THE FUTURE OF NUCLEAR POWER IN THE NORTHEAST

Vance L. Sailor and Ferdinand J. Shore

March 30, 1976

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Prepared for the
UNITED STATES ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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VANCE L. SAILOR AND FERDINAND J. SHORE*

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Work supported by
THE DIVISION OF BIOMEDICAL AND ENVIRONMENTAL RESEARCH
of the
UNITED STATES ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
in the context of
THE BROOKHAVEN NATIONAL LABORATORY REGIONAL ENERGY STUDIES PROGRAM

BROOKHAVEN NATIONAL LABORATORY
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Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Domestic ~~\$9.00~~ 8.00; Foreign \$11.50;
Microfiche \$2.25

April 1976

750 copies

SUMMARY

As of July 1975, there were 15 operable nuclear power plants in the Northeast*, representing approximately 11% of the regional electric generating capability. It is estimated that during 1975 these plants will produce approximately 13% of the electric energy generated in the region. At the present time (end of 1975), New England obtains about one-third of its electric energy from nuclear units; New York about 10%, and Mid-Atlantic about 15%. Production costs for the first half of 1975 averaged 12.69 mills/kwh for the nuclear plants, compared with a 19.78 mills/kwh average for coal and about 19.3 mills/kwh for a typical modern base-loaded oil-fired plant. Because of lower fuel costs, the nuclear plants were operated on a first priority basis and thus achieved higher average plant capacity factors during the first half of 1975 than did conventional fossil-fueled units.

Construction plans for the next two decades show a strong preference for nuclear units, there being 18 new units under construction and 33 additional units announced. Plans indicate that after 1985 the nuclear share of new capacity will be about 75% in New England, more than 85% in New York, and about 55% in Mid-Atlantic. If these plans were implemented, nuclear plants would supply approximately 40% of the electric energy needed in 1985, 50% in 1990 and 65% in 2000.

It is recognized that economic forecasts are subject to large uncertainties, particularly because of the current volatile international petroleum situation. Costs of constructing and operating nuclear plants are expected

* See pages 1 and 3 for geographical limits of the region and sub-regions.

to escalate very rapidly. However, the costs of fossil-fueled systems are expected to exhibit comparable escalation. Analyses indicate that nuclear units will retain or increase their economic advantage over coal and oil units. If so, and if the planned construction of nuclear capacity materializes, the dollar savings to the consuming public will be enormous. For example, assuming an ~ 15 mill/kwh differential between nuclear and fossil in 1985, the annual savings to customers in the Northeast would be in the range of \$3.5 billion. Substantial benefits will also accrue in occupational and public health and safety and in environmental impacts.

Despite the present favorable economics and performance of the nuclear units, and despite the strong preference of the planners for nuclear capacity to meet future demands, there are many factors which cast doubt on whether these plans will be executed. Cost escalation, combined with difficulties in raising capital funds, have forced many units to be deferred or canceled. Many such deferments and cancellations have occurred during preparation of this report, several too recently to be taken into account in the data presented herein. Although financial problems affect all types of generating facilities, the nuclear units have been more severely affected because of their inherently large size and capital intensive nature.

Undoubtedly, other factors have caused utilities to reexamine their plans. Many stages of the nuclear fuel cycle are in a state of disarray -- uranium prices have soared in recent months; there has been no decision on expanding uranium enrichment capacity; the recycle of plutonium has not been authorized; no reprocessing plants are operating, and the procedures for high-level radioactive waste management have not been selected. On top of this, public

opposition to nuclear power has increased and there is prospect of adoption of nuclear moratorium bills in several states.

This report presents three projections (scenarios) covering the period from 1976 to 2000. The Base Case Nuclear Scenario assumes that the construction schedules as of August 31, 1975 are implemented. Extrapolations were necessary for the period 1990-2000. A Nuclear Moratorium Scenario assumes that no new plants are undertaken after January 1, 1977. Finally, a Maximum Nuclear Growth Scenario postulates a concerted effort to add additional nuclear capacity beginning in 1982, but constrained by the ability of industry to expand the capabilities needed to supply the components and fuel. Appreciable differences in the three scenarios do not appear until about 1985, a consequence of the long lead time in making plans and completing construction. The potential economic impact of a nuclear moratorium is enormous. The cumulative incremental costs of the Nuclear Moratorium Scenario postulated in this study exceed \$160 billion by the year 2000.

In view of the long delay in the consequences and the potential magnitude of the economic impact, proposals for any form of nuclear moratorium deserve serious analysis.

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I. INTRODUCTION

A. OBJECTIVES:

The purpose of this report is to describe the role of nuclear energy in the "Northeastern Region"*, and to provide a basic background on the technical aspects of nuclear power stations which are relevant to decision-making processes at the local, state and regional levels. Included are:

- A review of the present regional dependence on nuclear steam-electric generating plants;
- A summary of commitments and announced plans for new units;
- An analysis of economic factors;
- A discussion of environmental impacts, and
- Non-technical descriptions of the basic principles of operation of nuclear power stations, and the elements of nuclear safety.

From the data presented, it is possible to construct scenarios for selected future years, which reveal the consequences of various public decisions. The scenarios range from a "nuclear moratorium" at one extreme to a "maximum-effort growth" at the other. These scenarios will be evaluated in a companion volume[†] which will include scenario components from all supply sectors of the energy system.

B. SUMMARY OF PRESENT STATUS:

As of July 1, 1975, there were 15 operable commercial nuclear power plants in the Northeast, with a total capacity of approximately 10,400 megawatts.

* For purposes of this study, the "Northeastern Region" includes Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, Pennsylvania, New Jersey, Delaware, Maryland, and District of Columbia.

† A Perspective on the Energy Future of the Northeast, Energy Policy Analysis Group, Department of Applied Science, Brookhaven National Laboratory, Upton, New York 11973 (to be published in March 1976).

This represents ~ 10.9 percent of the electrical generating capacity of the region. In 1974, the Northeast produced 342.5×10^6 MWh of electrical energy, of which 36.8×10^6 MWh, or 10.8%, was produced by nuclear stations.⁽¹⁾ The projections for 1975 indicate that nuclear plants will produce approximately 48×10^6 MWh (13%) of the 370×10^6 MWh total electric production for the region.⁽²⁾ The rapid increase in the nuclear share is attributed to several new plants which have been commissioned after January 1, 1975.

In addition to the 15 operable plants, one plant is undergoing modification until 1977, and 18 plants of about 18 million kilowatts capacity are under construction. 33 additional plants with capacities totaling more than 36 million kilowatts have been announced and are in various stages of planning, licensing and contracting.

In recent months, because of the economic depression, the operating dates of many new plants (both under construction and planned) have been postponed. The effects of such postponements will not be felt until the 1982-1987 time span; however, this report will present scenarios which will give an evaluation of the consequences of the postponements.

C. SUB-REGIONAL CHARACTERISTICS

Among the utilities of the Northeast there is a considerable variation in the "mix" of generating units. In each locality the present mix has evolved over the past two decades as the result of a variety of local considerations, e.g., the stringency of local air pollution standards, siting and environmental factors, and the relative delivered costs of various boiler fuels (domestic or foreign). The cost structure of boiler fuels has experienced unforeseen radical changes since October 1973, and consequently much of the existing generating

capacity is committed to extremely expensive fuel, i.e., imported residual and No. 2 oil.

Because of the variations within the Northeast, we shall consider three sub-regions separately:

- New England,
- New York, and
- Mid-Atlantic (Pennsylvania, New Jersey, Maryland, Delaware and the District of Columbia).

These sub-regions approximate the boundaries of the three major power pools within the Northeast, i.e., the New England Power Pool (NEPOOL), the New York Power Pool (NYPP), and the Pennsylvania-New Jersey-Maryland Interconnection (PJM).

1. New England

Most electrical utilities in New England participate in the New England Power Pool (NEPOOL) and effectively operate as an integrated system through the primary and satellite dispatching centers of the New England Power Exchange (NEPEX). The planning activities of the Pool are carried out by New England Power Planning (NEPLAN). The pooling of operations and planning is a recent development which had its beginnings in 1966. The NEPEX system became operational in 1970 and the NEPOOL agreements were completed in 1971. NEPOOL is a member of the Northeast Power Coordinating Council (NPCC), along with the New York Power Pool and parts of Canada.

New England must be classified as a "fuel-poor" region, having no appreciable resources of conventional fuels. A small amount of hydroelectric capacity is available which is seasonally dependent. In recent years,

air pollution constraints and lack of adequate abatement technology have eliminated coal as a viable fuel for generating stations. Most coal-fired units have been retired or converted to burn oil. The coal handling facilities at most of the converted plants have been dismantled and the transportation system for supplying coal is in a state of disrepair or has otherwise disappeared. Since about 1969 natural gas has been effectively unavailable in New England for power generation due to supply shortages and the priority system.

As a result of the combination of these forces, New England has become almost completely dependent on oil and nuclear for production of electricity. For example, in the five month period January-May 1975, 53.3% of the electric energy produced was from oil and 30.0% from nuclear, while coal contributed only 9.1% and hydro 7.6%.⁽³⁾ (It should be noted that the hydro contribution is seasonal, reaching its maximum during the spring season of the year.)

