formed in the reactor, its nuclear characteristics, the formation and properties of its dioxide (the chemical form in which it would be used in fuel), reprocessing of plutonium bearing spent fuel, and basic information on its radiobiological hazards.

Section 3.0 includes a review of work in research, development, and testing in direct connection with plutonium fuel recycling, in the form of mixed oxides of uranium and plutonium, for light water reactors. The history and status of domestic and foreign plutonium utilization programs, including reactor tests, are reviewed, as are mixed oxide fuel fabrication, reprocessing, transportation, and waste management developments.

2.0 PLUTONIUM: GENERAL BACKGROUND AND EXPERIENCE

With the exception of very minute quantities of ^{244}Pu recently discovered in nature and minute quantities of ^{239}Pu being formed in uranium bodies by the action of naturally occurring neutrons, plutonium is artificially produced. It was the first man made element to be produced in quantities sufficient to be seen. Plutonium was discovered by Glenn T. Seaborg, Arthur C. Wahl, and Joseph W. Kennedy at the University of California at Berkeley through a series of investigations which culminated in the identification of ^{238}Pu on February 24, 1941. A few months later, ^{239}Pu was identified. Plutonium is now known to have 15 isotopes ranging in atomic mass from 232 to 246. Microgram quantities were available for research in 1942, milligram quantities in 1943, and gram quantities in 1944. In 1945, a plutonium atomic bomb was exploded. In 1946 the first reactor to use plutonium fuel, the Los Alamos Fast Reactor, called "Clementine," began operation.

Beginning with wartime research and production activities, the United States has made an intensive study of plutonium. As a result, its properties and characteristics are better known today than those of most other elements and many commercial compounds. Plutonium has been produced in reactors, recovered from reactor fuel,

purified, and made into many chemical and physical forms. Fabrication, transportation and storage have involved safely handling many tons of the material.

If plutonium recycle is authorized for use in the fuel of LWR's, new facilities would have to be constructed and operated for the mixed oxide fuel cycle. These new plants would take into account past experiences in plutonium processing and would employ more advanced technology, new equipment, and improved methods for safely handling the material. The result should be greater production efficiency, improved safety and protection of employees and the public, and a reduced likelihood that detrimental environmental impacts could occur. The operations carried out by Federal contractors, both for commercial demonstration purposes and the classified plutonium nuclear weapons programs, have resulted in development of extensive information concerning normal and abnormal operating conditions, and have led to identification of safety considerations and safe operating techniques. The resulting information base has been used to design commercial reprocessing, mixed oxide fuel fabrication, and waste management facilities.

After World War II, when security restrictions on information about plutonium were eased, numerous scientific and technical articles were published in the open literature. During the early 1950's, there were one to two dozen publications on plutonium each year in the open literature; in the year 1958, about 200 such articles were published. The rate of such publication continued to grow during the following decade. Between 1968 and 1973, there were over 7,000 publications--more than 1,000 a year--on plutonium, its alloys and compounds, processing technology, utilization, analysis, and health and safety aspects.

A recent computer search of information systems operated by the Oak Ridge National Laboratory and covering specialized areas of science and engineering disclosed approximately 5,800 references to publications about plutonium in the literature of the United States and other countries. Of these there were over 2,000 references dealing with plutonium in relation to nuclear safety; 2,100 pertaining to environmental effects of plutonium; 135 covering plutonium metabolism and internal exposure in humans; and 360 dealing with medical aspects. Although this coverage of publications is not complete, the number of references dealing with plutonium indicates the extent of the body of knowledge that has been produced in 30 years of theoretical and applied work.

Virtually all of the U.S. research and development effort relating to plutonium has been supported by the Federal government under the U.S. Atomic Energy Commission. The cost of AEC supported research and development on commercial applications of plutonium and on its biomedical effects has amounted to several hundred million dollars.

2.1 The Formation of Plutonium in the Reactor

The standard LWR fuel contains uranium that is about 3% ^{235}U and 97% ^{238}U. Plutonium is formed in this fuel by the capture of neutrons in ^{238}U. The formation

of plutonium occurs principally when ^{238}U, the most plentiful (99.29%) isotope in natural uranium, absorbs a neutron to form ^{239}U. This isotope decays rapidly (half-life 23.5 minutes) to form ^{239}Np, which soon decays (half-life 2.3 days) to form ^{239}Pu, with a half life of about 24,000 years. The chain of events leading to formation of other plutonium isotopes is complex and is always in progress in the reactor. CHAPTER I, Appendix A, part I shows the genesis of plutonium in LWR's by a series of nuclear reactions.

Any of the uranium, plutonium, or neptunium isotopes present at a given instant in the reactor may decay radioactivity to form a new isotope; or absorb a neutron and form a heavier isotope; or absorb one neutron and eject two neutrons (n, 2n reaction) to form a lighter isotope; or absorb a neutron and undergo fission, forming two much lighter isotopes (fission products). A typical 1,000 MWe LWR, using uranium fuel without plutonium recycle, produces about 280 kilograms of plutonium per year, of which approximately 200 kilograms are the fissle isotopes, ^{239}Pu and ^{241}Pu.

In a typical PWR fuel management scheme, the fuel remains in the reactor for about 3 years. At the end of that time, part of the ^{235}U will have fissioned and the ^{235}U concentration will be about 0.8%; and the fissile plutonium will have built up to a concentration of about 0.6%. In a BWR the fuel lifetime is about 4 years and the final fissile plutonium concentration is about 0.5%. While the fuel is in the reactor its plutonium content increases and ^{235}U content decreases, so that shortly before the fuel is discharged, plutonium is contributing about as much to the production of energy as the uranium.

The use of mixed oxide fuel for LWR's will not result in formation of elements or isotopes which are not present in the uranium fuel at the end of fuel lifetimes. However, when plutonium is included in fresh fuel, the end of lifetime fuels will contain larger quantities of plutonium, particularly the heavier isotopes of plutonium, and transplutonium elements. The average plutonium content in an LWR mixed oxide fuel loading is about 3 times the final plutonium content of spent uranium fuel elements. See CHAPTER IV, Section C-4.0.

2.2 Nuclear Characteristics of Plutonium

Tables II-1 and II-2 show some of the nuclear characteristics of uranium and plutonium isotopes. The likelihood that neutrons will interact with any isotope to cause a particular nuclear reaction is proportional to the cross section (a measure of the probability) for that reaction; the larger the cross section, the more likely is the reaction. Both tables give cross section values for some of the more important neutron reactions involving uranium and plutonium. The data apply at specific temperature and energy levels and are useful to demonstrate some specific points. Figures II-1 and II-2 show the cross sections for the two important fissile isotopes of plutonium, ^{239}Pu and ^{241}Pu.[1]

Figure II-3 compares the nuclear characteristics of plutonium and uranium.[2] These effects of neutron absorptions by the plutonium isotopes are made more

Table II-1

SELECTED NUCLEAR CHARACTERISTICS OF URANIUM ISOTOPES

Isotope	Half-Life*	Specific Activity (dis/sec/g)	Spontaneous Fission Neutron Emission (n/sec/g)	Thermal Neutron Cross Sections		Neutrons Per Fission	Relative Isotopic Abundance in Second Recycle Fuel (weight %)
				Capture (barns)	Fission (barns)		
^{227}U	1.1m						
^{228}U	9.1m						
^{229}U	58m						
^{230}U	20.8d				25		
^{231}U	4.2d				300		
^{232}U	72y			73	75		
^{233}U	1.58×10^{5}y	$\alpha 3.6 \times 10^{8}$	$<1.9 \times 10^{-4}$	48	531	2.5	
^{234}U	2.44×10^{5}y	$\alpha 2.32 \times 10^{8}$	3.5×10^{-3}				0.04
^{235}U	7.04×10^{8}y	$\alpha 8.5 \times 10^{4}$	3.1×10^{-4}	99	582	2.4	3.35
^{236}U	2.34×10^{7}y	$\alpha 2.4 \times 10^{6}$	2.8×10^{-3}	5			0.20
^{237}U	6.75d	$\alpha 3 \times 10^{15}$	7.0×10^{-3}				
^{238}U	4.47×10^{9}y	$\alpha 1.2 \times 10^{4}$		3			96.41
^{239}U	23.5m			8	14		

*Half life in minutes (m), hours (h), days (d), and years (y).

Table II-2

SELECTED NUCLEAR CHARACTERISTICS OF PLUTONIUM ISOTOPES

Isotope	Half-Life*	Specific Activity (dis/sec/g)	Spontaneous Fission and (α-n) Neutron Emission (Oxide) (n/sec/g)	Thermal Neutron Cross Sections Capture (barns)	Thermal Neutron Cross Sections Fission (barns)	Neutrons Per Fission	Relative Isotopic Abundance in Second Recycle Fuel (weight %)
^{232}Pu	36m	$\alpha 8.5 \times 10^{17}$					
^{233}Pu	20m	$\alpha 1.3 \times 10^{18}$					
^{234}Pu	9h	$\alpha 5.5 \times 10^{16}$					
^{235}Pu	24.3m	$\alpha 3.4 \times 10^{13}$					
^{236}Pu	2.85y	$\alpha 2.0 \times 10^{13}$	$f 3.7 \times 10^{4}$		165		
^{237}Pu	45.6d	$\alpha 1.5 \times 10^{10}$			2400		
^{238}Pu	87.8y	$\alpha 6.3 \times 10^{11}$	$f 3.4 \times 10^{3}$ $(\alpha\text{-}n) 1.4 \times 10^{4}$	548	16.5		3.21
^{239}Pu	2.439×10^{4}y	$\alpha 2.3 \times 10^{9}$	$f 3.0 \times 10^{-2}$ $(\alpha\text{-}n) 4.5 \times 10^{1}$	268	754	2.9	40.25
^{240}Pu	6.54×10^{3}y	$\alpha 8.4 \times 10^{9}$	$f 1.0 \times 10^{3}$ $(\alpha\text{-}n) 1.7 \times 10^{2}$	289	.03		30.42
^{241}Pu	13.2y	$\beta 4.2 \times 10^{12}$		368	1009	3.1	15.91
^{242}Pu	3.87×10^{5}y	$\alpha 1.43 \times 10^{8}$	$f 1.7 \times 10^{3}$ $(\alpha\text{-}n) 2.7$	18		.2	10.21
^{243}Pu	4.96h	$\beta 9.6 \times 10^{16}$		60	196		
^{244}Pu	8.3×10^{7}y	$\alpha 7.0 \times 10^{5}$	$f 5.1 \times 10^{3}$	1.8			
^{245}Pu	10.5h	$\beta 4.7 \times 10^{6}$		150			
^{246}Pu	10.9d	$\beta 1.8 \times 10^{15}$					

*Half life in minutes (m), hours (h), days (d), and years (y).

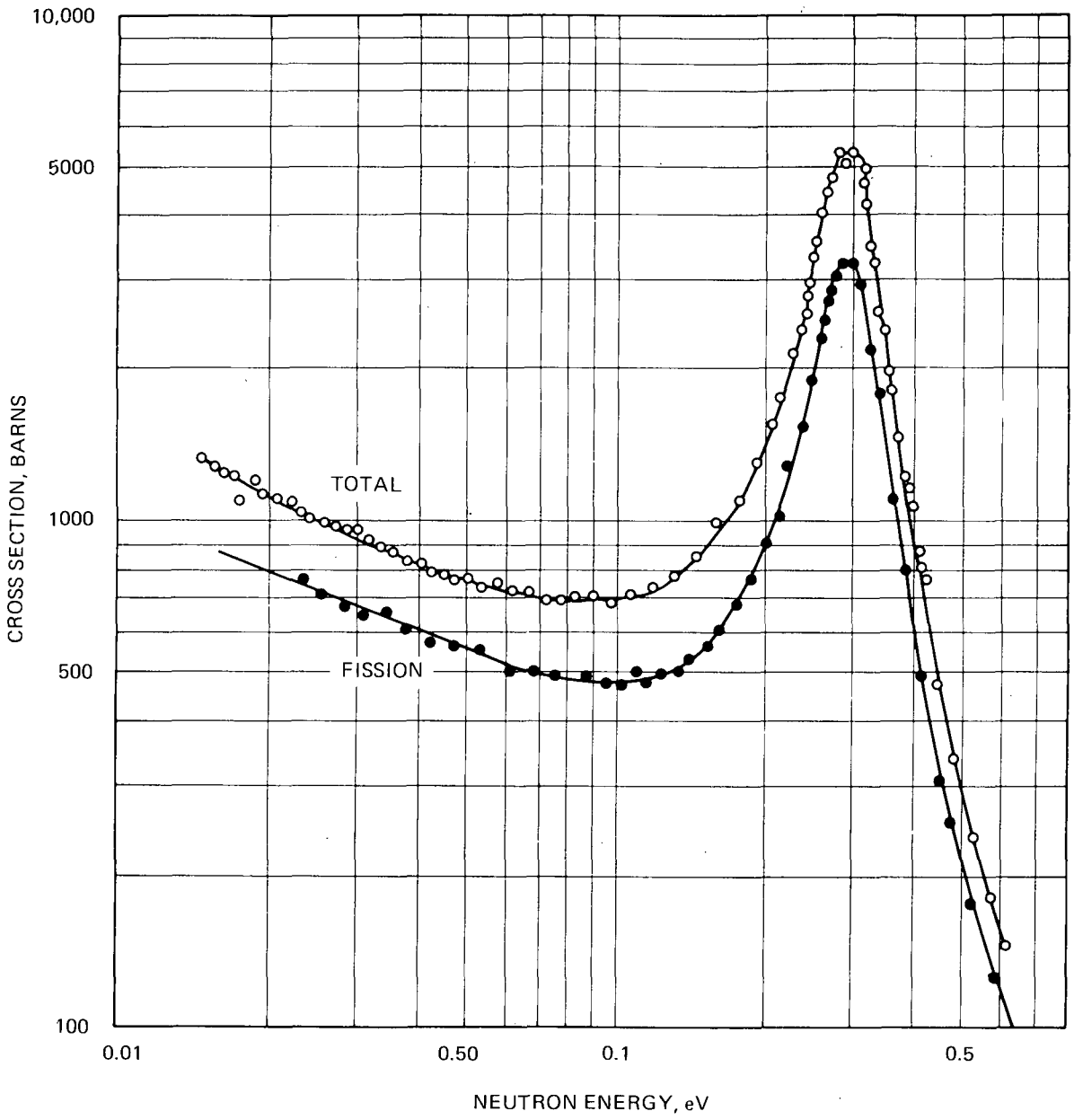


Figure II-1 The Total and Fission Cross Sections of ^{239}Pu at Low Neutron Energies

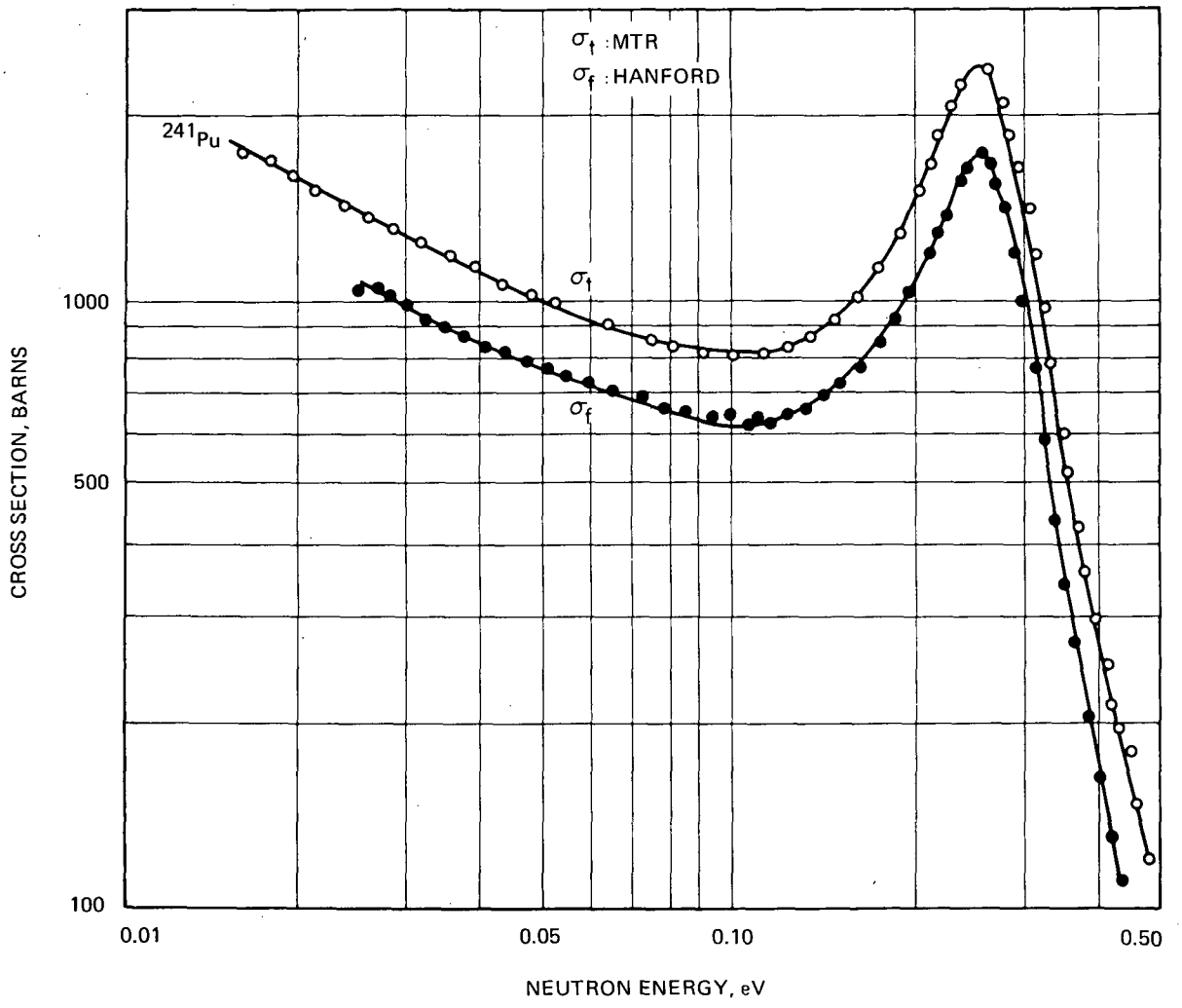
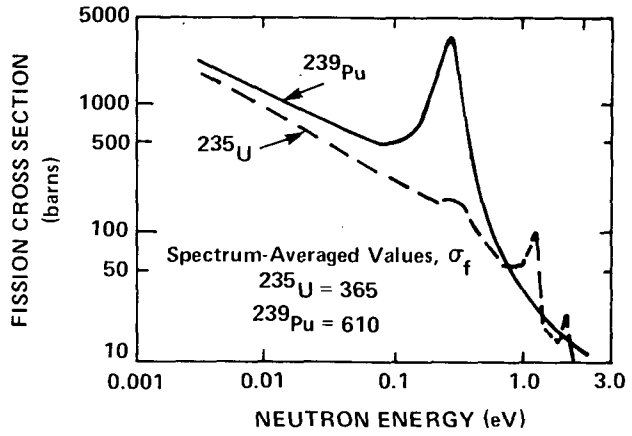
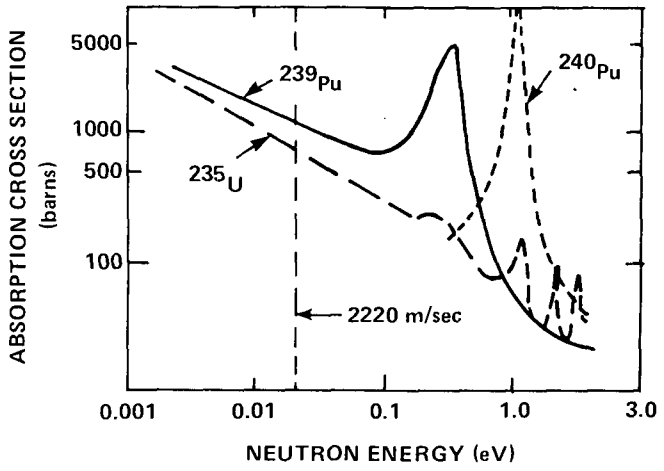


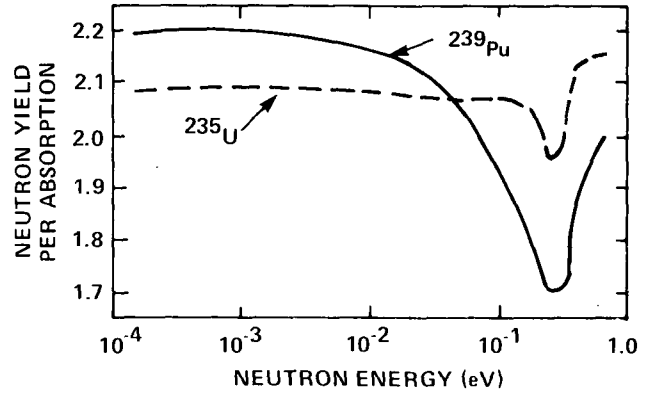
Figure II-2 The Total and Fission Cross Sections of ^{241}Pu at Low Neutron Energies



Relative comparison of fission cross sections below 3 eV for ^{235}U and ^{239}Pu.



Relative comparison of absorption cross sections below 3 eV for ^{235}U, ^{235}Pu, and ^{240}Pu.



Neutron yield per absorption for ^{235}U and ^{239}Pu.

Figure II-3 Nuclear Characteristics of ^{235}U and ^{239}Pu

pronounced by the fact that plutonium, on the average, releases more neutrons per fission than uranium, and thus increases the number of neutrons available to be absorbed. The cross section behavior of plutonium isotopes causes the various coefficients of reactivity (moderator temperature, fuel temperature, and void) to be more negative for plutonium systems. This is a favorable feature from a safety standpoint, but adds to the complexity of computing these coefficients. The presence of several fissile and fertile isotopes of plutonium also increases the complexity of computing the buildup, decay, and burnup of the higher isotopes. A great deal of the special research and development effort on plutonium recycle has gone into developing core behavior data to make calculations more precise. The success of these efforts is confirmed by the fact that the more complex plutonium uranium reactor core performance data can now be calculated with an accuracy approximately equal to that for the cores fueled with uranium only. The reactor core characteristics are discussed more thoroughly in CHAPTER IV, Section C-3.0.

2.3 The Chemistry of PuO_2

Plutonium dioxide[1,3] is the material that will be used in the mixed oxide fuel of LWR's if plutonium is recycled. It has a melting point of about 2,390°C and is very stable. For production purposes, purified plutonium nitrate is usually converted to PuO_2 by decomposition of precipitated Pu (IV) oxalate by heating at temperatures of 450°C-800°C in air. PuO_2 may be prepared by thermal decomposition of other compounds of plutonium:

- Decomposition of plutonium (IV) peroxide by heating to above 200°C
- Thermal decomposition of Pu (IV) nitrate at above 225°C
- Calcination of Pu (IV) iodate at 600°C in air
- Calcination of Pu (IV) sulfate at 800°C
- Calcination of plutonium (IV) hydroxide

2.4 Radiobiological Hazards of Plutonium[6]

Before the world's supply of plutonium was as much as one gram, research on the radiobiological hazards of plutonium had been started. The radiological hazards of plutonium have been the subject of continuing research by many scientists during the past 30 years.

The recycling of plutonium would have little effect on the exposures to the public from external radiation. However, in working with the material precautions must be exercised to avoid inhalation or ingestion of plutonium bearing materials because plutonium is extremely radiotoxic if taken into the body.

Since external radiation associated with plutonium can be readily controlled by relatively thin shielding in work areas or around handling equipment, the most important measures to protect workers and the public are precautions to prevent release and subsequent intake into the body. The most likely route of intake is by inhalation. Less likely routes of intake are

- Through the skin or through wounds

- Ingestion and subsequent absorption from the gastrointestinal tract

The route of entry into the body has a significant effect on 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 blood stream, in the lungs, and in body organs and bone. It is important to note that plutonium is not easily retained in the body fluids--solubility in water at room temperature is only about 20 micrograms per liter. In slightly alkaline conditions, such as would be found in the small bowel, for example, plutonium forms extremely insoluble hydroxides and hydrous oxides.

Since the advent of the Atomic Energy Commission programs in the United States, a number of people working with plutonium have accumulated quantities of plutonium measurable by urinary excretion. Case histories and data developed in thorough physical examinations of 37 individuals who had systemic burdens estimated to be in excess of the National Council of Radiation Protection (NCRP) established maximum permissible level (MPL) of 0.04 μCi of plutonium are available. Under observation for periods ranging from 5 to 25 years since exposure,[7] the cases concern persons who were exposed during the Manhattan Project or subsequently in government facilities operated by contractors. Twelve individuals in whom the original plutonium intakes occurred 23 and 24 years ago have been kept under surveillance and subjected to periodic careful and thorough examinations. These individuals have experienced no changes in their physical conditions not attributable to the natural aging process. Similarly, in the several cases where systemic burdens approached or were greater than 0.04 μCi that have occurred more recently in England, there have been no reports of lung, lymph node, liver or bone morbidity attributable to plutonium deposition. Although the number of cases is too few to support reliable extrapolations to the biological consequences of plutonium, this evidence suggests 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 was small. Plutonium uptake by plants from soil and growth media has been investigated in the field and in the 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 in the growth medium, and only about one ten thousandth of that in the soil. The fraction of available plutonium absorbed from the gastrointestinal tract of animals grazing on contaminated vegetation is less than one ten thousandth the total

intake of the element and measurements of plutonium transfer from the blood stream to milk suggest a further reduction in plutonium concentration by another factor of at least 10. Consumption of animal products by man will introduce another reduction factor of at least 10^{-4} in the plutonium concentration entering the systemic circulation, except in the very young infant where the factor may approach 0.01.[8] It appears, therefore, that the possibility of transfer of plutonium from soil to man by way of the food chain is negligible.

Studies at the Nevada Test Site for a period of 10 years following the 1955-1957 series of high explosive detonations involving plutonium, show that the uptake of plutonium by plants increases over the years. Although conclusive evidence was not obtained, it appears that the increase in plutonium uptake might be due to continued development of larger and deeper root systems, and to the action of natural chemical complexing agents present in soils that make plutonium more soluble. Although the increase in plutonium uptake is measurable, the levels are so low that, even with the increase, ingestion of plutonium through the consumption of plants would not represent a significant pathway to human exposure.[9] For example, during a 5-year period of growing test crops in the contaminated soil, the accumulation of plutonium in plant tissues increased from 3 d/m.g* (dry weight) to about 23 d/m.g. Even so, consumption of food grown in such contaminated soils has caused only extremely low plutonium uptake in the body. This conclusion is based on measurements of the tissues of persons exposed to fallout from past nuclear weapons tests, which in themselves have resulted in the production and dispersal of about 320,000 curies of plutonium.[6] These measurements also indicate a maximum plutonium concentration of 3×10^{-14} Ci/g in pulmonary lymph nodes. The highest concentration found in the lung was 5×15^{-15} Ci/g. These values also attest to the very low body uptake via inhalation in a slightly contaminated environment.

At Palomares, Spain, the nonnuclear explosion of a nuclear weapon dispersed a large quantity of PuO_2. Followup studies after an extensive cleanup campaign have not revealed any consistently measurable plutonium concentration levels in people or produce from the area, even though plutonium surface contamination levels approaching 500 $\mu g/m^2$ were plowed into the soil and in some areas, the plutonium could not be plowed under because of the rocky terrain.[6]

3.0 PLUTONIUM RECYCLE IN LWR's

3.1 Development and Testing of Mixed Oxide Fuels

The initial development of technology for plutonium recycle in LWR fuel was sponsored by the USAEC, with follow-on programs financed by utility companies and 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. After supporting the PUP program at Hanford and the Saxton MOX fuel development and testing program, the U.S. Government concluded that further development of plutonium recycle technology could be carried out by industry.

*d/m.g. = disintegrations/minute/gram

The Federal government-supported research and development program on plutonium recycle was essentially completed by the year 1970, with only a small program wrapup phase extending to 1972. Major industry programs were initiated in the year 1967 with the Edison Electric Institute supporting mixed oxide fuel development and testing performed by Westinghouse and General Electric, followed by the mixed oxide fuel performance demonstration programs in commercial reactors. As early as the year 1959, demonstrations of plutonium recycle were also initiated in foreign reactors. Each of the major programs carried out to establish the viability of plutonium recycle in LWR's is discussed below.

As a result of the experience acquired and the technology developed in various plutonium recycle programs, both in the United States and abroad, it has been demonstrated that plutonium recycle is technically feasible. This conclusion is based on successful irradiations of fuel in the Plutonium Recycle Test Reactor at Hanford, and in the Saxton, San Onofre, Big Rock Point, and Dresden Unit No. 1 U.S. reactors. Foreign experiments have involved tests of mixed oxide fuel in a number of reactors, but especially at Garigliano in Italy. The mixed oxide fuels were irradiated to specific power levels and to burnups typical of those expected in LWR's. The irradiations showed no abnormalities with respect to fuel behavior or predicted reactor control and core performance characteristics.

3.1.1 Plutonium Utilization Program

The Plutonium Utilization Program (PUP) sponsored by the AEC at its Battelle Pacific Northwest Laboratories (PNL) in Richland, Washington, to develop the technology for plutonium recycle in thermal reactors, began in the year 1956, about one year before the first demonstration nuclear plant began operation at Shippingport, Pennsylvania, in 1957.

It was not known in the 1950's what type of nuclear power reactors would dominate the commercial market or what type of fuel would be used; therefore, a great deal of the effort of the Plutonium Utilization Program was devoted to development and testing of fuels other than the mixed oxide pellet type which, if plutonium recycle proceeds, would be used in LWR's.

As a part of PUP, the 70 MWth Plutonium Recycle Test Reactor (PRTR) was built at PNL (formerly the Hanford Laboratory) for fuel performance tests; operating characteristics are shown in Table II-3. The PRTR was a heavy water moderated and cooled reactor with 85 vertical pressure tubes which contained individual fuel assemblies. It also included a Fuel Element Rupture Test Facility (FERTF) which was a test loop with a separate light water cooling system to be used for conducting high risk experiments with elements having intentional defects.

The major efforts in PUP were concentrated on development of mixed oxide fuels, their irradiation in the PRTR, and experimental and calculational neutronics studies. Other efforts included studies of chemical reprocessing, economic optimization, and reactor decontamination.

Table II-3

OPERATING CONDITIONS FOR THE
PLUTONIUM RECYCLE TEST REACTOR

Reactor Operating Pressure	1050 psi
Coolant Surface Velocity*	15 ft/sec
Inlet Coolant Temperature	235°C (455°F)
Outlet Coolant Temperature	275°C (527°F)
Coolant pH	6.0 to 7.5
Peak Linear Heat Rating*	20.1 kW/ft (464,000 $\frac{Btu}{hr\ ft}$)
Axial Peak-to-Average Power Ratio	1.27
Average Linear Heat Generation Rate of Maximum Rod*	16.1 kW/ft
Maximum Allowable Fuel Temperature	Incipient melting
Design Peak Burnup	35,000 MWd/MTHM
Film Coefficient (Calculated Value for 20 kW/ft)*	6520 Btu/hr/ft^2°F
Peak Cladding Surface Heat Flux*	475,000 Btu/hr/ft^2
Maximum Allowable Cladding Surface Heat Flux	650,000 Btu/hr/ft^2
Boiling Burnout Ratio*	1.85
Pressure Tube (Inside Diameter)	3.25±.01 in.
Equivalent Diameter*	0.3 in.
Flow Area*	12.11 in^2
Maximum Allowable Tube Power	1800 kW

*HPD PRTR fuel element. Nineteen-rod cluster of .565 in Zircaloy clad rods containing vibrationally compacted UO_2 with 2 wt% PuO_2 fuel.

In the area of fuel development and irradiation, the PUP program was directed almost exclusively toward vibratory packed particles rather than the pellet type UO_2 fuels which later came to be exclusively utilized in commercial LWR's. Also, in the earlier part of the program, metallic Pu-Al alloy elements were fabricated and irradiated, but these were of very little economic interest. The large effort on the vibratory packed (Vipac) particle fuel was spurred by what appeared to be potential economic advantages of this method and its adaptability to remote operation. But, as the program progressed, the economic advantage of Vipac fuel appeared marginal. For this reason and because of the good performance and general acceptance of pellet type fuel in commercial power reactors, the fuel fabricators designed their LWR fuel facilities to produce pellet-type fuel; and the Vipac fuel became a possible alternative. Table II-4 summarizes the fuel irradiation experiments performed in the PRTR during the Plutonium Utilization Program. These irradiations included 2 assemblies (38 rods) of mixed oxide hot pressed pellets and 13 individual rods of cold pressed and sintered pellets. The mixed oxide fuel designs tested in PRTR (Zircaloy clad fuel which was heterogeneously and homogeneously enriched) included three chronological phases as noted below. Some types were vibratory compacted and some were swage compacted types of fuel.

The irradiations carried out in the PRTR were classified into three chronological phases:

Phase I - Startup - experimental elements

Phase II - Continuation of tests - modified phase I elements

Phase III - Batch core experiments

In Phase I, which extended from the startup of the Plutonium Recycle Test Reactor in July 1961 to January 1965, a large variety of experimental elements was irradiated. The element types included Al Pu alloy elements; UO_2 elements fabricated by vibratory compaction and by swaging; and heterogeneously enriched (incrementally loaded) and homogeneously enriched mixed oxide fuels fabricated by swaging and by vibratory compaction. Peak burnups of 13,000 MWd/MTHM at peak linear heat rating of 12 kW/ft were attained during Phase I operation. The first plutonium produced in PRTR was recycled back into the reactor as a swage compacted UO_2 -0.5 wt% PuO_2 element in May 1963.

During the Phase I irradiation, 38 mixed oxide rods developed in service defects. With one exception, these defects were attributed to internal gas phase hydriding of the Zircaloy-2 cladding, caused by impurities in the fuel material. Three types of impurities were identified:

- Residual fluoride contamination in the plutonium oxide
- Absorbed moisture in the fuel

Table II-4

FUEL ELEMENTS IRRADIATED IN PLUTONIUM RECYCLE TEST REACTOR

Fuel Element Type	Number of Fuel Elements	Peak Linear Heat Rating (kW/ft)	Reactor Peak Burnup (MWd/MTHM)
Al - Pu	75	15.1	(80% of Pu)
UO_2	68		
Vipac	1	10.1	2,500
Swaged (1 not swaged)	65	14.1	15,300
Vipac Tubular	1	-	1,700
Vipac Inverted Cluster	1	-	170
UO_2 - PuO_2	216		
UO_2 - 0.5 wt% PuO_2	(81)		
Vipac	20	16.0	18,500
Swaged	61	13.0	12,500
UO_2 - 1.0 wt% PuO_2	(49)		
Vipac	16	13.6	11,500
Swaged	33	15.6	13,500
UO_2 - 1.5 wt% PuO_2	(1)	4.4	3,500
UO_2 - 2.0 wt% PuO_2	(84)		
Vipac	79	20.0	13,000
Swaged	2	20.0	7,800
Pellet (hot press)	2	21.6	3,150
Vipac Salt Cycle	1	17.1	1,800
UO_2 - 4.0 wt% PuO_2	(1)	27.0	1,250
Pellets (cold press)			
0.5 wt% PuO_2	9 rods	12.0	11,700
2.0 wt% PuO_2	4 rods	15.7	2,300

- Traces of hydrocarbons (oil) introduced in the fuel by leakage from mechanical processing equipment

Although hydriding of the cladding led to severe localized embrittlement and loss of cladding fragments in some instances, little or no fuel loss into the coolant resulted, and no severe reactor operating difficulties were experienced. By concerted efforts to identify and correct this problem, the impurity induced failures were confined to a short period of time, after which fuel materials of improved quality eliminated the problem.

Irradiation of Phase I first generation elements in PRTR was continued in Phase II. In Phase II (January 1965 through September 1965) irradiation tests were performed on modified design mixed oxide fuel elements which were developed to provide for operation at high power density, high burnups (~20,000 MWd/MTHM), and high linear heat ratings (~20 kW/ft). It was expected that these fuel elements would be used for a full fuel loading in the Batch Core Experiment under Phase III.

During Phase II of PRTR operation, peak burnups of 15,000 MWd/MTHM were attained on Phase I first generation mixed oxide fuel. Also during Phase II operation, peak burnups of about ~6,500 MWd were achieved on prototype high power density (HPD) fuel at peak linear heat ratings of about 21 kW/ft and maximum fuel temperatures above melting. Phase II operation was terminated as a result of the rupture of an intentionally defected mixed oxide element under irradiation in the Fuel Element Rupture Test Facility loop in the PRTR at a peak linear heat rating of about 27 kW/ft with significant fuel melting at the plane of the defect.

The Batch Core Experiment (BCE) was conducted in Phase III, which extended from January 1967 through July 1968. At the start, the PRTR was loaded with 66 fresh HPD UO_2 -2 wt% PuO_2 elements designed to operate at high specific powers to high burnups. The irradiation of selected first generation Phase I and Phase II elements was continued in the fringe positions of the BCE during this experiment.

At the end of Phase III operation, peak burnups of 13,000 MWd/MTHM were achieved on high-power density mixed oxide fuels that operated at nominal maximum peak heat ratings of 19 kW/ft with maximum fuel temperatures near melting. Peak heat ratings as high as 21.4 kW/ft with fuel temperatures above melting were achieved for short periods of time. Peak burnups of about 18,500 MWd/MT were attained on first generation mixed oxide fuels at maximum peak heat ratings of 17.1 kW/ft.

A large number and variety of experimental fuel elements were successfully irradiated in the PRTR to evaluate the irradiation performance of mixed oxide fuels suitable for plutonium utilization in water cooled reactors. Mixed oxide fuels were irradiated to peak burnup levels above 18,000 MWd/MTHM and to linear heat rates about 20 kW/ft.

The behavior of the various experimental mixed oxide fuel types operating under high performance conditions was generally excellent. Fabrication problems associated

with PRTR mixed oxide fuel elements of the first-generation design resulted in fuel rod defects which provided some of the first experience with gas phase hydriding defects in Zircaloy clad oxide fuel rods, and resulted in an improved understanding of the phenomenon. Consequently, improved fuel fabrication techniques were developed and no fuel rod defects occurred in the more advanced vibratory compacted HPD design mixed oxide elements irradiated in PRTR during the BCE.

The PUP placed major emphasis on packed particle fuels, and most of the fuel irradiations in PRTR were not demonstrations representative of the pellet type mixed oxide fuels planned to be utilized in current LWR's. However, it should be noted that the test results all indicated that the MOX pellet fuel currently in use would perform adequately under commercial LWR operating conditions.

Further details, summaries and references on PUP are available in Nuclear Technology (August 1972 and May 1973).[10,11]

3.1.2 Saxton Program

The Saxton Program was carried out by Westinghouse under an AEC contract to supplement the work at PNL and develop information on utilization of mixed oxide fuel in pressurized water reactors. Primary objectives were to

- Perform pilot-scale tests of plutonium enriched fuel in a pressurized water reactor environment
- Compare the performance of mixed oxide fuel fabricated by two economically promising techniques: pelletized versus vibratory compacted (Vipac)
- Obtain nuclear data of interest to plutonium recycling, especially in depletion and generation of transuranic isotopes
- Provide a preliminary basis for selection and design of plutonium fuel for a commercial PWR

The project included design and fabrication of mixed oxide fuel elements, reactor irradiation of the fuel, and post irradiation evaluation. The guidelines for mechanical, thermal, and hydraulic design of the mixed oxide fuel elements were

- 20,000 MWd/MT peak rod average burnup
- 16 kW/ft maximum design heat rating in the rods
- Internal gas pressure at end of design life to be less than external reactor operating pressure
- Fuel rod outside diameter, length, and lattice spacing to be the same as for the standard UO_2 fuel rods

The project was initiated early in the year 1964, and full power operation of the Saxton PWR with standard UO_2 fuel elements began in January 1966. The characteristics of the Saxton Reactor during the period of Core II operation are summarized in Table II-5.

Table II-5

SAXTON CORE II DESIGN OPERATING CONDITIONS

Reactor Type	PWR
Maximum Power Level	23.5 MWt
Maximum Linear Power Density	16 kW/ft
Maximum Heat Flux	531,400 Btu/hr-ft^2
Average Coolant Temperature	277°C (530°F)
System Pressure	2,000 psia
Maximum Clad Surface Temperature	339°C (642°F)
Average Clad Temperature at Hot Spot (stainless steel)	356°C (674°F)
Average Clad Temperature at Hot Spot (Zircaloy 4)	367°C (692°F)
Maximum Fuel Central Temperature	2,200°C (3992°F)
Peak Rod Average Burnup	25,000 MWd/MTHM
Chemical Shim, Beginning of Life	2,000 ppm boron
Initial Loading - MOX	345 kg in 9 assemblies
Initial Loading - UO_2	525 kg in 12 assemblies

Saxton Core I used standard UO_2 fuel elements to establish a core performance base line. Saxton Core II fuel loading consisted of nine central mixed oxide fuel assemblies (638 rods) and twelve outer fuel assemblies of standard UO_2. The mixed oxide contained 6.6 wt% PuO_2 in natural UO_2. The UO_2 assemblies were enriched to 5.7 wt% ^{235}U. Of the nine plutonium assemblies, two contained vibratory compacted (Vipac) fuel; the remaining seven assemblies, pelletized fuel. With the exception of some thirty fuel rods which were clad with 304 stainless steel, the mixed oxide fuel rods were clad with Zircaloy 4. Important elements requisite to nuclear operations analysis and fuel performance evaluation were:

- Analyses of at power boron (soluble neutron absorber) and control rod worths (ability to absorb neutrons to control reactor power level and shut down reactor during emergencies), temperature and power coefficients, core depletion rate (rate that fissile atoms fission; i.e., the rate of fuel burnup), and core flux wire* and detector maps**

*Flux wire - a special wire that can be inserted into the core for a short irradiation period. The wire, when withdrawn and passed by a radiation scanner, provides provides data that is indicative of the core neutron flux at the wire location. Neutron flux is a measure of the number of neutrons per square centimeter/second.

**Detector maps - in core radiation mapping, sensors positioned within the core produce three dimensional measurements of neutron density (radial axial flux maps).

- Evaluation of nuclear parameters in zero power tests, based on measurement of boron and control rod worths, temperature and pressure coefficients, minimum shutdown reactivity and xenon decay

- Nondestructive and destructive post-irradiation examinations of the fuel

Core II achieved 9,360 effective full power hours, corresponding to a core average burnup of 10,940 MWd/MTHM with an average burnup of 17,400 MWd/MTHM in the central region which contained the mixed oxide fuel. Subsequent measurements and data reduction showed that the burnups of the peak plutonium rod were 21,000 MWd/MTHM (rod average) and 28,000 MWd/MTHM (peak pellet).

Extensive examination of PuO_2 and UO_2 mixed oxide fuel rods after the Core II irradiation led to the following conclusions:

- Mixed oxide fuel performed satisfactorily, with no evidence of fuel rod failures, thus confirming the adequacy of design and fabrication procedures.

- The fuel rods exhibited good dimensional stability, with a maximum of 0.23 percent length increase and, with the exception of one rod, changes in mean diameter no greater than 0.003 inch.

- Pellet and vibratory compacted fuel performed equally well, although length increases with Vipac fuel were slightly less, and center fuel temperatures in peak power Vipac rods were somewhat higher than in highest power pellet fuel rods.