It is important to note that because of state-imposed low sulfur restrictions, most of the oil used in New England for power generation must be of foreign origin. Consequently, the OPEC boycott of October 1973 and the subsequent sharp price increase in OPEC oil had severe impact on the area. Not only was the region imperiled during the boycott by a near electrical crisis due to dwindling fuel reserves, but it has since borne a disproportionately heavy economic burden as a result of the higher prices and the Federal tariff on imported oil.

Clearly, New England faces a chronic problem in obtaining a long term reliable source of energy for production of electricity at reasonable cost. Recent studies indicate that it would be advantageous to

exploit nuclear power as quickly as possible.^(4,5) The NEPLAN projections for future additions to generating capacity reflect a strong preference for nuclear units.⁽⁶⁾

2. New York

The New York Power Pool (NYPP) was formed in 1966 and presently includes essentially all of the electrical systems in the state.⁽⁷⁾ NYPP serves both as an operating (dispatching) and planning unit. As noted in the previous section, NYPP is a member of the Northeast Power Coordinating Council (NPCC), along with NEPOOL and parts of Canada.

The dominating feature of the NYPP is the New York City metropolitan area, which consumes more than half of the electricity produced in the region. The metropolitan area is beset by problems of the first magnitude -- severe constraints on sites for new generating facilities and rights-of-way for new transmission lines, rigid air pollution standards which preclude the use of all but the lowest sulfur fuels, sharp summer and wintertime peak demands in the late afternoons, strong public opposition to new facilities, etc.

To the east of the city, Long Island has its own peculiar problems, being for all practical purposes geographically isolated insofar as rail transportation, pipeline and transmission corridor potential is concerned. Except for connections with Con Edison* transmissions links must be underwater across Long Island Sound to Connecticut. This geography largely precludes import of bulk power from other localities. The problem of providing adequate generating capacity is aggravated by the growth of population in central and eastern Long Island, which has one of the highest

*A 345 kV tie with Con Ed to be commissioned in 1978 will be underwater from Glenwood to Dunnwood.

growth rates of any locality in the United States.* Thus, Long Island must be self-sufficient in its electrical supply while satisfying a rapid increase in demand for new electrical capacity. To achieve this, the new generating plants must be sited on (or near to) Long Island and the fuel to supply these plants must be imported by ship and barge.

Unlike the metropolitan area, the central and western parts of the state can use coal for power generation. Adequate supplies are near at hand from Pennsylvania and rail facilities are still adequate. Air pollution constraints are not too severe because of the relatively low population densities.

Considerable hydro-power capacity exists in the northwestern region of the state, 80% of which is owned by the Power Authority of the State of New York which supplies blocks of power to the privately owned utilities of the state.

Despite the coal-burning and hydro capacity, more than half of the electricity generated by NYPP is produced from oil, of which most is of foreign origin. At the end of 1974, the summer generating capability of 25,443 MW was divided as follows: Oil (residual, No. 2 and diesel) 63.7%, Hydro 15.8%, Coal 12.8%, and Nuclear 7.7%.⁽⁷⁾

The "Long Range Generation Plan, 1975-1990" provides for an almost doubling of generating capacity during the next fifteen years. The "Base Schedule" calls for additions of capacity as follows: Nuclear 19,500 MW (76.8%), Coal 3,600 MW (14.2%), and Oil 2,300 MW (9.0%).⁽⁷⁾ This plan, if implemented, would result in a NYPP generation mix in 1990 which would be 41% nuclear.

*There are some recent indications that the rate of growth is decreasing rapidly.

3. Mid-Atlantic

In this report the "Mid-Atlantic sub-region" includes all of the states of Pennsylvania, New Jersey, Maryland, Delaware and the District of Columbia. In addition, the data shall include that small section of Virginia which is located on the Delmarva Peninsula.

Most of the Mid-Atlantic operates as a coordinated power pool, the Pennsylvania-New Jersey-Maryland Interconnection (PJM), which was established in 1956.* The planning unit of the pool is the Mid-Atlantic Area Council (MAAC). In addition to PJM members, our data include the franchise areas of the West Penn Power Co., Duquesne Light Co., and the Potomac Edison Co. of Pennsylvania.

The Mid-Atlantic region has a diversity of geographical, economic and social characteristics ranging from the highly industrialized and urbanized regions around Philadelphia, Pittsburgh, Baltimore and eastern New Jersey to farming and undeveloped areas over large portions. Although there appears to be large amounts of empty land near load centers, nuclear power plant siting has met spirited public opposition, forcing several changes in planning. As an indication of land-based constraints, the Public Service Electric & Gas Co. of New Jersey has proposed building nuclear plants in the Atlantic Ocean several miles off the coast of New Jersey.

An important regional factor is the large coal production by western Pennsylvania and the adjacent states. In the past, coal has been the primary boiler fuel. Projections indicate that coal will continue to be a major component of the fuel mix, but that nuclear energy will slightly surpass coal by 1985. A recent survey⁽²⁾ of MAAC and the non-member companies indicates that the nuclear share of power generation will increase

*The original agreement establishing the Pennsylvania-New Jersey interconnection was in 1927.

from 14.6% in 1975 to > 44% in 1985, whereas the coal share will drop from 58.7% to 42.0% during the same period. The MAAC planning shows a strong preference for nuclear units.⁽⁸⁾

D. UNCERTAINTIES IN FUTURE DEVELOPMENTS

The rapid increase in the rate of inflation, rising interest rates, regulatory delays in project approvals and rate adjustments have created economic dilemmas for electric utilities. The problems became severe in 1974, forcing the cancellation or postponement of many construction projects. Capital budget cuts for the 1974-1978 period probably exceed \$20 billion. More than half of the nuclear capacity planned for the future has been affected, as well as a substantial fraction of new fossil units and other facilities.

We have made an effort to incorporate in the data of this report all cancellations, postponements and new projects announced prior to August 31, 1975. In one or two cases even more recent information has been included.

The decreased economic activity of the past two years has arrested the rapid growth in electrical demand which has characterized the post-World War II period, i.e., ~ 7% per year or ~ 10 year doubling period. In 1974 the electrical demand in the Northeast actually decreased from 1973 by about 3.5%.⁽²⁾ However, there are strong indications that demand will resume its growth in the years ahead, although perhaps at a slower rate.^(6,7,8)

Because of the long lead time for power plant construction, utilities must plan and construct new capacity on the basis of forecast demand, with the forecast period being 8-10 years. The effects of enforced postponements and cancellations today (1975) will not be felt until the 1980-85 period. Any capacity shortages which do occur require several years to correct. Thus, the forecast demands and the planning for new capacity are of critical importance to the near future.

II. PRESENT STATUS

A. OPERATING PLANTS

1. Installed Capacity

The 15 operable nuclear power stations in the Northeast as of July 1, 1975 are listed in Table II-1⁽⁹⁾ and shown on the map of Figure II-1. The maximum dependable capacity* of these units totals 10,394 MWe. This total omits Shippingport 1 (90 MWe) which is federally owned, and Indian Point 1 (265 MWe) which is out of service until 1977 for plant modification. Peach Bottom 1, a small (40 MWe) demonstration HTGR, has completed its mission successfully and is in the process of decommissioning.

The total generating capacity of the Northeast is approximately 96,000 MWe,⁽²⁾ excluding pumped storage. Thus the operable nuclear capacity represents 10.9% of the primary generating capability.

2. Operating Experience

The operating experience of a power plant is reflected by several factors, among which are: 1) net electrical energy generated**, 2) the capacity factor†, and 3) the unit service factor‡. Although additional factors reveal more

* Maximum Dependable Capacity - the dependable main-unit capacity (gross or net), winter or summer, whichever is smaller. The maximum dependable capacity often differs from the unit Design Electrical Rating, which is a nominal value, because the turbine generator output may vary during the year with the temperature of the condenser cooling water. The net maximum dependable capacity is used herein to compute the unit capacity factor. The net maximum dependable capacity is the gross electrical output as measured at the output terminals of the turbine generator during the most restrictive seasonal conditions (usually summer), less the normal station service loads.

** Net Electrical Energy Generated (Output) - the gross electrical output of the unit measured at the output terminals of the turbine generator minus the normal station service loads. We shall express this in units of million megawatt hours (10^6 MWh).

† The capacity factor is the net energy actually produced, divided by the net energy that would have been produced if the plant had operated 100% of the time at the maximum dependable capacity.

‡ The unit service factor is the quotient of the time that the unit actually was operated with the turbine generator on-line during a given period, expressed as a percent.