- The cold-reduced and stress-relieved Zircaloy 4 cladding employed in the plutonium region of Saxton Core II performed well. Oxidation of the outer surface was highly variable and, in some areas, greater than had been predicted from out of pile testing. Hydrogen uptake by the Zircaloy during operation was less than 50 ppm, which indicated few chemically reactive impurities in the fuel. The resulting hydrides were randomly or circumferentially oriented. Mechanical tests of clad samples indicated moderate irradiation strengthening but retention of significant ductility (at least 2.5 percent uniform elongation as measured in tensile tests).

- One fuel rod, which had anomalous dimensions, exhibited local massive hydriding but did not fail. The source of the excess hydrogen was probably stray contamination introduced during fabrication.

- None of the changes in dimensions, microstructure, or properties was of sufficient consequence to impose basic operation limits for MOX fuel in irradiation environments similar to those of Saxton Core II. As a result, it was determined that the mixed oxide irradiations could be carried to peak pellet burnups approaching 50,000 MWd/MTHM by reconstituting the

mixed oxide fuel rods into a looser lattice configuration employing 250 rods. This lattice change was made before starting Core III operations.

Core III remained in operation until May 1, 1972, at which time the peak pellet burnup ranged from 40,000 to 51,000 MWd/MTHM and a peak linear power of 21.2 kW/ft had been achieved.

Analysis and evaluation of the mixed oxide rods from Core III indicated good overall performance, even at the peak pellet burnups experienced. Progressive changes were observed in rod length, fuel microstructure, fuel clad interaction, corrosion of the cladding material, and mechanical properties of cladding. However, these changes were consistent with increased irradiation time and had no apparent effect on fuel performance. Profilometer scans, fission gas collection, and hydrogen analysis showed results similar to those observed at the end of Core II irradiation.

In the Core III irradiation, 33 rods developed defects when the burnup reached 40,000 to 42,000 MWd/MTHM. The defects were limited to rods near the upper end of the power spectrum and were associated with an anomalous crud condition not seen previously on any Saxton fuel rods. The defective rods were not considered indicative of an inherent power, burnup, or other performance limitation in Zircaloy clad mixed fuel, but appeared to be related to the presence of significant quantities of adherent crud, which suggested a change in core environment, such as water chemistry, after the midlife shutdown.

With respect to core reactivity, effectiveness of the control rods, and the prediction of neutron flux patterns and power densities, the methods of calculation which had been used for reactor cores with uranium fuels proved readily adaptable and accurate when used in computing the characteristics and performance of reactor cores with mixed oxide fuels. The predicted values were always within 5% of measured values and, for most parameters, within 2%.

It was shown that a reactor core designed for uranium fuels can accept mixed oxide fuel without change in the mechanical design, and that it can achieve longer life (with mixed oxide fuels) if the lattice spacing is increased.

AEC support of the Saxton Plutonium Program was terminated in 1972. Reports of the work are available in the documents listed in References 12-20 at the end of this chapter.

3.1.3 Edison Electric Institute/Westinghouse

Industry participation in mixed oxide fuel development was provided by the Edison Electric Institute (EEI), an investor owned electric utility company trade association organization through which support is provided for research and development projects of interest to the industry. A contract was entered between EEI and Westinghouse Electric Corporation (W) for a plutonium utilization development program directed toward the use of mixed oxide fuel in pressurized water reactors. The AEC contributed

to the work under this program by providing plutonium at a reduced charge. The EEI/W program was initiated in the year 1967, with the first phase of the work devoted to study factors that influence the economics of Pu recycle and the distinctive characteristics of plutonium fueled pressurized water reactors.

Using analytic and semiempirical adjustments to reactor core calculational techniques, Westinghouse improved the computer codes to make it possible to calculate the initial criticality of plutonium fueled systems with an accuracy consistent with that for uranium-fueled systems. In cores containing both plutonium fuel and enriched uranium fuel, calculations indicated that the use of separate and distinct core regions for each fuel type would be the most promising method for fuel loading. This could be accomplished either by arranging two distinct fuel regions in each assembly, or by use of individual assemblies of each fuel type.

Calculations and critical experiments showed no inherent limits which would restrict the use of a full plutonium core in a pressurized water reactor. However, in the core lattice configuration of existing reactors, a core consisting entirely of mixed oxide rods would experience a reduction in control rod worth. This results from the already noted fact that the fission cross sections for the fissile plutonium isotopes are about twice that of ^{235}U; consequently the same power density may be maintained with about half the neutron flux. Thus, with mixed oxide fuel, control rods have only about half as many neutrons to act on. This phenomenon is somewhat complicated by the fact that nonfissile plutonium isotopes have very high neutron absorption resonances in the thermalization neutron energy range, further reducing the number of neutrons available for the control rods to act on. The EEI/W experiments showed that, with a core design incorporating a larger number of control rods and a more open lattice spacing, a core with all mixed oxide rods could be operated safely. In a standard PWR core employing both mixed oxide fuel rods and rods containing UO_2 only, adequate control rod worth can be assured by positioning the UO_2 rods adjacent to all control rods and positioning the mixed oxide rods so as to obtain the desired power distribution. See CHAPTER IV, Section C-3.0, for a more complete treatment of this subject.

During the early studies and experiments under the EEI/W program, certain areas were identified as requiring a continuing effort:

- In the fabrication studies, the nature and extent of the shielding (primarily for neutrons) required for the high burnup plutonium fabrication, and the effects of this shielding on the cost of performing fabrication operations needed further resolution.

- Although initial criticality could be calculated satisfactorily, the depletion characteristics of large mixed oxide fueled cores contained uncertainties which could be resolved only through actual irradiation and subsequent destructive examination of the mixed oxide fuel. In addition, nuclear design uncertainties remained in the calculation of the power

distribution characteristics and control rod requirements for cores containing both UO_2 fuel rods and mixed oxide fuel rods. A demonstration fuel loading for a large PWR would assist in resolving this area of uncertainty.

- Based on the work at PNWL, the inpile materials performance of mixed oxide fuel was expected to be similar to and as satisfactory as that of uranium fuel; however, before this performance could be established with a high level of confidence, large quantities of plutonium fuel would have to be irradiated in the typical PWR environment.

In the preliminary core region design study conducted under Phase 2 of the EEI/W program, a 1,000 MWe four loop plant with a core containing both mixed oxide and UO_2 fuels was selected as the reference case. Calculations were made for the reference core and an identical core fueled with UO_2 only. The self-generated recycle mode of refueling with plutonium was assumed; this required each region reload to include both mixed oxide and uranium oxide fuel. To simulate equilibrium recycle conditions, operation with a 1/3 loading of mixed oxide fuel introduced in sequential loadings* was analyzed and compared with a UO_2 core that had operated for four fuel cycles. These analyses yielded several conclusions:

- An average enrichment of 4.2 wt% Pu is required to achieve the 33,000 MWd/MTHM burnup reached in the reference UO_2 core.

- Using the discrete assembly concept (all rods in single assembly contain either mixed oxide or UO_2), self-generated Pu recycle can be accomplished with all mixed oxide rods located in assemblies that do not contain control rods. This can be done without increasing the peak power density and without reducing the core power capability or lifetime.

- At equilibrium, with one-third of the core containing mixed oxide fuel elements, it is not necessary to install additional control rods or to position mixed oxide rods in assemblies containing the control rods.

- The moderator temperature coefficient for the core containing mixed oxide is 6.5% more negative, with the result that, as the reactor core temperature increases, the control rod worth decreases slightly.

- Natural uranium shows an economic advantage over depleted uranium as the mixed oxide diluent.

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*The calculations were based on introducing all of the mixed oxide fuel (1/3 loading) over a 3 year period.

As a part of phase 2 of the EEI/W Plutonium Recycle Demonstration Program, a total of 720 PuO_2 and UO_2, Zircaloy 4 clad fuel rods in four assemblies were irradiated in San Onofre Nuclear Generating Station Unit No. 1. All rods in each fuel assembly contained mixed oxide pellets. The fuel rods were of three different plutonium enrichments and positioned so as to control local power. The number of fuel assemblies selected for the demonstration program was representative of the initial loading for self-generated plutonium recycle. These four assemblies, containing 45 kg of plutonium (fissile) in the mixed oxide rods, were inserted into the San Onofre reactor during the first refueling in November 1970. The demonstration mixed oxide assemblies were operated through two normal reactor cycles (San Onofre Cycles 2 and 3). The original plan was to irradiate these assemblies for three cycles. However, because of the possibility of problems identified subsequent to their insertion, caused by fuel densification in UO_2 fuels and the consequent limitation on power operation, irradiation was restricted to two cycles. One of the ways in which the UO_2 fuel densification problems was manifested was by the collapse of the clad material onto the pellets. This was compensated for by pressurizing the fuel rods. The mixed oxide rods were not pressurized and rather than risk fuel densification problems, it was decided to remove the mixed oxide assemblies even though they had shown no signs of trouble.

The San Onofre core consists of 157 fuel assemblies. During the first refueling at the end of cycle 1, 105 fuel assemblies from the initial core were reloaded according to the standard plan, and 52 fresh fuel assemblies were added, consisting of 48 UO_2 assemblies and the four PuO_2 and UO_2 demonstration assemblies. Two of the mixed oxide assemblies each had 52 removable and 128 nonremovable fuel rods. At the end of cycle 2, removable mixed oxide rods were examined and returned to the core. Four of these were replaced with natural UO_2 rods. Two of the four discharged rods were subjected to postirradiation examinations.

After one cycle, the peak pellet burnup on these assemblies was 12,600 MWd/MTHM, and the highest rod average burnup was 10,500 MWd/MTHM. Visual examination of the four assemblies and eight of the removable rods showed them to be in excellent condition.

After two cycles of irradiation were completed in June 1973, the peak pellet burnup on these assemblies was 25,050 MWd/MTHM and the highest rod average burnup was 21,050 MWd/MTHM. The assembly average burnup was 18,950 MWd/MTHM. Visual examination of the four assemblies and of six removable rods showed them to be in excellent condition. Although there was one indication of possible local clad hydriding on a peripheral rod in one of the assemblies, the rod was still intact, with no evidence of mechanical degradation. Rod length, diameter, and ovality measurements were made on six rods, four of which had previously been measured after one cycle of irradiation. The measurements showed no unusual conditions.

Two rods irradiated for one cycle and two rods irradiated for two cycles were selected for a program of nondestructive and destructive postirradiation examination. The examinations showed no anomalous conditions.

Details on the EEI/W Plutonium Program are available in the documents listed in References 21-25 at the end of this chapter.

3.1.4 Edison Electric Institute/General Electric

The Edison Electric Institute also sponsored work by the General Electric Company (GE) on plutonium utilization in boiling water reactors. AEC contributed by providing plutonium at a reduced charge. The EEI/GE mixed oxide fuel investigation was initiated in the year 1957 and pursued in parallel with the PWR mixed oxide program. The first phase was a study of the technical and economic aspects of plutonium recycle in BWR fuel. The following conclusions were reached on the work to be performed in subsequent parts of the program:

- It is technically and economically feasible to utilize recycle plutonium in BWR's.
- The fabrication method (hot pressed vs cold pressed pellets) needs to be evaluated with respect to effects on cost and performance.
- In reactor operating experience on fuel is needed.
- Further work is required concerning the trend toward reduced control margins when plutonium is utilized.
- Nuclear calculational methods require improvement.
- Fast transient tests are required to evaluate safety, because plutonium segregation within the fuel rod is possible as a result of diffusion or some other mechanism.

Under the development and testing phase of the EEI/GE plutonium recycle demonstration program, mixed oxide fuels of several types were tested in operating reactors to evaluate their performance. Major tests were planned for the Big Rock Point nuclear power reactor. In addition, four assemblies which were fabricated originally for use in the first core of Vermont Yankee were instead now being irradiated in the Quad Cities Unit No. 1 reactor. Optimization of mixed oxide fuel element design was continued, taking into account improvements in methods, technology, and economic studies.

The irradiations of mixed oxide fuel carried out in Big Rock Point under this program began in March 1969, and included 32 rods; irradiation of three bundles, each containing 68 mixed oxide rods, was initiated in March 1970. These tests are described subsequently.

3.1.4.1 Rod Irradiations

The fuel rod tests were designed to compare the performance of

- Rods containing mixed oxide pellets with flat ends so that the pellets would stack within the cladding to make a solid rod

- Rods containing pellets with dished ends which would create about 3% voids within the fuel rods

- Rods containing annular pellets

These fuel forms would be compared with each other and with standard UO_2 fuel. The major differences in the fuel rod designs are shown in Table II-6. In this test, emphasis was placed on annular fuels in which the annular pellets are stacked within the rod cladding so that there is a vertical hole sealed inside the rod. This has the effect of reducing the plutonium in the core without changing the fuel rod size or spacing. The four rods containing cylindrical solid pellets and the four containing dished pellets supplied the performance link between UO_2 fuel of current design and mixed oxide fuel. These eight rods were also designed to show incremental performance differences between the three pellet geometries. See Table II-8. Tables II-7 and II-9 present fuel rod design information.

The plutonium content in each rod was originally designed to be constant, and the plutonium concentration was varied to make up for changes in fuel density and geometry. Thus, the linear power characteristics of each rod were similar. The rods were positioned initially in the Big Rock Point reactor core to maintain these similar power characteristics.

The 32-rod irradiation began with Cycle 7 of the Big Rock Point reactor in March 1969 and continued through Cycle 11, which ended in March 1974. It should be noted that during the early operation of Big Rock Point, the copper-nickel tubes in the feedwater heater led to high crudding rates on the surface of all fuel rods in Big Rock Point. This in turn led to a restriction of 70% of rated power on the reactor power level and consequent derating of the specific power of the mixed oxide fuel rods during part of the operating period. Nevertheless, the mixed oxide rods operated between 5 and 15 kW/ft. The 32 rods were examined visually after Cycles 7, 8, 9, 10, and 11.

Four rods were given destructive examinations after Cycle 7. Additional rods were removed after each cycle for possible destructive examination. Both the visual examinations and the destructive tests in the hot cells showed no flaws or inadequacies in any of the fuel rods. Peak rod exposures of 23,100 MWd/MTHM were achieved.

Table II-6

EEI/GE - BIG ROCK POINT REACTOR
32 ROD PROGRAM EXPERIMENT DESIGN

	Solid	Dished	Annular Hole 0.1 in.	Annular Hole 0.2 in.
Density, % of Theoretical	92	95	92	92
Enrichment, %	1.22	1.22	1.36	1.59
Hole Size, diam., inches	-	-	0.100*	0.200*
Dishing, %	-	3.0	-	-
Rods, No.	4	4	12	12

*Hole sizes of 0.10 and 0.20 inches are calculated to assure no melting at peak calculated linear heat generation rates of 21.6 and 26.9 kW/ft, respectively.

Table II-7

EEI/GE - BIG ROCK POINT
MOX FUEL DATA

	MOX Rods
Fuel	
Material	UO_2 and PuO_2
Pellet Diameter, in.	0.471
Active Length, in.	68.62
Density, % of Theoretical	92-95
Cladding	
Material	Zircaloy-2
Thickness, in.	0.040
Outside Diameter, in.	0.5625
Rod Pitch, in.	0.707
PuO_2 and UO_2 Rods per Bundle	2
Plutonium Fissile content (Weight % in PuO_2 and UO_2)	
1.22 Nondished	
1.22 Dished	
1.36 0.1-in. Annular Hole	
1.59 0.2-in. Annular Hole	

Table II-8

EEI/GE - BIG ROCK POINT MIXED OXIDE FUEL
THERMAL PERFORMANCE CHARACTERISTICS

	MOX Fuel			
			Annular Hole	
	Solid	Dished	0.1 in.	0.2 in.
Fuel Pellets				
Outside Diameter, in.	0.471	0.471	0.471	0.471
Inside Diameter, in.	0.0	0.0	0.1	0.2
Cladding				
Thickness, in.	0.040	0.040	0.040	0.040
Outside Diameter, in.	0.5625	0.5625	0.5625	0.5625
Incipient Melting Temperature of UO_2, °F	5080	5080	5080	5080
Fuel Density, % of Theoretical	94	94	94	94
Centerline Temperature				
at 500,000 Btu/h-ft^2-°F	5080	5080	4850	3950
at 410,000 Btu/h-ft^2-°F	4600	4350	4100	3250
Heat Flux for Incipient Melting, Btu/h-ft^2	465,000	490,000	530,000	670,000
Area Fraction Molten at Peak Heat Flux	0.09	0.03	0	0

Table II-9

EEI/GE - BIG ROCK POINT
FUEL PELLET SPECIFICATIONS, THREE BUNDLES

No. of MOX Rods	204
Diameter (in.)	0.471 ± 0.002
Annulus (in.)	0.150 ± 0.005
Density (% TD)	92.0 ± 1.5
Enrichment (%)	
Pu Fissile/Pu + U	1.46
	2.30
	4.95
	8.16
	2.04
^{235}U	0.7
Oxygen to Heavy Metal Ratio	1.98 - 2.02
Gas Content	
Moisture (μℓ/g)	<12
Gas (μℓ/g)	28
Homogeneity	100% <500 μm, at 95% confidence level
	95% <100 μm, at 95% confidence level

The fuel rod examination phase responsibility was assumed by the Electric Power Research Institute (EPRI). It was expected that fuel rod characterization, metallographic examination of fuel rod sections and microprobe analysis for fission product transport would be included in the laboratory examination.

3.1.4.2 Bundle Irradiation Demonstrations

Three bundles containing 204 mixed oxide rods were designed to demonstrate the performance of complete mixed oxide fuel bundles in the Big Rock Point reactor. The normal UO_2 bundle mechanical design was used. MOX fuel loading was designed to be interchangeable with the UO_2 fuel, with respect to performance and exposure capability. Bundles contained MOX rods of four different plutonium concentrations designed to provide the desired power distribution for operation in the reactor through four cycles. The peak fuel bundle exposure achieved was 17,500 MWd/MTHM. Special rods were included for irradiation of some 80% fissile plutonium from the Dresden reactor.

The MOX rods all contained cold pressed and sintered fuel pellets of annular design prepared from mechanically blended ceramic grade PuO_2 and UO_2 powders. The annular hole was 0.150 inch diameter and the fuel matrix was nominally 92% of theoretical density. The only rod to rod variation was the plutonium enrichment and the removability of four of the rods.

Each bundle contained four of the removable fuel rods which could be examined to monitor the performance of the fuel. The four cobalt corner rods were also removable. Twice the usual number of burnable poison (Gd_2O_3) rods were used because of reduced worth in a mixed oxide fuel bundle. Table II-9 shows the fuel pellet specifications for the MOX rods.

The bundle irradiations were initiated with Cycle 8 in the year 1970 and continued through Cycle 10 with all three bundles. Only one bundle was reinstalled for Cycle 11, as decribed later. Irradiation of this bundle continued through Cycle 11.

It has been reported informally that the fission product leakage tests showed evidence of rod failures in two of the bundles. Two rods in the third bundle failed in a decrudding operation during the Cycle 10 shutdown. With replacement of these two rods,* the bundle was returned to the reactor for continued irradiation during Cycle 11.

On the basis of performance evaluation to date, the investigators felt that the mixed oxide fuel in these three bundles, as well as in the 32 individual rods previously irradiated, behaved similarly to UO_2 fuel--with no abnormal behavior resulting from the use of mixed oxide fuel.

*These rods also were to be examined by EPRI. See paragraph 3.1.4.1.

3.1.4.3 MOX Fuel Irradiation - Quad Cities Unit No. 1

The reload plutonium recycle fuel bundle was designed with the same envelope dimensions as the initial core fuel. See CHAPTER IV, Section C-2.0. It could, therefore, be inserted, without restriction, into all locations within the reactor core at Quad Cities or other similar BWR cores. The basic lattice arrangement of 49 rods in a seven by seven array is the same as the initial core fuel, with a centrally located spacer capture rod, and eight tie rods located symmetrically around the periphery of the fuel bundle.

Prototype MOX fuel bundles were of the same general mechanical configuration that GE had been designing and manufacturing for the past 12 years, with gadolinium for reactivity control augmentation. Gadolinium containing reload fuel had been the subject of past AEC safety analyses for Dresden Unit No. 1, Big Rock Point, Humboldt Bay Unit No. 3, Dresden Units No. 2 and No. 3, Quad Cities Units No. 1 and No. 2, Nine Mile Point and others, and had been approved for use in each case. The mixed oxide fuel bundles also incorporated design improvements which had also demonstrated their value in initial core fuel for Browns Ferry Unit No. 1, Peach Bottom Unit No. 2, and Cooper Station.

Two types of mixed oxide fuel assemblies were designed. Four assemblies of Type A31 contained 40 of the 48 rods and were designed to be loaded in the central reactor positions around the center control blade. The uranium enrichments in the UO_2 fuel rods were the same as the standard UO_2 reload fuel, with the exception that 10 Type 5 high enrichment UO_2 rods were introduced to improve power distribution. The four identical Type A31 assemblies were designed to be irradiated under well controlled conditions in the center of the reactor. This would maximize the benefits of possible following program gamma scans and isotopic measurements.

Two types of plutonium were utilized in the mixed oxide fuel assemblies: Dresden Unit No. 1 recycle Pu (80% fissile) and AEC Pu (90% fissile). The Dresden Unit No. 1 recycle plutonium was used in reduced concentration in mixed oxide rods at the outside of the mixed oxide rod island and provided some flattening of local power peaking as well as improving the steam void dependence of the local power peaking. The remaining eight MOX rods were incorporated in a special peripheral fuel assembly design, Type A32--two rods of each of the four mixed oxide rod fuel types. Irradiation of the Type A32 assembly provides a directly comparable low power environment for fuel rods identical to those located in the central fuel assemblies, for future evaluations of the observed fuel performance. The environment at the periphery also results in the coolest possible BWR neutron spectrum and will provide reactor physics data of significance. These BWR prototype fuel assemblies were inserted in Quad Cities Unit No. 1 core in July 1974. The average burnup for the four center fuel assemblies was nearly 8,000 MWd/MTHM as of January, 1976 when the assemblies were visually examined during a reactor refueling outage. The peripheral fuel assembly reached a burnup of about 3,000 MWd/MTHM.

Reports covering the EEI/GE program are listed as References 26-38 at the end of this chapter.

3.1.5 Gulf United Nuclear Corporation/Commonwealth Edison

In the year 1957, Gulf United Nuclear Corporation and Commonwealth Edison joined in sponsoring a plutonium recycle demonstration program in the Dresden Unit No. 1 nuclear power reactor for the overall purpose of gaining experience in all aspects of the recycle operation. Objectives of the Dresden Plutonium Recycle Demonstration Program were to

- Establish the adequacy of a full-size plutonium recycle assembly under actual operating conditions
- Fabricate mixed oxide fuel assemblies on a semiproduction scale
- Establish fuel cycle costs for MOX assemblies under commerical conditions
- Evaluate reactor performance for a core containing a significant quantity of mixed oxide fuel
- Verify the adequacy of analytical models for calculating reactivity and power distributions in mixed oxide assemblies
- Obtain measured reactivity and local power distributions for mixed oxide assemblies by critical experiments prior to irradiation
- Obtain postirradiation isotopic and burnup data from hot cell examinations of removed rods

The available plutonium for fabricating the demonstration assemblies had the isotopic composition shown in Table II-10. This isotopic distribution is characteristic of Dresden fuel at 12,000 MWd/MTHM--rather than at discharge (23,000 MWd/MTHM), which would have been preferable for demonstration assemblies. The total assembly plutonium fissile content, 0.45 wt%, was maintained even though the isotopic composition differed from equilibrium discharge plutonium.

Table II-10

ISOTOPIC COMPOSITION OF PLUTONIUM FOR DRESDEN PLUTONIUM RECYCLE ASSEMBLIES

	Composition of Plutonium wt%
^{238}Pu	0.4
^{239}Pu	71.3
^{240}Pu	20.6
^{241}Pu	6.1
^{242}Pu	1.6

Percent fissile = 77.4 wt%

At 77.4 wt% fissile, the total plutonium contained in the 11 demonstration assemblies was 6.6 kg.

It was desirable from a fabrication and economic standpoint to use the standard Dresden UO_2 fuel rods in non-plutonium bearing rod locations. The number of mixed oxide fuel rods and their location were established on the basis of utilizing self generation plutonium (0.45 wt% fissile plutonium per assembly) in the minimum number of rods while still meeting the local power peaking limitations. Nine mixed oxide rods were chosen as a compromise between power peaking and fabrication penalty. With nine mixed oxide rods at a fissile plutonium content of 1.78 wt%, a beginning of life-peak-to-local power ratio of 1.28 was calculated for the assembly--the same as the reference UO_2 beginning of life peak.

The specific locations of the mixed oxide assemblies in the Dresden reactor core at the beginning of Cycle 7 were selected primarily to distribute these elements throughout the core. This permitted core uniformity and eliminated distortion of the core by any unexpected performance of the mixed oxide elements. The two instrumented assemblies were placed incore at locations along the north south axis. Four other mixed oxide elements were loaded adjacent to instrumented UO_2 assemblies. Thus, any effects of the mixed oxide assemblies on their uranium neighbors could be observed in the instrument responses. The thermal hydraulic characteristics of the plutonium bearing assemblies were identical to those of the UO_2 fuel assemblies which constituted the major portion of the reload batch.

After two cycles in the reactor core, the mixed oxide assemblies had attained an average exposure of 15,900 MWd/MTHM, a highest assembly exposure of 17,470 MWd/MTHM and a peak pellet exposure of 22,830 MWd/MTHM. At that time all eleven mixed oxide assemblies were tested for fission product gas leakage: six appeared to contain leaking rods and were given detailed visual inspection by closed circuit television. The inspections revealed end plug weld fractures in both the standard UO_2 and the MOX fuel rods. Clad blisters and a major rod fracture were also observed in UO_2 rods. Similar failures have been observed in the same rod locations in fuel assemblies containing only UO_2 rods.

End plug weld failures were the most common visual evidence of failure in all types of fuel rods and the only observed fault in the mixed oxide rods.

The five assemblies that did not show indication of leaks were reinserted for Cycle 9, which started in March 1974. They were examined in September 1975 at the end of the cycle. Two fuel assemblies with fuel clad leaks were removed. The average burnup exposure of the 23 mixed oxide rods in the three fuel assemblies was 15,000 - 17,000 MWd/MTHM.

Present plans are to perform post irradiation examination, including isotopic composition measurements of two rods from Cycle 8 and two rods from Cycle 10. Another fuel inspection is planned at the end of Cycle 10, expected in November 1976.

Details of the GUNC/Commonwealth Edison Program are available in the documents listed in References 39 through 41 at the end of this chapter.

3.1.6 Big Rock Point/Exxon/NFS

Exxon Multiple Cycle Plutonium Utilization

One of the ongoing programs at Big Rock Point includes two uranium assemblies and four mixed oxide assemblies. The four mixed oxide assemblies contain a total of 96 plutonium-bearing rods. Two of these MOX assemblies with the 9 x 9 rod matrix design which characterized commercial uranium fuel designs prevalent at that time, were inserted into the Big Rock Point core in May 1972. The maximum assembly exposure achieved so far is 17,800 MWd/MTHM. The remaining two assemblies, incorporating the 11 x 11 fuel rod matrix design with smaller fuel pins and more heat transfer area, were inserted in April 1973. The 11 x 11 design served as a forerunner to the commercial mixed oxide fuel design discussed later, and was first inserted in the Big Rock Point core in July 1974. The maximum assembly exposure reached on this design is 15,400 MWd/MTHM. The two uranium assemblies provide a standard for reference in evaluating the four Exxon mixed oxide fuel assemblies. All six fuel assemblies have remained in the core since first inserted. It is expected that assembly exposures exceeding 20,000 MWd/MTHM will be achieved by the end of the year 1976 (Cycle 14).

Examination of the rods in the program is primarily nondestructive in nature. Typical poolside examinations include visual inspection and measurements:

- Visual inspection by periscope (individual fuel rods and overall assembly)
- Rod diameter measurements by profilometer
- Cladding integrity testing by eddy current
- Pellet column length by gamma scan, eddy current, and plenum gauge methods
- Pellet column continuity verification by gamma scan
- Relative rod power measurements by gamma scan
- Cladding growth measurements by mechanical fixture

Destructive examinations are planned, however, for isotopic analysis and for features revealed by the nondestructive examination. Four rods with only 672 hours of irradiation will be destructively examined for densification data.

As the rods from this program are discharged, the plutonium fuel will be recovered, refabricated, and reinserted into the reactor. This will allow gathering isotopic data on multiple recycle plutonium.

NFS Demonstration Assemblies

Four demonstration assemblies manufactured by Nuclear Fuel Services were inserted in the Big Rock Point core in February 1973. Each assembly contains 73 mixed oxide rods; the first assembly has accumulated an exposure of 13,700 MWd/MTHM. All of these

mixed oxide assemblies have remained in the core since first inserted. Burnup to 20,000 MWd/MTHM is planned unless fuel integrity is compromised. No plans have been made for destructive examination of these assemblies.

Exxon Commercial Irradiation

Irradiation of mixed oxide assemblies on a commercial scale began in July 1974 with the insertion of eighteen assemblies, each of the 11 x 11 design with 24 mixed oxide rods. Eight additional mixed oxide assemblies were inserted during the spring refueling of 1976. Commercial irradiation of plutonium at Big Rock Point is currently restricted to 50 kg.*

Experience

Experience with both developmental and commercial mixed oxide fuel at Big Rock Point has been extremely good. Off-gas activity--an indicator of fuel integrity--has shown a downward trend over the last several years. The recently completed cycle 13 had the lowest off-gas activity of any full length cycle. Examinations of the fuel at the end of this cycle revealed no leaking mixed oxide assemblies.

3.1.7 The Belgian Plutonium Recycle Program[43]

The Belgian plutonium recycle program was initiated in the year 1959 under EURATOM sponsorship. It was described in 1971 as a "1000 man-year effort." The program has emphasized plutonium recycle for LWR's and has included extensive testing as well as research and development. The Belgian 11.5 MWe BR-2 reactor was the first LWR to be loaded with plutonium fuel; it has since been supplemented with additional core loadings which carried burnup tests as high as 50,000 MWd/T. Most recent tests involve fuel elements in the BWR's at Dodewaard and Garigliano, Italy. PWR fuel tests are being conducted in the SENA reactor.

Some of the conclusions reached by the Belgians are summarized as follows:

- In equilibrium recycle cores, the water to fuel ratio should be increased to achieve better plutonium utilization and to compensate for control rod worth decreases; this water to fuel ratio increase is limited by the associated decrease in temperature coefficients.

- There is an economic incentive to increase the burnup of mixed oxide fuel beyond that which would be optimum for enriched uranium to compensate for higher mixed oxide fuel fabrication costs.

- The first generation PWR plants can advantageously make use of plutonium recycle.

*Memo and Order from the USNRC, August 1, 1975.

- The so called "plutonium island" fuel assembly type (plutonium zone surrounded by enriched uranium only fuel) is recommended for some core configurations where the shutdown margins remain practically unaffected; in the SENA case the relative control rod worth is decreased by less than 2%.

- Plutonium utilization in BWR's appears economically less attractive than in PWR's, but several BWR characteristics favor progressive conversion into plutonium burners.

- Relatively independent behavior of the fuel assemblies inside individual shrouds is observed when assemblies are separated by large water gaps (flexibility to adapt the water moderator/metal ratio).

- The practice of power distribution flattening by control rod movements is recommended.

- Routine utilization of multiple enrichments within the fuel assemblies gives a lower relative penalty for plutonium fuels.

3.1.8 CNEN/ENEL Plutonium Utilization Programs in Italy[44]

In the year 1966, the Italians launched a major program of study and development related to plutonium utilization. The ENEL (Ente Nazionale per l'Energia Elettrica) program investigated the feasibility of plutonium recycling by loading mixed oxide fuel rods into operating reactors. CNEN (Comitato Nazionale per l'Energia Nucleare) worked on mixed oxide fuel technology, including physics, fuel element design, and fabrication methods.

Under the CNEN program, a pilot plant at Saluggia undertook reprocessing of irradiated mixed oxide fuels to separate both uranium and plutonium. The Reactor Physics Laboratory at Casaccia Nuclear Research Center investigated the neutronic behavior of MOX fuels in cooperation with Battelle Pacific Northwest Laboratory. The mixed oxide fuel rods for the initial work in Italy were provided by the USAEC. A new plutonium laboratory was completed at Casaccia in the year 1968 and used thereafter for fuel element fabrication research and development.

Mixed oxide fuel pins were irradiated in reactors in Sweden, Norway, Germany, England and France as well as in Italy. Many irradiations involved single rods for research investigations; the Swedish and German reactors accepted complete fuel assemblies for tests to burnups of 15,000 and 25,000 MWd/MTHM, respectively. The activities of the CNEN program provided a basis for planning experiments with mixed oxide fuels in the ENEL nuclear power reactors.[42]

The Garigliano BWR power station was used by ENEL for a plutonium recycle demonstration program which began in the year 1968. A total of 600 mixed oxide fuel rods was incorporated into fuel assemblies for the Garigliano reactor. Critical experiments were performed with mixed oxide fuel assemblies, and irradiated fuel assemblies

were examined in detail to determine how closely the calculated values agreed with measured values. Agreement was considered to be good, proving the validity of computer codes for use with mixed oxide cores. Examination of 12 assemblies after the first shutdown showed no abnormal conditions. This examination included both a fission product gas leakage analysis and a visual examination. Postirradiation metallurgical examination of a mixed oxide fuel rod after 10,000 MWd/MTHM peak pellet burnup showed the plutonium distribution to be similar to the pre-irradiation distribution.

Four reload assemblies containing 96 mixed oxide fuel rods were provided by General Electric in the year 1968 as part of a group of 24 plutonium bearing fuel elements for irradiation in the Garigliano reactor. Four of these were discharged from the reactor in the year 1975, and 46 new mixed oxide fuel assemblies added. The new elements were fabricated by Fabbricazioni Nucleari at Bascomarengo, Italy, using fuel rods fabricated by Belgonucleaire. All of the new assemblies are of the plutonium island type. To date, irradiated fuel from the Italian reactors has been processed at Windscale, England, and Mol, Belgium, for separation and purification of plutonium. Fabrication of fuel rods containing plutonium initially was performed for the Italians by contractors in the United States, Germany, and other European countries, but the CNEN mixed oxide fabrication plant at Casaccia, Italy, is now in operation. Italy's current plans are to recycle no more plutonium in the LWR's, but to recover the plutonium and save it for use in fast breeder reactors. The Italian experimental fast breeder is scheduled for startup in the year 1978.

3.1.9 Obrigheim Reactor Demonstration of Mixed Oxide Fuel

In a cooperative program with the West Germany Kraftwerk Union (KWU), Combustion Engineering (CE), through ALKEM, fabricated mixed oxide fuel assemblies in Europe for the Obrigheim reactor. The demonstration began in the year 1972 with insertion of a single demonstration assembly. Eight additional mixed oxide assemblies were added during the September 1973 refueling. Since that time, more mixed oxide fuel assemblies have been added and some have been removed. The announced intention is to continue adding mixed oxide rods until the equivalent of self generation levels is achieved. As of early 1976, one mixed oxide fuel assembly is in its third cycle, 11 are in the second cycle, and 8 are in the first cycle. Because of a cooperative agreement with KWU, CE has complete access to data from this program. In addition to the Obrigheim demonstration, there have been other CE/KWU programs to determine the irradiation performance and densification properties of mixed oxides and a program to dynamically measure fuel properties, including densification, in the Halden, Norway, reactor.

The 111 assemblies, representing a collective exposure of 230 operating cycles, have only developed one leaking assembly--the prototype assembly in KWO. This assembly was shown by postirradiation examination to have failed by internal hydriding and from a failure that was characteristic of similar failures in UO_2 fuel assemblies. The visual inspection of the mixed oxide assemblies together with destructive postirradiation examination of 12 mixed oxide fuel rods did not show any significant differences from rods from UO_2 assemblies. The accumulated burnup of mixed oxide assemblies to date is shown in Table II-11.

Table II-11

SUMMARY OF THE IRRADIATION OF MIXED OXIDE FUEL ASSEMBLIES OPERATED IN KRAFTWERK UNION (KWU) SUPPLIED PLANTS

Nuclear Power Plant*	Year of Insertion	Number of Inserted Fuel Assemblies	Number of Inserted Fuel Rods	Amount of Fissile Pu, kg	Burnup, MWd/MTU	Number of Cycles	Matrix Material
VAK	1966	41	557	18.4	15,000	4	Natural uranium
KRB	1974	40	1400	94.0	22,000	2	Natural uranium
KWL	1970	1	15	1.0	18,000	5	Natural uranium plus 232Th
MZFR	1972	8	296	11.8	12,000	4	Natural uranium
KWO	1972	21	3780	158.9	28,500	3	Natural uranium

*VAK: Versuchsatomkraftwerk Kahl
KRB: Kernkraftwerk RWE Bayernwerk (Gundremmingen)
KWL: Kernkraftwerk Lingen
MZFR: Mehrzweckforschungsreaktor (Karlsruhe)
KWO: Kernkraftwerk Obrigheim

The KWU mixed oxide fuel rods were fabricated by ALKEM, while the assembly was carried out by Reaktor-Brennelement Union (RBU); both organizations being affiliates of KWU. The current capacity of ALKEM is 20 metric tons of heavy metal per year and will increase to 40 metric tons in about 1980.

The KWU experience with mixed oxide fuel assemblies was summarized by CE as follows:

- 6,048 fuel rods in 111 fuel assemblies
- 1 defected fuel assembly
- No significant restrictions in fuel cycle management
- No licensing restrictions

Thus, from a technical point of view, KWU's experience is that the performance of mixed oxide fuel assemblies is essentially equivalent to that of uranium oxide fuels.

3.1.10 Worldwide Plutonium Utilization Plans and Programs

Many countries have been developing and testing the technology required for recycle of plutonium in thermal reactors. A large amount of plutonium is expected to have been produced in commercial reactors around the world by the year 1980. Because most countries do not yet have an established reprocessing industry, it is uncertain how much of this plutonium will be separated from spent fuel and purified in a form suitable for recycling in nuclear fuel. 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. The fuel reprocessing aspects of the plutonium recycle studies are generally not so far

advanced. Although fuel reprocessing plants have operated in the past, there are no commercial plants now in operation anywhere in the world. A reprocessing plant in France may start up late in the year 1976. Others in England and the United States may be started up a few years later but operations today are limited to pilot plants or special noncommercial fuel reprocessing facilities.

In the United States, assuming favorable regulatory decisions, Allied-General Nuclear Services' Plant at Barnwell, South Carolina, is expected to start operations in the early 1980's; similarly, Nuclear Fuel Services' Plant at West Valley, New York, is expected to start up again in the early 1980's after completing planned modifications.

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 for the various countries are summarized in the following paragraphs, adapted from a report prepared for the Electric Power Research Institute[45] in Palo Alto, California, with updates from other sources.

Belgium: Belgium has a well established plutonium recycle development program. An industrial facility capable of producing 900 to 1,000 kg/week of mixed oxide fuel has been in operation since the year 1973. The Eurochemic fuel reprocessing plant processed 120 tons of fuel in the years 1973 and 1974, but has been shut down since that time. Demonstrations of the behavior of plutonium fuels have been in progress for several years in PWR and BWR plants. In parallel, a few samples were and are being irradiated in material testing reactors to assess particular details of the specifications or to investigate the fuel behavior at extreme conditions. Belgium has purposely followed a policy of scaling up its mixed oxide fuel manufacturing capacity in order to fulfill not only its needs but to allow it to act as a subcontractor for foreign reload suppliers.

Canada: The plutonium utilization program in Canada is directed towards solving the technical problems of plutonium recycle in CANDU (natural uranium, heavy water) reactors and establishing conditions for economic viability. To provide a focus for these investigations, the Canadians have performed a design study which used a conceptual design for a 1,200 MWe CANDU BLW reactor as the basis for an examination of all aspects of the reactor system and fuel cycle. Similar studies are in progress, to examine plutonium recycle in the CANDU PHW and the use of plutonium as the initial fissile feed for a thorium ^{233}U fuel cycle in CANDU reactors.

A 3-ton per year pilot facility for the fabrication of mixed oxide fuel was completed in the year 1974. The plant is being operated to fabricate 200 to 300 CANDU fuel bundles or 3.2 to 4.8 tons of fuel (Th and Pu). The intent is to obtain sufficient experience to permit reliable fuel fabrication cost estimates and to demonstrate the successful operation of mixed oxide fuel bundles in Canadian Power Reactors. Canada has no fuel reprocessing plant at present.

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

Phase II of plutonium recycle in the FRG for the years 1975 to 1980 will be conducted by a joint venture of utilities, the nuclear fuel recycling industry, and the government. The primary goal of this program is to advance the technology of commercial plutonium recycling. Additional aims are to demonstrate technology by which the environmental impact of plutonium can be held as low as possible and to develop technology needed for fast breeder fuel element production. Present plans call for operation of a fuel reprocessing plant about the year 1985.

Plutonium utilization in thermal power reactors is considered to be a necessity at least in the next decade. The first core loads for fast breeder reactors are not anticipated prior to the year 1990. An immediate recycling of plutonium in thermal power reactors will improve the economy of the nuclear fuel cycle because stored Pu has a high financial value. The Federal Republic of Germany does not plan to consider the alternative of plutonium storage, either in purified form after chemical separation or in the form of spent fuel elements after discharge from the reactor. The key objectives in Pu recycling, the demonstrations of Pu technology, and the technical and economical aspects of Pu handling are also directed toward the development and introduction of fuel fabrication technology for fast breeder reactors.

France: France has decided to concentrate on the development of fast breeder reactors; thus interest in the recycle of plutonium as fuel in thermal reactors is secondary and at a low level. A few years ago it appeared that for about 10 years (1980 to 1990), France would have a great quantity of available plutonium and only a few fast breeder reactors. Today, it appears that spent fuel reprocessing has fallen behind schedule and plutonium accumulation during this period will not be large. A fuel reprocessing plant at Le Havre with a capacity of about 800 tons of fuel per year has been constructed and may start up near the end of the year 1976.

India: India plans to utilize the plutonium produced in CANDU type reactors as fuel for fast breeders when they become available. A 40 MWth fast breeder test reactor is presently under construction at the Reactor Research Center near Madras to gain experience with sodium cooled fast reactors.

The annual spent fuel discharge from the Tarapur Atomic Power Station (two BRW's at 200 MWe each) contains about 120 kg of Plutonium. The CANDU type power stations at Rajasthan, Madras and Navora will produce spent fuel containing about 150 kg plutonium per station per year. The fuel discharged up to this time from the Tarapur station contains about 200 kg of plutonium.

To operate the Tarapur Atomic Power Station, enriched fuel is imported from the United States, but India is taking serious note of the developments being made in the technology of plutonium recycle. The capability to reprocess spent fuel is being developed at Tarapur, though no firm decision has been made to utilize MOX technology. A plant is being set up to fabricate the fuel elements for the fast breeder test reactor.