TABLE II-1: OPERABLE COMMERCIAL NUCLEAR POWER STATIONS
IN THE NORTHEASTERN UNITED STATES

(Data as of June 30, 1975, Ref. 9)

Plant Name (a)	Operating Utility (b)	Location (c)	Power Pool	Type	Maximum Dependable Capacity MWe (net)	Date of Commercial Operation
Yankee-Rowe	New England Electric	Rowe, Mass.	NEPOOL	PWR	175	7/61
Indian Point 1	Con. Edison of N. Y.	Indian Pt., N.Y.	NYPP	PWR	(265) ^(d)	10/62
Connecticut Yankee	Northeast Utilities	Haddam Neck, Ct.	NEPOOL	PWR	540	1/1/68
Oyster Creek	Jersey Central Power and Light	Toms River, N.J.	PJM	BWR	620	12/69
Nine Mile Point 1	Niagara Mohawk	Scriba, N. Y.	NYPP	BWR	610	12/69
Ginna	Rochester Gas & Elec.	Ontario, N. Y.	NYPP	PWR	470	3/70
Millstone Point 1	Northeast Nuclear Energy Company	Waterford, Ct.	NEPOOL	BWR	652	3/71
Vermont Yankee	Cent. Vt. Pub. Serv. Co.	Vernon, Vt.	NEPOOL	BWR	504	11/29/72
Pilgrim 1	Boston Edison	Plymouth, Mass.	NEPOOL	BWR	670	12/72
Maine Yankee	Central Maine Power Co.	Wiscasset, Me.	NEPOOL	PWR	790	12/28/72
Indian Point 2	Con. Edison of N. Y.	Indian Pt., N.Y.	NYPP	PWR	864	8/73
Peach Bottom 2	Philadelphia Electric	Delta, Pa.	PJM	BWR	1051	7/5/74
Three Mile Island 1	Metropolitan Edison	Goldsboro, Pa.	PJM	PWR	792	9/2/74
Peach Bottom 3	Philadelphia Electric	Delta, Pa.	PJM	BWR	1035	12/23/74
Calvert Cliffs 1	Baltimore Gas & Elec.	Lusby, Md.	PJM	PWR	800	5/8/75
FitzPatrick	Niagara Mohawk	Scriba, N. Y.	NYPP	BWR	821	(e)

(a) The name listed is usually an abbreviated version of the formal name.

(b) Most plants are jointly owned by several utilities and often the licensee is a corporation formed by the participating companies. Column 2 lists the utility which operates the facility.

(c) Because of remote siting, the "location" frequently does not appear on common maps.

(d) Out of service from October 31, 1974 until 1977 for plant modification. Capacity listed is design rating.

(e) Commercial operation at 50% power began July 28, 1975. Capacity listed is design rating.

OPERATING NUCLEAR POWER STATIONS
IN THE NORTHEAST
(AS OF JULY 1975)

Figure II-1. Operating nuclear power stations in the Northeast (as of July 1975). Plant design capacity is in MWE(NET).

detail about what components within the plant are causing difficulties or what characteristics of the grid affect the usage of the plant, the above three factors disclose the most important facets of operating reliability, and ability to compete economically. At this stage of nuclear growth, the performance of plants is an important consideration. As might be expected with a new technology, most nuclear units have encountered various difficulties during the first year or two of their operation. The question of greatest interest is whether or not such difficulties are eliminated as the plant matures, and a good performance record can be achieved over the long haul.* At the present time this question cannot be answered unequivocally, since the number of mature plants is very limited and not enough operating experience has accrued. Furthermore, most of the "mature" plants differ in several significant characteristics from the contemporary plants now just coming into service. However, the data indicate an encouraging trend toward greater reliability in performance following the shakedown period associated with commissioning.

A brief operating history of each of the nuclear plants of the Northeast is given in Appendix A.

Over the past 18 months, some interesting comparisons between oil-fired and nuclear plants have emerged. A study conducted by the Edison Electric Institute⁽¹⁰⁾ showed that for the period from 1964-1973 the average cumulative capacity factor for fossil-fueled units of greater than 600 MWe capacity was 59.2%. The data reflect 203 unit years of operating experience. A recent survey⁽¹¹⁾ discloses that during the first half of 1975 the average capacity factor for oil-fired plants was 34.4%, compared to 55.9% for coal and 64.2% for nuclear. The corresponding availability factors were 75.1%, 80.9% and 71.3%, respectively, for oil, coal and nuclear. It is apparent that the nuclear

*Conventional fossil-fueled plants also experience similar breaking-in problems.

units are operated on a first priority basis whenever they are available, whereas the oil-fired units are used only as much as necessary to meet unfilled demand. The reason for the drop in capacity factor of the oil-fired units can be attributed to the sudden increase in imported oil prices since the October 1973 oil embargo. The total costs for electric generation, including amortized capital investment, fuel and operating costs, for the first half of 1975 in the Northeast averaged approximately as follows:

oil - 34.20; coal - 19.78; nuclear - 12.69 (mills/kwh).⁽¹²⁾

a) New England: As of July 1, 1975, NEPOOL had 6 operating nuclear power plants with total nominal dependable capacity of 3,331 MWe. The total installed production capability (omitting pumped storage and external purchases) was approximately 17,835 MWe. Thus, the nuclear component represented approximately 18.7% of the pool capability.⁽⁶⁾ In 1974, the nuclear plants produced 24.3% of the electricity generated by NEPOOL (16.9×10^6 MWh of the total 69.5×10^6 MWh),⁽³⁾ and between January 1 and May 31, 1975 the nuclear units produced 30.0% of the electricity generated by NEPOOL facilities (excluding pumped storage and outside purchases).⁽³⁾ The large output of the nuclear plants relative to their nominal share of installed capacity is attributed to the more favorable economic costs of the nuclear plants, as discussed above. The nuclear plants are operated on a preferential basis and are shut down only for scheduled refueling, maintenance or forced outages, whereas several of the more expensive oil-burning base-loaded plants perform the load following duties. From these data it is clear that New England already has a strong dependence on nuclear energy. A brief operating history of each New England plant is given in Section 1 of Appendix A.

b) New York: As of the end of July 1975, the NYPP had four operating nuclear power plants with a total maximum dependable capacity of 2765 MWe.⁽⁹⁾ The total installed production capability (omitting pumped storage and external purchases) was approximately 26,264 MWe. Thus, the nuclear component represented approximately 10.5% of the pool capability. In 1974, the nuclear plants then operating generated 8.9% of the electricity produced by NYPP.⁽¹⁾ (Note: Indian Point 1 shut down in November 1974 and Fitzpatrick did not start operating until 1975.) A brief operating history of each New York nuclear power station is given in Section 2 of Appendix A.

c) Mid-Atlantic: As of the end of July 1975, there were five nuclear power plants in operation in the Mid-Atlantic sub-region. These plants had a total maximum dependable capacity of 4298 MWe,⁽⁹⁾ or 9.4% of the total installed capability of approximately 45,570 MWe.⁽²⁾ Of the five plants now operating, only Oyster Creek was in operation prior to 1974. Peach Bottom 2 and 3 and Three Mile Island 1 began commercial operation in 1974, and Calvert Cliffs 1 in May 1975. In 1974 only 6.3% of the electric energy produced in the Mid-Atlantic was from nuclear. The nuclear share will be much larger in 1975, possibly of the order of 14.6% according to a recent estimate.⁽²⁾ A brief operating history of each Mid-Atlantic nuclear plant appears in Section 3 of Appendix A.

B. PLANNED ADDITIONS

1. Plants Under Construction

In the Northeast, 18 new nuclear units are under construction, and one plant, Indian Point 1, is undergoing modification. These units, having a total capacity of 18,206 MWe, are summarized in Table II-2. Their locations are

TABLE II-2: NUCLEAR POWER STATIONS UNDER CONSTRUCTION
(As of Jan. 1976)

Plant Name	Operating Utility ^(a)	Location	Type	Design Capacity (MWe)	Est. Date of Commercial Operation
<u>NEW ENGLAND</u>					
Millstone Point 2	Northeast Utilities	Waterford, Conn.	PWR	828	Dec. 1975
Millstone Point 3	Northeast Utilities	Waterford, Conn.	PWR	1156	Oct. 1979 ^(c)
<u>NEW YORK</u>					
Indian Point 3	Con. Edison of N.Y.	Indian Point, N.Y.	PWR	965	Spring 1976
Indian Point 1 ^(b)	Con. Edison of N.Y.	Indian Point, N.Y.	PWR	265	1977
Shoreham	Long Isl. Lighting Co.	Shoreham, N.Y.	BWR	820	May 1979
Nine Mile Point 2	Niagara Mohawk	Scriba, N.Y.	BWR	1080	Nov. 1982
<u>MID-ATLANTIC</u>					
Beaver Valley 1	Duquesne Light Co.	Shippingport, Pa.	PWR	852	Dec. 1975
Salem 1	Public Service Elec. and Gas	Salem, N.J.	PWR	1090	Sept. 1976
Calvert Cliffs 2	Baltimore Gas & Elec.	Lusby, Md.	PWR	845	Jan. 1977
Three Mile Island 2	Metropolitan Edison Co.	Goldsboro, Pa.	PWR	905	May 1978
Salem 2	Public Service Elec. and Gas	Salem, N.J.	PWR	1115	Sept. 1979
Susquehanna 1	Penn. Power & Light	Berwick, Pa.	BWR	1050	Nov. 1980
Limerick 1	Philadelphia Electric	Pottstown, Pa.	BWR	1065	Feb. 1981
Beaver Valley 2	Duquesne Light Co.	Shippingport, Pa.	PWR	852	May 1981

(a) Most plants are jointly owned by several utilities and often the licensee is a corporation formed by the participating companies. Column 2 lists the utility which operates the facility.

(b) Plant being modified. (c) Deferred until 1982.

Continued

TABLE II-2 (Cont'd)

Plant Name	Operating Utility	Location	Type	Design Capacity (MWe)	Est. Date of Commercial Operation
Limerick 2	Philadelphia Electric	Pottstown, Pa.	BWR	1065	July 1982
Susquehanna 2	Penn. Power & Light	Berwick, Pa.	BWR	1050	May 1982
Forked River 1	Jersey Central Power & Light	Forked River, N.Y.	PWR	1070	May 1982
Hope Creek 1	Public Service Elec. & Gas	Salem County, N.J.	BWR	1067	Dec. 1982
Hope Creek 2	Public Service Elec. & Gas	Salem County, N.J.	BWR	1067	May 1984

NUCLEAR POWER STATIONS
UNDER CONSTRUCTION IN THE NORTHEAST
(AS OF JULY 1975)

Figure II-2. Nuclear power stations under construction in the Northeast (as of July 1975). Plant design capacity is in MWE(NET). Estimated date for commercial operation is shown in parentheses for each unit.

shown on the map in Figure II-2. During the past year the commissioning dates of many of these units have been deferred. Table II-2 reflects the latest available information on estimated dates for commercial operation.

a) New England: New England has only two plants under construction, Millstone Point, Units 2 and 3. Millstone 2 is essentially completed and is expected to begin commercial operation near the end of 1975. Millstone 3, originally scheduled for operation in December 1978, has been rescheduled for 1982.⁽¹³⁾ Construction is about 15% completed.⁽¹⁴⁾ From these data it is seen that New England will not add much new nuclear capacity prior to 1980.

b) New York: The NYPP has three nuclear plants under construction with startup dates ranging from early 1976 through 1982. All three of these units have experienced long delays in licensing and construction, e.g., the Shoreham Plant on Long Island was delayed by approximately three years due to opposition by a private group of intervenors in the construction permit hearings. The licensing proceedings for Shoreham started before Millstone 2, and the plant should have been completed in 1975 prior to the commissioning of Millstone 2. The owner and licensee for Indian Point 3, Consolidated Edison Co. of New York, has proposed selling the plant to the Power Authority of the State of New York and leasing it back for operation.* Indian Point 1, a relatively small and older unit, has been shut down for about three years to retrofit an emergency core cooling system in order to meet revised licensing requirements. There is some doubt as to whether this modification will be carried out. If not, the plant will be decommissioned. These data show that the NYPP will not add substantial nuclear capacity until after 1982.

*Sold to PASNY in December 1975.

c) Mid-Atlantic: The Mid-Atlantic region has 13 nuclear plants under construction, with startup dates ranging from late 1975 through 1984. One new plant is scheduled to start each year between 1975 and 1980, with two new plants in 1981 and four in 1982. These data reflect the very strong commitment of PJM to nuclear units.

2. Additions Announced but Not Yet Under Construction

In addition to the 15 units in operation, and 19 under construction or modification, plans have been announced for the construction of 33 additional units. For most of these projects, contracts between the utilities, vendors and architect-engineers have been signed, and proposed sites have been identified. In many cases applications for construction permits are pending with NRC, and public hearings are already underway. The planned units are summarized in Table II-3, and their proposed locations are shown in Figure II-3.

It must be anticipated that the "estimated dates of commercial operation" will be modified for many of these units, unless some dramatic change occurs in the financial capability of the utilities. The dates shown in Table II-3 reflect the latest information available as of about the end of July 1975.

In addition to the facilities listed in Table II-3, the long range plans of the power pools provide for a large increase in nuclear capacity after 1990.

a) New England: New England utilities have announced eight nuclear projects to be completed between 1980 and 1988, having a total capacity of 9280 MWe. A ninth unit, the previously announced Pilgrim 3, has been postponed indefinitely. In NEPOOL, more than three-quarters of the

TABLE II-3: ANNOUNCED PLANS FOR ADDITIONAL NUCLEAR POWER STATIONS
(As of July 1975)

Plant Name	Operating Utility (a)	Location	Type	Design Capacity (MWe)	Est. Date of Commercial Operation
<u>NEW ENGLAND</u>					
Seabrook 1	Public Service Co. of New Hampshire	Seabrook, N. H.	PWR	1150	Nov. 1981
Seabrook 2	Public Service Co. of New Hampshire	Seabrook, N. H.	PWR	1150	May 1983
Pilgrim 2	Boston Edison Co.	Plymouth, Mass.	PWR	1180	Oct. 1982
Sears Island 1	Central Maine Power Co.	Searsport, Maine	PWR	1150	1984
New England 1	New England Electric System	Charleston, R.I.	PWR	1150	Nov. 1984
New England 2	New England Electric System	Charleston, R.I.	PWR	1150	Nov. 1986
Montague 1	Northeast Utilities	Montague, Mass.	BWR	1150	Apr. 1986
Montague 2	Northeast Utilities	Montague, Mass.	BWR	1150	Jan. 1988
Pilgrim 3	Boston Edison Co.	Plymouth, Mass.	PWR	1150	Indefinite
<u>NEW YORK</u>					
Jamesport 1	Long Island Lighting Co.	Jamesport, N. Y.	PWR	1150	May 1983
Greene County	Power Authority, State of New York	Catskill, N. Y.	PWR	1160	Dec. 1983
Sterling 1	Rochester Gas & Electric	Sterling, N. Y.	PWR	1150	Apr. 1984
Jamesport 2	Long Island Lighting Co.	Jamesport, N. Y.	PWR	1150	May 1985

(a) Most plants are jointly owned by several utilities and often the licensee is a corporation formed by the participating companies. Column 2 lists the utility which operates the facility.

Continued .

TABLE II-3 (Cont'd)

Plant Name	Utility ^(a)	Location	Type	Design Capacity (MWe)	Est. Date of Commercial Operation ^(c)
Somerset 1	N.Y. State Electric & Gas	Somerset, N. Y.	BWR	1220	1984
Somerset 2	N.Y. State Electric & Gas	Somerset, N. Y.	BWR	1220	1986
Mid-Hudson East 1	New York Power Pool	Not specified	---	1300	1987
Shoreham West 1	New York Power Pool	Shoreham, N. Y.	---	1300	1987
St. Lawrence 1	New York Power Pool	Not specified	---	1300	1988
Mid-Hudson East 2	New York Power Pool	Not specified	---	1300	1989
Shoreham West 2	New York Power Pool	Shoreham, N. Y.	---	1300	1989
St. Lawrence 2	New York Power Pool	Not specified	---	1300	1990
Mid-Hudson West	New York Power Pool	Not specified	---	1300	1990
<u>MID-ATLANTIC</u>					
Summit 1 ^(b)	Delmarva Power & Light Co.	Summit, Delaware	HTGR	770	1981 ^(b)
Summit 2 ^(b)	Delmarva Power & Light Co.	Summit, Delaware	HTGR	770	1984 ^(b)
Fulton 1 ^(c)	Philadelphia Elec. Co.	Fulton Township, Pa.	HTGR	1160	June 1984 ^(b)
Douglas Point 1	Potomac Elec. Power Co.	Nanjemoy, Md.	BWR	1178	Mar. 1985
Atlantic 1	Public Service Electric and Gas Co.	Little Egg Inlet, N.J. (Offshore)	PWR	1150	May 1985
Fulton 2 ^(b)	Philadelphia Elec. Co.	Fulton Township, Pa.	HTGR	1160	June 1986 ^(b)
Douglas Point 2	Potomac Elec. Power Co.	Nanjemoy, Md.	BWR	1178	Mar. 1987
Atlantic 2	Public Service Electric and Gas Co.	Little Egg Inlet, N.J. (Offshore)	PWR	1150	May 1987
Atlantic 3	Pub. Serv. Elec. & Gas.	Not specified	PWR	1150	1990
Atlantic 4	Pub. Serv. Elec. & Gas	Not specified	PWR	1150	1992
Portland 5	Metropolitan Edison Co.	Portland, Pa.	PWR	1075	1994

^(b) Plans to build HTGR units were canceled in September and October 1975.

^(c) Dates are uncertain.