Japan: The Power Reactor and Nuclear Fuel Development Corporation (PNC) is now planning to initiate plutonium recycling at an early stage. It plans to irradiate plutonium fuel assemblies in JPDR (PWR, 90 MWth). Another program is under way to load four plutonium fuel assemblies in MIHAMA-1 (PWR, 340 MWe) by the year 1977 or later. In the Advanced Thermal Reactor (ATR, 165 MWe), reactor physics experiments have been carried out since the year 1972; ATR is scheduled to be critical in 1976. A reprocessing facility (PNC, 200 tons/year) has been operated on a test basis since the year 1975. The reprocessing facility is not currently scheduled for production operation. In addition, a conversion facility at PNC is scheduled to be operative in the year 1977 for conversion of plutonium nitrate produced from PNC's reprocessing facility to PuO_2 which is used for fabrication of FBR, ATR, and Pu-thermal reactor fuel. The present fabrication capacity is insufficient for Pu fuel assembly loading programs, and therefore expansion is under consideration. The total amount of Pu produced from thermal reactors in Japan will increase to about 14 tons by the year 1980.

The Netherlands: At present there are two operational thermal power reactors in the Netherlands. One is at Dodewaard (BWR, 50 MWe), the second at Borssele (PWR, 450 MWe).

At the start of the second cycle of the BWR plant at Dodewaard, two prototype Pu-island elements were loaded. They remained in the core during Cycles 2, 3, 4, and 5. Average burnup on removal was about 20,000 MWd/MTHM. At the start of Cycle 5, four Pu-island elements were loaded (two with gadolinium as burnable poison). At the start of Cycle 6, one fresh Pu-island element was added with gadolinium burnable poison.

In the near future, Dodewaard will most probably sell its plutonium. The production rate at equilibrium is about 12 kg fissile Pu per year. The Borssele plant will probably recycle its own plutonium--with the exception of the plutonium of the first discharge. The production rate is about 78 kg fissile Pu per year at equilibrium (assuming no Pu recycling).

The sol-gel processes are being evaluated for application in producing spherical fuel particles as feed material for vibratory compaction--the Vibrasol process. It has been successfully applied to production of about 100 UO_2 fuel rods for irradiation purposes and has now been further developed for mixed oxide rods. Mixed oxide Vibrasol rods are at present under irradiation in the High Flux Reactor (HFR) at Petten. It is felt that the Vibrasol process has distinct advantages as a fabrication method, especially for mixed oxide. Furthermore, as indicated by the irradiation of instrumented fuel assemblies in the Halden Reactor, Vibrasol fuel rods may have better operating behavior, due to less interaction between the fuel and the cladding.

United Kingdom: The major research and development effort of the United Kingdom Atomic Energy Authority (UKAEA) is directed towards the exploitation of the sodium cooled fast reactor (SCFR). However, adequate expertise and manufacturing capacity for producing plutonium bearing fuels for experimental purposes for either gas or water cooled thermal reactors are being maintained by both the UKAEA and British Nuclear Fuels Limited (BNFL). This could form the basis of development programs for plutonium recycling should the UK Electricity Generating Board require that option. If the UK decides to develop the plutonium recycle option, the earliest date at which large scale recycling could commence is the year 1986. This timescale is set primarily by the steam generating heavy water reactor (SGHWR) commissioning program and the desirability of a few years of successful operation experience with uranium fuel before introducing plutonium recycle as fuel on a large scale. A demonstration plutonium recycle program would involve the irradiation of a series of trial assemblies beginning about the year 1975, initially to check validity of possible manufacturing routes arising within the fabrication plant development program, and later to include studies of the operational and fuel management aspects of recycle. Fuel for the initial stages of a demonstration program would be manufactured in laboratory and development facilities which have already provided mixed oxide fuel that has been irradiated in a number of different types of reactors. The fuel reprocessing plant in England has been shut down since a chemical explosion that occurred in 1973.[46] When that explosion occurred, the plant was starting up for a new processing campaign using the tritex (dibutyl carbitol) solvent extraction process. Fission product residues (mainly ruthenium-106) from previous processing operations were released inside the building and 35 employees received fission product contamination of skin and lungs. No health effects have been observed, and no offsite contamination occurred. Current plans call for a 1,000 metric ton per year plant to be started up in the early 1980's.

Sweden: The accumulated plutonium from Swedish nuclear power plants is estimated to be 1.4 tons by 1980 and 15 to 18 tons by the year 1990. Because it appears improbable that breeder reactors will be introduced commercially before the 1990's, it is likely that the plutonium will be recycled as fuel. This is not expected to start before the year 1979.

Development work is in progress along several different lines. The critical facility KRITZ at Studsvik is large enough to accommodate full length assemblies, and measurements can be performed at different temperatures up to 250°C. At the plutonium laboratory at Studsvik, mixed oxide pellets have been produced for 10 years for internal experiments and, more recently, for AECL. Experimental fuel pins have been irradiated with the aim of studying fabrication parameters.

Demonstration irradiations of plutonium fuel started in the Agesta PHWR in the year 1966, in cooperation with the UKAEA. The first plutonium fuel to be used in an LWR is represented by three assemblies which have been loaded into Oskarshamn I. ASEA-ATOM is responsible for the design and manufacture of the island-type assemblies, but since there is currently no fabrication of such elements on a commercial scale in Sweden, the mixed oxide rods were obtained from Belgonucleaire.

3.2 Mixed Oxide Fuel Fabrication

The mixed oxide fuel fabrication operation may begin with conversion of uranium hexafluoride to uranium dioxide; it then involves special techniques for blending uranium and plutonium oxide powders together, pressing the mixed oxides into pellets, sintering the pellets at temperatures up to 1,750°C, grinding pellets to final dimensional requirements, encapsulating pellets in Zircaloy or stainless steel tubing, and assembling the resulting fuel rods into fuel bundles or assemblies. More details on these operations can be found in CHAPTER IV, Section D.

Because plutonium is much more radiotoxic than uranium, the incorporation of plutonium into LWR fuels requires different fabrication techniques and equipment than for low enriched uranium fuel fabrication. Such techniques and equipment have been developed for use in AEC programs over the past 30 years.

Fabrication and processing of MOX fuel are carried out in equipment and facilities designed for handling plutonium. In these facilities the plutonium is contained to the maximum extent practicable in the process equipment itself, which in turn, is located in glovebox enclosures. Where transfers are required from one glovebox operation to another, plutonium bearing materials may be handled in trays or other containers--sealed inside a plastic bag, a duct, or other enclosure to assure that no plutonium escapes during the transfer. The MOX fuel is similarly protected until it is sealed inside the cladding of the fuel rod. After decontamination of the fuel rods to remove all traces of plutonium from the outside surfaces, they are brought into the fuel assembly area where they may be handled directly and manually. This is done with appropriate measures to assure that employees are adequately protected from penetrating radiation, which is substantially higher than from UO_2 rods.

There are multiple levels of plutonium confinement in a plutonium fabrication facility. Confinement, in this context, means a complete enclosure around the plutonium, with the atmospheric pressure inside the contained volume maintained lower than pressure in the surrounding area so that any leakage in the enclosure will draw material inward rather than allow plutonium to escape outward. Confinement systems require complete enclosures and associated ventilation equipment. In a room that serves as a confinement barrier, doors and other openings are normally closed, and the room atmosphere is kept at a lower pressure than its surroundings.

The first level of confinement is the process vessel or equipment inside the glovebox; the second level is the glovebox or other equipment enclosure or a totally enclosed transfer device. (In some plants another level of confinement is effected by dividing the processes into individual process areas which are totally separated from one another, including separate ventilation systems.) Final confinement is provided by the building structure itself, designed as the ultimate barrier against release into the environment, under all conservatively selected design basis conditions. Structures housing new plutonium fabrication facilities are required to be capable of withstanding the effects of natural phenomena such as tornadoes, hurricanes, earthquakes, and floods.

Emergency power is provided to operate the ventilation systems in the event of a power failure. Air from each of the confinement areas is exhausted through at least two high efficiency particulate air (HEPA) filters to remove particulate plutonium.

The design of plutonium fuel fabrication facilities is based upon the need to protect plant workers from the toxicity of the element and to prevent release to the environment in quantities that could present a hazard to the general public. The cost of a mixed oxide fuel fabrication plant may be several times that of a plant of equal size that processes only low-enriched uranium.[47] CHAPTER IV, Section D, discusses design of plutonium fuel fabrication facilities in more detail.

3.3 Reprocessing of Mixed Oxide Fuels

During World War II, one major objective of the Manhattan Project was to produce and purify plutonium. Reactors were built at the Hanford Engineer Works for the specific purpose of producing plutonium by the irradiation of natural uranium. Radiochemical processing plants were built to separate the plutonium from natural uranium and from fission products contained in the irradiated uranium. Since that time, the United States has produced plutonium and purified it by a variety of processing methods. Of these, the solvent extraction process is now employed almost universally.

The large scale separation of plutonium by solvent extraction (the Purex process), has been developed into a well tested industrial technology. In the United States, the processing has been done in Government owned plants and in one commercial facility. Four privately owned fuel reprocessing plants have been built or are planned to handle the fuel from LWR nuclear power reactors, separating uranium and plutonium from each other and from fission products: Nuclear Fuel Services (West Valley, New York) was in operation from 1966 to 1972, and is now shut down for modification. Midwest Fuel Recovery Plant (Morris, Illinois) has been constructed, but is not being operated because of technical difficulties encountered in the preoperational tests. The difficulties are related to implementation of a new design concept for preparing and handling the solid uranium product and wastes, which have no connection with the solvent extraction separation part of the process. The Barnwell Nuclear Fuel Plant (Barnwell, South Carolina) is under construction, with the separations facility and the UF_6 conversion facility nearing completion. See CHAPTER IV, Section E, for details. The fourth plant, Exxon's Nuclear Fuel Recovery and Recycle Center (Oak Ridge, Tennessee), is under design.

In the processing of enriched uranium or plutonium, a potential hazard unique to the nuclear industry must be dealt with: a nuclear chain reaction (criticality) can occur in the processing equipment if too large a quantity of fissile material accumulates under certain conditions. There have been a total of six criticality accidents associated with the processing of highly enriched uranium or plutonium in the United States during the past 30 years. One, involving highly enriched uranium, occurred in a commercial facility; none has occurred with the low enriched uranium used in

commercial LWR fuels. Two occurred in the chemical processing of plutonium. In both instances the nuclear reactions caused only minor physical damage to the equipment and facilities, but did result in radiation overexposures to some workers in the vicinity, and the death of one process technician. Brief summaries of two nuclear chain reaction (criticality) incidents involving plutonium and four with highly enriched uranium, are included in paragraph 3.6 to give a clearer picture of the nature of this special hazard. There have been no criticality accidents in commercial fuel cycle plants in the past 12 years.

Plutonium has a smaller critical mass than highly enriched ^{235}U and a much smaller critical mass than the low enriched uranium used in LWR fuels. Therefore, increasing the quantity of plutonium to be handled in fuel reprocessing also increases the need for attention to be given to preventing accidental criticality. However, the recycle of plutonium compared to the uranium recycle does not necessarily indicate a corresponding increase in risk of criticality accidents. Built-in safety features such as safe geometry vessels, safe volumes, and other design features, and administrative controls are employed to prevent plutonium from collecting in sufficient quantities to form a critical mass.

In the reprocessing of spent fuel, the high radiation levels associated with fission products and other radioactive materials formed in the reactor far overshadow the comparatively low radiation levels from plutonium and uranium. In the reprocessing operations, the presence or absence of plutonium would have no effect on personnel exposures only after the plutonium is separated from the spent fuel. Also, after the unconsumed fuel is recovered, the presence or absence of plutonium in recycle fuel (in fuel fabrication plants) makes a considerable difference in the radiological safety precautions to be employed--plutonium is highly radiotoxic due to the combination of its specific radioactivity and biochemistry (see paragraph 2.4). The specific activity of the predominant plutonium isotopes is about 100,000 times that of the uranium isotopes. The potential physical effects of plutonium are also more serious, because it is retained in the body much longer than uranium and is absorbed and held in certain organs of the body.

The difference in the handling of plutonium and uranium in the fuel fabrication plant is the need to conduct plutonium operations in sealed gloveboxes--some with shielding and operated remotely--whereas many uranium processing operations can be safely performed without such isolation measures. Plutonium presents more severe problems than uranium, if involved in an abnormal event that would allow escape from processing equipment or storage facilities.

3.4 Effects of Plutonium Recycle on Transportation

For shipping from the nuclear power reactor to the spent fuel reprocessing plant, spent fuel elements are placed in large shielded shipping casks for transport either by rail or truck. Principal design criteria for the casks include important requirements to assure that a cask will maintain its safety functions even in the highly unlikely event that there is a severe accident. Adoption of criteria for spent fuel

shipping casks to handle mixed oxide fuels for LWR's would require provisions that take account of the higher heat content of these fuels, but it is not judged that this would require any significant change in the procedures or the shipping casks now used for uranium spent fuels.

The AEC (now ERDA) has extensive experience in the shipment of radioactive materials, including plutonium. Analysis of accidents[48,49,50] incurred in this shipping experience indicates that probabilities of release and dispersion of radioactive material are very small. Shipment of these materials in the nuclear fuel cycle is usually accomplished by means of truck or rail transportation modes, but some shipments may be made on aircraft. Historically, plutonium shipments in some military programs have been made by air and other modes. Regulations of shipments of radioactive materials have historically not differentiated among transport modes. Recently public concern has been raised about air shipments of plutonium and other special nuclear materials.[51] A Federal law[52] recently enacted in the United States requires the U.S. Nuclear Regulatory Commission to prohibit its licensees from transporting plutonium by air until it has certified to the Joint Committee on Atomic Energy of the Congress "that a safe container has been developed and tested which will not rupture under crash and blast testing equivalent to the crash and explosion of a high-flying aircraft." Except for plutonium contained in a medical device designed for individual human application, the restriction applies to air transport of plutonium in any form or quantity, whether for exports, imports, or domestic shipments. As a result of this law, the Nuclear Regulatory Commission has initiated a program to (1) evaluate the conditions which could be produced in severe accidents; (2) develop qualification criteria prescribing appropriate performance requirements and acceptance standards for packages used to transport plutonium by air; and, (3) perform a series of physical tests and engineering studies to demonstrate that a plutonium package design meets the qualification criteria. After a package design has been demonstrated to meet the criteria, it will be certified as required by law.

NRC regulations governing transportation of radioactive materials (§ 71.42, 10 CFR Part 71) require that plutonium in excess of 20 curies per package be shipped as a doubly contained solid after June 17, 1978. See CHAPTER IV, Section G, for a more detailed discussion.

Shipment of plutonium compounds or of new mixed oxide fuel assemblies to LWR's would require some changes in container design because of the toxicity, heat generation properties and shielding requirements. Safeguards required to prevent theft or misuse of the plutonium is an added consideration in shipments of plutonium. This subject is reviewed in detail in the GESMO draft supplement for safeguards considerations.

3.5 Effects of Plutonium Recycle as Fuel on Waste Management

In the bulk of the fuel reprocessing activities conducted to date, both the high level radioactive wastes, which contain all of the fission products separated in the first-cycle solvent extraction system, and the concentrated wastes from subsequent processing operations have been stored as liquids in underground tanks. In planning

for long term storage of high level wastes from commercial reprocessing plants, the NRC requires conversion of high level wastes to a solid form for permanent storage (Appendix F, 10 CFR Part 50). Meanwhile, evaluation of geological formations and sites is being continued by ERDA, with the eventual goal of using these formations for permanent disposal of the waste in a Federal repository. Extensive effort is being devoted to the details of packaging requirements, and the physical and chemical form of the high level waste that might be required for such storage.

The quantity of radioactivity 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 will be stored with essentially all the radioactivity still contained 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 will be solidified and stored as high level waste. The solidified high level waste will contain most of the radioactivity which otherwise would have been stored in the spent fuel; but, with the uranium removed, it will occupy about half the volume even after the addition of chemicals to convert it to solid form.

The volume of other-than high level radioactive wastes from reprocessing and other recycle operations will increase, but the wastes from mining, milling, UF_6 conversion, and enrichment will decrease by about 22%. The major environmental impacts are the reductions in mill tailings and in the releases of radon from mining and milling activities. This is partially offset by the releases of tritium, krypton-85 and carbon-14 from reprocessing operations and by the increase in plutonium contaminated wastes from reprocessing and MOX fuel fabrication operations. Some differences in waste composition as a result of plutonium recycle should be noted. The transuranium elements such as americium and curium will be formed in substantially greater quantities in mixed oxide fuel than in UO_2 fuel, and these are expected to be completely passed 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. With plutonium recycle about 0.5% of the plutonium in fuel reprocessing operations is expected to remain in the radioactive wastes. Because of the increased quantities of transuranium elements in mixed oxide fuels, the decay heat released 10 years after discharge from the reactor will be about 25% higher than from UO_2 fuel. Waste container designs now being developed will be able to accommodate this higher heat generation. For a detailed discussion on radioactive waste management, refer to CHAPTER IV, Section H.

3.6 Summary of Accident Experience

A summary of operational accidents in U.S. Government facilities, from 1943 to 1970, is given in WASH-1192.[5] For those facilities and operations having a general resemblance to the various mixed oxide fuel cycle steps (in the areas of fuel reprocessing, fuel fabrication, and scrap recovery) there have been a number of accidents. Those which involved the possibility of environmental release include the following:

- Five solution criticality events (1958--2 events; one each in 1959, 1961, and 1962) in reprocessing or recovery operations involving highly enriched uranium or plutonium. All were of small consequence in terms of property damage or releases of radioactivity to the environment, but one fatality and several high radiation exposures occurred among operating personnel.[5,53]

- Chemical explosion in evaporator (1953),[54] related to fuel reprocessing.

- Explosion and fire in plutonium purification facility (1963).[55]

- Metallic fuel fire (reactive metal) in process dissolver (1960),[56] related to fuel reprocessing.

- Spontaneous fire in radioactively contaminated, combustible waste (1951).[57]

- Two fires at the Rocky Flats plutonium fabrication and recovery facility, (1957)[58] and (1969).[59] The 1969 fire caused $45 million in property damage. Both fires are attributable to spontaneous ignition of plutonium metal which is not involved in the mixed oxide fuel cycle.

- Fire around an anion exchange column, fuel reprocessing plant (1964).

Some of these accidents occurred during the early years of operations with new facilities and newly developed technologies. All were investigated and corrective actions were taken (e.g., design changes) to make the events unlikely of recurrence. Such corrective actions have been carried forward, where applicable, into design practices for new facilities, both government and commercial. During the past decade, criticality accidents have disappeared from the accident scene, and fire or explosion involving reactive metals has become the predominant major accident in government facilities.

On a comparable basis, accident experience in commercial facilities to date include:

- A solution criticality accident in recovery operations involving highly enriched uranium, fatal to operator (1964).[53]

- A series of dissolver "fires" (reactive metal), fuel reprocessing plant (1967-1968).[60]

- Final HEPA filter bank failure (inadequate mechanical support), fuel reprocessing plant (1968).[61]

- Fire in plutonium contaminated wastes, fuel fabrication facility (1973).[62] There was no detectable release of plutonium to the environment.

- Explosion in plutonium glovebox, fuel fabrication facility (1972).[63] About 5.6 μCi of alpha activity was released via the stack.

The above adverse experiences in the nuclear field to date are a matter of record, and, in the context of this discussion, the experiences at the Rocky Flats plant are most prominent among them.[64,65] There is no question that adverse experience must be taken into account when projecting future expectation, but the most constructive use of past adverse experience is as guidance for present and future actions. The assessment of future expectations properly includes an assessment of all pertinent experience, good and bad, along with an assessment of procedures, practices, regulatory guides, regulations, improved technology, etc., that have come into being and have an important bearing on future actions.

The measured and estimated quantities of long-lived alpha activity released from the Rocky Flats plant during its first 20 years of operation are summarized in Table II-12.[66] The removal of contaminated oil from the protected confines of the plant for long term outside storage effectively compromised the plant's ability to confine alpha activity. It did so to a much greater extent than did the 1957 fire, which extensively damaged the containment filter system of the building in which the fire occurred.

Table II-12

LONG-LIVED ALPHA ACTIVITY RELEASED FROM ROCKY FLATS

Date	Circumstances	Quantity
1958-1968	Leakage of Pu contaminated machine oil stored at the Rocky Flats site	5.3 Ci to soil at drum storage area
1957	Fire in Bldg. 771 resulting in major damage to filter system	60 μCi, airborne, mostly during fire
1969	Fire in Bldg. 776	0.2 μCi, airborne, over 6-day period during and after fire
1953-1970	Normal effluent releases (cumulative)	< 41 μCi, airborne* 91 μCi, liquid effluents

*18 μCi could be subtracted from this amount as a contribution of the 1957 fire or, more specifically, as an indication of high samples observed in October 1957 from contamination in the ductwork and plenum following restoration of the filter system. Additionally, it should be noted that daily stack samples for airborne alpha particulates were normally below detectable limits so that the cumulative numerical value is derived by taking the minimum detectable quantity as the maximum possible release. It can be inferred that normal alpha particulate releases averaged something less than 1.3 μCi per year:

$$\frac{<41 - 18\ \mu Ci}{18\ \text{years}} = <1.3\ \mu Ci/yr$$

Practices adopted for the design, construction, and operation of government facilities, and regulations governing comparable practices in licensed commercial facilities have been influenced as a result of past experience. Among other things, they are intended to make past adverse experience, such as that at Rocky Flats, highly unlikely of recurrence. Moreover, recognizing that human error and equipment failures are unavoidable in an absolute sense, considerable effort has gone into the continuing development of regulations and regulatory guides to provide criteria for the increased protection of the public, operating personnel and facilities in the event that such errors or failures do occur.

The specific and extensive modifications made to all plutonium handling facilities at Rocky Flats subsequent to the 1957 fire (especially the substitution of flame resistant filters for those formerly used, and the addition of fire protection in the filter banks and plenums) were clearly responsible for the vastly improved containment of alpha activity during the 1969 fire. The new plutonium recovery facility now under construction at Rocky Flats (as a replacement for older facilities) is being built under criteria that should provide even greater assurance that the facility will be able to confine plutonium releases to exceedingly small values, even under severe abnormal circumstances--including natural events, such as tornados.[67]

The criteria governing the design and construction of the new Rocky Flats facility apply to all comparable government facilities under construction or to be built in the future. Strictly comparable criteria exist as regulatory guides for commercial facilities that process or fabricate plutonium.[68,69,70,71] In addition, commercial facilities are required to meet the effects of natural phenomena such as floods, tornados, and earthquakes. The assumed characteristics of the various model mixed oxide fuel cycle facilities, and the assessment of future expectations with respect to their performance under routine and accident circumstances, are based on the currently applied regulations, guides, criteria, and practices.

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CHAPTER III

PROJECTED PLUTONIUM RECYCLE INDUSTRY

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CHAPTER III
PROJECTED PLUTONIUM RECYCLE INDUSTRY

SUMMARY

This generic environmental statement analyzes the cumulative differences in environmental impacts that would result over the 26-year period from 1975 - 2000 if only uranium or if both uranium and plutonium are recycled as compared to no recycle of any fuel. These differences would result primarily from changes in fuel composition, from introduction of fuel reprocessing and from reduction in the quantity of natural uranium resources required. The recycling of Pu would require changes in fuel composition (adding PuO_2 to the UO_2) and the construction and operating of mixed oxide fuel fabrication plants. The reduction of required uranium resources would decrease the number of mines, mills, UF_6 conversion plants and uranium enrichment plants needed in the uranium feed chain.

This chapter projects growth of the LWR industry through the remainder of this century in terms of the size, nature and number of the various fuel cycle facilities that would be required to support light water reactors under various fuel cycle options. The options considered are no recycle, recycle or uranium only and recycle of both uranium and plutonium. These projections are part of the analyses of differential environmental impacts presented in CHAPTER IV and the economic analysis in CHAPTER XI.

In selecting a forecast of growth of the LWR industry for use, the NRC considered projections of growth in the consumption of energy in the US, of energy resources, and of growth in electrical generating capacity. Several different projections of growth in total electric and nuclear generating capacity by Federal and private organizations are presented. WASH-1139 (updated), appropriately modified by the NRC, was selected as the basis for sizing the LWR industry. The modification consisted of decreasing the estimate of nuclear generating capacity to reflect the recent withdrawal of commercial High Temperature Gas Cooled Reactors (HTGR's) from the market and to remove the effects of the Fast Breeder Reactor (FBR). With no FBR's, all plutonium recovered from LWR spent fuel would be recycled in LWR's. From the list of projections considered, NRC selected two cases (ERDA Moderate Growth (High) With Breeder and ERDA Low Growth Without Breeder) as a realistic bracket for the remainder of this century. The projected growth of nuclear generating capacity was then centered on the lower of the two projections because it was considered to be the more realistic.*

*Concurrently, the Federal Energy Administration (FEA) was revising its projections through 1985. These projections (recently published in National Energy Outlook Report No. FEA-N-75/713, February 1976) were a significant factor in establishing that the ERDA low growth forecast with modifications was a "best choice."

From the projected growth of the installed nuclear generating capacity in the US from 1975 through the year 2000, the number of model LWR's required to generate the projected power was estimated and material balances were calculated for each step of the supporting fuel cycle. These material balances served as the basis for estimating the number of each type of model fuel cycle facility needed to support the estimated number of LWR's. The number of LWR's and supporting fuel cycle facilities estimated to constitute the LWR fuel cycle industry from 1975 through the year 2000 with no recycle, with uranium recycle and with recycle of both uranium and plutonium are summarized at 5-year intervals in Tables III-1, III-2 and III-3. The number of LWR's is the same for all recycle options.

Environmental impacts of the industry were integrated over the 26-year period from 1975 through the year 2000 and the industry was characterized at the end of that period.

Table III-1

THE PROJECTED LWR INDUSTRY FOR THE PERIOD 1975-2000 WITH NO RECYCLE

LWR Industry Components	Annual Capacity of Model	Number of Facilities					
		1975	1980	1985	1990	1995	2000
LWR's	1,000 MWe	37	71	156	269	400	507
Mines							
Underground	20,000 ST ore	140	440	1,050	2,185	3,500	5,600
Acres disturbed		1,400	4,400	10,500	21,850	35,000	56,000
Open Pit	200,000 ST ore	19	48	93	152	197	240
Acres disturbed		21,700	32,000	106,000	173,300	224,600	273,600
Mills	1,050 ST U_3O_8	10	25	45	71	94	109
UF_6 Conversion Plants	15,000 MTU	2	2	3	5	6	7
Uranium Enrichment Plants	8.75×10^6 SWU	3	3	3	4	5	6
UO_2 Fuel Fabrication Plants	1,500 MTU	9	6	6	6	8	9
Commercial Burial Grounds	1×10^6 ft^3*	6**	6**	6**	6**	9	11
Federal Repositories for Spent Fuel	15,000 elements	0	0	1	1	2	2

*Total Capacity is 25 million cubic feet.

**Fewer required. Six is indicated because that many exist.

Table III-2

THE PROJECTED LWR INDUSTRY FOR THE PERIOD 1975-2000
WITH RECYCLE OF URANIUM ONLY

LWR Industry Components	Annual Capacity of Model	Number of Facilities					
		1975	1980	1985	1990	1995	2000
LWR's	1,000 MWe	37	71	156	269	400	507
Mines							
Underground	20,000 ST ore	140	440	1,040	1,855	3,070	4,855
Acres disturbed		1,400	4,400	10,400	18,600	30,700	48,600
Open Pit	200,000 ST ore	19	48	93	129	173	209
Acres disturbed		21,700	32,000	106,000	147,000	197,000	238,000
Mills	1,050 ST U_3O_8	10	25	45	60	83	95
UF_6 Conversion Plants	15,000 MTU	2	2	3	4	5	6
Enrichment Plants	8.75×10^6 SWU	3	3	3	4	5	6
UO_2 Fuel Fabrication Plants	1,500 MTU	9	6	6	6	8	9
Reprocessing Plants	2,000 MTHM	0	0	1	4	4	5
Commerical Burial Grounds	$1 \times 10^6 ft^3$*	6**	6**	6**	6	9	11
Federal Repositories for Storage of High Level & Transuranic Waste	$360 m^3$ High Level $6,000 m^3$ Transuranic	0	0	1	2	2	2

*Total Capacity is 25 million cubic feet.

**Fewer required. Six is indicated because that many exist now.

Table III-3

THE PROJECTED LWR INDUSTRY FOR THE PERIOD 1975-2000
WITH RECYCLE OF BOTH URANIUM AND PLUTONIUM

LWR Industry Components	Annual Capacity of Model	Number of Facilities					
		1975	1980	1985	1990	1995	2000
LWR's	1,000 MWe	37	71	156	269	400	507
Mines							
Underground	20,000 ST ore	140	375	885	1,735	2,605	3,955
Acres disturbed		1,400	3,750	8,900	17,400	26,000	39,600
Open Pit	200,000 ST ore	19	41	79	121	147	170
Acres disturbed		21,700	46,800	90,000	138,000	167,600	194,000
Mills	1,050 ST U_3O_8	10	21	38	56	70	77
UF_6 Conversion Plants	15,000 MTU	2	2	3	4	5	5
Enrichment Plants	8.75×10^6 SWU	3	3	3	3	4	5
UO_2 Fuel Fabrication Plants	1,500 MTU	9	6	6	6	7	7
Reprocessing Plants	2,000 MTHM	0	1	1	3	4	5
MOX Plants	360 MTHM	0	1	2	3	6	8
Commercial Burial Grounds	$1 \times 10^6 ft^3$*	6**	6**	6**	6	9	11
Federal Repositories for Storage of High Level Waste & Transuranic Waste	$360m^3$ High Level $6000m^3$ Transuranic	0	0	1	2	2	2

*Total Capacity is 25 million cubic feet.

**Fewer required. Six is indicated because that many exist now.

1.0 INTRODUCTION

The purpose of this chapter is to present background information on the overall projected national energy picture and its nuclear component, and to describe the growth of a nuclear fuel recycle industry that provides the basis for an assessment of the environmental impact and for an analysis of the costs versus the benefits of using mixed-oxide fuels in light-water reactors. First, the rate of consumption of energy in the United States and a reasonable projection of its increase in the future are presented. This is followed by a discussion of potential energy resources. Then the fraction of this energy that is likely to be utilized as electricity, the various technologies for generating the electricity and the fraction of the total electrical generating capacity that might reasonably be provided by light-water reactors is presented. The nuclear fuel cycle alternatives are discussed and the effect of utilizing plutonium on the conservation of domestic supplies of uranium is examined. The components of the fuel recycle industry and the growth that might be expected to the year 2000 are described.

In the second part of this chapter, specific scenarios are selected and described which represent, in the NRC staff's opinion, reasonable bounds to the development of the light-water reactor industry. These scenarios are independent of the complications of competing reactor types and will serve as the basic cases for the assessment of the environmental impacts of plutonium recycle to light-water reactors. The particular scenarios selected allow these impacts to be quantified without introducing the multitude of considerations not germane to the purpose of this report.

Additional discussions of growth projections for nuclear capacity are presented in Appendix B.

The information on energy consumption rates, electrical generation rates, and technologies capable of supplying electricity have been derived primarily from the work of the following:

> Proposed Final Environmental Statement - Liquid Metal Fast Breeder Reactor, WASH-1535, U. S. Atomic Energy Commission, December 1974; the Energy Research and Development Administration's February 1975 update of Nuclear Power Growth 1974-2000, WASH-1139; United States Energy Through the Year 2000 (Revised), Bureau of Mines, U. S. Department of the Interior, December 1975; and National Energy Outlook - February 1976, Federal Energy Administration.

The NRC has reviewed the information and it appears the relevant parts represent reasonable assessments of present knowledge and projections of future developments. The information is summarized in this chapter, sometimes in the words of the subject reports, and reference is made to those reports for more complete discussions.

2.0 CONSUMPTION OF ENERGY IN THE UNITED STATES

2.1 Relationship of Energy Consumption to Gross National Product

The history of industrialized nations has shown that economic progress depends, in part, on the development and utilization of an abundant supply of energy. The positive correlation between a nation's per capita energy consumption and its per capita gross national product is shown in Figure III-1.[1] Although this chart and other data[2] suggest that some countries may use energy more efficiently than others, the more industrialized countries, with higher per capita gross national product, have higher per capita energy consumption rates. The very close historic positive relationship between gross national product and energy consumption rate and between changes in gross national product and changes in energy consumption rate for the US can be seen in Figures III-2 and III-3.[3]

Our consumption of nonrenewable resources of fossil fuel and the environmental impact associated with the consumption of most energy sources, indicate that energy will be used more effectively in the future. Sufficient attention must be given to efficiency and conservation.

Energy is consumed in the US primarily for transportation, space heating and industrial processing. The distribution of usage among major applications in 1968 is shown in Table III-4.[4] In 1974, the gross energy inputs to the household and commercial sector, the industrial sector, and the transportation sector, respectively, were 29%, 40% and 31% of the total gross input of 73.1 quadrillion BTU.[5]

2.2 Forecasts of Future Rates of Energy Consumption

Projections of energy growth into the future have been based on extrapolations of past experience, current trends, population growth rates, anticipated changes in human activities, projected industrial production, cost forecasts and other factors. Because so many technological, economic, social and environmental changes could significantly affect the supply of energy and the demand, the projections are subject to uncertainties, the magnitude of which generally increase with extension into the future.

In this environmental statement, the NRC is primarily concerned with the period through the year 2000 because that appears to be as far into the future as projections can be made with a reasonable degree of accuracy. Most of the recent projections of the demand for energy in the year 2000 fall in the range of about 135 to 210 quadrillion BTU.[6] This may be compared with the consumption of about 73.1 quadrillion BTU in 1974. In an updating of previous studies, the Department of Interior has forecast that energy will be consumed in the US through the year 2000 at the increasing rate shown in Table III-5.[7] The anticipated distribution of consumption among the major consuming sectors is shown in Table III-6.[7] In 1974, about 58% of the electricity was consumed by the household and commercial sector and 42% was consumed by the industrial sector. The percentage consumed by the industrial sector was projected to rise to 50% in the year 2000.[7]

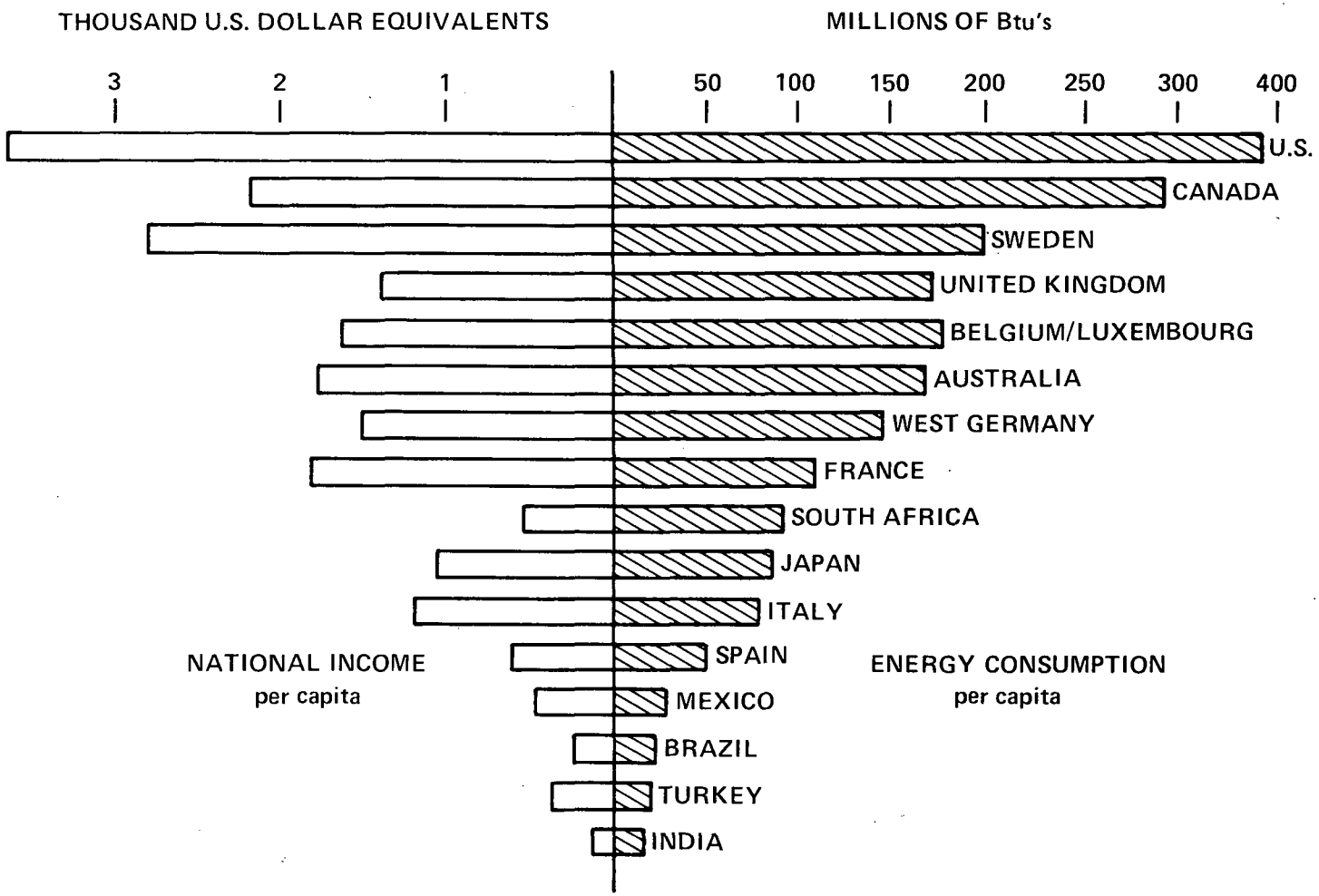


Figure III-1 1968 Per Capita Income and Energy Consumption

SOURCE:
U.S. DEPT. OF INTERIOR' "U.S. ENERGY, A SUMMARY REVIEW, " JANUARY 1972

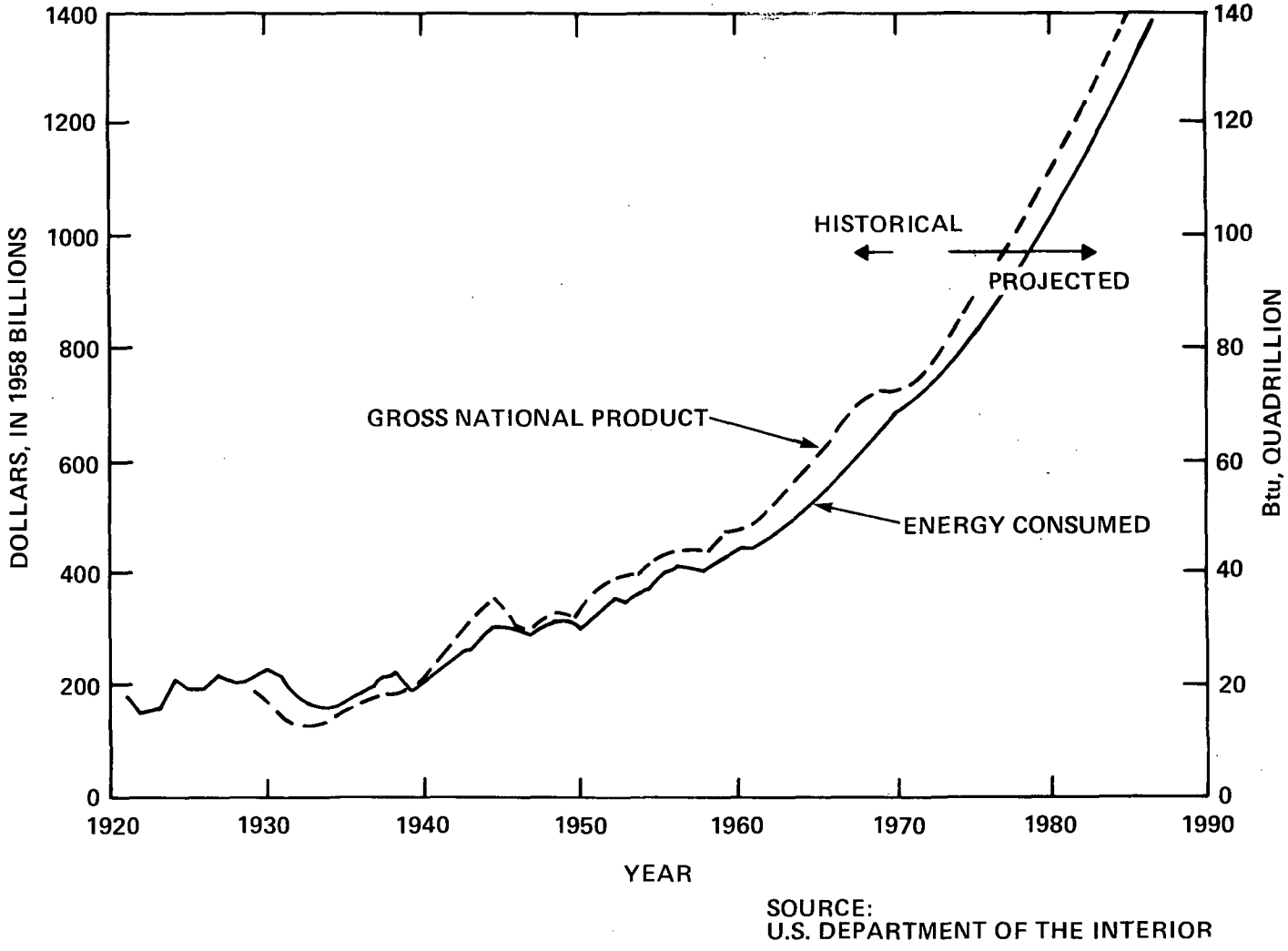


Figure III-2 Energy Consumption and Gross National Product, 1920-1970, With Projections to 1990

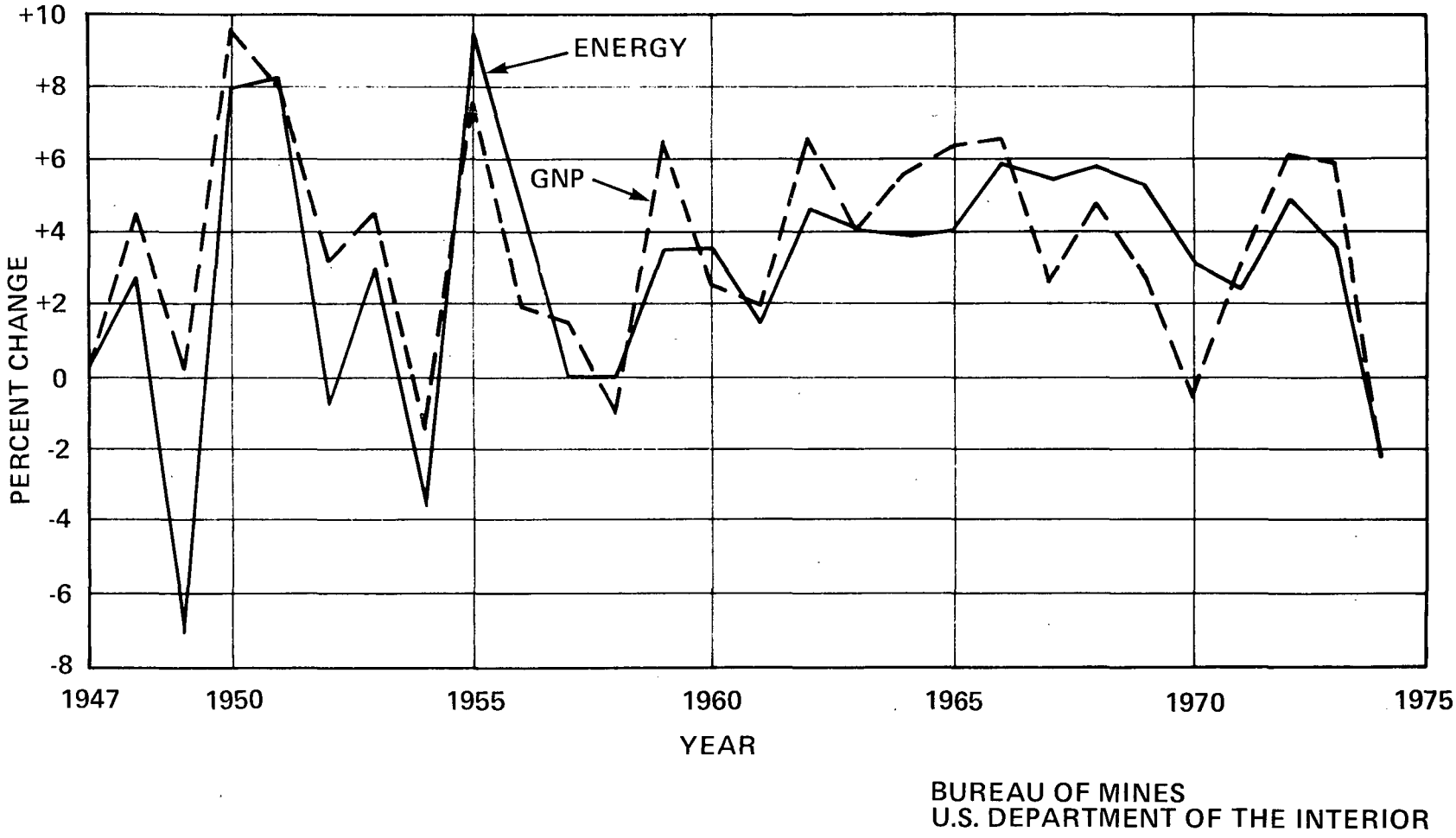


Figure III-3 Changes in Energy and GNP, 1947-1974

Table III-4

ENERGY USAGE FOR VARIOUS APPLICATIONS (1968)[4]

Application	Percent of Total
Transportation (fuel; excludes lubes and greases)	24.9
Space heating (residential and commercial)	17.9
Process steam* (industrial)	16.7
Direct heat (industrial)	11.5
Electric drive (industrial)	7.9
Feedstocks, raw materials (commercial, industrial, and transportation)	5.5
Water heating (residential and commercial)	4.0
Air conditioning (residential and commercial)	2.5
Refrigeration (residential and commercial)	2.2
Lighting (residential and commercial)	1.5
Cooking (residential and commercial)	1.3
Electrolytic processes (industrial)	1.2
TOTAL	97.1

*Includes some uses for space heating, probably enough to bring space heating to about 20%.