ANNOUNCED PLANS FOR ADDITIONAL
NUCLEAR POWER STATIONS IN THE
NORTHEAST
(AS OF SEPT. 1975)

ESTIMATED DATE FOR COMMERCIAL OPERATION
IS SHOWN IN PARENTHESES

SEVERAL PLANTS HAVE BEEN ANNOUNCED BUT
NO SITES HAVE BEEN FIXED

Figure II-3. Announced plans for additional nuclear power stations in the Northeast (as of Sept. 1975).

base-load capacity scheduled to be added between 1977 and 1985 is nuclear. No information has been obtained for the period beyond 1985, except for the two plants listed in Table II-3, which were originally scheduled for earlier completion but subsequently postponed beyond 1985.

b) New York: Participants in NYPP have announced plans for 13 new plants, having a total capacity of 16,150 MWe, to be completed between 1982 and 1990.* One of these, Greene County, is to be built by the Power Authority of the State of New York. In order to finance, construct and operate the other 12 plants, the member utilities of NYPP are forming a joint subsidiary, Empire State Power Resources, Inc. (ESPRI). ESPRI, when organized, will assume ownership and responsibility for all of the New York facilities listed in Table II-3 (except Greene County), and for Nine Mile Point 2 which is already under construction. The capacity additions in New York between 1980 and 1990 are scheduled to be 86.4% nuclear.

c) Mid-Atlantic: In addition to units under construction, plans have been announced for 11 units, having a total capacity of 11,891 MWe, to be completed between 1981 and 1994. The proposed capacity additions between 1985 through 1994 are 54.4% nuclear, 34.5% fossil-fueled, and 11% hydro.

Four planned units are of special technical interest, representing the first large scale high temperature gas-cooled reactors (HTGR). Peach Bottom 1, a small demonstration HTGR, operated successfully for eight years, serving as a test bed for development of HTGR technology. Only one other HTGR, an intermediate sized reactor at Fort St. Vrain, Colorado, has been built and is just starting operation after a long

*Dates are uncertain.

period of commissioning difficulties. Therefore, the Summit 1 and 2 and the Fulton 1 and 2 units have attracted considerable interest. In September, Philadelphia Electric Co. and General Atomic announced the suspension of the Fulton 1 and 2 units because they had been unable to negotiate a mutually satisfactory contract.⁽¹⁵⁾ This was followed by an announcement in October 1975 that the two HTGR units at Summit, Delaware had been cancelled. These cancellations are regrettable because they mark the end of HTGR technology in the United States for the foreseeable future. This will have significant long-term undesirable economic, resource and environmental implications because the HTGR technology promised to fill a critical void of two or three decades between the LWR and fast breeder technologies. The HTGR's were an attractive solution to many problems which will arise in the 1990 to 2010 era because of their higher thermal efficiencies and their ability to make use of more abundant thorium resources rather than being fully dependent on uranium.

III. THE ECONOMICS OF NUCLEAR POWER

The cost of producing electricity in an electric generating station can be divided into three components: 1) capital investment costs, 2) fuel cycle costs, and 3) operating and maintenance expenses. Of course, production costs are only a part of the price of electricity paid by the customer. Other items contributing to the sales price include company overhead and profit, transmission and distribution costs, company taxes, depreciation (other than on the power station), etc. In the following we shall consider only production costs and not the sales price.*

Production costs in a nuclear power plant are distributed in the approximate proportions: amortization of capital investment - 75%; fuel cycle costs - 17%; operating and maintenance expenses - 8%. An important variable in the production cost is related to how much of the time the plant is in service and at what fraction of its maximum capacity. This variable is expressed quantitatively in terms of the plant capacity factor (see footnote[†] on page 9). For example, if a plant operates at full capacity for half of a month, the plant capacity factor for that month is 50%. Similarly, if a plant operates continuously during a given period at three-quarters capacity, its plant capacity factor for that period is 75%. Since the interest on capital investment must be paid whether or not the plant is running at full capacity, a large capacity factor yields cheaper electricity. In recent years the capital costs have varied over wide limits because of rapid escalation in interest rates and inflation of construction costs. Because of the variation in these two factors -- capital investment and average plant capacity factor -- the production costs vary widely from one station to another.

* In 1974 the U.S. average retail price of electricity for residential customers was 28.5 mills/kwh (per Electrical World), March 15, 1975).

A. PRESENT PRODUCTION COSTS OF OPERATING UNITS

1. Present Average Costs

A recent nationwide survey⁽¹²⁾ yields the weighted average production costs for stations in the Northeast as follows:

Production Costs for Period January 1 - June 30, 1975

Nuclear: 12.69 mills/kwh (range 8.47 to 18.81)

Oil-fired: 34.20 mills/kwh (range 18.58 to 66.23)

Coal-fired: 19.78 mills/kwh (range 14.27 to 24.12)

It should be noted that these data included only those utility systems which had operating nuclear units. Because of the high price of fuel, the oil-fired units were run only as much as necessary to meet local demands in excess of nuclear, hydro and coal capacities. As a result, the plant capacity factors for the oil-fired units were significantly lower than for nuclear or coal. Also, it appears that the data included oil-fired peaking units (gas turbines and diesels) which yield notoriously high production costs. These two factors tend to push the oil-fired production costs upward relative to nuclear. A utility operating entirely with oil-fired units would tend to yield lower production costs than the average obtained in the survey.*

Despite these modifying factors which tend to bias the data in favor of nuclear, it is clear that the nuclear units now operating in the Northeast have a significant economic advantage over both oil and coal.

2. Relative Costs of Newer Units

Nuclear units commissioned in the period 1974-1976 will tend to have substantially higher production costs than the older units because of higher

* For example, the Long Island Lighting Co., which has no operating nuclear or coal-fired units in its systems, reports average production costs for oil-fired units during the period January 1 - June 30, 1975 to have been 19.31 mills/kwh, with average costs of residual fuel oil of \$10.82 per bbl.

capital costs and because of the startup and shakedown problems which are commonly associated with immature plants.

Often the newly commissioned plants temporarily have some operating constraints imposed which limit their maximum power to some fraction of the rated capacity. Such constraints usually result from inability to meet one or more of the operating criteria or limits which are a part of the regulating "technical specifications" contained in the operating license issued by the Nuclear Regulatory Commission. In some cases the problem can be easily corrected and such corrections are made at the first convenient time. In other cases, abatement or other processing systems have to be added which require equipment to be ordered and additional construction for installation.

One example which illustrates such a situation and the effect on production costs is the Maine-Yankee unit. The plant as built could not meet the stringent condenser cooling discharge water temperature criteria of the State of Maine (maximum surface temperature 77°F, maximum increase above ambient water temperature 1½°F in summer and 4°F in winter). Although these criteria were promulgated after the plant had been designed and was under construction, the unit was not granted a "grandfather" waiver but was required to meet the criteria. This required the addition of a diffuser system on the plant cooling water discharge. Prior to commissioning the new diffuser system in July 1975, the plant operation was constrained to operate in the range of 75-85% of rated capacity, with levels as low as 35% during the summer months. During the period January 1 - March 31, 1975, the average production cost was 13.60 mills/kwh⁽¹²⁾ with an average capacity factor of 79.9%.⁽¹¹⁾ During the last 5 months of 1975, when operation at full capacity

was allowed, the production costs dropped to approximately 10.3 mills/kwh. (16)

The cost advantage of operating nuclear units at high average plant capacity factor is obvious, but its importance should not be overemphasized.

B. PROJECTING FUTURE PRODUCTION COSTS

The energy system decision makers are faced with several important economic questions:

- What will be the relative cost of various alternative systems?
- How much capital must be raised to execute various plans?
- What is the required annual cash flow to execute the plans?
- What will be the cost and availability of fuel over the lifetime of the plant?
- What will be the operating and maintenance costs?
- Will the public utilities commissions grant the necessary rates to sustain the cash flow and total capital requirements?
- Will the load growth materialize to justify the plant?

Although such questions cannot be answered with precision, the relative costs between various options are largely independent of assumptions about economic trends, provided the same ground rules are followed in all of the forecasts. Such ground rules include the set of assumptions made for the annual trends in interest rates, and escalation rates for labor, equipment and materials. Each system to be analyzed must be broken down into numerous components and the appropriate inflationary factors applied to each component. These include the costs of engineering design, legal fees, insurance, site acquisition, quality control, purchase of equipment, construction materials and labor, etc.

1. Capital Investment Costs

A computer code, CONCEPT, has been developed by the Studies and Evaluation Program at Oak Ridge National Laboratory which provides a consistent means of calculating power plant capital costs for various assumed sets of economic and technical factors. A variety of studies using the CONCEPT model were summarized in a report issued in October 1974.⁽¹⁷⁾ Results from this report have been used to obtain the capital costs projection given in Table III-1. The projections assume a compounded escalation factor of 10% per year for labor and 5% for equipment and materials. Under these assumptions the net escalation factor for a nuclear plant is about 7.39% per year (compounded). Interest rates are assumed to be 7½%.*

The "reference plant" assumes a site location in the Northeast (local variations have been neglected), two identical 1150 MWe units built on the same site with the second unit being commissioned two years after the first, natural draft evaporative cooling towers, prevailing regulatory requirements for safety systems, etc. (see Ref. 17 for more detail).

The actual costs of a specific project must be expected to deviate from the average projections shown in Table III-1. Such variations would be caused by local factors related to the site, the investment structure for financing, and deviations from the nominal 1150 MWe capacity.

The distribution among the categories that contribute to the capital costs has changed dramatically in the past several years. This can be seen in Table III-2. For a plant commissioned in 1973, 70.6% was for direct costs -- the reactor, turbine-generator, construction materials and labor.

*This assumption is probably unrealistically low under present conditions. Contemporary experience is in the range 10-12%.

TABLE III-1: Projected Capital Costs for a 1150 MWe LWR
Nuclear Power Plant Located in the Northeast

This "reference plant" assumes two identical units built on the same site with second unit commissioned two years after the first, and natural draft evaporative cooling towers. Projections are based on data in Ref. 17.*

<u>Year of Commissioning of Unit 1</u>	<u>Total Cost Unit 1 (\$ Million)</u>	<u>Total Cost Unit 2 (\$ Million)</u>	<u>Avg. Cost per Unit (\$ Million)</u>	<u>Avg. Cost per kwe (\$/kwe)</u>
1981	728	716	722	628
1985	966	950	958	833
1990	1376	1352	1364	1186
1995	1958	1925	1942	1689
2000	2788	2741	2764	2403

*Several utilities in the Region have commented that these projections are lower than their present best estimates; however, no quantitative corrections are available.

TABLE III-2: CHANGES IN DISTRIBUTION OF CAPITAL COSTS

(Data are based on Figure 2 of Ref. 17)

	<u>Year of Commissioning</u>	
	<u>1973</u>	<u>1981</u>
	(percent of total cost)	
<u>Direct Costs</u>		
Nuclear Steam Supply System	22.5	8.5
Turbine Generator	18.3	5.7
Construction Material and Equipment	15.2	14.5
Craft Labor	14.6	16.2
<u>Indirect Costs</u>		
Professional Services	5.1	8.2
Construction Tools and Materials	4.4	5.0
Contingency	2.5	2.7
<u>Time-Related Costs</u>		
Escalation During Construction	9.5	22.3
Interest During Construction	7.9	17.1

For a 1983 unit, the direct costs have dropped to 44.9%, and almost 40% of the cost must be attributed to escalation during construction and interest paid during construction. Delays in the construction schedule are very costly -- interest piles up, the dollars sunk in construction earn no return and the cost of labor and materials escalates.

The staggering increases in estimated capital investment requirements to sustain the construction plans of the power pools are ominous. Table III-3 gives an estimate of the average investment cash flow needed to sustain the projected "Base Case Nuclear Scenario" for the Northeast (Table IX-1d, page 152). These data are plotted in Figure III-1. In the light of today's economic situation, it appears doubtful that the utilities can be successful in raising the required funds. It should be noted, however, that similar projected increases will affect the capital investment needed for coal- or oil-fired base-loaded capacity. Therefore, the capital investment problem seems to be generic to steam-electric generating plants and will have only secondary impact on the choice between nuclear and fossil-fueled plants.

Capital investment for facilities to support the fuel cycle is substantial but small compared to the total for the power plants themselves.

2. Fuel Cycle Costs

Nuclear fuel cycle costs include a) the purchase price of uranium feedstocks, b) isotopic enrichment charges, c) chemical processing of enriched uranium and fuel fabrication, d) reprocessing of spent fuel, e) radioactive waste management charges, f) carrying charges on fuel inventory, and g) credits for salvaged uranium and plutonium from spent fuel.

TABLE III-3: Projected Capital Investment Cash Flow Necessary to Sustain "Nuclear Base Case Scenario" Construction for the Northeast

The projections assume capacity additions as currently planned by the three regional power pools, as shown in Table IX-1d. The projections apply to plants having two identical 1150 MWe units on each site. The average interest rate was assumed to be 7½%, and costs were escalated at the compound rate of 7.32%. Prior to 1985 irregularities reflect the detailed plans of the power pools. Beyond 1985 irregularities are arithmetical artifacts resulting from the Base Case projections in 5-year intervals. Projections end at 1993, since plants to be commissioned after the year 2000 have not been included.

<u>Year</u>	<u>Annual Capital Investment Required (\$ Billion)</u>	<u>Cumulative Investment Requirements After 1975 (\$ Billion)</u>
1976	1.446	1.446
1977	2.068	3.514
1978	2.860	6.374
1979	3.562	9.936
1980	3.831	13.767
1981	4.042	17.809
1982	4.085	21.894
1983	4.434	26.328
1984	4.989	31.317
1985	5.699	37.016
1986	6.490	43.506
1987	7.272	50.778
1988	8.051	58.829
1989	8.993	67.822
1990	10.179	78.001
1991	11.574	89.575
1992	13.089	102.664
1993	14.725	117.389

Figure III-1. Cumulative capital investment cash flow required to sustain "base case" construction plans for Northeast.

The approximate distribution of the costs estimated for 1982 is given in Table III-4.⁽¹⁸⁾

TABLE III-4: FUEL CYCLE COST DISTRIBUTION (1982)

(Data from Chart 10 of Ref. 18)

	<u>mills/kwh</u>	<u>Percent of Total Cost</u>
Uranium Feed	0.82	27.2
Uranium Enrichment	1.07	35.4
Fuel Fabrication	0.27	8.9
Reprocessing	0.43	14.2
Waste Management	0.05	1.7
Fuel Inventory Carrying Charge	0.87	28.8
Plutonium Credit	<u>-0.49</u>	<u>-16.2</u>
Total Fuel Cost	3.02	100.0

Events of recent months have thrown all elements of the fuel cycle costs into a state of confusion.

a) Cost of Uranium Feed: Utilities or their fuel suppliers must purchase uranium to serve as feedstock for the enrichment process. The uranium supply is usually in the form of the chemical compounds U_3O_8 or "yellow cake", which are the products of the mining and milling industry. Purchases are made not only for immediate delivery, but also contracts are signed for delivery in various future years. The trend in typical quoted prices has been sharply upward since mid-1973, as shown in Table III-5.⁽¹⁹⁾

* "Yellow Cake" is a term applied to various uranium concentrates which are the output of the milling process, e.g., $(NH_4)_2U_2O_7$, $Na_2U_2O_7$, $Na_2O \cdot 2U_2O_3 \cdot V_2O_5$, etc.

TABLE III-5: TYPICAL QUOTATIONS FOR YELLOWCAKE SINCE 1973

(Data were taken from Figure 1 of Ref. 19)

<u>Time of Quotation</u>	<u>Price of Yellowcake for Delivery in Year Indicated (\$ per Pound)</u>		
	<u>1976</u>	<u>1978</u>	<u>1980</u>
January 1973	8	8½	9
January 1974	11½	13	15
January 1975	18	25	31

Estimates for delivery in 1985 range from \$50 to \$100/lb. Some of this rise can be attributed to the jump in all fuels that were initiated by the OPEC increases in crude oil. Part of the increment recently noted for coal can be attributed to increased production costs resulting from new mine safety laws, escalating labor costs, and general inflation. At the present writing there is an imbalance between utility demand for U_3O_8 and production capability from high grade ore, which decreased sharply after a boom in the early 1960's. The necessity to work low grade ores has helped drive prices upward because production costs have increased several-fold.

As a result of the sharp increases in the price of yellowcake, Westinghouse announced in September 1975 that it would renegotiate many contracts to supply fuel to utilities. Recently a Federal court has ruled that Westinghouse must provide each utility with a pro rata share of U_3O_8 from its inventory or from firmly committed sources.

b) Uranium Enrichment: At the present time all uranium enrichment is carried out in federally owned facilities. The present price (based on

full recovery of government costs) is \$53.35/SWU*, but future enrichment costs may rise sharply in the next decade. The size of the increase cannot be accurately forecast, since it depends strongly on decisions which have not yet been taken as to how much the government enrichment capabilities will be expanded and how much private capability will emerge. The A. D. Little/Stoller group estimated \$71/SWU by the year 1990 and \$79/SWU by 2000. These numbers appear to be low when compared with projected ERDA commercial prices of about \$100/SWU by 1978 and \$125/SWU by 1982.⁽²⁰⁾

c) Fuel Fabrication Costs: Fuel fabrication costs discounting inflation are forecast to remain fairly constant over the next decade, after which the relative cost might show some decrease as a result of growth of industrial experience.⁽²¹⁾ The use of recycled plutonium in fuel will increase fabrication costs some $2\frac{1}{2}$ times, but this incremental cost will be more than offset by the corresponding decrease in enrichment requirements.

d) Reprocessing of Spent Fuel: At the present time no commercial fuel reprocessing facilities are in operation. Startup of facilities has been delayed by the postponement of decision by the Nuclear Regulatory Commission on approval of plutonium recycle, and procedures for radioactive waste management.⁽²²⁾ In the presence of such indecision and lack of commercial experience, projections of reprocessing economics is difficult. Estimates for transportation and reprocessing range from 0.43 mills/kwh in 1982 (1982 dollars)⁽¹⁸⁾ to 1.5 mills/kwh in 1984 (1984 dollars).⁽²³⁾

*See page 58 for definition of SWU.

e) Radioactive Waste Management Costs: Until the federal government reaches a final decision on waste management procedures, waste management charges cannot be accurately estimated. The costs of converting wastes to approved form, transporting to the federal repository, and maintaining the repository will have to be borne by the utilities. In any case, this is expected to be a very small fraction of the total fuel cycle cost. As shown in Table III-4, page 35, the current estimate is 1.7%.

f) Carrying Charges on Fuel Inventory: As noted in Table III-4, Ref. 18 estimates carrying charges (@ 15%) to average about 0.87 mills/kwh, or 28.8% of the fuel cycle. These costs must be expected to escalate in proportion to costs of other items in fuel cycle.

g) Credits for Salvaged Uranium and Plutonium: If the NRC fails to approve plutonium recycle, the credit shown for Pu in Table III-4 will disappear. In fact, the plutonium in spent fuel could increase the waste management charge. Each year that NRC postpones the plutonium recycle decision, the value of accumulated Pu decreases because of storage costs and dollar escalation. Plutonium in a warehouse earns no interest! Considering all of the above factors, F. Schworer⁽²⁴⁾ has recently forecast nuclear fuel cycle costs in 1985 to be in the range of 4.1 mills/kwh (1975 dollars), compared with 2.4 mills/kwh in 1975. These data converted to cents/billion Btu are compared with coal in Table III-6.