Table III-5

DEPARTMENT OF THE INTERIOR FORECAST OF U.S. ENERGY CONSUMPTION[7]

Year	Population (million)	Gross National Product (billion 1958 dollars)	Gross Energy Input (quadrillion BTU)	Per Capita Input (million BTU)
1950	152	355	34.0	223
1960	181	488	44.6	247
1970	205	722	67.1	328
1974	212	821	73.1	345
1980	224	1092	87.1	389
1985	236	1294	104.0	441
2000	264	2105	163.0	617

Table III-6

PROJECTED DISTRIBUTION OF CONSUMPTION AMONG CONSUMING SECTORS[7]

Sector	Fraction of Gross Input by Year			
	1974	1980	1985	2000
Household and Commercial	0.19	0.18	0.16	0.10
Industrial	.29	.26	.22	.15
Transportation	.25	.24	.23	.18
Electrical generation	.27	.32	.38	.48
Synthetic gas and liquids	--	.002	.015	.08

Table III-7

FEDERAL ENERGY ADMINISTRATION FORECAST OF US ENERGY DEMAND[5]

Year	Gross Energy Input (quadrillion BTU) for Imported Oil Price		
	$8/bbl	$13/bbl	$16/bbl
1980 Reference Case	85.4	81.6	80.2
1985 Reference Case	103.4	98.9	97.3
Range*	95-106	92-102	91-101
1990 Reference Case	121.7	116.1	114.0

*Variability is related to assumptions concerning conservation, regulation, electrification, supply, and restrictions on energy development.

The Federal Energy Administration has recently revised its forecast for 1985 and extended the forecast to 1990.[6] The result are summarized in Table III-7, and the anticipated distribution among consuming sectors is shown in Table III-8 for the reference cases with imported oil costing $13/bbl.[8] The Federal Energy Administration analysis projects that the fraction of the electrical generation consumed by the Household and Commercial Sector will rise from about 50% of the total in 1974 to 63% in 1990.[8] The projected rise in demand for energy is substantial but the rate of rise is somewhat smaller than that forecast by the Department of the Interior. The distribution of energy consumption among consuming sectors in the two forecasts is similar, but the Federal Energy Agency projects a slower growth in electrical generation and in industrial usage of electricity.

Table III-8

FEDERAL ENERGY ADMINISTRATION DISTRIBUTION OF ENERGY DEMAND AMONG CONSUMING SECTORS

	Fraction of Total Demand		
	1980	1985	1990
Household and Commercial	.16	.15	0.14
Industrial	.28	.27	.27
Transportation	.25	.24	.22
Electrical Generation	.31	.34	.37
Synthetics	--	.0009	.0012

Whether growth in the rate of consumption of energy such as that described above is necessary or desirable is a matter of concern that has received increased attention since the oil embargo of 1973/1974. Institution of measures to improve the efficiency of usage and to conserve energy could lead to substantially lower consumption rates than those forecast by the Department of the Interior. Such measures are reflected in the lower values of the range of energy demand forecast for 1985 by the Federal Energy Administration (Table III-7). As indicated in paragraph 4.1, the electrical generation capacity growth rate selected as the basis for the GESMO analysis contemplates an effective conservation of energy effort.

3.0 POTENTIAL ENERGY RESOURCES

3.1 Fossil Fuels

Fossil fuels now provide about 94% of our total energy needs. Hydropower supplies about 4% and nuclear power about 2%. In 1974, about 18% of the fossil fuel energy was obtained from 559 million tons of coal, 46% was from 6,070 million barrels of petroleum and 30% was from 21,512 billion cubic feet of natural gas.[9] The declining reserves of domestic oil and gas as well as the projected growth in energy demand--in the U.S. and throughout the world--indicate the need to develop additional practical sources of energy. Sources of energy and methods of utilizing those sources are described in detail in Section 6 of Reference 1.

Present estimates of the total energy obtainable from the estimated recoverable resources of fossil fuels are shown in Table III-9.[10] The numbers take into account the inefficiencies generally experienced in recovery operations. Of the US resource of 44.1 Q,* as much as 10 Q[11] might be considered to be measured or proven reserves recoverable at or near present prices by use of established technology. Much of the remaining 34 Q is expected to be recoverable, but with increasing cost and difficulty.

*Q units are usually used in reporting large quantities of energy. 1 Q = 10^{18} BTU = 1000 quadrillion BTU.

Table III-9[11]

TOTAL ESTIMATED RECOVERABLE RESOURCES OF FOSSIL FUELS

(Q units - 10^{18} BTU)

	United States	World (Includes U.S.)
Coal	34	200
Oil	1.4	14
Oil Shale	7	17
Natural Gas	1.7	10
	44.1	241

Some estimates of U.S. fossil fuel resources range as high as 125 Q. All estimates include, however, "educated guesses" that considerable quantities exist in undiscovered deposits of marginal quality. Estimates of recoverable quantities of fossil fuels, such as those in Table III-9, necessarily involve judgments that could result in substantial overestimates or underestimates of the actual resources.

3.2 Hydro, Tidal, and Geothermal Resources

Estimates of the energy available from hydroelectric, tidal, and geothermal resources are presented in Table III-10.

Table III-10[12]

HYDROELECTRIC, TIDAL, AND GEOTHERMAL RESOURCES

	United States		World	
	Max Potential* kWh(e)/yr	Q/yr**	Max Potential kWh(e)/yr	Q/yr**
Hydroelectric	500×10^9	0.005	4500×10^9	0.045
Tidal (North America)	260×10^9	.003	560×10^9	.006
Geothermal		.001-.004		
Total		∿0.009-0.012		∿0.05

*In 1970 about 40% of the estimated maximum hydroelectric potential of the US had been developed. A small fraction of the geothermal potential and none of the tidal potential had been developed.

**Equivalent to the energy in fossil or nuclear fuel that would otherwise be consumed to produce the indicated electrical energy, assuming a conversion efficiency of 33-1/3%.

3.3 Solar Energy

Energy from the sun falls on the earth's atmosphere at a rate of about 130 watts per square foot of exposed surface. Nights, weather, seasons, attentuation by the atmosphere, and variations in latitude reduce this rate at the surface of the earth. The rate at which solar energy is incident on the surface of the US ranges from about

12 watts per square foot for parts of Michigan and Wisconsin to about 24 watts per square foot for southern Arizona and New Mexico. The total energy incident on the coterminous U.S. amounts to about 1.43×10^9 megawatt thermal years per year[13] or 43 Q per year.

3.4 Uranium

The present ERDA estimates of U.S. uranium resources in relation to cost of recovery and the amount of energy obtainable therefrom are presented in Table III-11. As is explained in paragraph 1.2 of CHAPTER IV, Section F, the resources shown include the potential resources. The Q values are based on fissioning of 1% of the uranium in light water reactors or 70% in breeder reactors.

Table III-11

U.S. URANIUM RESOURCES

Forward Cost of U_3O_8 Price/lb up to	U_3O_8 Resource 1000 tons	Q at 1% of Energy Available**	Q at 70% of Energy Available**
$10*	1,275*	0.75	53
15*	2,050*	1.2	85
30*	3,560*	2.1	146

*Chapter IV, Section F, Table IV F-2. Vast quantities of uranium would be recoverable at higher cost from granites, shales, and ocean waters.

**Based on 3.5×10^{10} BTU/lb of U fissioned.

3.5 Thermonuclear Fuels

If controlled thermonuclear fusion can be achieved and successfully applied, energy can be produced by reactions in which tritium nuclei combine with deuterium nuclei or deuterium nuclei combine with deuterium nuclei to form helium. The deuterium fuel can be obtained by separating the hydrogen isotopes in sea water. Tritium, however, does not occur in quantity naturally and must be produced by means of neutron absorption in lithium. An estimate of the energy resources that would be available from fusion reactions is shown in Table III-12.

Table III-12[13]

FUSION FUEL RESOURCES

Lithium resources	220 Q(*)
Deuterium resources	750,000,000 Q(**)

(*)Based on estimated U.S. lithium deposits. Sea water, in which the lithium concentration is 0.1 ppm, is another possible source.

(**)Assumes use of 10% of the deuterium in ocean waters.

3.6 Consumption of Resources

Given the above basic energy resources, the extent to which any one will be used depends on a variety of factors related to recovery, transport, method of utilization, and disposal of wastes. Ultimately, the distribution of usage among the alternatives depends on the total cost and the convenience of using each source for each application. In 1974, the consumption of the various energy sources was distributed among the consuming sectors in the manner shown in Table III-13.[9]

Table III-13[9]

U.S. CONSUMPTION OF ENERGY RESOURCES BY MAJOR SOURCES AND CONSUMING SECTORS IN 1974

	Household and Commercial	Industrial	Transportation	Electrical Generation	Total
Coal	11.4				
million short tons	11.4	157.8	0.08	389.7	559
quadrillion BTU	0.31	4.36	.002	8.54	13.21
Petroleum					
billion barrels	1.06	1.16	3.29	0.56	6.07
quadrillion BTU	6.06	6.15	17.72	3.48	33.41
Natural gas					
trillion cubic feet	7.34	10.07	0.67	3.43	21.51
quadrillion BTU	7.52	10.31	0.69	3.51	22.03
Nuclear power					
billion kWh				113.	113.
quadrillion BTU				1.20	1.20
Hydropower and Geothermal					
billion kWh		3.00		314.	317.
quadrillion BTU		0.037		3.25	3.29
Total gross energy input quadrillion BTU	13.89	20.86	18.41	19.98	73.14
Utility electricty distributed					
billion kWh	993	711	5.1		1709
quadrillion BTU	3.39	2.42	.017		5.83
Total net energy input quadrillion BTU	17.28	23.28	18.43		58.99

Judging from past experience, the development of any new energy source to the point of large scale commercial use can be expected to take several decades of time. It appears, therefore, that the Nation will have to rely on its fossil fuel resources and on uranium fuel used in current types of commercial nuclear power plants for meeting most of its energy needs for the rest of this century. This expectation in the forecasts by the Department of Interior in Table III-14[7] and by the Federal Energy Administration in Table III-15.[14]

Table III-14[7]

DEPARTMENT OF THE INTERIOR FORECAST OF CONSUMPTION OF ENERGY BY MAJOR SOURCE

Energy Source	Consumption Rate (quadrillion BTU/yr) 1980	1985	2000
Coal	17.2	21.3	34.8
Petroleum	41.0	45.6	51.2
Natural gas	20.6	20.1	19.6
Oil Shale	--	.87	5.73
Nuclear power	4.55	11.8	46.1
Hydropower and Geothermal	3.80	3.85	6.07
TOTAL	87.2	103.5	163.5

Table III-15[14]

FEDERAL ENERGY ADMINSTRATION FORECAST OF CONSUMPTION OF ENERGY BY MAJOR SOURCE

Energy Source	Consumption Rates (quadrillion BTU/yr) 1980 Reference(*)	1985 Reference(*)	1985 Range	1990 Reference(*)
Coal	15.7	20.6	16.6-25.4	25.8
Petroleum	35.6	41.5	54.7-34.5	50.0
Natural gas	22.7	24.2	21.5-27.4	22.8
Nuclear power	3.9	8.7	5.8- 9.9	13.3
Geo, Hydro, Solar power	3.7	3.9	3.9- 4.4	4.2
TOTAL	81.6	98.9	91 - 106	116.1

(*)Reference values given here are for oil at $13/bbl.

4.0 ELECTRICAL ENERGY

4.1 Growth in the Generation of Electricity

Historically, the electric power generating industry has grown at a rapid rate. In the past few decades, the electric power demand has grown at an average annual rate of about 7%, resulting in a doubling of load about every 10 years. This growth has been related to two basic trends--a growth in population of about 1.3% per year and an increasing per capita use. Per capita consumption in the US over the period 1920 to 1970, for example, increased from about 540 kWh per year to about 8000 kWh per year--a 15-fold increase. Some further appreciation of the rapid growth of the electric power industry can be gained from examination of the statistics in Table III-16.[15]

Table III-16[15]

U.S. ELECTRIC POWER STATISTICS 1947 - 1974

Year	Population (millions)	Generating Capacity (million kW)	Kilowatts per Capita	Total Consumption (trillion kWh)	Per Capita Consumption kWh
1947	144	52.3	0.36	0.26	1800
1950	152	68.9	.45	.33	2200
1955	166	115.	.69	.55	3300
1960	181	168.	.93	.75	4100
1965	194	236.	1.22	1.06	5500
1970	205	341.	1.67	1.56	7600
1974	212	474.	2.24	1.87	8800

For many decades, the electric power industry has steadily increased its share of the total energy market. In 1930, generation of electricity consumed about 9% of the gross energy input in the U.S. By 1950, this had increased to about 15% and by 1974 to about 27% of the gross energy input. This increase in energy consumption was accompanied by an increase in efficiency of conversion of heat into electricity. Electricity was generated with a thermal efficiency of only 5 to 10% in the early plants. The thermal efficiency is about 40% in modern fossil fueled plants and 33% in light water nuclear power plants. Even with this improvement, 60% and more of the energy released by the fuel is discharged to the environment as waste heat.

The electricity is, however, much more useful than the raw fuel and has become a preferred source of energy in our society. It is readily transported and distributed. At the point of use, it is clean, versatile, easily controlled, and converted to heat, work, or other function with high efficiency. The fuel for electric power production can be burned in large, efficient, centrally located power plants. This feature is essential to the utilization of uranium as a fuel. It is important to the reduction of pollution that has characterized widespread burning of coal and oil in relatively uncontrolled and inefficient small heating and power units in the past.

Through its convenience and utility, electricity has become vital to the functioning and growth of modern civilization. Although the rates of growth in the consumption of energy and of electricity have decreased in the past few years and are expected to be substantially lower in the future than in the past, the gradual increase in the fraction of the energy devoted to production of electricity seems destined to continue. In addition to a normal increase, the use of electricity, generated from less versatile fuels, can be expected to rise to replace natural gas and possibly oil in some home and industrial applications as those fuels become increasingly expensive or are set aside for other uses.

Forecasts of the demand for electricity many years into the future contain many uncertainties, even though they may be based on very elaborate models of the U.S. economy. As a result, the projections of different individuals or groups vary widely. The forecasts of the growth in electrical generating capacity in the U.S. through the year 2000, made by the Energy Research and Development Administration (ERDA) in 1975, are shown in Figure III-4. Also shown for comparison are data from the forecasts of the Federal Power Commission, the Department of the Interior, the Federal Energy Agency, and the Electric Power Research Institute. After examining the results of many studies, the NRC concluded that the growth in total electrical generation capacity to the year 2000 could reasonably be expected to fall within the range of the ERDA Moderate Growth/High and Low Growth forecasts. The bases for these two projections are summarized below.

Moderate Growth/High: Reasonable conservation and improved utilization of energy are assumed along with continued improvement in the standard of living and development of the economy. The demand for electricity is projected to grow at an annual rate of 6.25% through 1985 and 5.85% for the last 15 years of this century.[16]

Low Growth: Stringent conservation of total energy is assumed with electricity continuing to provide an increasing portion of the total energy. Although electrical generation is projected to grow at a rate of only 5.8% per year through 1985 and 4.75% per year for the balance of the century, it would provide 51% of the total energy in 2000.[16]

4.2 Technologies Capable of Supplying Electricity

In 1974 in the U.S. 44.5% of the utility-generated electricity was produced in coal-fired plants, 33.2% was from oil or gas-fueled plants, 16.2% was from hydro and geothermal plants, and 6.0% was from nuclear plants.[14] These technologies are firmly established and are expected to provide most of the electricity during the remainder of this century.

Other Federal agencies and private organizations have projected future electrical requirements and estimated the quantity of electricity that each of the various technologies could provide. These projections and estimates seem reasonable to NRC. On that basis, NRC projected the LWR requirements from 1975 through the year 2000.

The established technologies for producing electrical energy and those with potential significance beyond the year 2000 are summarized on the following pages. Conservation is also discussed.

4.2.1 Fossil Fuel Power

Generating plants that use fossil fuels as the source of heat are expected to be a major source of electrical energy as long as adequate resources exist. Because oil and gas are so much less abundant than coal in the US and are so valuable for transportation, chemical and other uses, the percentage of fossil-fuel based electricity

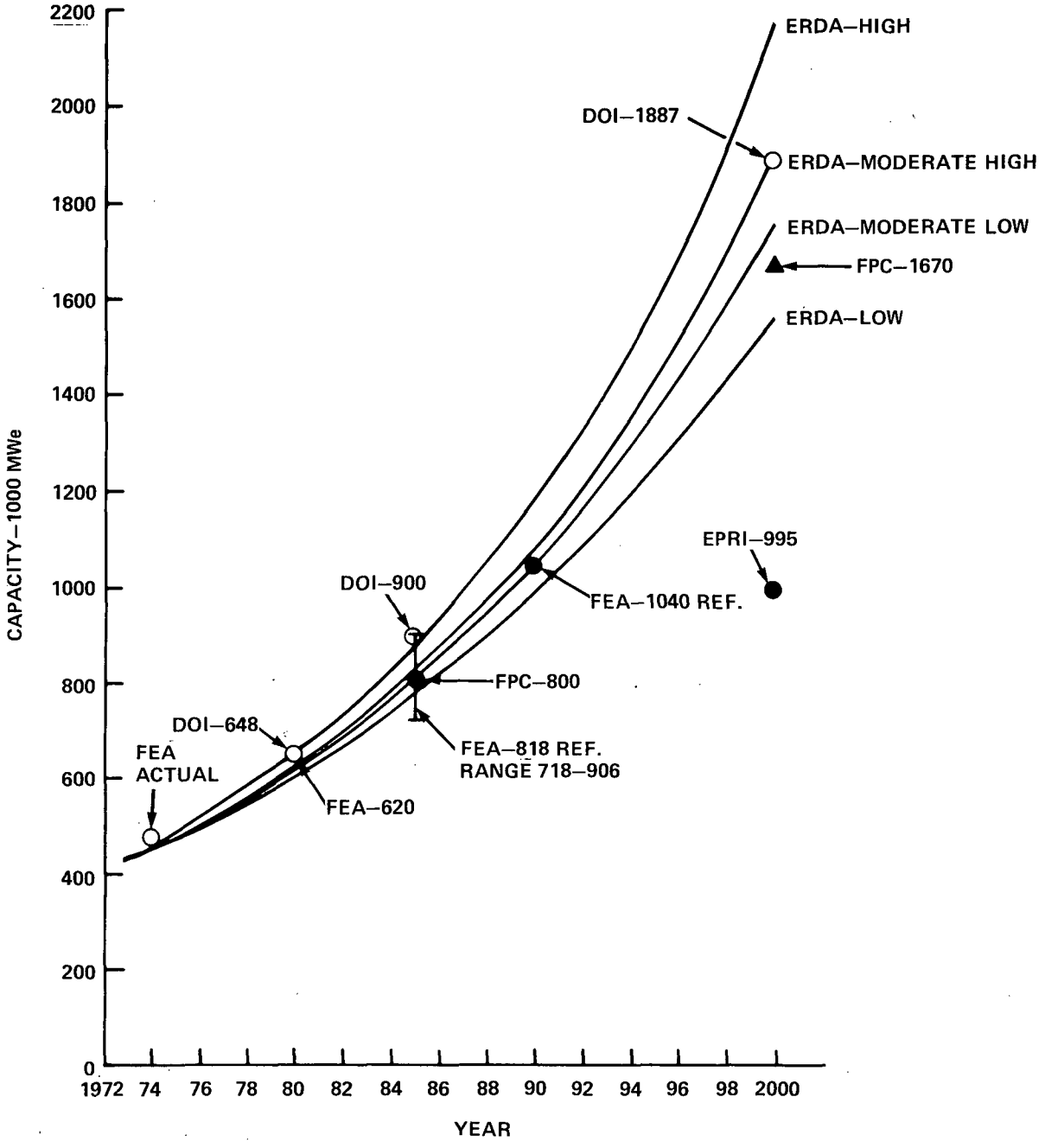


Figure III-4 Forecasts of Growth in Total Electrical Generation Capacity

produced in coal fired plants is expected to rise from the 57% of 1974 to 80% or more by 2000.[17,18]

Improved thermal efficiency in fossil fueled plants (especially coal fired plants) could have significant economic and environmental impact. Higher thermal efficiency would result in the burning of less fuel and the release of less gaseous pollutants per unit of electrical energy produced. The average thermal efficiency of fossil fueled plants in the U.S. increased from about 24% in 1950 to about 33% in 1970 and large plants being constructed today have thermal efficiencies of about 40 percent. The consumption of power by pollution abatement equipment and the increasing use of cooling towers will reduce the thermal efficiency of the plants. There are, however, developments aimed at reducing the losses and at raising the thermal efficiency of future plants. The Department of the Interior projects an efficiency of 38 percent for fossil fueled plants for the year 2000 as compared with its estimate of 32 percent for 1974.[19]

In the year 2000 the annual consumption of electricity in the U.S. is projected to be 8,600 billion kWh for the ERDA Moderate/High forecast of generation capacity and 7,020 billion kWh for the ERDA Low forecast.[16] If the average thermal efficiency were 40 percent and all the electricity were produced in coal fired plants, the corresponding rates of consumption would be 3.2 and 2.6 billion tons per year of bituminous coal (11,500 BTU/lb) or larger amounts of lower grade coal. This compares with a total of 0.611 billion tons of coal consumed--about 0.390 billion tons for generating electricity --in the U.S. in 1974. If the coal were a typical soft coal, 260 to 320 million tons of ash and 130 to 160 million tons of oxides of sulfur would have to be disposed of each year. Removal of the oxides of sulfur by reaction with limestone would, depending on the process, require that limestone be supplied at a rate of 2.3 to 4.6 tons per ton of sulfur oxides, amounting to a requirement of 300 to 700 million tons of limestone.

The U.S. reserves are sufficient to provide coal at the above rates for at least several hundred years. The estimated reserve of coal containing 1% or less of sulfur and economically recoverable by current methods from established formations could provide 3.2 billion tons of coal per year for about 40 years.[20] The use of coal for other purposes can be expected to increase the total demand by 0.5 billion tons per year or more in 2000.

The enormous expansion that would be required in the coal mining and transportation industries, the large increase in qualified miners and the difficulty of preventing serious widespread degradation of the environment provide incentive for using other sources of energy for generating electricity to satisfy part of the demand. As pointed out above, the burning of coal produces large amounts of solid waste that must be disposed of and of gaseous pollutants that must be removed or maintained at safe levels. In the past, coal mining has been one of the most hazardous of industrial occupations, surface mining has spoiled large areas of the land, and the run-off from strip mined areas and from the refuse heaps at coal processing plants has polluted surface waters. This situation can be changed, but expanding the industry even to levels presently projected while reducing the hazards and insuring that air, land, and water are protected would be a demanding task.

4.2.2 Hydroelectric Power

In 1974, conventional hydroelectric power plants constituted about 13 percent of the installed generating capacity in the U.S. and produced just over 16 percent of the electricity.[14,18] Although the installed capacity and the annual production will increase in years to come, the limited number of acceptable sites will cause the growth rate to fall below that of other segments of the industry.

The Federal Power Commission has estimated the conventional hydroelectric potential of the coterminous U.S. to be 147,200 MWe and of the 50 states to be 179,900 MWe. These estimates take into consideration probable engineering feasibility but do not consider economic feasibility, environmental constraints, and legislative prohibitions. These latter considerations will substantially reduce the number of developable sites. By 1974, more than 40 percent of the estimated potential in the coterminous states had been developed, and the Federal Power Commission estimated that the capacity installed there would reach 82,000 MWe or 56 percent of the potential by 1990.[21] This would be about 5 percent of the projected total generating capacity at that time.

The largest increase in hydroelectric capacity is expected to be in pumped storage projects. These projects are normally constructed in conjunction with base load generating plants with low fuel costs such as nuclear units. The Federal Power Commission estimates that pumped storage capacity will increase from the 3700 MWe of installed capacity in 1970 to about 70,000 MWe in 1990. This reduces the peak generating capacity required of plants that use other fuels but does not decrease the total electricity that must be generated by those plants.

4.2.3 Geothermal Power

This resource is regionally located. Geothermal steam provided about 0.1 percent of the electricity consumed in the U.S. in 1974. This electricity was produced at the 400 MWe installation of the Pacific Gas and Electric Co. at the Geysers in California. Plans call for expanding the capacity of that installation by about 100 MWe per year until the ultimate capacity of the field [estimated to be as much as 5000 MWe] is developed. Beyond this development, no firm plans have been made for future geothermal capacity.[22]

Estimates of economically recoverable geothermal resources vary from the equivalent of less than one-half year of supply at the total consumption rates projected for the year 2000, to several years and several hundred years at that same rate. The lower estimates generally include only known hydrothermal reserves recoverable at present or moderately higher cost by use of present or somewhat improved technology. The higher estimates assume technological breakthroughs and the extraction of heat from dry hot rock.

The environmental effects associated with a geothermal plant can vary considerably but are significant. From present data it can be concluded that a 1000 MWe plant would require several hundred wells spread over several thousand acres during a 30-year lifetime. Those wells would be connected to the generating plant by a network of

pipes, some as large as 30 in. diam. The steam from geothermal wells often contains large quantities of such noxious gases as hydrogen sulfide and ammonia. The liquids usually contain large amounts of corrosive salts. Special provisions must be made for safe disposal of the gases and liquids. The steam from geothermal sources is at a low temperature, so the thermal efficiency is low and 3 to 4 times as much heat is rejected to the environment as would be rejected from a modern coal-fired plant of the same capacity.

Several studies have been made of the geothermal power capacity that might reasonably be developed in the U.S. by 2000. Generally, they conclude that a moderate research, development, and exploration program could lead to an installed capacity of 40,000 to 100,000 MWe by 2000.[23] ERDA proposes a program intended to provide a capacity of 40,000 to 100,000 MWe in 2000.[24]

4.2.4 Solar Power

Solar energy includes utilization of its several forms--photons from the sun, the winds, thermal gradients of the oceans, and plant life. Solar energy is used now on a small scale for heating water and for heating and cooling a few homes and commercial buildings. Development of such systems is being supported by ERDA and has generated substantial commercial interest. Use of solar energy can be expected to increase but at a rate that will depend on the cost of energy from other sources and on whether other incentives are offered to encourage such use. Solar heating and cooling will reduce, somewhat, the rate at which the demand for electricity might otherwise grow. The effect is not likely to be so large as to cause the growth in demand to fall outside the range of projections in Figure III-4.

Radiation from the sun can be used to produce electricity by thermal conversion and by photovoltaic conversion. In the thermal conversion process, the energy is used to generate steam which is expanded through a turbine to turn a generator to generate electricity in the conventional way. In the photovoltaic process, solar energy is converted directly into electricity in solar cells. The technology is available to produce electricity by either method. The problem lies in lowering the cost to a competitive level.

Two factors have an important bearing on the cost. The availability of solar power is regional, i.e., the sun shines on any given location only part of each day and not on every day of the year. Electrical, mechanical, or thermal storage capacity must be provided so that electricity can be supplied during period when the sun is not producing.

Solar energy incident on the earth is dilute. In the southwestern U.S., collecting surface spread over at least 6,400 acres (10 square miles) would be needed for a solar-thermal power plant to provide an electrical output equal to the output from a 1000 MWe fossil-fueled or nuclear plant operating, on the average, at 70% capacity. A photovoltaic power plant of the same output and operating at an overall efficiency of 10% for collection, storage, and DC-AC conversion would require about 9,500 acres of

cell surface spread over about 19,000 acres of land. Larger areas would be required in other parts of the country.

Although the fuel cost is zero, the present cost of the equipment would be so high as to make the cost of electricity from a solar-thermal or photovoltaic power plant far greater than that from conventional sources. Substantial development programs are underway to bring about the advances in materials, engineering, and manufacturing that are necessary to bring the costs into the competitive range. Whether this can be accomplished is highly uncertain, but the ERDA program has as its objective the installation of a total of 50,000 to 95,000 MWe of capacity in solar-thermal and photovoltaic power plants by the year 2000.[24] This could reduce the need for electricity from other sources by about 3 to 6% in the year 2000.

Enormous amounts of energy are contained in the winds and in the thermal gradients of the seas and serious efforts will be made in the next several decades to develop economical means of converting some of that energy into electricity. Windmills have been used for centuries and a turbine with an output of 1.25 MWe fed electricity into the power grid in Vermont intermittently for several years in the 1940's. Improved wind power units are being developed, and it is proposed that assemblies of units having capacities in the range of 10 to 100 MWe be installed in the early 1980's.

Large numbers of wind machines would be required to meet a significant fraction of the projected needs. For example, it has been suggested that 1400 billion kWh or 16 to 20 percent of the expected electrical generation in the year 2000 could be obtained from wind machines spread over an area of 350,000 square miles in the Great Plains. Towers, 600 ft high and each containing an array of 20 machines with 50 ft diam blades, would be centered on each square mile of the area. An annual use factor of 30 percent is considered to be on the high side so the storage capacity required to provide firm power would be substantial. The ERDA program foresees the installation of 20,000 to 50,000 MWe of wind energy conversion systems by 2000.[26]

In many places in the tropical and subtropical regions, the ocean surface temperatures are between 75 and 85°F. The warm surface layer circulates toward the poles, where it is cooled, and flows back along the deep ocean trenches. In these lower layers of the ocean, say 2,000 ft below the surface, the temperature is 35 to 45°F. The temperature difference between the surface and the depths could be used to drive a Rankine-cycle heat engine and produce electricity. The thermal efficiency of a real plant would be 2 to 4 percent. The working fluid for the power cycle might be ammonia, propane, or one of the freons.

Two practical difficulties appear to exist with power plants that operate on ocean temperature differentials. Because the temperature difference is small, a very large amount of water must be transported between the depths and the surface and circulated over a very large heat transfer surface. The design and construction of large economical plants requires solutions to many technological problems. Also, most favorable sites tend to be some distance at sea. Most plants must be seagoing plants

and the electricity must be transmitted long distances to load centers. Development programs to resolve the technological and economic uncertainties are being supported by ERDA with the objective of achieving a capacity of 10,000 to 25,000 MWe by the year 2000[26] (about 0.6 to 1.5% of projected total electric power requirements for the year 2000).

4.2.5 Thermonuclear Power

Controlled thermonuclear fusion offers the promise of a virtually limitless source of energy and has been the subject of large research and development programs throughout the world for more than 20 years. Although great progress has been made in the science and engineering of controlled thermonuclear devices, a self-sustaining reaction has yet to be demonstrated. Present program plans call for the demonstration of controlled fusion in test reactors in the early 1980's. Experimental power reactors are to be operated to produce useful amounts of electricity between 1985 and 1990. A commercial scale demonstration power reactor is projected for 1997,[27] but this may be optimistic. The advances in science and engineering that must be demonstrated before commercial plants can be built make it all but certain that controlled thermonuclear reactors will not help to satisfy the Nation's energy needs before 2000.

4.2.6 Nuclear Power

A substantial domestic industry has been established to supply and operate nuclear power plants. In 1975 about 9 percent of the electricity consumed in the U.S. came from nuclear power plants. As of July 1976, 59 commercial nuclear power plants with a total generating capability of over 41,000 MWe had been completed and licensed to operate. In addition, 157 plants with a generating capacity of about 170,000 MWe were under construction or on order.[25] The combined capacity of all these plants is about 25 percent of the total generating capacity projected for 1985.

Almost all these plants are LWR plants. It appears likely that almost all the commercial nuclear power plants built in the U.S. between now and 2000 will be LWR plants. The only competitor for near-term use in the U.S. has been the high temperature gas-cooled reactor (HTGR). The General Atomic Company, developer and promoter of the HTGR, announced on October 1975 that it was temporarily withdrawing from the commercial HTGR business.

LWR's can make a significant contribution to U.S. electrical requirements for the rest of this century because it is unlikely that breeder reactors will generate more than a few percent of U.S. electrical power during that period. Because uranium resources are finite (Table III-8), breeder reactors may play a major role in the generation of nuclear power beyond the year 2000. The Liquid Metal Fast Breeder Reactor (LMFBR) has been under development in the U.S. since the mid-1940's and presently is a major part of the ERDA program. Three experimental reactors have been built and oeprated. A 400-MW(t) reactor for testing fuels, materials, and components is under construction. A demonstration plant, the Clinch River Breeder Reactor, designed for an output of 350 MW(e), is awaiting a construction permit and is scheduled

to begin operating in about 1983. Plans propose operation of the first commercial LMFBR in 1993 and rapid expansion of LMFBR capacity thereafter. It is unlikely that the electricity generation capacity in LMFBR plants in the year 2000 will constitute more than a few percent of the total nuclear generating capacity.

The basic rationale for building most of the nuclear power plants now operating, being constructed, or on order, is that over the lifetime of the plant, the cost of the power produced is expected to be less than the cost of power from a fossil-fueled plant.

For the LWR nuclear technology, the cost of the nuclear fuel cycle is a small part of the total cost of generating electricity. Further, the cost differential due to the form or composition of the nuclear fuel used is a small part of the fuel cycle cost and as a result makes only a slight contribution to the total nuclear generating cost.

Therefore, the recycle of plutonium in LWR's compared to no recycle is judged to play a very small part in any economic consideration that may result in the selection of a particular nuclear plant over alternate technologies. Thus, the degree of penetration of LWR nuclear power into the total electric power generation field is considered to be essentially independent of the type of fuel.

There is reason to expect that the costs can remain competitive at least until the resources available at a maximum forward cost of $30 per pound of U_3O_8 have been committed.

In any comparison of the costs of electricity, the costs of environmental effects have to be understood. In many instances the effects can only be considered qualitatively. In terms of land area affected at the plant site, there is no great difference between a nuclear plant and a coal-fired plant. Since the LWR plant has a thermal efficiency of 33 percent, it discharges about 35 percent more heat to the surrounding area than would a moderate coal-fired plant of equal capacity. To a considerable extent, this difference is manifest in the greater cost of the cooling water facilities necessary to ensure that the plant will comply with Federal and State water quality standards.

The nuclear plant is clean by comparison with a coal-fired plant. The volumes of nuclear fuel and liquid and solid wastes are trivial when compared with the volumes of coal, noxious stack gas, ash, and, when SO_2 is removed, stack gas scrubber waste. The wastes from a nuclear plant are, however, radioactive. Special precautions and equipment must be provided to contain most of the radioactivity and ensure that the radiation from the materials released will add only slightly to the natural background.

The uranium ore from which U_3O_8 can be extracted for $30 per pound or less contains at least 0.08 percent U_3O_8 (see CHAPTER IV, Section F, p. IV F-9). A 1000-MWe LWR, in which only 0.8 percent of the uranium is fissioned, would require the production

of 650 tons of such ore for each day of full power operation. Because the uranium ore is processed to separate the U_3O_8 at a plant near the mining site, only 0.52 tons has to be shipped any distance. A modern 1000 MWe coal-fired plant burns about 8,950 tons of coal for each day of full power operation. This great difference in amount of material that must be mined and transported accounts in large measure for the lower fuel costs of nuclear plants and for the smaller, readily visible, damaging impact on the environment.

As explained in CHAPTER I, the uranium fuel that is removed from the reactor contains highly radioactive fission and transmutation products and plutonium. Because of the hazards associated with this material, appropriate precautions must be taken in handling, shipping, and processing the irradiated fuel and in disposing of the wastes and safeguarding the plutonium. These matters are considered in great detail in other parts of this report. Plants and equipment, procedures, and regulations, believed by the industry and the government to be more than adequate to ensure that the radioactivity and the plutonium will be safely controlled and confined in the reactor and throughout the remainder of the fuel cycle, have been or are being developed. The costs of protecting the environment are contained in the plant and fuel cycle costs.

4.2.7 Conservation

Conservation of electricity through reductions in losses during transmission and distribution, improvements in efficiency of end use devices, and reductions in end use requirements can serve to considerably reduce the growth in usage of electricity and in generating capacity. Conservation was at least partly responsible for the lack of growth in demand in 1974 and 1975[28] and the more moderate forecasts of growth rates in the future.

About 8 percent of the electricity that is generated is lost in transmission and distribution to the customers. Transmission losses can be reduced by raising transmission voltages, reducing line currents, reducing line resistances by use of innovative cable systems and power control. Distribution losses can be reduced by optimizing the load on transformers and reducing the current or resistance of the distribution lines. Research and development now in progress and that planned for the future may result in reduced transmission and distribution losses. The value of the energy saved must, however, be balanced against the cost of the equipment. The balance may show that measures necessary to make a substantial reduction in the 8 percent would not be economical.

The principal end uses of electricity and the rates of growth in consumption by use from 1960 through 1968 are shown in Table III-17.[29] Conservation programs undertaken by government and industry are aimed at increasing the efficiency of electrical devices and reducing the waste in the applications of greatest consumption and greatest growth. Better insulation and sealing of homes and commercial buildings, maintaining the temperatures at 68°F or cooler in the winter and 78°F or warmer in the summer and increased use of heat pumps can be expected to effect important savings in heating and/or air conditioning applications. More conservative lighting practices and control

of hot water usage can provide further savings. Improvement in the efficiencies of residential and commercial appliances and industrial equipment and processes can help to reduce the rate of growth in demand for electricity. Numerous studies have indicated that by combining many conservation measures, the projected energy needs of the Nation for the year 2000 could be reduced by 25 percent or more without resorting to an austere life style. The forecasts used for specifying the size of the LWR industry for this report were based on the precept that conservation would result in a substantial reduction in the historical rate of growth of consumption of electricity.

Table III-17

CONSUMPTION AND GROWTH OF PURCHASED ELECTRICITY SECTOR AND END USE 1960-1963

Sector and End Use	Consumption (trillion BTU)* 1960	1968	Average Annual Rate of Growth 1960-1968 (percent)
Residential			
Space heating	29	164	24.3
Water heating	155	223	4.6
Cooking	73	96	3.4
Clothes drying	23	51	10.4
Refrigeration	122	250	9.3
Air conditioning	48	154	15.6
Other**	292	462	5.6
Total	742	1,390	8.2
Commercial			
Space heating	nil	nil	
Water heating	70	84	2.3
Cooking	5	8	6.0
Refrigeration	193	244	3.0
Air conditioning	200	370	8.0
Other**	52	373	27.7
Total	520	1,079	9.5
Industrial			
Electric drive	1324	1958	5.0
Electrolytic process	202	258	4.4
Direct heat	79	130	6.4
Other**	51	80	5.8
Electricity generation	-350	-410	-2.0
Total	1,306	2,043	5.8
Transportation	18	18	

*Values are net values and do not include heat wasted in the production of electricity.

**Other inlcudes lighting, TV sets, small appliances, elevators, business machines, computers, etc.

4.2.8 NRC Conclusions

Projections by other federal agencies and private organizations 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 to be by construction of fossil-fueled and LWR nuclear power plants. 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 and 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. In view of 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. Thus, it does not appear that the new technologies under development by ERDA will impact significantly on the number of LWR's projected in this statement for the 26-year period from 1975-2000. 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.

4.3 Growth in Nuclear Electric Generating Capacity

Based on assessments of the resource base and projections of the total cost of power from nuclear plants 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. The ERDA moderate high and low growth forecasts,[30] and several others for comparison,[18,30] are shown in Figure III-5. Additional information on some of the forecasts is given in Appendix B. Although the forecasts may differ in the rate of growth predicted for the nuclear power generation capacity, almost all indicate that, absent a legislated moratorium or ban on nuclear plant construction, the electricity generated by nuclear plants can be expected to increase from the 6 percent of the total generation in 1974 to 40% to 60% in 2000.

As part of its consideration of the various forecasts, the NRC modified the ERDA projections to reflect certain factors. The ERDA projections are based on the commercialization of high temperature gas cooled reactors (HTGR's) in the 1980's and fast breeder reactors (LMFBR's) beginning in 1993. The HTGR plants were removed from the ERDA forecast due to the lack of commercial penetration. The FBR's were also removed to avoid the influence of the breeder reactors on the assessments of plutonium recycle in LWR's. This resulted in two modified forecasts--ERDA Moderate (High) Without Breeder and ERDA Low Without Breeder. These two projections are also shown in Figure III-5.

As a result of study of the various forecasts, the NRC concluded that the ERDA Moderate (High) With Breeder and ERDA Low Without Breeder projections defined reasonable bounds for the range of growth in LWR nuclear power generation capacity that could be expected. The ERDA Moderate (High) With Breeder and Low Without Breeder forecasts project installed nuclear capacities of 197,000 and 156,000 MWe, respectively,

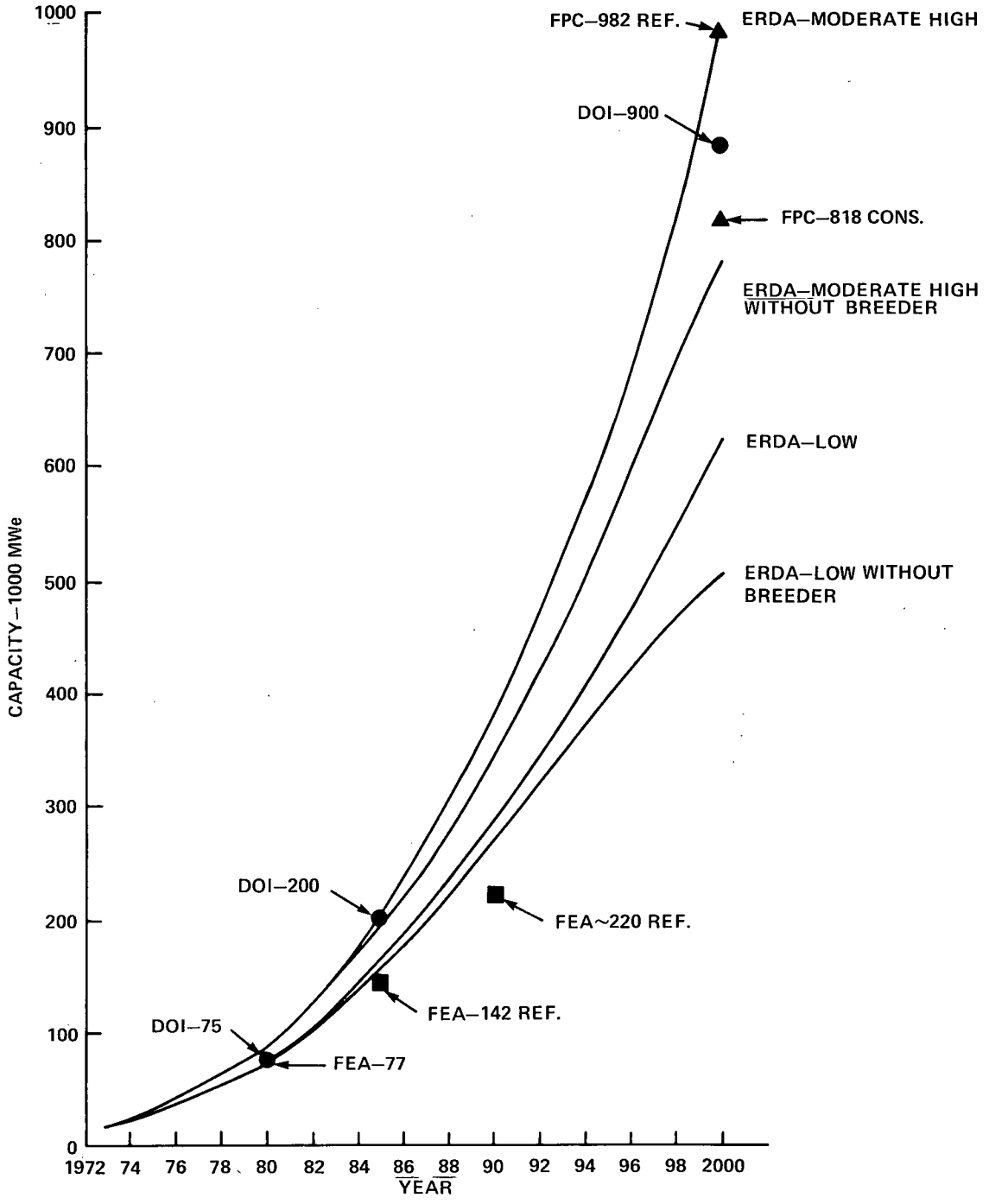


Figure III-5 Forecasts of Growth in Nuclear Power Generation Capacity

in 1985 and 893,000 and 507,000 MWe, respectively, in the year 2000. NRC has chosen to base the industry size on the Low Without Breeder forecast because some reactors have been cancelled and others have been deferred since the draft GESMO was issued in 1974; thus, the lower projections of installed nuclear generating capacity are considered realistic. FBR's are excluded so that all plutonium generated in LWR's will be recycled in LWR's. This removes the perturbation of FRB's from the analyses. The computer printouts of the ERDA Low Without Breeder forecast are presented in Appendix A of this chapter. These printouts are from the NUFUEL Program with corrections by Battelle Pacific Northwest Laboratories for the nuclear poisoning effects of ^{242}Pu and ^{236}U in recycle fuels.

The economic analyses presented in CHAPTER XI are centered on growth patterns bounded by the Moderate (High) With Breeder case and the Low Without Breeder case. The Moderate (High) Without Breeder and Low With Breeder cases were also analyzed to determine the sensitivity of the costs to the size of the LWR industry.

In the absence of other constraints, the growth in LWR nuclear power generation will depend on the total cost of the electricity generated by nuclear power plants, including the costs of all the safeguards, compared to the cost of electricity generated by other sources. If the growth of nuclear power is even less than forecast, the benefits will be less than forecast in this report. Because differential environmental impacts are also proportional to the quantity of nuclear power generated, they also can be expected to change directly with the size of the LWR industry.

5.0 ROLE OF PLUTONIUM RECYCLE

5.1 Domestic Uranium Resources and Relation to Use of LWR's

The analyses presented in this statement cover the 26-year period from 1975-2000, a period during which reasonable projections may apply. A longer range projection, beyond that time frame into the next century, would have to include additional considerations such as the long term availability of uranium resources, the emergence of other technologies such as laser enrichment and the contribution of other potentially cheaper power systems such as fusion, solar and geothermal. The ERDA estimates of the domestic uranium resources that are economically recoverable, 3.6 million tons of U_3O_8, are presented in Table III-11. The ERDA estimate is on the low side of a range of 2 to 10 million tons, which (CHAPTER XI) represents a spectrum of views by industry sources on this subject. The ERDA estimate is considered to be conservative because it is based on reports that, historically, have been made to ERDA only when industry is preparing to mine such resources.

Figure III-6[24] shows the ERDA projection of the quantity of uranium that would be committed for the various scenarios for projection of nuclear power generation. Scenario III is based on a projected nuclear generation capacity of about 720 GWe in the year 2000 with recycle of both uranium and plutonium. With no recycle, the same quantity of U_3O_8 would fuel about 540 GWe. As shown, the ERDA estimate of economically recoverable uranium resources exceeds the projected uranium commitments for LWR's.

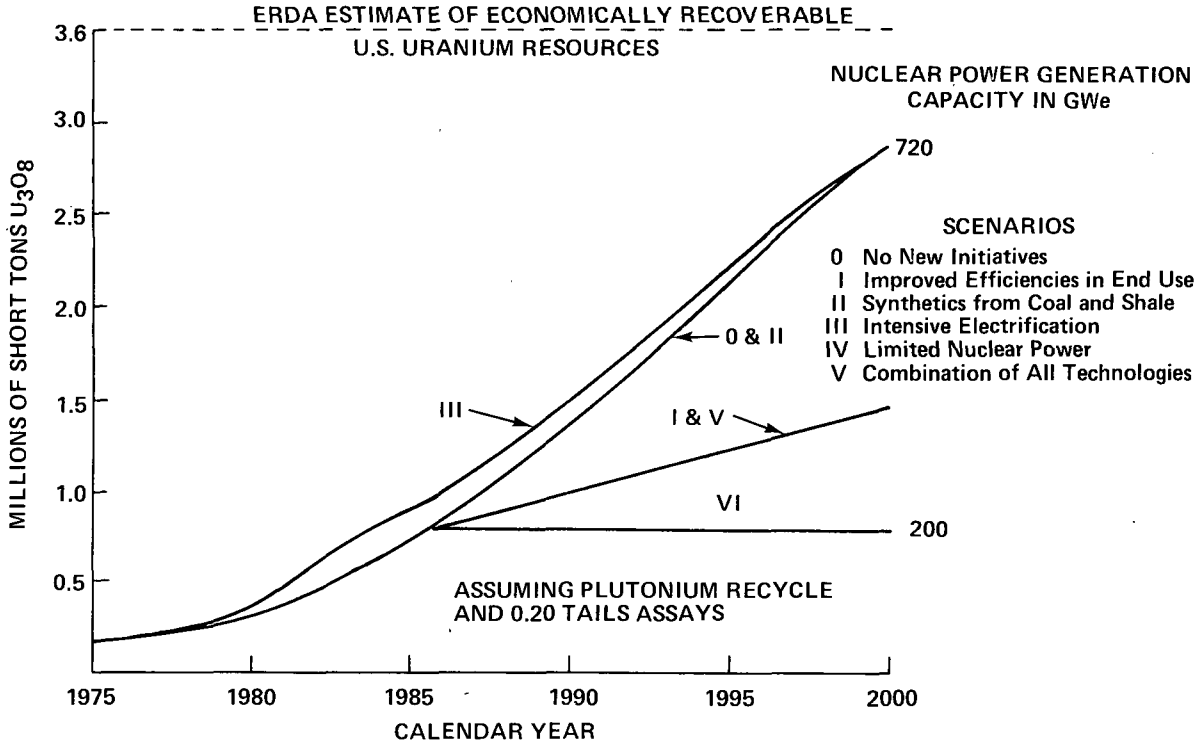


Figure III-6 Projected U_3O_8 Commitments for Model LWR's
(Source: ERDA 48)

A second potential impact on the nuclear growth scenario depends not on the total available uranium ore resource but on the ability of the mining and milling industry to produce sufficient refined U_3O_8 to meet the demand on a year-by-year basis. Development of this capability by the industry does depend in part on the availability of resources, since capital commitments to mines and mills will not be made until ore deposits are confirmed, but it also depends on the inherent ability of the industry to expand rapidly enough to meet the demand. This limitation on ore production capability, if it occurs, may impact LWR power production in the mid-1980's.

While uranium and plutonium recycle can have an appreciable effect in stretching out the potential power available from fixed ore resources by as much as 30%, the impact of recycling fuel on a near-term basis will be considerably less, reducing the ore demand by about 16% in 1985 and about 20% in 1990 (see paragraph 1.5, CHAPTER IV, Section F). This is because in a growing nuclear economy much of the ore will be needed to provide initial cores for new reactors and these new reactors will not contribute to the overall production rate for several years after initial operation.

In summary, the supply of uranium ore available in this country may be an important factor in determining the long term (in the 21st century) size of the LWR industry. If the supply is less than projected by ERDA, the installation rate of LWRs may be lower than projected; on the other hand if the supply is greater, more LWR's than projected may be built. In addition, independent of overall uranium supply, the growth of installed LWR generating capacity could be limited by the ability of the uranium mining-milling industry to meet the demand. Uranium and plutonium recycle to LWR's could serve to mitigate any effects of uranium supply to some extent and allow the industry additional time to exploit alternate energy sources; however, for this analysis, recycle of only uranium or recycle of both uranium and plutonium are not judged to affect the number of LWR's in the time period considered by the GESMO Statement.

5.2 Availability and Dependence on Foreign Supplies

Uranium resources have been discovered and are being exploited in a number of foreign countries. Currently estimates of reasonably assumed uranium resources in the $15/lb category outside the United States are slightly over one million tons with the majority of the deposits (75%) occurring in Australia, Canada, and South and Southwest Africa. (Additional details on foreign uranium resources are given in paragraph 1.3 of CHAPTER IV, Section F of this report.) However, expanding nuclear programs in other countries are expected to place heavy demands on these supplies.[31] This, plus the fact that dependence on foreign ore would leave a major source of U.S. electrical generation capacity depending on the vagaries of international politics (witness the current concerns over our dependence on imported petroleum), makes dependence on foreign uranium resources highly undesirable.

5.3 Relationship Between Pu Recycle and the Long Term Nuclear Option

In the context of currently recognized technological capability and the availability of fossil fuel reserves, nuclear power is envisioned as a major contributor to

the overall national energy supply in the twenty-first century. From the foregoing discussion on uranium ore resources and the demands made on them by "burner" reactors it is clear that such a long term nuclear option can be sustained only by development of alternate "synthetic" supplies of fissionable material. There are two candidates in this area, plutonium bred from fertile ^{238}U and ^{233}U bred from fertile ^{232}Th.

The national plan for energy research and development[24] envisions the former of the two options as the most promising. Therefore, the bulk of the ERDA research and development effort has been and will be directed toward the liquid metal fast breeder reactor (LMFBR) concept which utilizes the ^{238}U-Pu fuel cycle. If the ERDA plan is realized, plutonium recycle will be required because it forms the basis of the fuel supply for the breeder reactor. In this larger context, plutonium recycle to LWR's will assume a relatively minor status. However, in the early stages of implementation of the nuclear plan, LWR plutonium production, reclamation, and utilization assumes a major role, both because of its potential to augment a valuable natural resource and because LWR plutonium will be necessary for the initial charges to the first generation of breeder reactors. If the ERDA estimate of uranium resources is correct there will be ample plutonium produced by LWR's to supply both the LMFBR initial core requirements and provide a substantial incremental contribution to LWR produced power. If the ore supplies are limited, LWR fuel will still have to be reprocessed and the plutonium saved if the breeder program is to succeed. To the extent that plutonium is not needed by the plutonium breeder concept, plutonium recycle to LWR's will allow an extension of the period during which LWR reactor power can utilized.

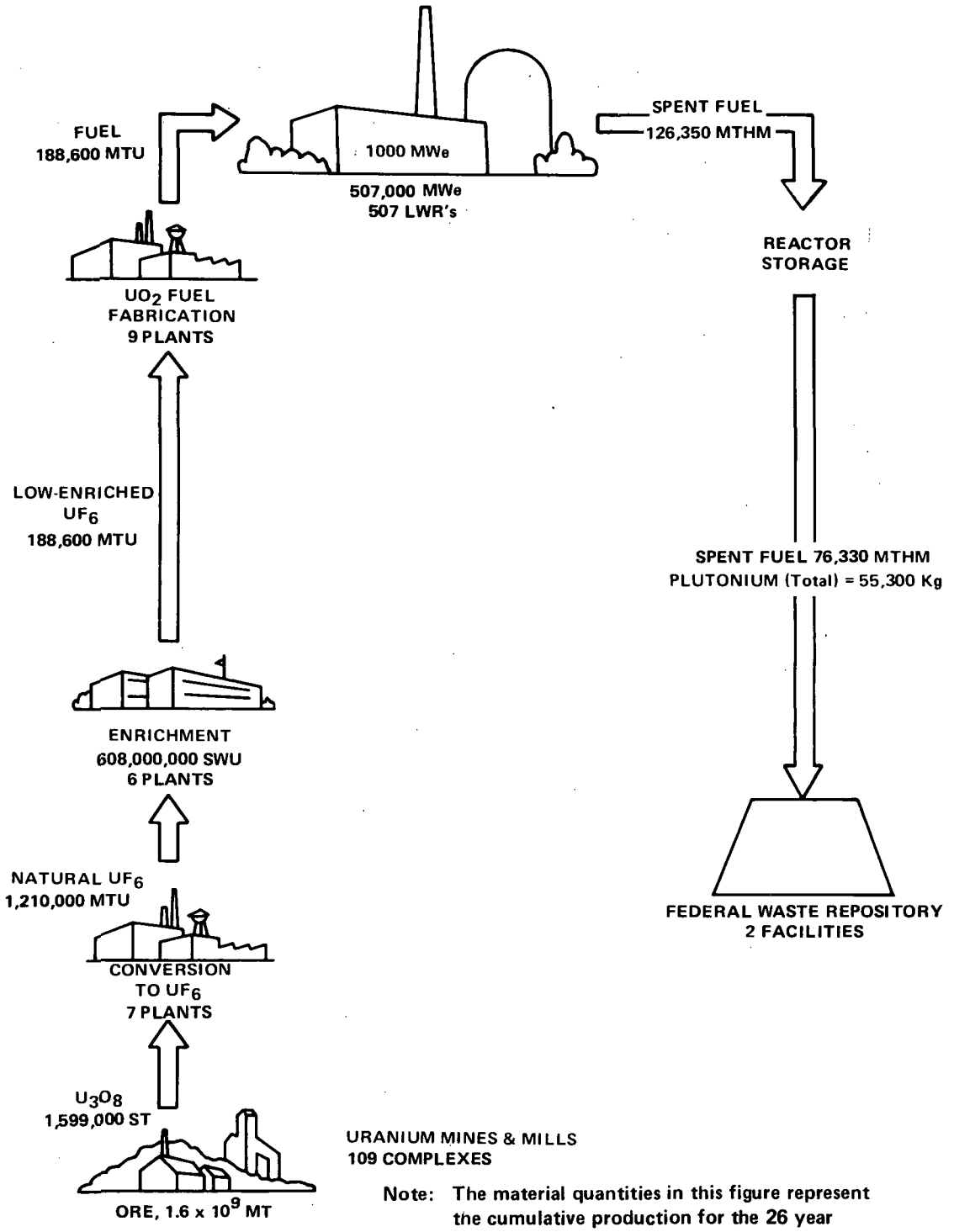
5.4 The Availability of Plutonium

The cumulative quantity of fissile plutonium recovered from spent LWR fuel is shown in Table III-18 for the ERDA Low Case Without Breeder. In the year 2000, the cumulative quantity of fissile plutonium recovered is 689 metric tons (MT) for the uranium only recycle option and 790 MT for recycle of both uranium and plutonium.

Although this analysis centers on a case that excludes FBR's (Low Growth Without Breeders), the recycle of both uranium and plutonium in LWR's would result in the development of fuel cycle facilities needed for the FBR fuel cycle, such as reprocessing plants, PuO_2 conversion facilities and MOX fuel fabrication plants. Unless both U and Pu are recycled in LWR's, these fuel cycle facilities might not be in place when needed for FBR's. Additional benefits would accrue from the fact that the safeguards and transportation systems for plutonium would be in place. Conversely, if LWR fuel is not recycled, there would be no commercial plutonium available to fuel the early FBR's.

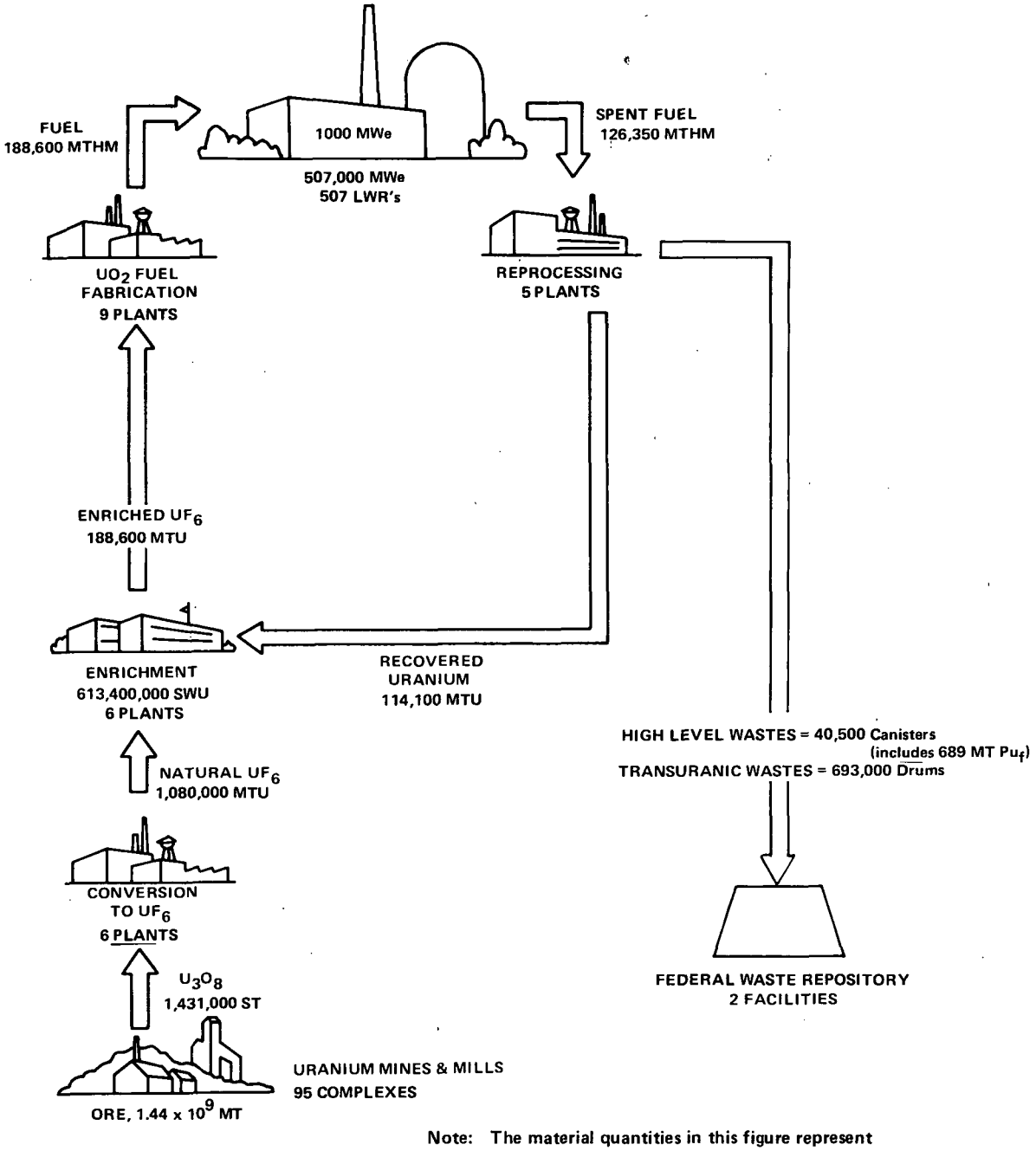
6.0 THE LWR INDUSTRY IN THE YEAR 2000

The LWR industry projected in the year 2000 for each of the three recycle options is shown graphically in Figures III-7, III-8, and III-9. The materials flow is shown for each step of the fuel cycle as well as the cumulative quantity of material processed for the period 1975 through 2000 and the numbers of each type of fuel cycle facility in the year 2000. (See also Tables III-1, III-2 and III-3.)



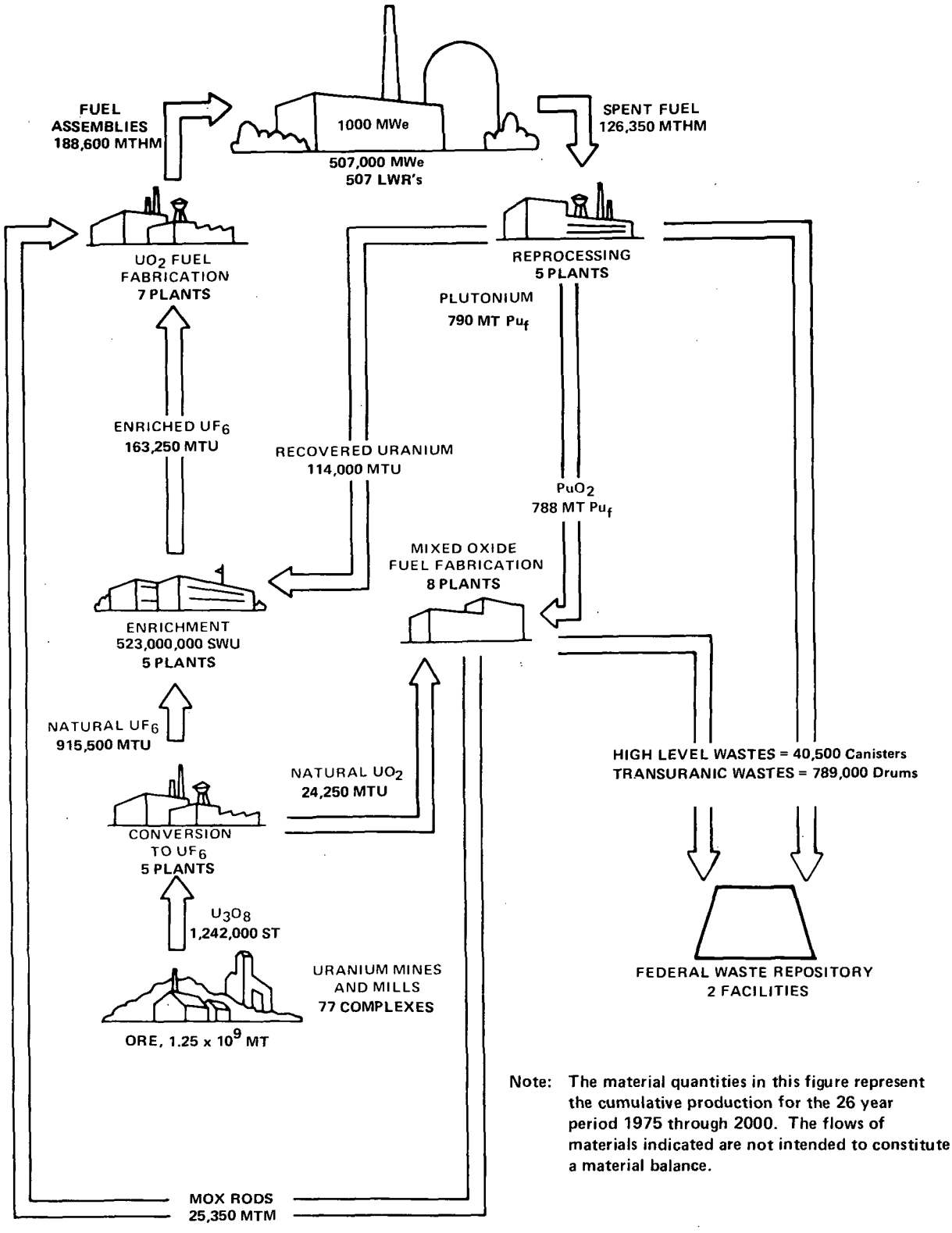
Note: The material quantities in this figure represent the cumulative production for the 26 year period 1975 through 2000. The flows of materials indicated are not intended to constitute a material balance.

Figure III-7 The Model Light Water Reactor Industry in the Year 2000 Without Uranium or Plutonium Recycle, ERDA - OPA, 1975 Projection, Low Growth, Without Breeder



Note: The material quantities in this figure represent the cumulative production for the 26 year period 1975 through 2000. The flows of materials indicated are not intended to constitute a material balance.

Figure III-8 The Model Light Water Reactor Industry in the Year 2000 With Uranium Recycle Only, ERDA - OPA, 1975 Projection, Low Growth, Without Breeder



Note: The material quantities in this figure represent the cumulative production for the 26 year period 1975 through 2000. The flows of materials indicated are not intended to constitute a material balance.

Figure III-9 The Model Light Water Reactor Industry in the Year 2000 With Uranium and Plutonium Recycle, ERDA - OPA, 1975 Projection, Low Growth, Without Breeder

Table III-18

CUMULATIVE FISSILE PLUTONIUM RECOVERED FROM LWR's
(ERDA LOW CASE WITHOUT BREEDERS)

Year	U Recycle Only (MT)	Recycle of Both U & Pu (MT)
1975	0	0
1980	0	12
1985	0	68
1990	142	190
1995	386	431
2000	689	790

Models based on estimated capacity and process were developed for each type of fuel cycle facility. These models are described in the various sections of CHAPTER IV.

The LWR industry projected in this chapter is an extrapolation of the present industry. It is the basis used throughout this statement for assessing the incremental environmental and economic impacts of recycling uranium only or recycling both uranium and plutonium. Both recycle options are based on the assumptions that spent fuel will be reprocessed, that liquid high level wastes will be solidified and that the solidified wastes will be sent to a Federal respository and be managed by the Federal Government. Variations of those recycle options to reflect variations in timing are discussed as alternatives in subsequent chapters. Those alternatives are discussed in detail in CHAPTER VIII and are compared in CHAPTER XI. The detailed economic analyses are also presented in CHAPTER XI.

6.1 The Components of the LWR Industry

The components of the LWR industry will be described in more depth for each of the three options:

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

6.1.1 Reactors

More than 500 nuclear power plants of 1,000 MWe generating capacity each are projected for the LWR industry in the year 2000 regardless of which option is under consideration. With no recycle or with recycle or uranium only, all 500 reactors would be fueled with slightly enriched UO_2. If both uranium and plutonium were recycled, it

is likely that some of the fuel in about half the reactors would be mixed oxide and the remaining LWR's would be fueled with the standard type of slightly enriched UO_2 with no plutonium added.

The light water reactor industry has two types of reactors, pressurized water reactors (PWR's) and boiling water reactors (BWR's). For equivalent power ratings, BWR's typically have larger cores and longer fuel residence times than PWR's; hence, the inventory of long half life nuclides including plutonium accumulated in the core is noticeably larger in BWR's than in equivalent PWR's. Therefore, for purposes of assessing the potential environmental impact of LWR operations, the boiling water reactor has been chosen as the basis for characterizing the model reactor. This was done to provide an assured margin of safety for the evaluation of radioactive effluents at LWR sites.

If uranium and plutonium were both recycled, 13.4% of the total fuel fabricated for the LWR industry over the 26-year period would be mixed oxide. In the year 2000, 2,650 MTHM of MOX fuel and 10,850 MTH of UO_2 fuel would be fabricated (Appendix III-A, p. III A-8). This study assumes that the model plutonium recycle reactor would contain 1.15 times as much plutonium as had been generated in its own fuel. The 1.15 self-generation rate (1.15 SGR) is discussed in CHAPTER IV, Section C. In the model reactor, approximately 40% of the fuel rods contain mixed oxide and 60% contain low enriched UO_2. Because 2,650 MTHM of the 13,500 MTHM fuel required for the industry in the year 2000 would be mixed oxide and because mixed oxide is assumed to be contained only in equilibrium SGR's, then it follows that the number of such equilibrium SGR's in the year 2000 would be about 250.* Thus, with recycle of both uranium and plutonium, about half of the 500 reactors of 1,000 MWe each in the year 2000 would be using some mixed oxide fuel. The remaining half of the LWR's would be fueled solely with slightly enriched UO_2.**

6.1.2 Mixed Oxide Fuel Fabrication

Recycle of plutonium in light water reactors would require production of about 25,000 MTHM of mixed oxide (UO_2 + PuO_2) fuels over the 26-year period and about 2,600 MTHM in the year 2000. Production of 2,600 MTHM in the year 2000 is projected to take place in 8 model mixed oxide fuel fabrication facilities; each having a capacity of 360 MTHM/yr.

Mixed oxide fuel fabrication would require special facilities that would not be required for the options with no recycle of plutonium. Because of the toxicity and radioactivity of the plutonium it is judged that manufacture of mixed oxide fuels in

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* $\frac{2,650}{13,500 \times 0.4} \times 507 = 249$

An alternative calculation based upon 81.6 MT Pu_f from p. III A-8, 581 Kg Pu_t in 1/3 of the reactors (BWR's) (from CHAPTER IV, Section C) and 485 Kg Pu_t in 2/3 of the reactors (PWR's) (not reported elsewhere in this document) and $\frac{Pu_f}{Pu_t}$ ratio of 0.6 yields an estimate of the number of 1.15 SGR's in 2000 as 264, i.e., about 250.

**The number of reactors employing some MOX fuel could be higher if some of them have less than an equilibrium 1.15 SGR loading of plutonium.

existing or modified low enriched UO_2 fuels fabrication plants would not be feasible. There are currently no commercial production scale manufacturing plants for mixed oxide fuel although five pilot scale plants with a total estimated capacity of 50 to 70 MTHM/yr are licensed to fabricate mixed oxide fuel (CHAPTER IV, Section D). The Westinghouse Electric Corporation has applied for a license for a production scale facility (Westinghouse Recycle Fuels Plant) for the manufacture of mixed oxide fuel rods. This plant is planned for a nominal capacity of 200 MTHM/yr with eventual expansion to 400 MTHM/yr. If a decision is made by about 1977 to recycle Pu, commercial operation could begin in the early 1980's.

It is anticipated that commercial mixed oxide fuel fabrication plants will be designed for large production capacities to take advantage of scale. Large throughputs will be important economically because the requirements for safety, safeguards and protection of the environment for each new plant will make such plants capital intensive.

The net impact on the mixed oxide fuel fabrication industry of recycling plutonium in LWR's is to increase the size of the industry from essentially none at present to about 8 fuel fabrication facilities (360 MTHM/yr capacity each) by the year 2000.

6.1.3 Fuel Reprocessing

Fuel reprocessing plants would be required if uranium or both uranium and plutonium were recycled.

The anticipated total reprocessing load would be approximately 115,000 MTHM over the 26-year period and 10,250 MTHM in the year 2000. Thus, at the end of this century five equivalent model reprocessing plants would be required if uranium only were recycled of if both uranium and plutonium were recycled. This is discussed in detail in CHAPTER IV, Section E.

6.1.4 The Supporting Uranium Cycle

The total demand for low enriched UO_2 fuels during the entire period from 1975-2000 would be about 188,000 MTU if only uranium were recycled and about 163,000 MTU if both uranium and plutonium were recycled. In the year 2000, the total annual demand for low enriched UO_2 fuels would be 13,500 MTU for no recycle or if only uranium were recycled and 10,850 MTU if both uranium and plutonium were recycled. These estimates show that recycle of both uranium and plutonium result in reductions of 13% for the total requirement for UO_2 over the 26-year period and 20% for the requirement in the year 2000. These reductions would be achieved by substituting a total of 25,330 MTHM of mixed oxide fuel (UO_2 + PuO_2) for low enriched UO_2 fuel from 1975 through 2000 and 2,647 MTHM in the year 2000. About ninety-five percent of the mixed oxide fuel would be non-enriched UO_2. This study assumes that mixed oxide fuel would be made with recycle PuO_2 diluted with natural UO_2 and that the natural UO_2 would be supplied to the mixed oxide plants by the UF_6 industry as an intermediate product.

Thus, the individual components of the supporting uranium cycle would experience a decrease in demand if uranium only were recycled and a greater decrease if both uranium and plutonium were recycled. The components of the supporting uranium fuel cycle in which the decreased demand would be experienced are the following:

- Mine-mill complexes
- UF_6 conversion
- U enrichment
- UO_2 fuel fabrication

6.1.4.1 Mine-Mill Complexes

Mine-mill complexes* are postulated to consist of one mill and the associated mines that provide ore to it. In the year 2000, two sizes of mills are anticipated. The average capacity of existing mills is about 1,800 tons** or ore per day, whereas the capacity of newer mills is expected to average 3,500 tons daily. It is assumed that each mill would receive ore from both underground and open pit mines, 60% from underground mines and 40% from open pit mines. The annual ore production of existing underground mines averages about 14,000 tons, but newer mines are expected to have an average annual capacity of about 20,000 tons. The annual production of existing open pit mines averaged about 140,000 tons of ore in 1974 but the newer open pit mines are expected to have an average annual capacity of 200,000 tons of ore each. In the past, the ore grade has averaged about 0.2% U_3O_8; in the year 2000, the grade is estimated to average about 0.1% U_3O_8, meaning that twice as much ore would have to be processed for each ton of U_3O_8. A typical mine-mill complex in existence today consists of one mill, about eight underground mines and one open pit mine. A typical newer mine-mill complex is postulated to consist of one mill, one open pit mine, and about 37 underground mines.

If uranium and plutonium are not recycled, the estimated U_3O_8 required to fuel LWR's is 1,600,000 short tons over the 26-year period, and 113,900 short tons in the year 2000. This would require processing about 125 million short tons of ore per year in about 16 older mine-mill complexes that now exist and 93 newer mine-mill complexes for a total of 109 mine-mill complexes in the year 2000.

If only uranium is recycled, the projected U_3O_8 requirements would be reduced by 170,000 tons (10.5%) over the 26-year period and by 15,000 tons (13.3%) in the year 2000. This would require processing about 125 million short tons of ore per year in about 16 older mine-mill complexes that now exist and 93 newer mine-mill complexes for a total of 109 mine-mill complexes in the year 2000. The reduced quantity of ore and U_3O_8 could be processed by about 77 model mine-mill complexes (16 older, 61 newer).

*The concept of "mine-mill complex" is used here to facilitate discussion of the mining and milling industry. Accordingly, a conceptual model of an average size mill and a group of average size mines to supply ore to the mill was developed. In actuality, the sizes of mills and mines vary widely and there is no "average complex."

**Tons indicates short tons, and MT indicates metric tons.

If both uranium and plutonium are recycled, the U_3O_8 requirements could be reduced by 22.3% over the 26-year period and 29.3% in the year 2000. The reduced quantity of ore and U_3O_8 could be processed by about 77 model mine-mill complexes (16 older, 61 newer).

Thus, the net effect of recycling only uranium or of recycling both uranium and plutonium in LWR's is to reduce the number of typical mine-mill complexes from 109 to 95 and from 109 to 77, respectively. Because 16 complexes are already in place and assumed to continue operating, recycling uranium only would reduce the number of new complexes required by 13% and recycle of both uranium and plutonium would reduce the number by 29%.

6.1.4.2 UF_6 Conversion

Two types of plants are expected to convert U_3O_8 to UF_6 in the year 2000. One is based on an aqueous process using solvent extraction purification. It is called the wet process for UF_6 because it is based on aqueous technology. The other uses the Hydrofluor process (dry process), which is based upon nonaqueous technology wherein purification is effected by distillation of volatile uranium hexafluoride. The Hydrofluor process produces relatively low volumes of liquid effluents. There are now two operating commercial UF_6 facilities. One uses the dry process, is located at Metropolis, Illinois, and has the capacity to convert annually 14,000 tons of uranium as U_3O_8 to UF_6. The other uses the wet process, is located at Sequoyah, Oklahoma, and has the capacity to convert annually 5,000 tons of U as U_3O_8 to UF_6.

The UF_6 conversion requirement for the 26-year period is projected to be 1,200,000 MTU with no uranium or plutonium recycle, 1,100,000 MTU with recycle of uranium only and 920,000 MTU with recycle of both uranium and plutonium. In the year 2000, the annual requirement for each of the 3 recycle options would be 87,300 MTU, 75,500 MTU and 59,300 MTU, respectively.

This analysis assumes that the UF_6 conversion industry in the year 2000 would consist of the two existing facilities (with the wet process plant upgraded to a capacity of 9,100 MTU/yr) plus 5, 6, or 7 new 15,000 MTU/yr plants, depending on whether the choice is recycle of both uranium and plutonium, only uranium or no recycle. Because there appears to be no unanimous preference for either process, it is expected that the new facilities would be evenly divided between the two processes if only uranium is recycled. If there is no recycle, or if both uranium and plutonium are recycled, it is assumed that four and three of the new plants, respectively, would use the dry process and three and two, respectively, would use the wet process.

Thus, in the year 2000, the recycle of uranium only would reduce the number of 15,000 MTU/yr UF_6 conversion plants from 7 to 6 and the recycle of both uranium and plutonium would reduce the number of large plants from 7 to 5. To prorate associated environmental impacts, it is assumed that if only uranium were recycled, the reduction would be about 1/2 of a 15,000 MTU/yr wet process plant and 1/2 of a dry process plant. The reduction would be one plant of each type if both uranium and plutonium were recycled.

6.1.4.3 Uranium Enrichment

This study projects that the enrichment of uranium in the United States in the year 2000 would be performed in two types of enrichment facilities. One type would consist of the three existing gaseous diffusion plants (owned by the U.S. Government) upgraded to provide an aggregate capacity of 27.7 million separative work units per year (SWU/yr). A second type would be gas centrifuge facilities that are expected to have an annual capacity of about 8.75 million SWU each. It is assumed that the first new enrichment plant would be an 8.75 million SWU gaseous diffusion plant and that all subsequent plants would utilize the gas centrifuge technique. The annual volume of low level waste from a model gas centrifuge process is expected to be about 56 times greater than that from a model gaseous diffusion plant for the same quantity of separative work. However, the impact due to release of radiological effluents to the environment is about the same for each type of plant.

The projected uranium enrichment demand for the 26-year period from 1975 through the year 2000 would be 608 million SWU if there is no recycle, 613 million SWU if only uranium is recycled and 523 million SWU if both uranium and plutonium are recycled. In the year 2000 alone, the annual enrichment demand for no recycle, recycle of uranium only or recycle of both uranium and plutonium would be 45, 45.5 and 36.1 million SWU's, respectively. If uranium and plutonium were not recycled or if only uranium were recycled, the enrichment requirement would be essentially the same and could be met by six plants, i.e., the three upgraded facilities and three new facilities. If both uranium and plutonium are recycled, only two new facilities would be required. Thus, recycle of both uranium and plutonium would reduce the size of the uranium enrichment industry by one 8.75 million SWU/yr capacity plant.

6.1.4.4 UO_2 Fuel Fabrication

A typical UO_2 fuel fabrication plant is expected to have an annual capacity of 1,500 MTU/yr. It would be capable of processing slightly enriched UF_6 into UO_2 fuel assemblies. A typical facility would also be capable of processing its own dirty scrap using a nitric acid based aqueous process. Two types of processes for converting UF_6 to UO_2 powder are expected to be in use at the end of this century. One is the traditional ammonium diurante (ADU) process wherein UF_6 is reacted with water and ammonia to yield a precipitate of ammonium diuranate and large volumes of liquid effluents. The other process, which is often referred to as the dry conversion or direct conversion process, reacts UF_6 with steam and hydrogen to yield UO_2. Although the dry process when fully developed is expected to yield lower volumes of liquid effluents, this study conservatively assumes all plants would use the ADU process.*

The projected requirement for UO_2 fuel fabrication for the 26-year period is 188,600 MTU if there is no recycle or if only uranium is recycled and 163,240 MTU if both uranium and plutonium are recycled.

In the year 2000, the projected 507 operating LWR's would require about 13,500 MT of fuel. If there is no recycle or if only uranium is recycled, the industry would be

*See CHAPTER IV, Section F, for more detailed description of plants.

the same and the entire 13,500 MT would be supplied as UO_2 fuel from nine 1,500 MTU/yr plants. If both uranium and plutonium are recycled, the UO_2 fuel fabrication industry would supply about 10,800 MTU and 7 plants would be required. This study assumes that if both U and Pu were recycled, natural UO_2 would be used in the 2,650 MT of mixed oxide fuel requirement projected for the year 2000. This natural UO_2 would be supplied to the mixed oxide plants by the UF_6 conversion industry as an intermediate product.

Thus, the environmental impact of the uranium fuel fabrication industry would be essentially the same if there is no recycle or if only uranium is recycled. However, if both uranium and plutonium are recycled, the effect would be the reduction in size of the industry from nine to seven 1,500 MTU/yr plants, thus saving two plants.

6.2 Transportation

The impact of the transportation component on the LWR industry for each of three options is assessed in terms of differences in the numbers of total shipments of fuel to and from the reactors and shipments of various plant feedstocks, products, scrap and wastes.

If there is no recycle of uranium and plutonium, the significant transportation component would consist of shipment of enriched UO_2 from the enrichment plants to the fuel fabrication plants, shipment of unirradiated fuel assemblies to the reactor and, ultimately, shipment of irradiated fuel assemblies from the reactor to interim storage or to a Federal repository. If only uranium is recycled, the significant transportation component would consist of shipment of enriched UO_2 from the enrichment plants to the fuel fabrication plants, shipment of unirradiated fuel assemblies to the reactor, shipment of irradiated fuel assemblies from storage at the reactor to a reprocessing plant and shipment of plutonium and high level waste to a Federal repository. Shipment of irradiated fuel assemblies to a Federal repository would be eliminated.

If both uranium and plutonium were recyled, the significant transportation component would consist of shipment of enriched UO_2 from the enrichment plants to the fuel fabrication plants, shipment of Pu to the MOX fuel fabrication plants, shipment of MOX fuel rods to the UO_2 fuel fabrication plants, shipment of unirradiated fuel assemblies to the reactors, shipment of irradiated fuel assemblies from storage at the reactors to the reprocessing plants and shipment of high level waste to a Federal repository. Shipment of plutonium to a Federal repository would be eliminated.