TABLE III-6: COMPARISONS OF NUCLEAR FUEL COSTS WITH COAL

<u>Year</u>	<u>Nuclear Fuel</u> <u>(cents/million Btu)</u>	<u>Coal</u>
1975	23	150
1985	40 $\pm$ 10 ^(a)	220 ^(a)

(a) Expressed in 1975 dollars.

Despite the large uncertainties in the nuclear fuel cycle costs, the effect on the projected cost of electricity is small because in a nuclear plant the fuel costs are only a small fraction ($\sim 17\%$) of the production costs.

3. Projected Production Costs

Because of the existing uncertainties in future interest rates and inflation rates, projections of absolute production costs have little significance. However, projections of relative production costs which compare nuclear with oil and coal can serve as useful guides for the decision-maker. To be valid, such projections must follow an internally consistent set of ground rules. The results of several economic projections are summarized in the following sections.

a) Projections for Utilities in New England: Just prior to the October 1973 OPEC oil boycott, a study was completed by Arthur D. Little, Inc. for Northeast Utilities.⁽⁴⁾ (This will be referred to as "Study '73".)* Comparison was made between three alternatives, nuclear, oil- and coal-fired base-loaded plants of nominal 1150 MWe capacity, to be commissioned in 1980. The levelized power production costs were projected to be:

<u>"STUDY '73"</u>		
<u>Type of Unit</u>	<u>Levelized Production Cost (mills/kwh)</u>	<u>Ratio to Dual Nuclear</u>
Nuclear (dual unit)	20.33	1.00
Nuclear (single unit)	21.29	1.05
Coal-fired	25.49	1.25
Oil-fired	27.27	1.34

The ensuing events have invalidated these projections. However, they illustrate the economic advantage of nuclear even before the unforeseen disruptive step-increase in OPEC oil had occurred.

*Additional details about the economic assumptions made for "Studies '73, '74 and '75" are given in Appendix B.

In March 1975 a new study⁽⁵⁾, "Study '75", was completed for the New England Electric System for alternative base-loaded plants to be commissioned in the 1983-85 period. The levelized power production costs were projected to be:

<u>Type of Unit</u>	<u>"STUDY '75"</u>	
	<u>Levelized Production Cost (mills/kwh)</u>	<u>Ratio to Dual Nuclear</u>
Nuclear (dual unit)	36.22	1.00
Coal (no scrubber)	49.64	1.37
Coal (with scrubber)	56.79	1.57
Oil	51.88	1.43

We see that following the oil price increase, the economic advantage of nuclear had increased substantially over both coal and oil. A coal plant equipped with a stack gas "scrubber" to remove sulfur appears even more costly than oil, because of the large capital cost of the scrubber and the decreased net thermal efficiency of the plant. It should be noted that Study '75 used an estimated average capital cost for each of the dual units of \$863/kwh, which is about 20% higher than our projection for a plant to be commissioned in 1983 (see Table III-1, page 30). Entry for 1983, not listed in the table, would be \$723/kwh. The "present worth" of the cumulative power costs of the four alternatives was estimated as follows:

<u>Alternative</u>	<u>"STUDY '75"</u>	
	<u>Present Worth Cumulative Power Costs (\$ Million)</u>	<u>Difference Relative to Nuclear (\$ Million)</u>
Nuclear	3821	--
Coal	5238	1417
Coal with scrubber	5993	2172
Oil	5474	1653

Thus, savings to New England customers from a nuclear plant are quite large.

b) Projections for a Utility in New York: "Study '74", similar to the above, was completed for the Long Island Lighting Company in June 1974.⁽²⁵⁾ "Study '74" assumed dual nuclear units to be commissioned in 1981 and 1983 and coal-fired units with stack gas sulfur removal systems. Capital investment required for creating the fuel transportation system is included (e.g., colliers and unloading docks for coal supply).

<u>"STUDY '74"</u>		
<u>Type of Unit</u>	<u>Levelized Production Cost (mills/kwh)</u>	<u>Ratio to Dual Nuclear</u>
Nuclear	22.04	--
Coal (with scrubber)	34.22	1.55
Oil	39.79	1.81

The "present worth" of cumulative power costs was found to be:

<u>"STUDY '74"</u>		
<u>Alternative</u>	<u>Present Worth Cumulative Power Costs (\$ Million)</u>	<u>Difference Relative to Nuclear (\$ Million)</u>
Nuclear	2266	--
Coal (with scrubber)	3517	1251
Oil	4089	1823

"Study '74" estimates a larger relative advantage for nuclear than do "Study '73" and "Study '75". Aside from rapidly changing economic conditions which occurred between completion of the three studies, some

differences in the basic assumptions should be noted. The Long Island "Study '74" predicated on 0.5% sulfur oil, whereas "Study '75" was based on 1% sulfur oil. This environmental constraint widens the gap between nuclear and oil for Long Island. The use of low sulfur western coal was not considered to be a viable alternative for Long Island because of lack of a proper rail link.

Although the forecast production costs differ considerably, Studies '74 and '75 predict similar ratios between nuclear and coal with scrubbers.

c) Philadelphia Electric Company Projections: In September 1975, the Philadelphia Electric Company made the following estimate for production costs for dual 1160 MWe plants. (26)

<u>Alternative</u>	Production Costs (mills/kwh)	
	<u>1975</u>	<u>1985</u>
Nuclear	11.9	28.0
Coal (tall stacks)	17.7	38.8
Coal (scrubbers)	21.4	45.7
Oil	24.9	44.5

Annual savings of nuclear over coal (1160 MWe unit) were estimated at \$108 million, and nuclear over oil at \$131 million. The annual equivalent oil savings of a nuclear unit is 12 million barrels.

The above analyses, although diverse in their assumed escalation rates and other ground rules, predict a substantial economic advantage for nuclear in comparison with other alternatives.

IV. CONSTRAINTS ON FUTURE GROWTH

A. ECONOMIC CONSTRAINTS

1. Problems in Raising Capital

Total electric revenue, gross corporate income, net income, and retained earnings of the investor-owned electric utility companies have shown steady advance each year through 1974⁽²⁷⁾, as shown in Table IV-1. In 1974 the total revenue showed a 25.3% gain over 1973 despite a 0.56% drop in sales of electric energy. The revenue gain was due to authorized rate increases and fuel adjustment charges. The average price of electricity jumped by 23.7% from 18.6 mills/kwh in 1973 to 23.0 in 1974. This price increase only partially reflected the enormous jump in operating costs of 39.1% from 1973 to 1974.

During 1974 gains in net income, dividends and retained earnings failed to keep pace with inflation. Decreasing or stagnating loads in some cases, higher fuel prices, decreased purchasing power of the dollar, and inflating costs of all types greatly eroded the financial position of the utilities. Also, during a period of escalating costs, the time lag for rate increase approvals by the Public Service Commission diminished revenues and earnings. (During most of the 80 year history of electric utilities, the cost of producing and delivering electricity was decreasing. Thus the rates were generally decreasing and the regulatory time lag enhanced earnings.) Depressed earnings mean less surplus for reinvestment and reduced attractiveness to outside investors. During the past two years several planned new stock and bond issues were canceled because of markedly unfavorable prospects in the market, and in some cases new issues were marketed below book value. These factors have forced heavier dependence on

TABLE IV-1: INVESTOR-OWNED ELECTRIC UTILITY INCOME

In 1974, the gross revenue of investor-owned utilities comprised 88% of U.S. gross electric revenue. Data are taken from Ref. 27 and have been rounded to nearest \$0.1 billion. Percent gains over previous year are calculated on basis of unrounded data.