The total mileage and impacts from shipments of fuel material and waste materials for the three options are discussed in CHAPTER IV, Section G. Compared to no recycle, the total shipping distances for the 26-year period (for categories of shipments affected by recycle of U or both U and Pu) including return of empty containers would decrease by approximately 17% if only uranium is recycled and by about 6% if both uranium and plutonium are recycled. The decrease is due to reduced shipments of spent fuel assemblies. The study assumes that for no recycle the spent fuel assemblies would be shipped twice (first from the reactor to a spent fuel storage facility and later to a Federal repository) but for recycle of U or U and Pu, the spent fuel would be shipped once (from reactor to reprocessing plant). Two significant mileage increases would

result from shipping PuO_2 powder to the mixed oxide fuel fabrication plants and shipping mixed oxide fuel rods to the UO_2 fuel fabrication plants. A mileage decrease would result from shipping less PuO_2 to storage.

The recycle of uranium or both uranium and plutonium would result in reduced total shipping distances for radioactive wastes and for uranium ore and U_3O_8 concentrates over the 26-year period and in the year 2000. Major mileage increases would result from shipment of low level alpha waste* from reprocessing plants to a Federal repository.

Shipment of uranium ore from mines to mills and shipment of U_3O_8 concentrates from mills to UF_6 conversion plants does not impact significantly on the environment; however, these shipments would be reduced if only uranium or both uranium and plutonium are recycled. For example, if only uranium is recycled, the shipments would be decreased by 10 percent over the 26-year period and by 13 percent in the year 2000. If both uranium and plutonium are recycled, the shipments would be reduced by 13 percent over the 26-year period and by 18.5 percent in the year 2000.

Other reductions in shipping mileage would accrue from recycle both uranium and plutonium. Over the 26-year year period, shipments of UF_6 to enrichment plants and low enriched UF_6 to UO_2 fuel fabrication plants would be decreased by 13 percent. In the year 2000, these shipments would be decreased by approximately 20 percent.

Transportation is discussed in detail in CHAPTER IV, Section G.

6.3 Waste Management

Although radioactive wastes are produced in all steps of the fuel cycle, if only uranium or both uranium and plutonium are recycled, the wastes produced at the separation step of fuel reprocessing would contain more than 99% of the total activity of all the wastes produced. The reprocessing wastes contain virtually all of the fission products and transplutonium actinides plus about 0.5% of the uranium and plutonium present in the spent fuel from LWR's. All other radioactive wastes are categorized as other than high level wastes. These other radioactive wastes are generated during reactor operations, MOX fuel fabrication, fuel reprocessing (other than U and Pu separation) and UO_2 support cycle operations.

Other than high level wastes that contain in excess of some limit* of transuranium alpha activity are a special subdivision of other than high level wastes and are expected to be sent to a Federal repository. Designs of the disposal facilities are not final but the concept is discussed in detail in the section on waste management (CHAPTER IV, Section H).

Other than high level wastes that contain more than trace concentration of transuranium alpha activity are expected to be managed by burial at commercially operated

*Low level alpha wastes are other than high level wastes containing not more than trace concentrations of transuranics, e.g., 10 nCi/g.

burial sites located on State or Federally owned land. These wastes are essentially the same for any fuel cycle option selected. A model burial site consists of about 100 acres with a total capacity of 25 million cu ft of waste.

The solid wastes resulting from reactor operations consist of spent ion exchange resin, filters, filter sludge and evaporator bottoms. The quantity of this waste would be about the same for all three options and the radioactive composition of the waste would not vary significantly. It is projected that the total wastes generated from all LWR's over the 26-year period would be about 18 million drums (135 million cu ft). Because this waste is not expected to contain more than trace concentrations of transsuranium alpha activity, it could be sent to a commercial burial ground. Approximately 540 acres of commercial waste burial ground would be required for this reactor generated waste. The projected cumulative waste for the 26-year period from 1975-2000 is summarized for each of the three recycle options in Table III-19.

Table III-19

PROJECTED CUMULATIVE WASTE INVENTORY
IN THE YEAR 2000

Type of Waste	Fuel Cycle Option		
	No Recycle	U Recycle Only	U and Pu Recycle
1. Spent Fuel Assemblies	400,000	37,000*	37,000*
2. High Level	None	37,000 canisters	37,000 canisters
3. Transuranic Waste	None	365,000 drums	460,000 drums
4. Hulls and Other Parts of Spent Fuel Elements Transuranic Waste	None	250,000 drums	250,000 drums
5. Low Level Waste			
a. From Reactors	18×10^6 drums	18×10^6 drums	18×10^6 drums
b. From All Sources	20×10^6 drums	20×10^6 drums	20×10^6 drums

*These 37,000 fuel assemblies would be in inventory awaiting reprocessing. They would would not be waste.

6.3.1 No Recycle of Uranium or Plutonium

If there is no recycle of uranium or plutonium, there would be no reprocessing and the spent fuel elements themselves would constitute the high level waste; thus, more than 99% of the activity in the waste resulting from the entire fuel cycle would remain in the spent fuel assemblies. For the 26-year period, the projected cumulative inventory of spent fuel in fuel assemblies would be about 126,350 MTHM or about 400,000 fuel assemblies (based upon 2/3 of the reactors being PWR's and 1/3 being BWR's). These spent fuel assemblies could remain up to 10 years or longer in storage

pools at the reactors or special storage facilities, but would ultimately be sent to Federal repositories for packaging and permanent storage. Two Federal repositories are projected for the year 2000 (Table III-1). Spent fuel storage is discussed in detail in CHAPTER IV, Section K.

6.3.2 Recycle of Uranium Only or Recycle of Both Uranium and Plutonium

If only uranium is recycled, spent fuel would be reprocessed to recover usable ^{235}U and plutonium would be sent to a Federal repository. (As shown in Table III-2, two Federal repositories are projected for the year 2000.) The most difficult of the radioactive wastes to handle from a standpoint of heat and shielding would be the high level liquid wastes (defined as aqueous waste resulting from operation of the first cycle extraction system and the concentrated waste of subsequent extraction cycles in a facility for reprocessing irradiated fuels). These wastes would contain essentially all of the fission products, transplutonium elements and neptunium. They also would contain about 1/2% of the uranium and plutonium in the spent fuel. One of the major steps in the management of wastes would be converting high level liquid wastes and Pu solutions to solids prior to transportation and storage.

It is assumed that solidified high level waste would be stored in canisters 10 feet long and up to 14 in. in diameter. A canister would contain 6.28 cu ft of solidified high level waste from about 3.14 MT of fuel processed. Thus, for the 26-year period, the total solidified waste from the total reprocessing load of 115,000 MTHM would be contained in about 37,000 canisters.

The same facilities would be used to store solidified high level waste if only uranium were recycled or if both uranium and plutonium are recycled.

Final storage provisions now under consideration for high level waste consist of isolation in geologic formations such as saltbeds or shale. It is projected that Federal facilities would be utilized to accommodate storage of spent fuel assemblies or all high level wastes accumulated through the year 2000 for each of the three fuel cycle options.

The recycle of both uranium and plutonium would result in the cumulative generation for the 26-year period of approximately five million cu ft of transuranic waste in the form of fuel hulls and other parts of fuel assemblies. Because this waste also contains activation products and small quantities of fission products, interim storage at the reprocessing plant may be desirable to allow some decay of radionuclides that emit penetrating beta and gamma radiation before transferral to a Federal repository.

The recycle of uranium only would entail sending plutonium to permanent geologic storage, probably in the same Federal repository used to store high level waste. The projected total plutonium inventory for the LWR industry in the year 2000 is about 1,000 MT if only uranium were recycled.

If only uranium is recycled or if both uranium and plutonium are recycled, the conversion of the recovered uranium to UF_6 would result in a total of about 110,000 drums (55-gal. drums) of low level waste over the 26-year period. Recycle of plutonium would eliminate the need to send plutonium to final storage. A detailed discussion of waste management is presented in CHAPTER IV, Section H.

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APPENDIX A

COMPUTER PRINTOUTS FOR CENTERLINE CASE
(LOW GROWTH WITH NO BREEDER)

This appendix consists of computer printouts from the NUFUEL Program for the ERDA Low Growth Without Breeder case. Corrections for the nuclear poisoning effects of ^{242}Pu and ^{236}U in recycle fuels were made by Battelle Pacific Northwest Laboratories.

ALT III - CASES 36 AND 38 - LOW GROWTH - 70% CF - 1978 RLP - 1981 REC - NO FBR 3.15.76 .01 .02

CUMULATED RESULTS

PLUTONIUM RECYCLE

GROSS WITHDRAWALS AT GDR TAILS ASSAY = .300

YEAR -CY-	URANIUM -MT-	U-235 -MT-	VALUE FN -MT-	SEP WORK - K SWU-	U AS UF6 -MT-	U IOA -MT-	NATURAL URANIUM -MT-	PLUTONIUM REQUIRED -MT-
1974	1190.	31.685	4082.	3385.	6840.	7816.	0.	0.
1975	1076.	31.511	3555.	3558.	6882.	9427.	0.	0.
1976	1457.	42.498	4822.	4785.	9277.	14106.	0.	0.
1977	1849.	51.986	6213.	5739.	11299.	15835.	0.	0.
1978	1946.	54.251	6561.	5959.	11779.	19035.	0.	0.
1979	2641.	71.936	8981.	7796.	15575.	17905.	0.	0.
1980	2985.	79.775	10233.	8658.	17231.	25013.	104.	3.
1981	3366.	88.364	11623.	9380.	19043.	26827.	294.	9.
1982	3738.	98.318	12999.	10452.	21193.	30222.	463.	14.
1983	3817.	104.998	12959.	11469.	22761.	38329.	368.	11.
1984	5263.	141.029	18042.	15164.	30472.	34714.	402.	12.
1985	5703.	151.683	19602.	16234.	32743.	44419.	449.	14.
1986	5374.	151.098	18088.	16709.	32841.	48536.	553.	17.
1987	6281.	174.372	21247.	19146.	37842.	53234.	709.	22.
1988	6808.	188.123	23066.	20599.	40803.	55178.	784.	24.
1989	7438.	206.906	25133.	22758.	44935.	61017.	813.	25.
1990	7841.	218.182	26503.	23988.	47362.	64820.	1018.	31.
1991	8310.	232.475	28032.	25645.	50498.	68756.	1250.	38.
1992	8722.	244.998	29376.	27089.	53244.	73434.	1420.	43.
1993	9235.	260.149	31070.	28808.	56556.	77135.	1580.	47.
1994	9470.	268.747	31769.	29883.	58476.	79498.	1807.	54.
1995	9727.	278.546	32815.	31127.	60672.	83479.	1949.	58.
1996	10193.	292.676	34332.	32752.	63770.	87242.	1956.	59.
1997	10579.	303.394	35432.	33924.	66097.	89055.	2006.	63.
1998	10566.	303.378	35269.	33941.	66102.	89817.	2332.	73.
1999	10734.	308.860	35794.	34592.	67314.	91435.	2486.	79.
2000	10873.	313.937	36210.	35224.	68447.	92401.	2586.	82.
2001	10934.	316.784	36359.	35609.	69095.	91167.	2698.	85.
2002	10028.	297.288	33029.	33822.	65013.	88738.	2857.	91.
2003	10361.	310.432	33973.	35511.	67968.	48239.	2434.	77.

ALT III - CASES 36 AND 38 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR 3.15.76 .01 .02

CUMULATED RESULTS PLUTONIUM RECYCLE

IRRADIATED RETURNS AT GDP TAILS ASSAY = .300

YEAR -CY-	URANIUM -MT-	U-235 -MT-	VALUE FN -MT-	SEP WORK - K SWU-	U AS UF6 -MT-	U3O8 -ST.	PLUTONIUM RECOVERED -MT-
1974	0.	0.000	0.	0.	0.	0.	0.
1975	0.	0.000	0.	0.	0.	0.	0.
1976	0.	0.000	0.	0.	0.	0.	0.
1977	0.	0.000	0.	0.	0.	0.	0.
1978	249.	2.113	1146.	22.	333.	957.	2.
1979	747.	7.395	3349.	230.	1243.	1823.	4.
1980	1243.	9.479	5555.	-24.	1414.	2216.	7.
1981	1491.	11.405	7011.	-34.	1704.	2264.	8.
1982	1589.	12.303	7454.	-18.	1850.	2551.	10.
1983	1887.	14.465	8878.	-32.	2163.	3002.	11.
1984	2085.	15.767	9829.	-66.	2341.	3372.	13.
1985	2235.	17.822	10462.	82.	2723.	3341.	14.
1986	2532.	18.538	12022.	-139.	2702.	3866.	17.
1987	3177.	22.844	15159.	-204.	3293.	4448.	22.
1988	3874.	26.061	18800.	-372.	3600.	5214.	24.
1989	4226.	29.234	20394.	-324.	4114.	5491.	26.
1990	4518.	31.617	21746.	-312.	4482.	6443.	32.
1991	5156.	37.116	24674.	-251.	5354.	7349.	38.
1992	5853.	42.275	27961.	-296.	6111.	8266.	43.
1993	6493.	46.234	31132.	-381.	6625.	9028.	48.
1994	7141.	50.488	34259.	-485.	7204.	9794.	54.
1995	7839.	55.510	37581.	-533.	7928.	10753.	58.
1996	8186.	57.598	39290.	-603.	8193.	10581.	59.
1997	8684.	61.735	41636.	-533.	8838.	12166.	63.
1998	9669.	67.840	46516.	-655.	9633.	13079.	75.
1999	10170.	70.705	49043.	-728.	9981.	12829.	79.
2000	10133.	69.531	49026.	-788.	9733.	12589.	82.
2001	10142.	68.602	49289.	-806.	9513.	12303.	86.
2002	10612.	72.241	51460.	-847.	10060.	13746.	91.
2003	11568.	78.905	56067.	-911.	11002.	7328.	75.

ALT III - CASES 36 AND 38 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR 3.15.76 .01 .02

CUMULATED RESULTS PLUTONIUM RECYCLE

YEAR -CY-	NET REQUIREMENTS AT GDP TAILS ASSAY = .300(URANIUM -MT-	U-235 -MT-	VALUE FN -MT-	SEP WORK $ K SMU-	U AS UF6 -MT-	U3O8 -ST-	NATURAL URANIUM -MT-	PLUTONIUM YR-END INV -MT-	REVENUE BASED ON CONTRACT -$M-
1974	1190.	31.689	4082.	3385.	6840.	7898.	0.	0.	0.
1975	1076.	31.511	3555.	3558.	6882.	9427.	0.	0.	0.
1976	1457.	42.498	4822.	4785.	9277.	14144.	0.	0.	0.
1977	1849.	51.986	6213.	5739.	11299.	15835.	0.	0.	0.
1978	1697.	52.138	5415.	5937.	11446.	18078.	0.	2.	0.
1979	1894.	64.541	5633.	7566.	14332.	16142.	0.	5.	0.
1980	1741.	70.295	4377.	8582.	15818.	22797.	104.	9.	0.
1981	1875.	76.959	4612.	9414.	17339.	24564.	294.	9.	0.
1982	2149.	86.019	5444.	10469.	19343.	27671.	463.	5.	0.
1983	1930.	90.533	4080.	11501.	20597.	35321.	368.	5.	0.
1984	3178.	125.263	8213.	15230.	28131.	31377.	402.	6.	0.
1985	3469.	133.060	9140.	16152.	30020.	41077.	449.	7.	0.
1986	2843.	132.560	6064.	16848.	30139.	44706.	553.	7.	0.
1987	3104.	151.528	6087.	19350.	34548.	48787.	709.	7.	0.
1988	2933.	162.062	4266.	20970.	37203.	49964.	784.	7.	0.
1989	3212.	177.762	4739.	23082.	40821.	55526.	813.	7.	0.
1990	3324.	186.565	4757.	24300.	42880.	58378.	1018.	8.	0.
1991	3153.	195.359	3358.	25897.	45144.	61416.	1250.	8.	0.
1992	2869.	202.723	1415.	27385.	47133.	65167.	1420.	8.	0.
1993	2742.	213.915	-62.	29189.	49930.	68127.	1580.	9.	0.
1994	2329.	218.259	-2490.	30368.	51272.	69704.	1807.	9.	0.
1995	1889.	223.038	-5065.	31661.	52744.	72726.	1949.	9.	0.
1996	2007.	235.079	-5257.	33355.	55577.	7666 .	1956.	9.	0.
1997	1895.	241.658	-6304.	34458.	57258.	76889.	2006.	9.	0.
1998	897.	235.538	-11247.	34597.	56469.	76742.	2332.	11.	0.
1999	563.	238.156	-13249.	35321.	57332.	78606.	2486.	12.	0.
2000	740.	244.409	-12817.	36012.	58714.	79810.	2586.	12.	0.
2001	792.	248.182	-12930.	36416.	59583.	78864.	2698.	13.	0.
2002	-584.	225.047	-18431.	34669.	54953.	74991.	2857.	14.	0.
2003	-1206.	231.528	-22094.	36422.	56966.	40911.	2434.	12.	0.

ALT III - CASES 36 AND 3A - LOW GROWTH - 70% CF - 1978 RER - 1981 REC - NO FBR - 3.15.76 .01 .02

CUMULATED RESULTS — PLUTONIUM RECYCLE

SPENT FUEL STORAGE AND REPROCESSING IN -MT. OF HEAVY METAL BY QUARTER YEARS

FOR LIGHT WATER REACTORS

-CY-	ADDITIONS TO STORAGE BASINS (1)	(2)	(3)	(4)	FUEL REPROCESSING (1)	(2)	(3)	(4)	STORAGE BASIN REQUIREMENTS (1)	(2)	(3)	(4)
1974	727.	0.	77.	120.	0.	0.	0.	0.	727.	727.	804.	924.
1975	54.	189.	47.	361.	0.	0.	0.	0.	978.	1167.	1215.	1575.
1976	158.	229.	173.	204.	0.	0.	0.	0.	1734.	1962.	2135.	2339.
1977	297.	281.	368.	148.	0.	0.	0.	0.	2636.	2917.	3286.	3433.
1978	308.	274.	433.	301.	125.	125.	125.	125.	3616.	3765.	4073.	4249.
1979	204.	284.	406.	467.	250.	250.	250.	250.	4204.	4238.	4394.	4611.
1980	260.	197.	477.	514.	375.	375.	375.	375.	4496.	4319.	4421.	4560.
1981	336.	247.	597.	479.	375.	375.	374.	374.	4522.	4394.	4617.	4721.
1982	477.	237.	596.	640.	400.	450.	449.	449.	4798.	4586.	4732.	4923.
1983	479.	549.	491.	813.	500.	500.	499.	499.	4902.	4951.	4943.	5257.
1984	585.	552.	730.	720.	550.	550.	550.	600.	5292.	5295.	5475.	5595.
1985	924.	567.	964.	726.	550.	549.	550.	600.	5970.	5988.	6402.	6529.
1986	1138.	667.	961.	1102.	700.	699.	700.	750.	6968.	6936.	7197.	7549.
1987	1195.	845.	1105.	1097.	849.	850.	899.	900.	7894.	7839.	8045.	8242.
1988	1192.	1214.	1265.	1225.	1049.	1049.	1050.	1102.	8385.	8549.	8764.	8887.
1989	1352.	1084.	1505.	1474.	1050.	1049.	1049.	1099.	9189.	9224.	9680.	10055.
1990	1438.	1056.	1760.	1615.	1200.	1200.	1199.	1245.	10293.	10148.	10709.	11079.
1991	1496.	1260.	1853.	1735.	1349.	1350.	1398.	1398.	11225.	11086.	11541.	11878.
1992	1653.	1428.	2000.	1828.	1550.	1550.	1549.	1597.	11981.	11861.	12312.	12543.
1993	1806.	1517.	2203.	1978.	1695.	1695.	1699.	1747.	12653.	12472.	12976.	13207.
1994	1945.	1673.	2350.	2128.	1849.	1850.	1899.	1899.	13303.	13077.	13528.	13757.
1995	2098.	1825.	2488.	2275.	2049.	2050.	2049.	2099.	13806.	13582.	14021.	14198.
1996	2248.	1978.	2638.	2426.	2049.	2050.	2049.	2099.	14397.	14326.	14915.	15241.
1997	2383.	2119.	2767.	2556.	2299.	2299.	2300.	2352.	15326.	15147.	15614.	15818.
1998	2511.	2239.	2875.	2663.	2549.	2550.	2550.	2604.	15779.	15478.	15803.	15862.
1999	2624.	2348.	2977.	2765.	2548.	2547.	2534.	2589.	15938.	15739.	16182.	16357.
2000	2721.	2451.	3073.	2859.	2545.	2547.	2541.	2599.	16534.	16438.	16971.	17231.
2001	2808.	2544.	3155.	2939.	2541.	2546.	2541.	2596.	17497.	17496.	18109.	18452.
2002	2887.	2625.	3226.	3012.	2790.	2795.	2781.	2830.	18549.	18399.	18844.	19026.
2003	0.	0.	0.	0.	3031.	3034.	0.	0.	15995.	12971.	12971.	12971.

ALT III - CASES 36 AND 38 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR 3.15.76 .01 .02

YEAR -CY-	ANNUAL POWER ADDITIONS BY REACTOR TYPE, ELECTRICAL MEGAWATTS HTGR	PWR	AWR	OTHR	NAT	FBR	TOTL	RETD	CUMD	PLUTONIUM RECYCLE GENERATION MILLIONS OF KWH
1974	0.	7190.	4594.	850.	0.	0.	12634.	0.	29993.	150290.
1975	0.	3403.	3647.	0.	0.	0.	7050.	200.	36843.	205846.
1976	0.	5475.	1972.	0.	0.	0.	7447.	0.	44290.	250443.
1977	0.	7020.	0.	0.	0.	0.	7020.	0.	51310.	295317.
1978	0.	6118.	0.	0.	0.	0.	6118.	0.	57428.	330573.
1979	0.	3304.	1928.	0.	0.	0.	5232.	850.	61810.	366808.
1980	0.	5605.	2777.	0.	0.	0.	8382.	0.	70192.	413978.
1981	0.	6331.	6447.	0.	0.	0.	12778.	200.	82770.	476291.
1982	0.	11492.	5342.	0.	0.	0.	16834.	175.	99429.	563683.
1983	0.	11849.	5935.	0.	0.	350.	18134.	0.	117563.	666079.
1984	0.	10728.	6897.	0.	0.	0.	17625.	139.	135049.	784371.
1985	0.	14670.	6121.	0.	0.	0.	20791.	0.	155840.	903487.
1986	0.	14699.	9122.	0.	0.	0.	23821.	0.	179661.	1046865.
1987	0.	13755.	7818.	0.	0.	0.	21573.	0.	201234.	1183551.
1988	0.	14405.	6562.	0.	0.	0.	20967.	0.	222201.	1307040.
1989	0.	17240.	6216.	0.	0.	0.	23456.	0.	245657.	1440866.
1990	0.	14917.	8016.	0.	0.	0.	22933.	50.	268540.	1578177.
1991	0.	17497.	7516.	0.	0.	0.	25013.	0.	293553.	1719663.
1992	0.	17564.	8784.	0.	0.	0.	26348.	0.	319901.	1867762.
1993	0.	17508.	8756.	0.	0.	0.	26264.	0.	346165.	2018932.
1994	0.	17708.	8852.	0.	0.	0.	26560.	0.	372725.	2170994.
1995	0.	18132.	9068.	0.	0.	0.	27200.	0.	399925.	2324487.
1996	0.	16432.	8216.	0.	0.	0.	24648.	0.	424573.	2467422.
1997	0.	14732.	7368.	0.	0.	0.	22100.	0.	446673.	2594310.
1998	0.	14164.	7084.	0.	0.	0.	21248.	0.	467921.	2709981.
1999	0.	13600.	6800.	0.	0.	0.	20400.	0.	488321.	2816080.
2000	0.	12468.	6232.	0.	0.	0.	18700.	0.	507021.	2910197.
2001	0.	11900.	5948.	0.	0.	0.	17848.	0.	524869.	2993310.
2002	0.	10764.	5384.	0.	0.	0.	16148.	0.	541017.	3063830.
2003	0.	9632.	4816.	0.	0.	0.	14448.	0.	555465.	3117615.

ALT III - CASES 36 AND 38 - LOW GROWTH - 70% CF - 1978 REF - 1981 REC - NO FBR 3.15.76 .01 .02

PLUTONIUM RECYCLE

YEAR	NUCLEAR POWER CAPACITY BY REACTOR TYPE, ELECTRICAL MEGAWATTS							CUMULATED		CAPACITY FACTOR
-CY-	HTGR	PWR	BWR	OTHR	NAT	FBR	TOTL	ADDNS	RETD	PERCENT
1974	0.	17292.	11851.	850.	0.	0.	29993.	29993.	0.	64.
1975	0.	20495.	15498.	850.	0.	0.	36843.	37043.	200.	65.
1976	0.	25970.	17470.	850.	0.	0.	44290.	44490.	200.	66.
1977	0.	32990.	17470.	850.	0.	0.	51310.	51510.	200.	67.
1978	0.	39108.	17470.	850.	0.	0.	57428.	57628.	200.	68.
1979	0.	42412.	19398.	0.	0.	0.	61810.	62860.	1050.	68.
1980	0.	48017.	22175.	0.	0.	0.	70192.	71242.	1050.	67.
1981	0.	54348.	28422.	0.	0.	0.	82770.	84020.	1250.	68.
1982	0.	65665.	33764.	0.	0.	0.	99429.	100854.	1425.	67.
1983	0.	77514.	39699.	0.	0.	350.	117563.	118988.	1425.	67.
1984	0.	88242.	46457.	0.	0.	350.	135049.	136613.	1564.	67.
1985	0.	102912.	52578.	0.	0.	350.	155840.	157404.	1564.	67.
1986	0.	117611.	61700.	0.	0.	350.	179661.	181225.	1564.	68.
1987	0.	131366.	69518.	0.	0.	350.	201234.	202798.	1564.	67.
1988	0.	145771.	76080.	0.	0.	350.	222201.	223765.	1564.	68.
1989	0.	163011.	82296.	0.	0.	350.	245657.	247221.	1564.	68.
1990	0.	177928.	90262.	0.	0.	350.	268540.	270154.	1614.	68.
1991	0.	195425.	97778.	0.	0.	350.	293553.	295167.	1614.	67.
1992	0.	212989.	106562.	0.	0.	350.	319901.	321515.	1614.	67.
1993	0.	230497.	115318.	0.	0.	350.	346165.	347779.	1614.	67.
1994	0.	248205.	124170.	0.	0.	350.	372725.	374339.	1614.	67.
1995	0.	266337.	133238.	0.	0.	350.	399925.	401539.	1614.	67.
1996	0.	282769.	141464.	0.	0.	350.	424573.	426187.	1614.	67.
1997	0.	297501.	148822.	0.	0.	350.	446673.	448287.	1614.	67.
1998	0.	311665.	155906.	0.	0.	350.	467921.	469535.	1614.	66.
1999	0.	325265.	162706.	0.	0.	350.	488321.	489935.	1614.	66.
2000	0.	337733.	168938.	0.	0.	350.	507021.	508635.	1614.	66.
2001	0.	349633.	174886.	0.	0.	350.	524869.	526483.	1614.	65.
2002	0.	360397.	180270.	0.	0.	350.	541017.	542631.	1614.	65.
2003	0.	370029.	185086.	0.	0.	350.	555465.	557079.	1614.	64.

ALT III - CASES 36 AND 38 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR 3.15.76 .01 .02

PLUTONIUM RECYCLE

FISSILE PLUTONIUM RECOVERY AND UTILIZATION, METRIC TONS

YEAR -CY-	RECOVERY					UTILIZATION					YEAR-END INVENTORY	PU RECYD
	LWR	BREEDER	NAT AND OTHER	TOTAL ANNUAL	CUMULATED	LWR RECYCLE	BREEDER FUEL	OTHER USES	TOTAL ANNUAL	CUMULATED		
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1978	1.54	0.00	0.00	1.54	1.54	0.00	0.00	0.00	0.00	0.00	1.54	0.
1979	3.71	0.00	0.00	3.71	5.25	0.00	0.00	1.00	1.00	1.00	4.25	0.
1980	7.20	0.00	0.00	7.20	12.44	3.11	0.00	1.20	4.31	5.31	7.13	27.
1981	7.91	0.00	0.00	7.91	20.35	8.62	0.00	1.20	9.82	15.13	5.22	57.
1982	9.59	0.00	0.00	9.59	29.93	13.60	0.00	1.00	14.60	29.73	.20	92.
1983	11.43	0.00	0.00	11.43	41.36	10.64	0.00	.80	11.44	41.17	.19	92.
1984	12.66	0.00	0.00	12.66	54.02	12.00	0.00	.75	12.75	53.92	.10	93.
1985	14.16	0.00	0.00	14.16	68.18	13.69	0.00	.40	14.09	68.01	.17	96.
1986	17.36	0.00	0.00	17.36	85.54	17.02	0.00	.30	17.32	85.33	.21	97.
1987	22.15	0.00	0.00	22.15	107.69	22.03	0.00	.25	22.28	107.61	.09	98.
1988	24.44	0.00	0.00	24.44	132.13	24.45	0.00	.25	24.70	132.31	-.17	100.
1989	25.72	0.00	0.00	25.72	157.85	25.32	0.00	.25	25.57	157.88	-.02	99.
1990	31.75	0.00	0.00	31.75	189.60	31.39	0.00	.25	31.64	189.52	.08	99.
1991	38.43	0.00	0.00	38.43	228.03	37.96	0.00	.25	38.21	227.73	.30	99.
1992	42.92	0.00	0.00	42.92	270.95	42.77	0.00	.25	43.02	270.75	.20	99.
1993	47.66	0.00	0.00	47.66	318.61	47.45	0.00	.25	47.70	318.45	.16	99.
1994	54.22	0.00	0.00	54.22	372.83	53.99	0.00	.25	54.24	372.69	.14	99.
1995	58.37	0.00	0.00	58.37	431.19	58.06	0.00	.25	58.31	431.00	.20	99.
1996	59.42	0.00	0.00	59.42	490.61	59.31	0.00	.25	59.56	490.56	.05	99.
1997	62.93	0.00	0.00	62.93	553.54	62.76	0.00	.25	63.01	553.57	-.03	100.
1998	75.09	0.00	0.00	75.09	628.63	73.49	0.00	.25	73.74	627.31	1.32	98.
1999	79.25	0.00	0.00	79.25	707.88	78.50	0.00	.25	78.75	706.06	1.82	97.
2000	82.24	0.00	0.00	82.24	790.13	81.76	0.00	.25	82.01	788.07	2.06	97.
2001	85.96	0.00	0.00	85.96	876.09	85.41	0.00	.25	85.66	873.73	2.36	97.
2002	91.29	0.00	0.00	91.29	967.37	90.53	0.00	.25	90.78	964.51	2.87	97.
2003	75.20	0.00	0.00	75.20	1042.58	77.20	0.00	.25	77.45	1041.95	.63	99.

ALT III - CASES 36 AND 38 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR 3.15.76 .01 .02

PLUTONIUM RECYCLE

YEAR -CY-	CONVERSION TO UF6 IN MT OF U, XW & .300(NATURAL URANIUM	RECOVERED URANIUM	FRESH FUEL FABRICATION LOAD IN METRIC TONS OF HEAVY METAL LWR UO2	LWR MIXED OX	HTGR FISSILE	HTGR FERTILE	FBR MIXED OX	FBR BLANKET	SPENT FUEL REPROCESSING LOAD IN METRIC TONS OF HEAVY METAL LWR, NAT MIXED OX	HTGR FISSILE	HTGR FERTILE	FBR MIXED OX
1974	7646.	0.	1009.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1975	6181.	0.	919.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1976	10407.	0.	1337.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1977	11498.	0.	1758.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1978	13039.	373.	1972.	0.	0.	0.	0.	0.	500.	0.	0.	0.
1979	14571.	871.	2345.	0.	0.	0.	0.	0.	999.	0.	0.	0.
1980	16501.	1367.	3106.	75.	0.	0.	0.	0.	1499.	0.	0.	0.
1981	17343.	1490.	2570.	255.	0.	0.	4.	5.	1498.	0.	0.	0.
1982	19238.	1664.	3806.	413.	0.	0.	4.	5.	1748.	0.	0.	0.
1983	22462.	1937.	4137.	395.	0.	0.	3.	3.	1998.	0.	0.	0.
1984	27070.	2135.	5230.	378.	0.	0.	3.	3.	2249.	0.	0.	0.
1985	30245.	2234.	5383.	437.	0.	0.	3.	2.	2248.	0.	0.	5.
1986	31984.	2681.	5347.	602.	0.	0.	3.	2.	2848.	0.	0.	5.
1987	35812.	3374.	6012.	692.	0.	0.	3.	2.	3548.	0.	0.	5.
1988	38260.	4024.	6787.	716.	0.	0.	3.	2.	4291.	0.	0.	5.
1989	41427.	4224.	6991.	886.	0.	0.	3.	2.	4247.	0.	0.	5.
1990	43682.	4666.	7725.	981.	0.	0.	3.	2.	4844.	0.	0.	5.
1991	45111.	5354.	8193.	1251.	0.	0.	3.	2.	5545.	0.	0.	5.
1992	48242.	6002.	8577.	1387.	0.	0.	3.	2.	6244.	0.	0.	5.
1993	50623.	6642.	9126.	1565.	0.	0.	3.	2.	6839.	0.	0.	5.
1994	51000.	7340.	9471.	1771.	0.	0.	3.	2.	7545.	0.	0.	5.
1995	53421.	7987.	9812.	2022.	0.	0.	3.	2.	8246.	0.	0.	5.
1996	56519.	8186.	10087.	2004.	0.	0.	3.	2.	8246.	0.	0.	5.
1997	57035.	8933.	10512.	2040.	0.	0.	3.	2.	9249.	0.	0.	5.
1998	56753.	9917.	10620.	2281.	0.	0.	3.	2.	10243.	0.	0.	5.
1999	57700.	10153.	10683.	2532.	0.	0.	3.	2.	10219.	0.	0.	5.
2000	59332.	10139.	10846.	2647.	0.	0.	2.	2.	10231.	0.	0.	5.
2001	58714.	10142.	10891.	2789.	0.	0.	2.	2.	10224.	0.	0.	5.
2002	54115.	10851.	10325.	2921.	0.	0.	2.	2.	11176.	0.	0.	4.
2003	42749.	8809.	10231.	2600.	0.	0.	2.	2.	6055.	0.	0.	4.

ALT III - CASES 36 AND 3R - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR 3.15.76 .01 .02

TOTAL ENRICHMENT DEMAND PLUTONIUM RECYCLE

YEAR	GROSS WITHDRAWALS			IRRADIATED RETURNS			NET REQUIREMENTS		
-CY-	URANIUM -MT-	U-235 -MT-	VALUE FTN -MT-	URANIUM -MT-	U-235 -MT-	VALUE FTN -MT-	URANIUM -MT-	U-235 -MT-	VALUE FTN -MT-
1974	1190.	31.685	4082.	0.	0.000	0.	1190.	31.685	4082.
1975	1076.	31.511	3555.	0.	0.000	0.	1076.	31.511	3555.
1976	1457.	42.498	4822.	0.	0.000	0.	1457.	42.498	4822.
1977	1849.	51.986	6213.	0.	0.000	0.	1849.	51.986	6213.
1978	1946.	54.251	6561.	249.	2.113	1146.	1697.	52.138	5415.
1979	2641.	71.036	8981.	747.	7.395	3348.	1894.	64.541	5633.
1980	2985.	79.775	10233.	1243.	9.479	5855.	1741.	70.295	4377.
1981	3366.	88.364	11623.	1491.	11.405	7011.	1875.	76.959	4612.
1982	3738.	98.318	12899.	1589.	12.303	7454.	2149.	86.015	5444.
1983	3817.	104.998	12959.	1887.	14.465	8878.	1930.	90.533	4080.
1984	5263.	141.029	18042.	2085.	15.767	9829.	3178.	125.263	8213.
1985	5703.	151.683	19602.	2235.	17.822	10462.	3469.	133.860	9140.
1986	5374.	151.698	18088.	2532.	18.538	12022.	2843.	132.560	6066.
1987	6281.	174.372	21247.	3177.	22.844	15159.	3104.	151.528	6087.
1988	6808.	188.123	23066.	3874.	26.061	18800.	2933.	162.062	4266.
1989	7430.	205.996	25133.	4226.	29.234	20394.	3212.	177.762	4739.
1990	7841.	219.182	26503.	4518.	31.617	21746.	3324.	186.565	4757.
1991	8310.	232.475	28032.	5156.	37.116	24674.	3153.	195.359	3358.
1992	8722.	244.998	29376.	5853.	42.275	27961.	2869.	202.723	1415.
1993	9235.	260.149	31070.	6493.	46.234	31132.	2742.	213.915	-62.
1994	9470.	268.747	31769.	7141.	50.488	34259.	2329.	218.259	-2490.
1995	9727.	278.546	32515.	7839.	55.510	37581.	1889.	223.036	-5065.
1996	10193.	292.676	34032.	8186.	57.598	39290.	2007.	235.079	-5257.
1997	10579.	303.394	35332.	8684.	61.735	41636.	1895.	241.658	-6304.
1998	10566.	303.378	35269.	9669.	67.840	46516.	897.	235.538	-11247.
1999	10734.	308.860	35794.	10170.	70.705	49043.	563.	238.156	-13249.
2000	10873.	313.937	36210.	10133.	69.531	49026.	740.	244.405	-12817.
2001	10934.	316.784	36359.	10142.	68.602	49289.	792.	248.182	-12930.
2002	10028.	297.288	33029.	10612.	72.241	51460.	-584.	225.047	-18431.
2003	10361.	310.432	33973.	11568.	78.905	56067.	-1206.	231.528	-22094.

ALT III - CASES 36 AND 38 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR 3.15.76 .01 .02

TOTAL ENRICHMENT DEMAND

PLUTONIUM RECYCLE

YEAR	.200 PERCENT TAILS ASSAY			.250 PERCENT TAILS ASSAY			.300 PERCENT TAILS ASSAY			.400 PERCENT TAILS ASSAY		
-CY-	SEP WORK - K SWU-	FEED -MT-	U308 -ST-	SEP WORK - K SWU-	FEED -MT-	U308 -ST-	SEP WORK - K SWU-	FEED -MT-	U308 -ST-	SEP WORK - K SWU-	FEED -MT-	U308 -ST-
1974	4280.	5735.	7462.	3778.	6228.	8111.	3385.	6840.	8919.	2800.	8657.	11313.
1975	4478.	5746.	8769.	3961.	6252.	9540.	3558.	6882.	10502.	2956.	8749.	13350.
1976	6023.	7746.	11177.	5328.	8428.	12154.	4785.	9277.	13374.	3974.	11791.	16983.
1977	7235.	9450.	12342.	6395.	10274.	13431.	5739.	11299.	14784.	4759.	14338.	18797.
1978	7493.	9539.	13927.	6626.	10389.	15183.	5949.	11447.	16748.	4938.	14581.	21383.
1979	9593.	11889.	16226.	8488.	12973.	17721.	7625.	14321.	19599.	6337.	18317.	25141.
1980	10845.	13075.	17946.	9593.	14304.	19621.	8614.	15832.	21707.	7153.	20363.	27888.
1981	11905.	14327.	20088.	10529.	15677.	21941.	9453.	17356.	24246.	7849.	22334.	31078.
1982	13240.	15992.	22020.	11710.	17493.	24055.	10514.	19360.	26547.	8730.	24894.	34090.
1983	14510.	16962.	26627.	12849.	18592.	29104.	11550.	20619.	32181.	9613.	26628.	41308.
1984	19236.	23269.	31791.	17016.	25448.	34711.	15280.	28158.	38348.	12691.	36190.	49121.
1985	20434.	24838.	32866.	18073.	27156.	35923.	16227.	30038.	39723.	13474.	38581.	50988.
1986	21223.	24829.	36341.	18793.	27213.	38674.	16894.	30178.	42824.	14061.	38968.	55120.
1987	24386.	28438.	39273.	21587.	31186.	43007.	19398.	34602.	47649.	16134.	44730.	61412.
1988	26428.	30567.	42680.	23375.	33564.	46765.	20988.	37290.	51845.	17427.	48337.	66903.
1989	29089.	33530.	45735.	25738.	36818.	50120.	23119.	40907.	55572.	19213.	53027.	71735.
1990	30626.	35209.	48255.	27103.	38667.	52883.	24349.	42967.	58649.	20240.	55714.	75728.
1991	32640.	36997.	50728.	28900.	40667.	55629.	25976.	45231.	61723.	21615.	58761.	79788.
1992	34504.	38549.	53414.	30561.	42419.	58611.	27479.	47230.	65073.	22881.	61494.	84231.
1993	36768.	40789.	55735.	32564.	44916.	61200.	29277.	50046.	67994.	24375.	65257.	88137.
1994	38228.	41801.	57407.	33867.	46082.	63081.	30457.	51404.	70136.	25371.	67184.	91051.
1995	39836.	42908.	59813.	35304.	47356.	65751.	31760.	52888.	73133.	26475.	69286.	95020.
1996	41958.	45218.	62190.	37183.	49905.	68384.	33451.	55732.	76085.	27883.	73006.	98916.
1997	43366.	46550.	62595.	38431.	51393.	68974.	34574.	57415.	76749.	28820.	75267.	100005.
1998	43534.	45743.	62912.	38579.	50607.	69304.	34705.	56654.	77250.	28926.	74582.	100810.
1999	44441.	46395.	64240.	39377.	51355.	70809.	35419.	57534.	78927.	29515.	75853.	102994.
2000	45303.	47539.	65626.	40131.	52615.	72212.	36089.	58926.	80534.	30058.	77635.	105028.
2001	45815.	48258.	63646.	40570.	53406.	70154.	36470.	59807.	78246.	30353.	78782.	102235.
2002	43567.	44269.	62243.	38611.	49134.	68718.	34736.	55182.	76767.	28957.	73113.	100631.
2003	45750.	45781.	62676.	40558.	50877.	69361.	36499.	57213.	77537.	30444.	75998.	101956.

ALT III - CASES 36 AND 38 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR 3.15.76 .01 .02

TOTAL ENRICHMENT DEMAND

PLUTONIUM RECYCLE

YEAR	.200 PERCENT TAILS ASSAY CUMULATED TOTALS			.250 PERCENT TAILS ASSAY CUMULATED TOTALS			.300 PERCENT TAILS ASSAY CUMULATED TOTALS			.400 PERCENT TAILS ASSAY CUMULATED TOTALS		
	SEP WORK	FEED	U3O8	SEP WORK	FEED	U3O8	SEP WORK	FEED	U3O8	SEP WORK	FEED	U3O8
-CY-	- K SWU-	-MT-	-ST-	- K SWU-	-MT-	-ST-	- K SWU-	-MT-	-ST-	- K SWU-	-MT-	-ST-
1975	4478.	5746.	8769.	3961.	6252.	9542.	3558.	6882.	10502.	2956.	8749.	13350.
1976	10500.	13492.	19946.	9289.	14681.	21698.	8343.	16158.	23876.	6930.	20540.	30333.
1977	17736.	22942.	32248.	15685.	24955.	35119.	14081.	27458.	38660.	11690.	34878.	49130.
1978	25228.	32680.	44216.	22311.	35344.	50334.	20030.	38904.	55408.	16628.	49459.	70513.
1979	34821.	44369.	62442.	30799.	48317.	68043.	27655.	53225.	75007.	22965.	67775.	95653.
1980	45666.	57444.	80387.	40392.	62621.	87565.	36269.	69057.	96714.	30119.	88139.	123541.
1981	57571.	71771.	100475.	50921.	78298.	109507.	45722.	86414.	120960.	37967.	110473.	154619.
1982	70810.	87763.	122496.	62631.	95791.	133563.	56236.	105773.	147547.	46698.	135367.	188709.
1983	85320.	104724.	146122.	75479.	114383.	159606.	67786.	126392.	176228.	56311.	161995.	230017.
1984	104556.	127994.	180914.	92495.	139832.	197630.	83067.	154550.	218076.	69003.	198185.	279138.
1985	124991.	152832.	213780.	110568.	166987.	233412.	99294.	184588.	257799.	82476.	236765.	330127.
1986	146214.	177660.	249120.	129362.	194201.	272079.	116188.	214766.	300623.	96537.	275733.	385246.
1987	170600.	206099.	288393.	150948.	225387.	315015.	135586.	249368.	348272.	112671.	320463.	446659.
1988	197028.	236665.	331073.	174323.	258951.	361830.	156573.	286658.	400117.	130098.	368801.	513562.
1989	226117.	270195.	376807.	200061.	295769.	411970.	179693.	327565.	455688.	149310.	421828.	585297.
1990	256743.	305404.	425062.	227164.	334436.	464859.	204041.	370532.	514338.	169550.	477542.	661025.
1991	289383.	342401.	475790.	256064.	375103.	520418.	230018.	415763.	576060.	191166.	536303.	740813.
1992	323886.	380950.	529204.	286625.	417522.	579099.	257496.	462993.	641134.	214047.	597797.	825044.
1993	360665.	421739.	584939.	319189.	462438.	640299.	286774.	513039.	709128.	238422.	663054.	913181.
1994	398883.	463539.	642346.	353056.	508519.	703330.	317231.	564444.	779264.	263793.	730238.	1004232.
1995	438719.	506447.	702159.	388359.	555876.	769130.	348991.	617331.	852397.	290268.	799524.	1099252.
1996	480678.	551665.	764348.	425543.	605781.	837514.	382442.	673063.	928482.	318151.	872530.	1198168.
1997	524043.	598215.	826943.	463974.	657174.	906418.	417015.	730478.	1005231.	346970.	947797.	1298173.
1998	567578.	643957.	889855.	502552.	707780.	975722.	451720.	787132.	1082481.	375896.	1022380.	1398983.
1999	612019.	690343.	954134.	541930.	759135.	1046531.	487139.	844666.	1161408.	405411.	1098232.	1501977.
2000	657322.	737882.	1019761.	582061.	811750.	1118803.	523228.	903592.	1241942.	435470.	1175867.	1607005.
2001	703137.	786140.	1083407.	622631.	865156.	1188957.	559698.	963398.	1320188.	465823.	1254650.	1709240.
2002	746704.	830409.	1145651.	661242.	914290.	1257675.	594434.	1018581.	1396955.	494780.	1327763.	1809871.
2003	792454.	876190.	1208327.	701800.	965167.	1326975.	630933.	1075794.	1474493.	525224.	1403761.	1911821.

ALT V - CASE 39 - LOW GROWTH - 70% CF - NO FBR - 1986 REPROCESSIN 3.15.76 .01 .02

CUMULATED RESULTS

NO PLUTONIUM RECYCLE

YEAR -CY-	GROSS WITHDRAWALS AT GDR TAILS ASSAY = .300(URANIUM -MT-	U-235 -MT-	VALUE FN -MT-	SEP WORK - K SWU-	U AS UF6 -MT-	U3O8 -ST-	NATURAL URANIUM -MT-	PLUTONIUM REQUIRED -MT-
1974	1190.	31.685	4082.	9385.	6840.	7896.	0.	0.
1975	1076.	31.511	3555.	3558.	6882.	9427.	0.	0.
1976	1457.	42.498	4822.	4785.	9277.	14146.	0.	0.
1977	1849.	51.986	6213.	5739.	11299.	15839.	0.	0.
1978	1946.	54.251	6561.	5959.	11779.	19035.	0.	0.
1979	2641.	71.936	8981.	7796.	15575.	18446.	0.	0.
1980	3092.	83.005	10584.	8928.	17939.	26716.	0.	0.
1981	3668.	97.348	12615.	10401.	21008.	29683.	0.	0.
1982	4214.	112.493	14462.	12063.	24294.	32868.	0.	0.
1983	4195.	116.123	14204.	12726.	25192.	41027.	0.	0.
1984	5678.	153.486	19396.	16589.	33200.	38163.	0.	0.
1985	6166.	165.830	21106.	17867.	35847.	49075.	0.	0.
1986	5944.	168.642	19933.	18743.	36694.	52974.	0.	0.
1987	7012.	197.031	23607.	21783.	42821.	59183.	0.	0.
1988	7616.	213.255	25674.	23528.	46328.	61667.	0.	0.
1989	8276.	233.031	27838.	25791.	50658.	68422.	0.	0.
1990	8891.	250.534	29900.	27742.	54468.	73880.	0.	0.
1991	9598.	271.733	32222.	30170.	59109.	79108.	0.	0.
1992	10185.	289.317	34147.	32183.	62959.	84602.	0.	0.
1993	10863.	309.345	36385.	34458.	67337.	90023.	0.	0.
1994	11331.	324.784	37854.	36307.	70752.	93985.	0.	0.
1995	11735.	338.852	39085.	38032.	73880.	98169.	0.	0.
1996	12209.	354.037	40595.	39826.	77229.	102512.	0.	0.
1997	12647.	367.863	42001.	41448.	80273.	106031.	0.	0.
1998	12971.	378.748	43008.	42763.	82685.	108948.	0.	0.
1999	13298.	389.334	44039.	44019.	85022.	111824.	0.	0.
2000	13541.	397.726	44783.	45044.	86887.	113938.	0.	0.
2001	13717.	404.293	45301.	45871.	88356.	113892.	0.	0.
2002	12975.	390.019	42495.	44699.	85424.	110093.	0.	0.
2003	12872.	389.492	42036.	44788.	85371.	55439.	0.	0.

ALT V - CASE 39 - LOW GROWTH - 70% CF - NO FBR - 1986 REPROCESSIN 3.15.76 .01 .02

CUMULATED RESULTS

NO PLUTONIUM RECYCLE

IRRADIATED RETURNS AT GDP TAILS ASSAY = .300

YEAR -CY-	URANIUM -MT-	U-235 -MT-	VALUE FN -MT-	SEP WORK - K SWU-	U AS UF6 -MT-	U3O8 -ST-	PLUTONIUM RECOVERED -MT-
1974	0.	0.000	0.	0.	0.	0.	0.
1975	0.	0.000	0.	0.	0.	0.	0.
1976	0.	0.000	0.	0.	0.	0.	0.
1977	0.	0.000	0.	0.	0.	0.	0.
1978	0.	0.000	0.	0.	0.	0.	0.
1979	0.	0.000	0.	0.	0.	0.	0.
1980	0.	0.000	0.	0.	0.	0.	0.
1981	0.	0.000	0.	0.	0.	0.	0.
1982	0.	0.000	0.	0.	0.	0.	0.
1983	0.	0.000	0.	0.	0.	0.	0.
1984	0.	0.000	0.	0.	0.	0.	0.
1985	0.	0.000	0.	0.	0.	0.	0.
1986	646.	4.848	3047.	-27.	717.	2001.	6.
1987	2383.	19.432	11095.	132.	3002.	5310.	16.
1988	4570.	34.542	21539.	-152.	5127.	8559.	31.
1989	6503.	49.696	30589.	-144.	7421.	10876.	42.
1990	7502.	57.506	35310.	-101.	8602.	11063.	47.
1991	8004.	59.192	37926.	-300.	8677.	11717.	46.
1992	8199.	62.108	38646.	-242.	9229.	12194.	47.
1993	8195.	62.539	38575.	-176.	9332.	12068.	49.
1994	8198.	62.303	38621.	-205.	9275.	12057.	51.
1995	8197.	62.400	38596.	-203.	9298.	12103.	52.
1996	8197.	62.539	38580.	-183.	9330.	12117.	51.
1997	8697.	67.300	40819.	-80.	10118.	13993.	53.
1998	9686.	74.470	45490.	-180.	11157.	15220.	64.
1999	10181.	78.098	47836.	-212.	11686.	15146.	67.
2000	10180.	78.078	47829.	-215.	11682.	15205.	68.
2001	10179.	78.593	47747.	-167.	11802.	15320.	70.
2002	10673.	82.201	50091.	-196.	12327.	16829.	76.
2003	11667.	90.160	54715.	-186.	13545.	9185.	61.

ALT V - CASE 39 - LOW GROWTH - 70% CF - NO FBR - 1986 REPROCESSIN 3.15.76 .01 .02

CUMULATED RESULTS NO PLUTONIUM RECYCLE

YEAR -CY-	NET REQUIREMENTS AT GDP TAILS ASSAY = .300(URANIUM -MT-	U-235 -MT-	VALUE FN -MT-	SEP WORK - K SWU-	U AS UF6 -MT-	U3O8 -ST-	NATURAL URANIUM -MT-	PLUTONIUM YR-END INV -MT-	REVENUE BASED ON CONTRACT $M-
1974	1190.	31.689	4082.	3385.	6840.	7896.	0.	0.	0.
1975	1076.	31.511	3555.	3558.	6882.	9427.	0.	0.	0.
1976	1457.	42.498	4822.	4785.	9277.	14146.	0.	0.	0.
1977	1849.	51.986	6213.	5739.	11299.	15835.	0.	0.	0.
1978	1946.	54.251	6561.	5959.	11779.	19035.	0.	0.	0.
1979	2641.	71.936	8981.	7796.	15575.	18446.	0.	0.	0.
1980	3092.	83.005	10584.	8928.	17939.	26716.	0.	0.	0.
1981	3668.	97.348	12615.	10401.	21008.	29683.	0.	0.	0.
1982	4214.	112.493	14462.	12063.	24294.	32868.	0.	0.	0.
1983	4195.	116.123	14204.	12726.	25192.	41027.	0.	0.	0.
1984	5678.	153.486	19396.	16589.	33200.	38163.	0.	0.	0.
1985	6166.	165.830	21106.	17867.	35847.	49079.	0.	0.	0.
1986	5298.	163.794	16886.	18770.	35977.	50972.	0.	6.	0.
1987	4629.	177.599	12512.	21651.	39819.	53873.	0.	23.	0.
1988	3046.	178.713	4135.	23680.	41201.	53107.	0.	54.	0.
1989	1773.	183.335	-2751.	25935.	43237.	57546.	0.	96.	0.
1990	1309.	193.028	-5410.	27843.	45866.	62817.	0.	142.	0.
1991	1594.	212.541	-5704.	30550.	50432.	67391.	0.	188.	0.
1992	1985.	227.209	-4499.	32424.	53730.	72408.	0.	235.	0.
1993	2668.	246.806	-2190.	34634.	58006.	77955.	0.	284.	0.
1994	3134.	262.481	-767.	38512.	61477.	81928.	0.	335.	0.
1995	3538.	276.452	489.	38238.	64582.	86066.	0.	386.	0.
1996	4012.	291.499	2014.	40010.	67899.	90395.	0.	437.	0.
1997	3951.	300.563	1181.	41528.	70154.	92038.	0.	490.	0.
1998	3285.	304.277	-2482.	42943.	71527.	93728.	0.	555.	0.
1999	3117.	311.236	-3796.	44231.	73336.	96678.	0.	621.	0.
2000	3361.	319.648	-3046.	45259.	75204.	98673.	0.	689.	0.
2001	3538.	325.700	-2447.	46038.	76554.	98573.	0.	759.	0.
2002	2303.	307.818	-7595.	44895.	73097.	93263.	0.	835.	0.
2003	1205.	299.331	-12679.	44974.	71826.	46254.	0.	897.	0.

ALT II AND V - CASES 33 AND 39 - LOW GROWTH - 70% CF - NO FBR - 1986 REPROCESSIN 3.15.76 .01 .02

CUMULATED RESULTS
SPENT FUEL STORAGE AND REPROCESSING IN -MT- OF HEAVY METAL BY QUARTER YEARS
NO PLUTONIUM RECYCLE

FOR LIGHT WATER REACTORS

-CY-	ADDITIONS TO STORAGE BASINS (1)	(2)	(3)	(4)	FUEL REPROCESSING (1)	(2)	(3)	(4)	STORAGE BASIN REQUIREMENTS (1)	(2)	(3)	(4)
1974	727.	0.	77.	120.	0.	0.	0.	0.	727.	727.	804.	924.
1975	54.	189.	47.	361.	0.	0.	0.	0.	978.	1167.	1215.	1575.
1976	158.	229.	173.	204.	0.	0.	0.	0.	1734.	1962.	2135.	2339.
1977	297.	281.	368.	148.	0.	0.	0.	0.	2636.	2917.	3286.	3433.
1978	308.	274.	433.	901.	0.	0.	0.	0.	3741.	4015.	4448.	4749.
1979	204.	284.	406.	467.	0.	0.	0.	0.	4954.	5237.	5643.	6110.
1980	260.	197.	477.	514.	0.	0.	0.	0.	6370.	6567.	7044.	7558.
1981	336.	247.	597.	479.	0.	0.	0.	0.	7895.	8142.	8739.	9217.
1982	477.	237.	596.	640.	0.	0.	0.	0.	9694.	9932.	10527.	11167.
1983	479.	549.	491.	813.	0.	0.	0.	0.	11646.	12195.	12686.	13499.
1984	585.	552.	730.	720.	0.	0.	0.	0.	14004.	14636.	15366.	16086.
1985	924.	567.	964.	726.	0.	0.	0.	0.	17010.	17578.	18542.	19268.
1986	1138.	667.	961.	1102.	300.	350.	349.	349.	20106.	20423.	21035.	21787.
1987	1195.	845.	1105.	1097.	849.	848.	850.	850.	22133.	22129.	22384.	22631.
1988	1192.	1214.	1265.	1225.	1450.	1448.	1447.	1498.	22373.	22139.	21957.	21684.
1989	1352.	1084.	1505.	1474.	1799.	1797.	1800.	1849.	21237.	20524.	20229.	19854.
1990	1438.	1056.	1760.	1615.	1950.	1950.	1950.	2000.	19342.	18449.	18259.	17874.
1991	1496.	1260.	1853.	1735.	2050.	2050.	2050.	2100.	17320.	16531.	16334.	15969.
1992	1653.	1428.	2000.	1828.	2050.	2048.	2047.	2097.	15573.	14953.	14906.	14637.
1993	1806.	1517.	2203.	1978.	2050.	2050.	2050.	2099.	14393.	13860.	14013.	13892.
1994	1945.	1673.	2350.	2128.	2049.	2050.	2049.	2099.	13788.	13411.	13712.	13741.
1995	2008.	1825.	2488.	2275.	2049.	2050.	2049.	2099.	13709.	13564.	14003.	14179.
1996	2248.	1978.	2638.	2426.	2049.	2050.	2049.	2099.	14377.	14306.	14894.	15221.
1997	2383.	2119.	2767.	2556.	2299.	2300.	2299.	2349.	15304.	15124.	15592.	15798.
1998	2511.	2239.	2875.	2663.	2549.	2550.	2549.	2599.	15759.	15449.	15774.	15839.
1999	2624.	2348.	2977.	2765.	2549.	2550.	2549.	2599.	15913.	15711.	16138.	16304.
2000	2721.	2451.	3073.	2859.	2549.	2550.	2549.	2599.	16476.	16377.	16901.	17161.
2001	2808.	2544.	3155.	2939.	2549.	2550.	2549.	2599.	17419.	17413.	18019.	18358.
2002	2887.	2625.	3226.	3012.	2799.	2800.	2799.	2849.	18446.	18272.	18698.	18861.
2003	0.	0.	0.	0.	3049.	3050.	0.	0.	15811.	12762.	12762.	12762.

ALT V - CASE 39 - LOW GROWTH - 70% CF - NO FBR - 1986 REPROCESSIN 3.15.76 .01 .02

NO PLUTONIUM RECYCLE

YEAR	ANNUAL POWER ADDITIONS BY REACTOR TYPE. ELECTRICAL MEGAWATTS								GENERATION MILLIONS
-CY-	HTGR	PWR	BWR	OTHR	NAT	FBR	TOTL	RETD	CUMD	OF KWH
1974	0.	7190.	4594.	850.	0.	0.	12634.	0.	29993.	150290.
1975	0.	3403.	3647.	0.	0.	0.	7050.	200.	36843.	205846.
1976	0.	5475.	1972.	0.	0.	0.	7447.	0.	44290.	250443.
1977	0.	7020.	0.	0.	0.	0.	7020.	0.	51310.	295317.
1978	0.	6118.	0.	0.	0.	0.	6118.	0.	57428.	330573.
1979	0.	3304.	1928.	0.	0.	0.	5232.	850.	61810.	366808.
1980	0.	5605.	2777.	0.	0.	0.	8382.	0.	70192.	413978.
1981	0.	6331.	6447.	0.	0.	0.	12778.	200.	82770.	476291.
1982	0.	11492.	5342.	0.	0.	0.	16834.	175.	99429.	563683.
1983	0.	11849.	5935.	0.	0.	350.	18134.	0.	117563.	666079.
1984	0.	10728.	6897.	0.	0.	0.	17625.	139.	135049.	784371.
1985	0.	14670.	6121.	0.	0.	0.	20791.	0.	155840.	903487.
1986	0.	14699.	9122.	0.	0.	0.	23821.	0.	179661.	1046865.
1987	0.	13755.	7818.	0.	0.	0.	21573.	0.	201234.	1183551.
1988	0.	14405.	6562.	0.	0.	0.	20967.	0.	222201.	1307040.
1989	0.	17240.	6216.	0.	0.	0.	23456.	0.	245657.	1440866.
1990	0.	14917.	8016.	0.	0.	0.	22933.	50.	268540.	1578177.
1991	0.	17497.	7516.	0.	0.	0.	25013.	0.	293553.	1719663.
1992	0.	17564.	8784.	0.	0.	0.	26348.	0.	319901.	1867762.
1993	0.	17508.	8756.	0.	0.	0.	26264.	0.	346165.	2018932.
1994	0.	17708.	8852.	0.	0.	0.	26560.	0.	372725.	2170994.
1995	0.	18132.	9068.	0.	0.	0.	27200.	0.	399925.	2324487.
1996	0.	16432.	8216.	0.	0.	0.	24648.	0.	424573.	2467422.
1997	0.	14732.	7368.	0.	0.	0.	22100.	0.	446673.	2594310.
1998	0.	14164.	7084.	0.	0.	0.	21248.	0.	467921.	2709981.
1999	0.	13600.	6800.	0.	0.	0.	20400.	0.	488321.	2816080.
2000	0.	12468.	6232.	0.	0.	0.	18700.	0.	507021.	2910197.
2001	0.	11900.	5948.	0.	0.	0.	17848.	0.	524869.	2993310.
2002	0.	10764.	5384.	0.	0.	0.	16148.	0.	541017.	3063830.
2003	0.	9632.	4816.	0.	0.	0.	14448.	0.	555465.	3117615.

ALT V - CASE 39 - LOW GROWTH - 70% CF - NO FBR + 1986 REPROCESSIN 3.15.76 .01 .02

NO PLUTONIUM RECYCLE

YEAR	NUCLEAR POWER CAPACITY BY REACTOR TYPE, ELECTRICAL MEGAWATTS							CUMULATED		CAPACITY FACTOR
-CY-	HTGR	PWR	BWR	OTHR	NAT	FBR	TOTL	ADDNS	RETD	PERCENT
1974	0.	17292.	11851.	850.	0.	0.	29993.	29993.	0.	64.
1975	0.	20495.	15498.	850.	0.	0.	36843.	37043.	200.	65.
1976	0.	25970.	17470.	850.	0.	0.	44290.	44490.	200.	66.
1977	0.	32990.	17470.	850.	0.	0.	51310.	51510.	200.	67.
1978	0.	39108.	17470.	850.	0.	0.	57428.	57628.	200.	68.
1979	0.	42412.	19398.	0.	0.	0.	61810.	62860.	1050.	68.
1980	0.	48017.	22175.	0.	0.	0.	70192.	71242.	1050.	67.
1981	0.	54348.	28422.	0.	0.	0.	82770.	84020.	1250.	68.
1982	0.	65665.	33764.	0.	0.	0.	99429.	100854.	1425.	67.
1983	0.	77514.	39609.	0.	0.	350.	117563.	118988.	1425.	67.
1984	0.	88242.	46457.	0.	0.	350.	135049.	136613.	1564.	67.
1985	0.	102912.	52578.	0.	0.	350.	155840.	157404.	1564.	67.
1986	0.	117611.	61700.	0.	0.	350.	179661.	181225.	1564.	68.
1987	0.	131366.	69518.	0.	0.	350.	201234.	202798.	1564.	67.
1988	0.	145771.	76080.	0.	0.	350.	222201.	223765.	1564.	68.
1989	0.	163011.	82296.	0.	0.	350.	245657.	247221.	1564.	68.
1990	0.	177928.	90262.	0.	0.	350.	268540.	270154.	1614.	68.
1991	0.	195425.	97778.	0.	0.	350.	293553.	295167.	1614.	67.
1992	0.	212989.	106562.	0.	0.	350.	319901.	321515.	1614.	67.
1993	0.	230497.	115318.	0.	0.	350.	346165.	347779.	1614.	67.
1994	0.	248205.	124170.	0.	0.	350.	372725.	374339.	1614.	67.
1995	0.	266337.	133238.	0.	0.	350.	399925.	401539.	1614.	67.
1996	0.	282769.	141454.	0.	0.	350.	424573.	426187.	1614.	67.
1997	0.	297501.	148822.	0.	0.	350.	446673.	448287.	1614.	67.
1998	0.	311665.	155906.	0.	0.	350.	467921.	469535.	1614.	66.
1999	0.	325265.	162706.	0.	0.	350.	488321.	489935.	1614.	66.
2000	0.	337733.	168938.	0.	0.	350.	507021.	508635.	1614.	66.
2001	0.	349633.	174886.	0.	0.	350.	524869.	526483.	1614.	65.
2002	0.	360397.	180270.	0.	0.	350.	541017.	542631.	1614.	65.
2003	0.	370029.	185086.	0.	0.	350.	555465.	557079.	1614.	64.

ALT V - CASE 39 - LOW GROWTH - 70% CF - NO FBR - 1986 REPROCESSIN 3.15.76 .01 .02

NO PLUTONIUM RECYCLE

FISSILE PLUTONIUM RECOVERY AND UTILIZATION, METRIC TONS

YEAR -CY-	RECOVERY					UTILIZATION					YEAR-END INVENTORY	I PU RECYD
	LWR	BREEDER	NAT AND OTHER	TOTAL ANNUAL	CUMULATED	LWR RECYCLE	BREEDER FUEL	OTHER USES	TOTAL ANNUAL	CUMULATED		
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1979	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1986	6.21	0.00	0.00	6.21	6.21	0.00	0.00	2.20	2.20	2.20	4.01	0.
1987	16.31	0.00	0.00	16.31	22.52	0.00	0.00	2.20	2.20	4.40	18.12	0.
1988	31.16	0.00	0.00	31.16	53.68	0.00	0.00	1.55	1.55	5.95	47.73	0.
1989	41.97	0.00	0.00	41.97	95.65	0.00	0.00	.70	.70	6.65	89.00	0.
1990	46.73	0.00	0.00	46.73	142.38	0.00	0.00	.50	.50	7.15	135.23	0.
1991	45.59	0.00	0.00	45.59	187.97	0.00	0.00	.50	.50	7.65	180.32	0.
1992	46.92	0.00	0.00	46.92	234.89	0.00	0.00	.50	.50	8.15	226.74	0.
1993	48.86	0.00	0.00	48.86	283.75	0.00	0.00	.25	.25	8.40	275.35	0.
1994	51.24	0.00	0.00	51.24	334.99	0.00	0.00	.25	.25	8.65	326.34	0.
1995	51.50	0.00	0.00	51.50	386.49	0.00	0.00	.25	.25	8.90	377.59	0.
1996	50.71	0.00	0.00	50.71	437.20	0.00	0.00	.25	.25	9.15	428.05	0.
1997	53.08	0.00	0.00	53.08	490.28	0.00	0.00	.25	.25	9.40	480.88	0.
1998	64.33	0.00	0.00	64.33	554.61	0.00	0.00	.25	.25	9.65	544.96	0.
1999	66.73	0.00	0.00	66.73	621.34	0.00	0.00	.25	.25	9.90	611.44	0.
2000	68.11	0.00	0.00	68.11	689.45	0.00	0.00	.25	.25	10.15	679.30	0.
2001	69.77	0.00	0.00	69.77	759.22	0.00	0.00	.25	.25	10.40	748.82	0.
2002	76.23	0.00	0.00	76.23	835.45	0.00	0.00	.25	.25	10.65	824.80	0.
2003	61.42	0.00	0.00	61.42	896.87	0.00	0.00	.25	.25	10.90	885.97	0.

ALT V - CASE 39 - LOW GROWTH - 70% CF - NO FBR - 1986 REPROCESSIN 3.15.76 .01 .02

NO PLUTONIUM RECYCLE

YEAR -CY-	CONVERSION TO UF6 IN MT OF U, XW = .300(NATURAL URANIUM	RECOVERED URANIUM	FRESH FUEL FABRICATION LOAD IN METRIC TONS OF HEAVY METAL LWR UO2	LWR MIXED OX	HTGR FISSILE	HTGR FERTILE	FBR MIXED OX	FBR BLANKET	SPENT FUEL REPROCESSING LOAD IN METRIC TONS OF HEAVY METAL LWR, NAT MIXED OX	HTGR FISSILE	HTGR FERTILE	FBR MIXED OX
1974	7646.	0.	1009.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1975	6181.	0.	919.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1976	10407.	0.	1337.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1977	11498.	0.	1758.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1978	13541.	0.	1972.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1979	16093.	0.	2345.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1980	19121.	0.	3181.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1981	21261.	0.	2826.	0.	0.	0.	4.	5.	0.	0.	0.	0.
1982	24072.	0.	4310.	0.	0.	0.	4.	5.	0.	0.	0.	0.
1983	27103.	0.	4532.	0.	0.	0.	3.	3.	0.	0.	0.	0.
1984	32555.	0.	5608.	0.	0.	0.	3.	3.	0.	0.	0.	0.
1985	36385.	0.	5820.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1986	37458.	993.	5949.	0.	0.	0.	3.	2.	1348.	0.	0.	5.
1987	40615.	2880.	6704.	0.	0.	0.	3.	2.	3397.	0.	0.	5.
1988	41937.	5164.	7503.	0.	0.	0.	3.	2.	5843.	0.	0.	5.
1989	43917.	6852.	7877.	0.	0.	0.	3.	2.	7245.	0.	0.	5.
1990	47205.	7652.	8707.	0.	0.	0.	3.	2.	7849.	0.	0.	5.
1991	50806.	8103.	9444.	0.	0.	0.	3.	2.	8249.	0.	0.	5.
1992	54735.	8197.	9964.	0.	0.	0.	3.	2.	8241.	0.	0.	5.
1993	59140.	8197.	10692.	0.	0.	0.	3.	2.	8248.	0.	0.	5.
1994	62243.	8197.	11242.	0.	0.	0.	3.	2.	8248.	0.	0.	5.
1995	65347.	8196.	11634.	0.	0.	0.	3.	2.	8248.	0.	0.	5.
1996	68752.	8197.	12091.	0.	0.	0.	3.	2.	8248.	0.	0.	5.
1997	70482.	8945.	12552.	0.	0.	0.	3.	2.	9248.	0.	0.	5.
1998	71808.	9934.	12901.	0.	0.	0.	3.	2.	10248.	0.	0.	5.
1999	73093.	10181.	13216.	0.	0.	0.	3.	2.	10248.	0.	0.	5.
2000	75547.	10180.	13492.	0.	0.	0.	2.	2.	10248.	0.	0.	5.
2001	76935.	10178.	13680.	0.	0.	0.	2.	2.	10248.	0.	0.	5.
2002	71655.	10922.	13244.	0.	0.	0.	2.	2.	11248.	0.	0.	4.
2003	53336.	8887.	12831.	0.	0.	0.	2.	2.	6099.	0.	0.	4.

ALT V - CASE 39 - LOW GROWTH - 70% CF - NO FBR - 1986 REPROCESSIN 3.15.76 .01 .02

TOTAL ENRICHMENT DEMAND NO PLUTONIUM RECYCLE

	GROSS WITHDRAWALS			IRRADIATED RETURNS			NET REQUIREMENTS		
YEAR -CY-	URANIUM -MT-	U-235 -MT-	VALUE FTN -MT-	URANIUM -MT-	U-235 -MT-	VALUE FTN -MT-	URANIUM -MT-	U-235 -MT-	VALUE FTN -MT-
1974	1190.	31.685	4082.	0.	0.000	0.	1190.	31.685	4082.
1975	1076.	31.511	3555.	0.	0.000	0.	1076.	31.511	3555.
1976	1457.	42.498	4822.	0.	0.000	0.	1457.	42.498	4822.
1977	1849.	51.986	6213.	0.	0.000	0.	1849.	51.986	6213.
1978	1946.	54.251	6561.	0.	0.000	0.	1946.	54.251	6561.
1979	2641.	71.936	8981.	0.	0.000	0.	2641.	71.936	8981.
1980	3092.	83.005	10584.	0.	0.000	0.	3092.	83.005	10584.
1981	3668.	97.348	12615.	0.	0.000	0.	3668.	97.348	12615.
1982	4214.	112.493	14462.	0.	0.000	0.	4214.	112.493	14462.
1983	4195.	116.123	14204.	0.	0.000	0.	4195.	116.123	14204.
1984	5678.	153.486	19396.	0.	0.000	0.	5678.	153.486	19396.
1985	6166.	165.830	21106.	0.	0.000	0.	6166.	165.830	21106.
1986	5944.	160.642	19933.	646.	4.848	3047.	5298.	163.794	16886.
1987	7012.	197.031	23607.	2383.	19.432	11095.	4629.	177.599	12512.
1988	7616.	213.255	25674.	4570.	34.542	21539.	3046.	178.713	4135.
1989	8276.	233.031	27838.	6503.	49.696	30589.	1773.	183.335	-2751.
1990	8891.	250.534	29900.	7502.	57.506	35310.	1389.	193.028	-5410.
1991	9598.	271.733	32222.	8004.	59.192	37926.	1594.	212.541	-5704.
1992	10185.	289.317	34147.	8199.	62.108	38646.	1985.	227.209	-4499.
1993	10863.	309.345	36385.	8195.	62.539	38575.	2668.	246.806	-2190.
1994	11331.	324.784	37854.	8198.	62.303	38621.	3134.	262.481	-767.
1995	11735.	338.852	39085.	8197.	62.400	38596.	3538.	276.452	489.
1996	12209.	354.037	40595.	8197.	62.539	38580.	4012.	291.499	2014.
1997	12647.	367.863	42001.	8697.	67.300	40819.	3951.	300.563	1181.
1998	12971.	378.748	43008.	9686.	74.470	45490.	3285.	304.277	-2482.
1999	13299.	389.334	44039.	10181.	78.098	47836.	3117.	311.236	-3796.
2000	13541.	397.726	44783.	10180.	78.078	47829.	3361.	319.648	-3046.
2001	13717.	404.293	45301.	10179.	78.593	47747.	3538.	325.700	-2447.
2002	12975.	390.019	42495.	10673.	82.201	50091.	2303.	307.818	-7595.
2003	12872.	389.492	42036.	11667.	90.160	54715.	1205.	299.331	-12679.

ALT V - CASE 39 - LOW GROWTH - 70% CF - NO FBR - 1986 REPROCESSIN 3.15.76 .01 .02

TOTAL ENRICHMENT DEMAND

NO PLUTONIUM RECYCLE

YEAR	.200 PERCENT TAILS ASSAY			.250 PERCENT TAILS ASSAY			.300 PERCENT TAILS ASSAY			.400 PERCENT TAILS ASSAY		
-CY-	SEP WORK - K SWU-	FEED -MT-	U308 -ST-	SEP WORK - K SWU-	FEED -MT-	U308 -ST-	SEP WORK - K SWU-	FEED -MT-	U308 -ST-	SEP WORK - K SWU-	FEED -MT-	U308 -ST-
1974	4280.	5735.	7462.	3778.	6228.	8111.	3385.	6840.	8919.	2800.	8657.	11313.
1975	4478.	5746.	8769.	3961.	6252.	9542.	3558.	6882.	10502.	2956.	8749.	13350.
1976	6023.	7746.	11177.	5328.	8428.	12156.	4785.	9277.	13374.	3974.	11791.	16983.
1977	7235.	9450.	12548.	6395.	10274.	13641.	5739.	11299.	15000.	4759.	14338.	19030.
1978	7516.	9855.	14884.	6642.	10713.	16174.	5959.	11779.	17779.	4940.	14941.	22538.
1979	9845.	13044.	18250.	8695.	14172.	19825.	7796.	15575.	21783.	6456.	19734.	27589.
1980	11279.	15034.	21220.	9959.	16329.	23045.	8928.	17939.	25314.	7389.	22713.	32041.
1981	13147.	17615.	24686.	11606.	19127.	26807.	10401.	21008.	29445.	8604.	26583.	37265.
1982	15243.	20365.	26940.	13458.	22116.	29269.	12063.	24294.	32154.	9982.	30751.	40749.
1983	16051.	21083.	31782.	14184.	22914.	34533.	12726.	25192.	37953.	10550.	31943.	48093.
1984	20948.	27814.	37603.	18502.	30215.	40846.	16589.	33200.	44879.	13737.	42050.	56834.
1985	22567.	30039.	39010.	19929.	32628.	42433.	17867.	35847.	46689.	14791.	45391.	59306.
1986	23644.	29980.	40898.	20917.	32657.	44634.	18784.	35985.	49279.	15604.	45853.	63050.
1987	27316.	32943.	43369.	24187.	36014.	47532.	21741.	39832.	52707.	18092.	51152.	68051.
1988	29841.	33781.	44825.	26444.	37115.	49347.	23789.	41259.	54969.	19829.	53547.	71637.
1989	32681.	35184.	47007.	28989.	38807.	51949.	26103.	43313.	58019.	21798.	56670.	76014.
1990	35097.	37231.	50828.	31137.	41118.	56130.	28041.	45952.	62723.	23422.	60280.	82267.
1991	38463.	40969.	55024.	34112.	45240.	60739.	30711.	50549.	67845.	25637.	66290.	88912.
1992	40833.	43686.	59109.	36225.	48209.	65192.	32623.	53833.	72755.	27249.	70504.	95176.
1993	43522.	47254.	63303.	38695.	52090.	69760.	34843.	58102.	77788.	29098.	75927.	101588.
1994	45971.	50140.	66853.	40776.	55238.	73634.	36716.	61577.	82064.	30659.	80369.	107057.
1995	48124.	52716.	70320.	42689.	58049.	77415.	38441.	64681.	86236.	32105.	84341.	112387.
1996	50351.	55474.	73282.	44664.	61056.	80669.	40219.	67996.	89853.	33588.	88569.	117080.
1997	52271.	57272.	76092.	46378.	63056.	82727.	41772.	70246.	92219.	34901.	91563.	120359.
1998	54027.	58260.	74662.	47952.	64222.	84526.	43203.	71635.	94302.	36119.	93613.	123287.
1999	55638.	59687.	78598.	49387.	65823.	86666.	44500.	73452.	96697.	37211.	96067.	126436.
2000	56924.	61238.	80331.	50528.	67515.	88857.	45529.	75320.	98785.	38071.	98458.	129107.
2001	57899.	62353.	79095.	51400.	68732.	87282.	46319.	76664.	97416.	38741.	100177.	127519.
2002	56415.	59337.	76335.	50112.	65523.	84387.	45185.	73214.	94353.	37836.	96015.	123959.
2003	56502.	58106.	75535.	50214.	64278.	83557.	45298.	71951.	93532.	37966.	94699.	123103.

ALT V - CASE 39 - LOW GROWTH - 70% CF - NO FBR - 1986 REPROCESSIN 3.15.76 .01 .02

TOTAL ENRICHMENT DEMAND NO PLUTONIUM RECYCLE

YEAR -CY-	.200 PERCENT TAILS ASSAY CUMULATED TOTALS SEP WORK - K SWU-	FEED -MT-	U308 -ST-	.250 PERCENT TAILS ASSAY CUMULATED TOTALS SEP WORK - K SWU-	FEED -MT-	U308 -ST-	.300 PERCENT TAILS ASSAY CUMULATED TOTALS SEP WORK - K SWU-	FEED -MT-	U308 -ST-	.400 PERCENT TAILS ASSAY CUMULATED TOTALS SEP WORK - K SWU-	FEED -MT-	U308 -ST-
1975	4478.	5746.	8769.	3961.	6252.	9542.	3558.	6882.	10502.	2956.	8749.	13350.
1976	10500.	13492.	19946.	9289.	14681.	21698.	8343.	16158.	23876.	6930.	20540.	30333.
1977	17736.	22942.	32494.	15685.	24955.	35339.	14081.	27458.	38876.	11690.	34878.	49364.
1978	25252.	32797.	47377.	22327.	35667.	51514.	20040.	39237.	56656.	16630.	49819.	71901.
1979	35096.	45841.	65627.	31022.	49840.	71338.	27837.	54812.	78439.	23086.	69553.	99491.
1980	46375.	60874.	86847.	40981.	66168.	94384.	36764.	72751.	103753.	30475.	92266.	131532.
1981	59522.	78489.	111533.	52587.	85296.	121191.	47166.	93759.	133199.	39079.	118849.	168797.
1982	74765.	98853.	139473.	66046.	107412.	150459.	59229.	118053.	165363.	49061.	149600.	209546.
1983	90816.	119936.	170254.	80230.	130326.	184992.	71955.	143245.	203316.	59611.	181542.	257644.
1984	111764.	147750.	207857.	98732.	160542.	225838.	88544.	176445.	248195.	73348.	223593.	314473.
1985	134331.	177789.	246867.	118601.	193169.	268272.	106411.	212292.	294884.	88138.	268983.	373779.
1986	157975.	207769.	287766.	139577.	225826.	312906.	125195.	248277.	344163.	103742.	314836.	436829.
1987	185290.	240712.	331135.	163764.	261841.	360438.	146936.	288110.	396871.	121835.	365988.	504480.
1988	215131.	274494.	375960.	190208.	298955.	409785.	170725.	329369.	451840.	141664.	419534.	576518.
1989	247812.	309677.	423027.	219197.	337763.	461734.	196828.	372682.	509859.	163462.	476204.	652532.
1990	282909.	346908.	473855.	250334.	378881.	517865.	224869.	418634.	572582.	186884.	536484.	734799.
1991	321372.	387877.	528879.	284446.	424121.	578604.	255579.	469183.	640427.	212521.	602775.	823711.
1992	362205.	431564.	587987.	320671.	472330.	643795.	288202.	523015.	713182.	239770.	673279.	918887.
1993	405827.	478818.	651291.	359366.	524420.	713596.	323045.	581118.	790970.	268868.	749206.	1020475.
1994	451798.	528958.	718144.	400142.	579658.	787189.	359761.	642695.	873034.	299527.	829574.	1127532.
1995	499992.	581673.	788464.	442832.	637708.	866604.	398202.	707376.	959270.	331632.	913915.	1239918.
1996	550272.	637148.	861746.	487496.	698764.	945273.	438421.	775371.	1049123.	365219.	1002484.	1356999.
1997	602543.	694420.	936839.	533874.	761819.	1028000.	480193.	845617.	1141341.	400121.	1094047.	1477357.
1998	656570.	752698.	1013501.	581826.	826041.	1112525.	523396.	917252.	1235644.	436240.	1187660.	1600644.
1999	712208.	812367.	1092099.	631213.	891864.	1199192.	567896.	990704.	1332341.	473451.	1283727.	1727080.
2000	769132.	873605.	1172429.	681741.	959380.	1287749.	613425.	1066024.	1431126.	511522.	1382185.	1856187.
2001	827031.	935958.	1251525.	733141.	1028112.	1375011.	659744.	1142688.	1528542.	550262.	1482362.	1983706.
2002	883446.	995295.	1327859.	783253.	1093635.	1459377.	704930.	1215902.	1622895.	588099.	1578377.	2107664.
2003	939948.	1053401.	1403394.	833467.	1157913.	1542935.	750228.	1287852.	1716427.	626065.	1673076.	2230767.

ALT VI - CASE 40 - LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE 3.15.74 .01 .02

CUMULATED RESULTS

NO PLUTONIUM RECYCLE

YEAR -CY-	GROSS WITHDRAWALS AT GDP TAILS ASSAY = .300 URANIUM -MT-	U-235 -MT-	VALUE FN -MT-	SEP WORK - K SWU-	U AS UF6 -MT-	U3O8 -ST-	NATURAL URANIUM -MT-	PLUTONIUM REQUIRED -MT-
1974	1190.	31.685	4082.	3365.	6840.	7896.	0.	0.
1975	1076.	31.511	3555.	3558.	6802.	9427.	0.	0.
1976	1457.	42.498	4822.	4785.	9277.	14146.	0.	0.
1977	1849.	51.986	6213.	5709.	11299.	15835.	0.	0.
1978	1946.	54.251	6561.	5959.	11779.	19038.	0.	0.
1979	2641.	71.936	8981.	7796.	15575.	18446.	0.	0.
1980	3092.	83.005	10584.	8628.	17939.	26716.	0.	0.
1981	3668.	97.348	12615.	10401.	21008.	29603.	0.	0.
1982	4214.	112.493	14962.	12063.	24294.	32868.	0.	0.
1983	4195.	116.123	14204.	12726.	25192.	41027.	0.	0.
1984	5678.	153.486	19396.	16589.	33200.	38163.	0.	0.
1985	6165.	165.830	21106.	17867.	35847.	49075.	0.	0.
1986	5044.	164.642	19933.	17743.	36694.	52974.	0.	0.
1987	7612.	197.031	23607.	21783.	42821.	59183.	0.	0.
1988	7616.	213.255	25674.	23528.	46328.	61667.	0.	0.
1989	8276.	233.031	27838.	25791.	50658.	68422.	0.	0.
1990	8891.	250.534	29900.	27742.	54668.	73886.	0.	0.
1991	9593.	271.733	32222.	30170.	59109.	79108.	0.	0.
1992	10185.	289.317	34147.	32183.	62959.	84602.	0.	0.
1993	10863.	309.345	36485.	34458.	67337.	90063.	0.	0.
1994	11731.	324.784	37454.	36307.	70752.	93905.	0.	0.
1995	11735.	338.852	39985.	38032.	73880.	98169.	0.	0.
1996	12209.	354.037	40595.	39826.	77229.	102512.	0.	0.
1997	12647.	367.963	42901.	41446.	80273.	106031.	0.	0.
1998	12971.	379.748	43908.	42763.	82685.	108948.	0.	0.
1999	13298.	389.334	44139.	44019.	85022.	111824.	0.	0.
2000	13541.	397.725	44783.	45044.	86887.	113938.	0.	0.
2001	13717.	404.293	45301.	45871.	88356.	113892.	0.	0.
2002	12975.	390.019	42495.	44699.	85424.	110093.	0.	0.
2003	12872.	389.492	42036.	44788.	85371.	55439.	0.	0.

ALT VI - CASE 4A - LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE 3.15.76 .01 .02

CUMULATED RESULTS

NO PLUTONIUM RECYCLE

IRRADIATED RETURNS AT GDP TAILS ASSAY = .3001

YEAR -CY-	URANIUM -MT-	U-235 -MT-	VALUE FN -MT-	SEP WORK - K SWU-	U AS UF6 -MT-	U3O8 -ST-	PLUTONIUM RECOVERED -MT-
1974	0.	0.000	0.	0.	0.	0.	0.
1975	0.	0.000	0.	0.	0.	0.	0.
1976	0.	0.000	0.	0.	0.	0.	0.
1977	0.	0.000	0.	0.	0.	0.	0.
1978	0.	0.000	0.	0.	0.	0.	0.
1979	0.	0.000	0.	0.	0.	0.	0.
1980	0.	0.000	0.	0.	0.	0.	0.
1981	0.	0.000	0.	0.	0.	0.	0.
1982	0.	0.000	0.	0.	0.	0.	0.
1983	0.	0.000	0.	0.	0.	0.	0.
1984	0.	0.000	0.	0.	0.	0.	0.
1985	0.	0.000	0.	0.	0.	0.	0.
1986	0.	0.000	0.	0.	0.	0.	0.
1987	0.	0.000	0.	0.	0.	0.	0.
1988	0.	0.000	0.	0.	0.	0.	0.
1989	0.	0.000	0.	0.	0.	0.	0.
1990	0.	0.000	0.	0.	0.	0.	0.
1991	0.	0.000	0.	0.	0.	0.	0.
1992	0.	0.000	0.	0.	0.	0.	0.
1993	0.	0.000	0.	0.	0.	0.	0.
1994	0.	0.000	0.	0.	0.	0.	0.
1995	0.	0.000	0.	0.	0.	0.	0.
1996	0.	0.000	0.	0.	0.	0.	0.
1997	0.	0.000	0.	0.	0.	0.	0.
1998	0.	0.000	0.	0.	0.	0.	0.
1999	0.	0.000	0.	0.	0.	0.	0.
2000	0.	0.000	0.	0.	0.	0.	0.
2001	0.	0.000	0.	0.	0.	0.	0.
2002	0.	0.000	0.	0.	0.	0.	0.
2003	0.	0.000	0.	0.	0.	0.	0.

ALT V1 - CASE 40 = LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE 3.15.76 .01 .02

CUMULATED RESULTS NO PLUTONIUM RECYCLE

YEAR -CY-	NET REQUIREMENTS AT GDP TAILS ASSAY = .300 URANIUM -MT-	U-235 -MT-	VALUE FN -MT-	SEP WORK - K SWU-	U AS UF6 -MT-	U3U8 -ST-	NATURAL URANIUM -MT-	PLUTONIUM YR-END INV -MT-	REVENUE BASED ON CONTRACT -$M-
1974	1190.	31.665	4082.	3385.	6840.	7896.	0.	0.	0.
1975	1076.	31.511	3555.	3456.	6682.	9427.	0.	0.	0.
1976	1457.	42.498	4822.	4785.	9277.	14146.	0.	0.	0.
1977	1849.	51.986	6213.	5739.	11299.	15835.	0.	0.	0.
1978	1946.	54.251	6561.	5959.	11779.	19035.	0.	0.	0.
1979	2641.	71.936	8981.	7796.	15575.	18446.	0.	0.	0.
1980	3092.	83.005	10584.	8928.	17939.	26716.	0.	0.	0.
1981	3669.	97.348	12615.	10491.	21008.	29683.	0.	0.	0.
1982	4214.	112.463	14462.	12063.	24294.	32868.	0.	0.	0.
1983	4195.	116.123	14204.	12726.	25192.	41027.	0.	0.	0.
1984	5678.	153.486	19396.	16509.	33200.	38163.	0.	0.	0.
1985	6166.	165.930	21166.	17867.	35847.	49075.	0.	0.	0.
1986	5944.	159.642	19933.	16743.	36694.	52974.	0.	0.	0.
1987	7012.	197.031	23607.	21703.	42621.	59183.	0.	0.	0.
1988	7616.	213.255	25674.	23528.	46328.	61667.	0.	0.	0.
1989	8276.	233.031	27838.	25791.	50658.	68462.	0.	0.	0.
1990	8891.	250.534	29900.	27742.	54468.	73880.	0.	0.	0.
1991	9598.	271.734	32222.	30170.	59109.	79106.	0.	0.	0.
1992	10185.	288.317	34147.	32183.	62959.	84602.	0.	0.	0.
1993	10863.	309.345	36385.	34458.	67337.	90063.	0.	0.	0.
1994	11331.	324.784	37654.	36307.	70752.	93985.	0.	0.	0.
1995	11735.	338.852	39485.	38032.	73680.	98160.	0.	0.	0.
1996	12209.	354.037	40595.	39826.	77229.	102517.	0.	0.	0.
1997	12647.	367.963	42101.	41448.	80273.	106031.	0.	0.	0.
1998	12971.	378.748	43008.	42763.	82695.	108948.	0.	0.	0.
1999	13290.	389.334	44039.	44019.	85022.	111824.	0.	0.	0.
2000	13541.	397.726	44783.	45044.	86807.	113938.	0.	0.	0.
2001	13717.	404.293	45401.	45871.	88356.	113892.	0.	0.	0.
2002	13975.	390.619	42495.	44699.	85424.	110093.	0.	0.	0.
2003	12872.	380.492	42036.	44208.	85371.	55439.	0.	0.	0.

ALT VI - CASE 40 - LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE 3.15.76 .01 .02

CUMULATED RESULTS NO PLUTONIUM RECYCLE

SPENT FUEL STORAGE AND REPROCESSING IN -MT- OF HEAVY METAL BY QUARTER YEARS

FOR LIGHT WATER REACTORS

-CY-	ADDITIONS TO STORAGE BASINS (1)	(2)	(3)	(4)	FUEL REPROCESSING (1)	(2)	(3)	(4)	STORAGE BASIN REQUIREMENTS (1)	(2)	(3)	(4)
1974	727.	0.	77.	120.	0.	0.	0.	0.	727.	727.	804.	924.
1975	54.	189.	47.	361.	0.	0.	0.	0.	978.	1167.	1215.	1575.
1976	158.	229.	173.	214.	0.	0.	0.	0.	1734.	1962.	2135.	2339.
1977	297.	281.	308.	148.	0.	0.	0.	0.	2636.	2917.	3296.	3433.
1978	308.	274.	433.	301.	0.	0.	0.	0.	3741.	4015.	4448.	4749.
1979	204.	284.	408.	367.	0.	0.	0.	0.	4954.	5237.	5643.	6110.
1980	260.	197.	477.	514.	0.	0.	0.	0.	6370.	6567.	7044.	7558.
1981	336.	247.	597.	479.	0.	0.	0.	0.	7805.	8142.	8739.	9217.
1982	477.	237.	596.	640.	0.	0.	0.	0.	9694.	9932.	10527.	11167.
1983	479.	569.	491.	813.	0.	0.	0.	0.	11646.	12195.	12686.	13499.
1984	585.	552.	730.	720.	0.	0.	0.	0.	14004.	14636.	15366.	16086.
1985	924.	567.	964.	726.	0.	0.	0.	0.	17810.	17578.	18542.	19268.
1986	1138.	667.	961.	1102.	0.	0.	0.	0.	20466.	21073.	22034.	23136.
1987	1105.	845.	1105.	1007.	0.	0.	0.	0.	24330.	25175.	26280.	27377.
1988	1192.	1214.	1265.	1225.	0.	0.	0.	0.	28569.	29783.	31048.	32273.
1989	1352.	1084.	1505.	1474.	0.	0.	0.	0.	33625.	34709.	36214.	37688.
1990	1430.	1056.	1760.	1615.	0.	0.	0.	0.	39125.	40181.	41941.	43556.
1991	1406.	1260.	1853.	1735.	0.	0.	0.	0.	45562.	46312.	48165.	49900.
1992	1653.	1429.	2010.	1828.	0.	0.	0.	0.	51553.	52982.	54982.	56809.
1993	1806.	1517.	2203.	1978.	0.	0.	0.	0.	58615.	60132.	62334.	64313.
1994	1945.	1473.	2350.	2128.	0.	0.	0.	0.	66258.	67931.	70281.	72409.
1995	2008.	1825.	2498.	2275.	0.	0.	0.	0.	74506.	76332.	78820.	81095.
1996	2248.	1978.	2638.	2426.	0.	0.	0.	0.	83343.	85321.	87959.	90384.
1997	2303.	2119.	2767.	2556.	0.	0.	0.	0.	92767.	94887.	97654.	100210.
1998	2511.	2339.	2875.	2663.	0.	0.	0.	0.	102720.	104960.	107834.	110498.
1999	2624.	2348.	2977.	2765.	0.	0.	0.	0.	113122.	115469.	118446.	121211.
2000	2721.	2451.	3073.	2859.	0.	0.	0.	0.	123933.	126384.	129457.	132316.
2001	2808.	2544.	3155.	2939.	0.	0.	0.	0.	135124.	137668.	140823.	143762.
2002	2887.	2625.	3226.	3012.	0.	0.	0.	0.	146649.	149274.	152500.	155512.
2003	0.	0.	0.	0.	0.	0.	0.	0.	155512.	155512.	155512.	155512.

ALT VI - CASE 40 - LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE 3.15.76 .01 .02

NO PLUTONIUM RECYCLE

YEAR	ANNUAL POWER ADDITIONS BY REACTOR TYPE, ELECTRICAL MEGAWATTS									GENERATION MILLIONS
-CY-	HTGR	PWR	BWR	OTHR	NAT	FBR	TOTL	RETD	CUMD	OF KWH
1974	0.	7190.	4594.	850.	0.	0.	12634.	0.	29993.	150290.
1975	0.	3403.	3647.	0.	0.	0.	7050.	200.	35843.	205846.
1976	0.	5475.	1972.	0.	0.	0.	7447.	0.	44290.	250443.
1977	0.	7020.	0.	0.	0.	0.	7020.	0.	51310.	295317.
1978	0.	6118.	0.	0.	0.	0.	6118.	0.	57428.	330573.
1979	0.	3304.	1928.	0.	0.	0.	5232.	850.	61810.	366808.
1980	0.	5605.	2777.	0.	0.	0.	8382.	0.	70192.	413978.
1981	0.	6331.	6447.	0.	0.	0.	12778.	200.	82770.	476291.
1982	0.	11492.	5342.	0.	0.	0.	16834.	175.	99429.	563683.
1983	0.	11840.	5935.	0.	0.	350.	18124.	0.	117563.	666079.
1984	0.	10728.	6897.	0.	0.	0.	17625.	139.	135049.	784371.
1985	0.	14670.	6121.	0.	0.	0.	20791.	0.	155840.	903487.
1986	0.	14690.	9122.	0.	0.	0.	23821.	0.	179661.	1046865.
1987	0.	13756.	7618.	0.	0.	0.	21573.	0.	201234.	1183551.
1988	0.	14405.	6562.	0.	0.	0.	20967.	0.	222201.	1307040.
1989	0.	17240.	6216.	0.	0.	0.	23456.	0.	245657.	1440866.
1990	0.	14917.	8016.	0.	0.	0.	22933.	50.	268540.	1578177.
1991	0.	17497.	7516.	0.	0.	0.	25013.	0.	293553.	1719663.
1992	0.	17564.	8784.	0.	0.	0.	26348.	0.	319901.	1867762.
1993	0.	17508.	8756.	0.	0.	0.	26264.	0.	346165.	2018932.
1994	0.	17708.	8852.	0.	0.	0.	26560.	0.	372725.	2170994.
1995	0.	18132.	9068.	0.	0.	0.	27200.	0.	399925.	2324487.
1996	0.	16432.	8216.	0.	0.	0.	24648.	0.	424573.	2467422.
1997	0.	14732.	7368.	0.	0.	0.	22100.	0.	446673.	2594310.
1998	0.	14154.	7074.	0.	0.	0.	21228.	0.	467921.	2709981.
1999	0.	13600.	6800.	0.	0.	0.	20400.	0.	488321.	2816080.
2000	0.	12468.	6232.	0.	0.	0.	18700.	0.	507021.	2910197.
2001	0.	11900.	5948.	0.	0.	0.	17848.	0.	524869.	2993310.
2002	0.	10764.	5384.	0.	0.	0.	16148.	0.	541017.	3063830.
2003	0.	9632.	4816.	0.	0.	0.	14448.	0.	555465.	3117615.

ALT V) - CASE 40 = LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE 3.15.76 .01 .02

NO PLUTONIUM RECYCLE

YEAR	NUCLEAR POWER CAPACITY BY REACTOR TYPE. ELECTRICAL MEGAWATTS							CUMULATED		CAPACITY FACTOR
-CY-	HTGR	PWR	BWR	OTHR	NAT	FBR	TOTL	ADDNS	RETD	PERCENT
1974	0.	17292.	11851.	850.	0.	0.	29993.	29993.	0.	64.
1975	0.	20495.	15498.	850.	0.	0.	36843.	37043.	200.	65.
1976	0.	25970.	17470.	850.	0.	0.	44290.	44490.	200.	66.
1977	0.	32990.	17470.	850.	0.	0.	51310.	51510.	200.	67.
1978	0.	39108.	17470.	850.	0.	0.	57428.	57628.	200.	68.
1979	0.	42412.	19398.	0.	0.	0.	61810.	62860.	1050.	68.
1980	0.	48017.	22175.	0.	0.	0.	70192.	71242.	1050.	67.
1981	0.	54348.	28422.	0.	0.	0.	82770.	84020.	1250.	68.
1982	0.	65665.	33764.	0.	0.	0.	99429.	100854.	1425.	67.
1983	0.	77514.	39699.	0.	0.	350.	117563.	118988.	1425.	67.
1984	0.	88245.	46457.	0.	0.	350.	135049.	136613.	1564.	67.
1985	0.	102912.	52578.	0.	0.	350.	155840.	157404.	1564.	67.
1986	0.	117611.	61700.	0.	0.	350.	179661.	181225.	1564.	68.
1987	0.	131366.	69518.	0.	0.	350.	201234.	202798.	1564.	67.
1988	0.	145771.	76080.	0.	0.	350.	222201.	223765.	1564.	68.
1989	0.	163011.	82206.	0.	0.	350.	245657.	247221.	1564.	68.
1990	0.	177928.	90262.	0.	0.	350.	268540.	270154.	1614.	68.
1991	0.	195425.	97776.	0.	0.	350.	293553.	295167.	1614.	67.
1992	0.	212989.	106562.	0.	0.	350.	319901.	321515.	1614.	67.
1993	0.	230497.	115318.	0.	0.	350.	346165.	347779.	1614.	67.
1994	0.	248205.	124170.	0.	0.	350.	372725.	374339.	1614.	67.
1995	0.	266337.	133238.	0.	0.	350.	399925.	401539.	1614.	67.
1996	0.	282769.	141454.	0.	0.	350.	424573.	426187.	1614.	67.
1997	0.	297501.	148822.	0.	0.	350.	446673.	448287.	1614.	67.
1998	0.	311665.	155906.	0.	0.	350.	467921.	469535.	1614.	66.
1999	0.	325265.	162706.	0.	0.	350.	488321.	489935.	1614.	66.
2000	0.	337731.	168938.	0.	0.	350.	507021.	508635.	1614.	66.
2001	0.	349633.	174886.	0.	0.	350.	524869.	526483.	1614.	65.
2002	0.	360397.	180270.	0.	0.	350.	541017.	542631.	1614.	65.
2003	0.	370029.	185086.	0.	0.	350.	555465.	557079.	1614.	64.

ALT VI - CASE A0 = LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE 3.15.76 .01 .02

NO PLUTONIUM RECYCLE

FISSILE PLUTONIUM RECOVERY AND UTILIZATION, METRIC TONS

YEAR -CY-	RECOVERY					UTILIZATION					YEAR-END INVENTORY	PU RECYD
	LWR	BREEDER	NAT AND OTHER	TOTAL ANNUAL	CUMULATED	LWR RECYCLE	BREEDER FUEL	OTHER USES	TOTAL ANNUAL	CUMULATED		
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
1979	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	-1.00	0.
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	1.20	2.20	-2.20	0.
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	1.20	3.40	-3.40	0.
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	4.40	-4.40	0.
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.80	.80	5.20	-5.20	0.
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.75	.75	5.95	-5.95	0.
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.40	.40	6.35	-6.35	0.
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.30	.30	6.65	-6.65	0.
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	6.90	-6.90	0.
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	7.15	-7.15	0.
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	7.40	-7.40	0.
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	7.65	-7.65	0.
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	7.90	-7.90	0.
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	8.15	-8.15	0.
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	8.40	-8.40	0.
1994	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	8.65	-8.65	0.
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	8.90	-8.90	0.
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	9.15	-9.15	0.
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	9.40	-9.40	0.
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	9.65	-9.65	0.
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	9.90	-9.90	0.
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	10.15	-10.15	0.
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	10.40	-10.40	0.
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	10.65	-10.65	0.
2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.25	.25	10.90	-10.90	0.

ALT VI - CASE 40 - LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE 3.15.76 .01 .02

NO PLUTONIUM RECYCLE

YEAR -CY-	CONVERSION TO UF6 IN MT OF U, XW = .3001 NATURAL URANIUM	RECOVERED URANIUM	FRESH FUEL FABRICATION LOAD IN METRIC TONS OF HEAVY METAL LWR UO2	LWR MIXED OX	HTGR FISSILE	HTGR FERTILE	FBR MIXED OX	FBR BLANKET	SPENT FUEL REPROCESSING LOAD IN METRIC TONS OF HEAVY METAL LWR, NAT MIXED OX	HTGR FISSILE	HTGR FERTILE	FBR MIXED OX
1974	7646.	0.	1009.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1975	6181.	0.	919.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1976	10407.	0.	1337.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1977	11498.	0.	1758.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1978	13541.	0.	1972.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1979	16093.	0.	2345.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1980	19121.	0.	3181.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1981	21261.	0.	2826.	0.	0.	0.	4.	5.	0.	0.	0.	0.
1982	24072.	0.	4310.	0.	0.	0.	4.	5.	0.	0.	0.	0.
1983	27103.	0.	4532.	0.	0.	0.	3.	3.	0.	0.	0.	0.
1984	32556.	0.	5608.	0.	0.	0.	3.	3.	0.	0.	0.	0.
1985	36385.	0.	5820.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1986	39607.	0.	5949.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1987	44135.	0.	6764.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1988	47791.	0.	7503.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1989	51824.	0.	7877.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1990	55726.	0.	8707.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1991	59737.	0.	9444.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1992	64047.	0.	9964.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1993	68452.	0.	10692.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1994	71513.	0.	11242.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1995	74663.	0.	11634.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1996	78049.	0.	12091.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1997	80940.	0.	12552.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1998	83213.	0.	12901.	0.	0.	0.	3.	2.	0.	0.	0.	5.
1999	85590.	0.	13216.	0.	0.	0.	3.	2.	0.	0.	0.	5.
2000	87263.	0.	13492.	0.	0.	0.	2.	2.	0.	0.	0.	5.
2001	88488.	0.	13680.	0.	0.	0.	2.	2.	0.	0.	0.	5.
2002	84292.	0.	13244.	0.	0.	0.	2.	2.	0.	0.	0.	4.
2003	63688.	0.	12831.	0.	0.	0.	2.	2.	0.	0.	0.	4.

ALT V,I - CASE 40 - LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE 3.15.76 .01 .02

TOTAL ENRICHMENT DEMAND NO PLUTONIUM RECYCLE

YEAR -CY-	GROSS WITHDRAWALS URANIUM -MT-	U-235 -MT-	VALUE FTN -MT-	IRRADIATED RETURNS URANIUM -MT-	U-235 -MT-	VALUE FTN -MT-	NET REQUIREMENTS URANIUM -MT-	U-235 -MT-	VALUE FTN -MT-
1974	1190.	31.685	4082.	0.	0.000	0.	1190.	31.685	4082.
1975	1076.	31.511	3555.	0.	0.000	0.	1076.	31.511	3555.
1976	1457.	42.498	4822.	0.	0.000	0.	1457.	42.498	4822.
1977	1849.	51.986	6213.	0.	0.000	0.	1849.	51.986	6213.
1978	1946.	54.251	6561.	0.	0.000	0.	1946.	54.251	6561.
1979	2641.	71.936	8981.	0.	0.000	0.	2641.	71.936	8981.
1980	3092.	83.005	10584.	0.	0.000	0.	3092.	83.005	10584.
1981	3668.	97.348	12615.	0.	0.000	0.	3668.	97.348	12615.
1982	4214.	112.493	14462.	0.	0.000	0.	4214.	112.493	14462.
1983	4195.	116.123	14204.	0.	0.000	0.	4195.	116.123	14204.
1984	5678.	153.486	19396.	0.	0.000	0.	5678.	153.486	19396.
1985	6166.	165.830	21106.	0.	0.000	0.	6166.	165.830	21106.
1986	5944.	160.642	19933.	0.	0.000	0.	5944.	160.642	19933.
1987	7012.	197.031	23607.	0.	0.000	0.	7012.	197.031	23607.
1988	7616.	213.255	25674.	0.	0.000	0.	7616.	213.255	25674.
1989	8276.	233.031	27838.	0.	0.000	0.	8276.	233.031	27838.
1990	8891.	250.534	29900.	0.	0.000	0.	8891.	250.534	29900.
1991	9598.	271.733	32222.	0.	0.000	0.	9598.	271.733	32222.
1992	10185.	289.317	34147.	0.	0.000	0.	10185.	289.317	34147.
1993	10863.	309.345	36385.	0.	0.000	0.	10863.	309.345	36385.
1994	11331.	324.784	37854.	0.	0.000	0.	11331.	324.784	37854.
1995	11735.	338.852	39085.	0.	0.000	0.	11735.	338.852	39085.
1996	12209.	354.037	40595.	0.	0.000	0.	12209.	354.037	40595.
1997	12647.	367.863	42001.	0.	0.000	0.	12647.	367.863	42001.
1998	12971.	378.748	43008.	0.	0.000	0.	12971.	378.748	43008.
1999	13298.	389.334	44039.	0.	0.000	0.	13298.	389.334	44039.
2000	13541.	397.726	44783.	0.	0.000	0.	13541.	397.726	44783.
2001	13717.	404.293	45301.	0.	0.000	0.	13717.	404.293	45301.
2002	12975.	390.019	42495.	0.	0.000	0.	12975.	390.019	42495.
2003	12872.	389.492	42036.	0.	0.000	0.	12872.	389.492	42036.

ALT VI - CASE 40 - LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE 3.15.76 .01 .02

TOTAL ENRICHMENT DEMAND NO PLUTONIUM RECYCLE

YEAR -CY-	.200 PERCENT TAILS ASSAY SEP WORK - K SWU-	FEED -MT-	U308 -ST-	.250 PERCENT TAILS ASSAY SEP WORK - K SWU-	FEED -MT-	U308 -ST-	.300 PERCENT TAILS ASSAY SEP WORK - K SWU-	FEED -MT-	U308 -ST-	.400 PERCENT TAILS ASSAY SEP WORK - K SWU-	FEED -MT-	U308 -ST-
1974	4280.	5735.	7462.	3770.	6228.	8111.	3385.	6840.	8919.	2800.	8657.	11313.
1975	4478.	5746.	8749.	3961.	6252.	9542.	3558.	6802.	10502.	2956.	8749.	13350.
1976	6923.	7746.	11177.	5328.	8428.	12156.	4785.	9277.	13374.	3974.	11791.	16983.
1977	7235.	9450.	13548.	6395.	10274.	13641.	5739.	11299.	15000.	4759.	14338.	19030.
1978	7516.	9855.	14884.	6642.	10713.	16174.	5959.	11779.	17779.	4940.	14941.	22538.
1979	9945.	13044.	19250.	8695.	14172.	19025.	7796.	15575.	21793.	6456.	19734.	27589.
1980	11279.	15034.	21220.	9959.	16329.	23045.	8928.	17939.	25314.	7389.	22713.	32041.
1981	13147.	17615.	24606.	11606.	19127.	26807.	10401.	21008.	29445.	8604.	26583.	37265.
1982	15243.	20365.	28940.	13458.	22116.	29269.	12063.	24294.	32144.	9982.	30751.	40749.
1983	16951.	21883.	31782.	14184.	22914.	34533.	12726.	25192.	37953.	10550.	31943.	48093.
1984	20948.	27814.	37613.	18502.	30215.	40846.	16589.	33200.	44879.	13737.	42050.	56834.
1985	22567.	30039.	39463.	19929.	32628.	42889.	17867.	35847.	47149.	14791.	45391.	59779.
1986	23612.	30676.	43216.	20879.	33358.	46990.	18743.	36694.	51682.	15556.	46581.	65593.
1987	27454.	35814.	49496.	24271.	38938.	52691.	21783.	42821.	57945.	18072.	54336.	73519.
1988	29659.	38752.	52723.	26218.	42129.	57321.	23528.	46328.	63038.	19516.	58776.	79986.
1989	32503.	42364.	57140.	28736.	46061.	62128.	25791.	50658.	68359.	21399.	64286.	86711.
1990	34959.	45649.	61727.	30908.	49524.	67118.	27742.	54468.	73822.	23018.	69123.	93695.
1991	38011.	49420.	66331.	33610.	53739.	72130.	30170.	59109.	79341.	25039.	75029.	100718.
1992	40540.	52632.	70793.	35849.	57235.	76907.	32183.	62959.	84609.	26713.	79928.	107521.
1993	43401.	56285.	75013.	38381.	61212.	81584.	34458.	67337.	89754.	28605.	85496.	113975.
1994	45717.	59124.	78544.	40435.	64307.	85437.	36307.	70752.	94007.	30149.	89859.	119414.
1995	47873.	61719.	82042.	42350.	67140.	89252.	38032.	73880.	98217.	31591.	93863.	124793.
1996	50123.	64505.	85590.	44344.	70177.	93021.	39826.	77229.	102371.	33088.	98136.	130094.
1997	52157.	67033.	88449.	46147.	72938.	96236.	41448.	80273.	105918.	34440.	102017.	134620.
1998	53902.	69042.	91014.	47606.	75123.	99034.	42763.	82645.	109004.	35538.	105100.	138564.
1999	55377.	70986.	93483.	49002.	77243.	101809.	44019.	85022.	111736.	36585.	108084.	142055.
2000	56659.	72533.	95680.	50140.	78932.	103470.	45044.	86887.	113903.	37443.	110471.	144831.
2001	57490.	73749.	96243.	51057.	80261.	102583.	45871.	88356.	112952.	38135.	112356.	143692.
2002	56172.	71946.	92575.	49733.	77566.	100794.	44699.	85424.	111012.	37191.	108719.	141305.
2003	56269.	71183.	92534.	49825.	77508.	100756.	44788.	85371.	110978.	37275.	108683.	141281.

ALT VI - CASE 40 - LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE 3.15.76 .01 .02

TOTAL ENRICHMENT DEMAND NO PLUTONIUM RECYCLE

YEAR	.200 PERCENT TAILS ASSAY CUMULATED TOTALS			.250 PERCENT TAILS ASSAY CUMULATED TOTALS			.300 PERCENT TAILS ASSAY CUMULATED TOTALS			.400 PERCENT TAILS ASSAY CUMULATED TOTALS		
	SEP WORK	FEED	U3O8	SEP WORK	FEED	U3O8	SEP WORK	FEED	U3O8	SEP WORK	FEED	U3O8
-CY-	- K SWU-	-MT-	-ST-	- K SWU-	-MT-	-ST-	- K SWU-	-MT-	-ST-	- K SWU-	-MT-	-ST-
1975	4478.	5745.	8769.	3961.	6252.	9542.	3558.	6882.	10502.	2956.	8749.	13350.
1976	10500.	13492.	19946.	9289.	14681.	21698.	8343.	16158.	23876.	6930.	20540.	30333.
1977	17736.	22942.	32494.	15685.	24955.	35339.	14081.	27458.	38876.	11690.	34878.	49364.
1978	25252.	32797.	47377.	22327.	35667.	51514.	20040.	39237.	56656.	16630.	49819.	71901.
1979	35496.	45941.	66627.	31022.	49840.	71338.	27837.	54812.	78439.	23086.	69553.	99491.
1980	46375.	60374.	86847.	40981.	66158.	94384.	36764.	72751.	103753.	30475.	92266.	131532.
1981	59522.	78409.	111533.	52587.	85296.	121191.	47166.	93759.	133109.	39079.	118849.	168797.
1982	74765.	98853.	139473.	66046.	107412.	150459.	59229.	118053.	165363.	49061.	149600.	209546.
1983	90816.	119936.	170254.	80230.	130326.	184992.	71955.	143245.	203316.	59611.	181542.	257640.
1984	111764.	147750.	207857.	98732.	160542.	225838.	88544.	176445.	248105.	73348.	223593.	314473.
1985	134331.	177789.	247320.	118661.	193169.	268727.	106411.	212292.	295344.	88138.	268983.	374252.
1986	157943.	208465.	290536.	139540.	226528.	315718.	125154.	248985.	347026.	103694.	315564.	439645.
1987	186397.	244279.	339032.	163811.	265465.	368409.	146937.	291807.	404971.	121766.	369900.	513365.
1988	215055.	283031.	391725.	190029.	307595.	425730.	170465.	338135.	468009.	141282.	428676.	593351.
1989	247568.	325395.	448865.	218765.	353656.	487658.	196256.	388793.	536338.	162681.	492961.	680062.
1990	282517.	370943.	510592.	249673.	403180.	554976.	223998.	443260.	610159.	185699.	562084.	773757.
1991	320528.	420363.	576923.	283284.	456919.	627106.	254168.	502370.	689500.	210739.	637113.	874475.
1992	361068.	472395.	647716.	319133.	514155.	704054.	286351.	565329.	774109.	237452.	717041.	981994.
1993	404469.	529290.	722728.	357514.	575367.	785078.	320808.	632666.	863943.	266056.	802537.	1095971.
1994	450185.	588404.	801272.	397950.	639674.	871115.	357115.	703418.	957950.	296205.	892396.	1215395.
1995	498059.	650123.	883314.	440300.	706814.	960367.	395147.	777298.	1056167.	327797.	986259.	1340178.
1996	548182.	714628.	968814.	484644.	776991.	1053387.	434974.	854527.	1158538.	360884.	1084394.	1470272.
1997	600339.	781666.	1057262.	530790.	849929.	1149923.	476422.	934800.	1264456.	395324.	1186412.	1604692.
1998	654141.	850708.	1149276.	576397.	925052.	1248657.	519185.	1017484.	1373460.	430862.	1291512.	1743456.
1999	709518.	921695.	1241560.	627399.	1002295.	1350165.	563203.	1102507.	1485196.	467447.	1399596.	1885511.
2000	766177.	994228.	1336639.	677539.	1081227.	1453636.	608247.	1189393.	1599099.	504890.	1510067.	2030342.
2001	823367.	1067977.	1436882.	728595.	1161487.	1556219.	654118.	1277749.	1712050.	543025.	1622423.	2174034.
2002	880039.	1139223.	1532458.	778328.	1239054.	1657012.	698817.	1363173.	1823042.	580215.	1731142.	2315339.
2003	936308.	1210407.	1615992.	829153.	1316561.	1757768.	743605.	1448544.	1934040.	617490.	1839825.	2456621.

APPENDIX B

GROWTH PROJECTIONS FOR NUCLEAR GENERATING CAPACITY

At the end of 1975, 56 nuclear units representing a total capacity of over 38,000 MWe were in commercial operation. The total generating capacity for the contiguous United States at that time was about 505,000 MWe; nuclear generating capacity represented 7.7 percent of the total. By 1985, nuclear units representing 170,000 MWe or 20.4 percent of the total capacity of 785,000 MWe for the United States, are expected to be in commercial operation.[1]

Although capital and fuel costs have increased for nuclear power, they also have increased for coal and oil fired units so that nuclear generated steam has remained competitive. It should be noted, also, that there are many other considerations in selecting a power plant in addition to cost, such as siting, environmental impact and fuel availability. Taking these factors into account, the utility industry expects to add 164 nuclear units during the time frame 1975-1984. This amounts to about 170,000 MWe of capacity or about 50 percent of the total capacity to be added.

Growth Projections for Nuclear Generating Capacity

A number of long term forecasts, scenarios and projections of nuclear capacity have been published recently. Some of these are shown for the years 1985 and 2000 in Table III (B)-1 and include LWR, HTGR, LMFBR and fusion reactors. As in the case of demand for electricity, the magnitude of the forecasts of nuclear capacity depends highly on the assumptions that are made. For that reason, the assumptions for the various forecasts are summarized here. There is no real attempt to assess the likely probability of the various forecasts, scenarios or projections coming into being. This study should only be viewed as an abbreviated tabulation of the more pertinent results.

ERDA Update of WASH-1139(74)[32]

On April 28, 1975, Roger Legassie, Assistant Administrator for Planning and Analysis, ERDA, presented in congressional testimony an update of WASH-1139(74) that was completed in early 1975. These updated projections do not specifically address the future impact of expanded Federal energy research and development programs which is done later in "the Plan." The alternative projections presented should be viewed as such rather than as a forecast or set of forecasts. They are the following:

High Case. This case reflects the Presidential objectives for 200 new nuclear power plants through 1985 and a continuation of a concerted nuclear effort in the longer term coupled with continued high rates of growth in electric energy. For 1985 this case would require that all plants maintain schedule as currently announced for operation by that date plus an additional 30,000 MWe be scheduled for installation in the same period.

Table III (B)-1

COMPARISON OF FORECASTS, PROJECTIONS AND SCENARIOS OF TOTAL NUCLEAR GENERATING CAPACITY FOR 1985 AND THE YEAR 2000

Forecast	Case	Total Nuclear Capacity (Thousands of MWe) 1985	2000
Energy Research and Development Administration			
Update of WASH-1139(74) February 1975	Low	160	625
	Low/Moderate	185	800
	Moderate/High	205	1,000
	High	245	1,250
Federal Power Commission[33] Technical Advisory Committee on Power Supply	Base	not given	982
	Conservation	not given	818
	Substitution	not given	1,520
Council on Environmental[34] Quality "The Half and Half Plan"		140	571
Ford Foundation Energy Policy Project[35]	Historical		
	Domestic Oil and Gas or High Import	162	653
	High Nuclear	194	818
	Technical Fix		
	Self Sufficiency	130	180
	Environmental Protection	81	49
	Zero Energy Growth	81	49
Energy Research and Development Administration "The Plan"	0-No new Initiatives	185	720
	I-Improved Efficiencies in End Use	185	368
	II-Synthetics from Coal and Shale	185	720
	III-Intensive Electrification	225	801
	IV-Limited Nuclear Power	185	201
	V-Combination of All New Technologies	225	449

*Estimates based on fuel requirements that were given with assumed heat rates of 10,000 Btu's/kW-hr and capacity factor of 0.7.

Moderate/High Case--This case is primarily based on counting plants ordered in the short run with some allowance for additional slippage in schedules. The longer term presumes that nuclear power plants maintain an economic advantage over other type central station power plants and therefore capture the largest portion of new additions.

Moderate/Low Case--Within a setting of slower growth of electricity, the need for new central station plants is reduced, and consequently, a similar type reduction in nuclear power plants. While nuclear power maintains an economic advantage, the problems of high capital costs and long lead times cause some shifting to fossil-fuel plants.

Low Case--This case presents the lowest ERDA forecast of nuclear capacity. The assumption is made that delays in bringing nuclear plants on line continue to plague the industry. The sources of delay are manifold including late equipment deliveries, construction delays, strikes, poor labor productivity and regulatory problems. It is not assumed that any particular source of delay is predominant or that any particular source is corrected, but rather that some of these sources of delay will remain. During the long term, nuclear power plants are presumed to have only a marginal economic advantage over new technology fossil-fuel plants.

Federal Power Commission (FPC): Technical Advisory Committee on Power Supply (TACPS)[33]

The National Power Survey Technical Advisory Committee on Power Supply published three hypothetical forecasts. The full implications of the forecasts were not evaluated.

Base--A hypothetical situation occurring if prior conditions of plentiful supplies of low-cost oil and gas were to continue.

Conservation--Higher prices of energy supplies but still having adequate oil and gas supplies available at those prices.

Substitution--The authors claim that this is the one the most likely to occur. This case recognizes that the principal shortages will be concentrated in oil and natural gas; that these fuels will become increasingly unavailable at any price; and that coal and nuclear energy must be substituted for applications that currently use oil and natural gas.

Council on Environmental Quality (CEQ): The Half and Half Plan[34]

No assessment of the likelihood of the Half and Half Plan was stated. Some of the implications for energy supply are that:

- Major reliance must be placed on coal and nuclear fission. Coal will increase from 12.6 quadrillion Btu's in 1971 to 33.4 quadrillion Btu's in 2000; nuclear power from 0.4 to 35 quadrillion Btu's.

- Over 42 percent of total energy inputs will be used to produce electricity. This will result in substantial conversion losses--as much as 30.7 quadrillion Btu's in 2000.

- Limited petroleum resources must increasingly be reserved for transportation uses.

- Major research and development should be carried out on new energy resources such as nuclear fusion, solar and geothermal energy. Even with a major effort, however, it is not reasonable to expect more than 3 percent of U.S. total needs from these new sources by the year 2000.

Ford Foundation: Energy Policy Project (EPP)[35]

Three basic scenarios were examined which are described below. The relative likelihood of them coming into fruition should be judged by the individual reader by consulting Reference 7 to understand the full implications of the scenario.

Historical--If a conservative view of the likely fruits of energy research and development is taken there are three major sources of future supplies for the rest of the century: domestic fossil fuels, including synthetic oil and gas; nuclear power; and oil imports. The relative importance of these various sources depends upon such factors as environmental acceptability, relative price, and government policy concerning reliance on imports.

A basic feature of all supply options under Historical Growth is that the supply mix shifts away from oil and gas. Today gases and liquids make up more than three-quarters of our energy supply. But in the year 2000 they would account for only about half the total supply in the Historical Growth Scenario. In contrast, an even greater role is expected for coal and nuclear power, whose share of the energy supply increases from 20 to 50 percent between now and 2000. Roughly two-thirds of the growth in energy between now and 2000 in the Historical Growth scenario would be due to coal and nuclear power.

Technical Fix--A basic advantage of the Technical Fix scenario is that through energy conservation this country gains considerable flexibility in putting together an energy supply mix. It is important to emphasize, however, that even the low rate of growth in this scenario requires substantial additional energy supplies, and expansion of a number of sources will be required. With the lower growth rate, however, it is possible to forego development of some major energy sources, or alternately, to meet demand by expanding various sources at about half the rate required in the Historical Growth scenario.

There are two options in the Technical Fix scenario:

Self-sufficiency: In this option, the objective is to cut imports in half from the present level of about 6 million barrels per day to 3 million

barrels per day for the period 1985-2000. Half the growth in this option would come from nuclear power and coal.

Environmental protection: The thrust of this supply mix is to minimize demands on environmentally controversial sources of energy: developments in presently underdeveloped off shore areas, in Western coal and shale where water is scarce and reclamation difficult, and in nuclear power.

Zero Energy Growth (ZEG)--The energy supplies required for ZEG are not simply scaled down versions of the supply schedules for higher growth scenarios. Some of the motivations that curtail growth in demand are reflected in the supply mix for ZEG.

A decision to level off energy consumption a decade hence might stem in part from a desire to avoid development that causes serious environmental problems. This means avoiding the Atlantic and Pacific coasts, oil shale, and much western coal. It also means avoiding the expansion of nuclear power. Similarly, concern over climatic alterations from burning fossil fuels would motivate a limit on the growth in fossil fuels. Further, a concern over the "big brother" syndrome would lead to the de-emphasis of large energy technologies in favor of small scale total energy systems, roof top solar systems, organic waste energy systems, and wind power, and use of solar energy could help alleviate chronic air pollution.

Energy Research and Development Administration (ERDA): The Plan[24]

There are six scenarios discussed. It is important to evaluate the ultimate consequences of the various scenarios in order to appraise the relative likelihood of their occurrence. Because the matters are quite complex it is advised that the reader consult Reference 8. The supply assumptions for the scenarios will now be discussed.

Scenario 0--No New Initiatives

- Oil and gas production draws on remaining recoverable domestic resources

  According to lower estimates by the U.S. Geological Survey (1975) and the National Academy of Sciences

  Without tertiary or other new recovery

  Coal and nuclear converter reactors continue to expand to meet electricity demand, limited by ability to construct or convert plants

  Other energy sources (e.g., geothermal, hydroelectric, and urban wastes) expand according to historic projections of existing technologies which do not reflect recognition of a serious energy problem

Scenario I--Improved Efficiencies in End Use

- Domestic oil and gas production is increased above the base case (Scenario 0) by new enhanced recovery technologies.

- Solar heating and cooling are introduced.

- Geothermal heat is used for process and space heating.

- Waste materials are employed as fuels or are recycled to save new energy in production.

- Other assumptions are those of Scenario 0.

Scenario II--Synthetics from Coal and Shale

- Substantial new synthetic fuels production is introduced from

  Coal
  Oil shale
  Biomass

- Enhanced oil and gas recovery levels of Scenario I are included.

- Under used solar, geothermal, and waste sources included in Scenario 0 are not included here.

- The assumptions, unless previously stated, are those of the previous scenarios.

Scenario III--Intensive Electrification

- Electric power is intensively generated by coal and nuclear power as in prior scenarios.

- New technology sources are introduced as available to generate electricity:

  Breeder reactors
  Solar electric (wind, thermal, photovoltaics and ocean thermal)
  Fusion
  Geothermal electric

- A minimal contribution is assumed from waste materials (as in Scenario 0).

- Supply assumptions are consistent with Scenario 0.

Scenario IV--Limit on Nuclear Power

- Converter reactor energy levels are constrained to 200,000 MWe.

- Coal electric is at the levels in other scenarios to permit coal to be employed for synthetics.

- Additional sources of electricity depend on

  Accelerated geothermal development (more than a factor of two over Scenario III)

  Accelerated solar development (a factor of two over Scenario III)

  Fusion as in Scenario III

- Solar and geothermal heating are used (as in Scenarios I and III).

- Synthetic fuels are produced from coal, shale, and biomass at the level of Scenario II.

Scenario V--Combination of All New Technologies

Scenario V analyzes a case in which a combination of all major energy packages including nuclear, are simultaneously commercialized (i.e., improved end-use, synthetic fuels, and electrification). Complete success in all these complex endeavors is highly unlikely. The specific supply assumptions for this scenario are the same as Scenarios 0 through IV.

Overview

The ERDA Update of WASH 1139(74) Low Case study assumption of 625,000 MWe of nuclear capacity for the year 2000 is a representative forecast, scenario or projection compared to the many shown in Table III B-1 which appear likely to occur. The Low Case is very high under the assumption that the United States were to follow a Zero Energy Growth or Technical Fix Scenario envisioned by the Ford Energy Policy Project. Also, the Low Case is high compared to the ERDA Scenario I, Improved Efficiencies in End Use; Scenario IV, Limited Nuclear Power; or Scenario V, Combination of All Technologies. All three of these scenarios would likely require heavy government involvement to attempt to bring this about with no assurance of success.

Additional discussion of nuclear capacity projections, with particular attention to regional breakdown, may be found in the "Nuclear Energy Center Site Survey" report.[9]