	1974 ^(a)	1973	1972	1971	1970
	(\$ Billions)				
Total Electric Revenue	34.5	27.5	24.1	21.2	18.8
Expenses					
Operating	18.8	13.5	11.7	10.2	8.7
Depreciation	3.4	3.0	2.7	2.4	2.2
Taxes	4.9	4.6	4.2	3.7	3.5
Gross Corporate Income	9.7	8.4	7.4	6.4	5.6
Capital Charges	4.6	3.6	3.0	2.7	2.3
Net Income					
Dividends	3.7	3.4	3.0	2.7	2.4
Retained Earnings	1.5	1.4	1.3	1.1	1.0

	<u>Percent Gain Over Previous Year</u>				(b)
Total Electric Revenue	25.3	14.1	13.7	12.7	9.7
Expenses					
Operating	39.1	15.8	14.9	16.8	16.7
Depreciation	12.9	13.1	10.3	9.8	9.5
Taxes	7.6	9.6	12.7	6.8	-3.9
Gross Corporate Income	14.5	14.0	16.2	13.6	13.1
Capital Charges	24.9	19.5	15.0	16.7	24.5
Net Income					
Dividends	8.1	12.7	13.2	12.6	9.0
Retained Earnings	5.5	8.2	21.0	14.7	0.7

(a) 1974 data were estimated by Electrical World.

(b) Percent gain over 1969 calculated from data not displayed in upper section of table.

short-term borrowings at unprecedented interest rates, and have greatly impaired the ability to raise capital funds. (28)

The inability to finance proposed construction projects has forced cancellation or postponement of all types of generating units -- oil and coal as well as nuclear. However, because of its greater capital intensiveness, the nuclear cancellations/deferments have been more frequent than fossil. (29) This discrimination against nuclear has been made despite the greater uncertainties in costs of long-term supplies of oil and coal and despite the clear economic advantage of nuclear over the plant lifetime in the Northeast. (29)

Unless the economic climate improves greatly, the planned construction schedules for generating capacity of all types will not be met by a wide margin, and the capital intensive nuclear component will especially lag.

2. Effects of Fuel Cycle Uncertainties

Economic uncertainties in the nuclear fuel cycle were discussed in Section III B-2, page 32. Projections of fuel cycle costs in future years could prove to be in error by as much as a factor of 2. Even though fuel cycle costs constitute only a small fraction of the electric energy production cost in a nuclear plant, the uncertainties are disquieting, and tend to give pause to the planning.

Although all steps of the fuel cycle have been proven technically practical on an industrial scale, the commercial viability of many of the steps has not been demonstrated, and key regulatory decisions have not been made. Thus, utility decision-makers are faced with an array of unanswered questions about the fuel cycle: (18)

- Will there be an adequate supply of uranium (discussed in the next section)?

- Will there be adequate uranium enrichment capacity (discussed in Section IV B-2)?
- Will there be adequate commercial capacity for reprocessing spent fuel?
- Will the Nuclear Regulatory Commission authorize plutonium recycle?
- What will be the Federal requirements for high-level radioactive waste management from spent fuel?

Until about 1973, it appeared that all of the above questions would be resolved in a timely fashion. However, the events of the past two years have thrown the nuclear fuel cycle into a state of economic and regulatory confusion which precludes rational planning. Unless these questions are answered quickly, the entire nuclear industry will suffer a major set-back. Loss of experienced manpower and participating industries at various stages of the fuel cycle would be difficult to recoup, and growth of nuclear generating capacity could be severely curtailed. The unanswered fuel cycle questions make it highly doubtful that future construction schedules will be met.

B. RESOURCE LIMITATIONS

1. Supply of Uranium

Uranium makes up about 4 parts per million of the earth's crust, is more abundant than gold or silver, but is less abundant than base metals like nickel, copper, lead and zinc. It occurs naturally in chemical combination with other elements and forms more than 100 known minerals. Most of the uranium on earth is dilutely dispersed in sea water, hard rock such as granite, and in shales and soil. Economic considerations preclude recovery of uranium from these dilute resources. Only mineral deposits in the range of

0.2 weight per cent are now being mined, and then only when the extent of the deposit will yield about 10,000 tons or more of uranium over the lifetime of the mining and milling operation. The principal sources of U.S. ores are sedimentary strata such as sandstone, mudstone and limestone.

After the uranium-bearing ores are mined, they are milled and concentrated by various means, and a product called yellowcake results. The yellowcake is the final precipitate in the milling process and it contains U_3O_8 and various impurities which cannot exceed certain maximum percentages without price penalties. Yellowcake is usually considered to be $(NH_4)_2U_2O_7$ or $Na_2U_2O_7$, but depending on the precipitation conditions, the exact composition may vary. Purchases of ore are made on the basis of the U_3O_8 content, and chemical analyses of ore for uranium are made in terms of U_3O_8 .⁽³⁰⁾

At the present time only uranium from domestic sources can be used in U.S. power reactors. The U.S. uranium resources as of January 1, 1975 are shown in Table IV-2.⁽³¹⁾ The columns show the cumulative tonnage of U_3O_8 which is estimated to be available for the price per pound shown at the left of each row. In considering the table, it should be noted that the price per pound of U_3O_8 given for a row is merely a nominal figure expressing the cost structure obtained prior to 1974, before major price escalation occurred for oil, coal and uranium. Thus, during the past two years the market price for U_3O_8 has gone from about \$8/lb to \$25/lb for delivery in 1978, and will escalate to \$50/lb for delivery in 1985. Since the price per pound data before 1974 reflected the relative ease of mining the various concentrations of uranium ore, it is expected that the prices appearing in the table will be only relatively correct, but the tonnages available are not correct in terms of present actual market prices. Also note that the average price paid

TABLE IV-2: URANIUM RESOURCES IN THE U.S., JANUARY 1975

(Data are from Ref. 31)

Nominal Cost ^(a) (\$/lb of U ₃ O ₈)	Reserves	(Tons U ₃ O ₈) Potential			Total
		Probable	Possible	Speculative	
8 (c)	200,000	300,000	200,000	30,000	730,000
10 (c)	315,000	460,000	390,000	110,000	1,275,000
15 (c)	420,000	680,000	640,000	210,000	1,950,000
30 (c)	600,000	1,140,000	1,340,000	410,000	3,500,000 ^(b)

(a) This was the price as of 1/1/74 which has escalated markedly in the past twenty months along with prices for other fuels.

(b) Total is rounded.

(c) Each cost category includes reserves of lesser cost.

for the tonnage in a given row will be less than the price labelling the row, since the values shown are cumulative tonnages thought to be available at the listed price or lower.

The column labelled "reserves" represents ore which is reasonably assured on the basis of known deposits determined by drilling and from past and current mining activities. The three columns labelled "potential" represent resources which become increasingly speculative as one goes from probable to possible, and then to speculative. The probable reserves include those from known uranium districts in which extensions of known deposits are envisaged or in which new deposits are to be expected from mineralization trends observed by exploration. Possible potential resources are located in new deposits in formations or geologic settings known to be productive geologic areas. Speculative potential resources are in postulated deposits in settings that have not previously been productive. (31)

With the foregoing caveat, it is seen from the table that U.S. reasonably assured reserves increase by a factor of 3 from 200,000 tons of U_3O_8 to 600,000 tons as the cost changes by fourfold from \$8 per pound to \$30 per pound. Over the same price range the probable reserves go from 300,000 tons to 1,140,000 tons. The total resources are thought to be 730,000 tons at \$8/lb and 3,500,000 tons at \$30/lb.

To compare U.S. demand with supply, it is necessary to consider demand projections for U_3O_8 . As discussed in Section IX, there are several different projections which can be made based on different assumptions about future growth of nuclear power. Since the U_3O_8 demand generated in the northeastern United States must compete with the rest of the country for the U.S. supplies, it is necessary to estimate the total domestic demand and assume that the

northeast region will get the required fraction. Estimates derived from a recent projection by J. A. Patterson, Chief of the Supply and Evaluation Branch of ERDA, are shown in Figure IV-1. The forecast included recent changes in utilities plans, reduced capacity factors and energy growth, delay of recycle of plutonium, and deferral of the breeder reactor until 1993. Cumulative U.S. demand for U_3O_8 is plotted for the years 1975-2000. On the graph are also shown the reserves at different prices, as taken from Table IV-2, and also shown are the reserves plus probable potential reserves at various price levels.

From Figure IV-1, it appears that by 1982 the lowest price reserves will have been committed, and by 1989 the \$30 reserves will have been used. To supply the U_3O_8 to the year 2000, it is necessary to rely not only on the reserves now identified, but also the probable potential reserves. Thus, it appears that the uranium which is needed for the 1990's must be moved from the probable category to actuality. This can only be done by intensive surface exploration by various means, and by extensive drilling in likely areas.

There appears to be increasing difficulty in finding uranium reserves when one considers the recent history of drilling activity in the U.S. Thus, according to Patterson, the pounds of U_3O_8 added to the reserves per foot of hole drilled (success ratio) has been decreasing in the past few years. For example, in 1970-71 the ratio was about 5.0 lb/ft, whereas in 1973-74 it was about 1.5 lb/ft. During this time the average drilling depth went from about 400 feet to 500 feet, and the pounds per hole dropped from 2,000 to 800. If one projects these numbers into the future, say 1990, when the U.S. demand would require 86×10^3 ton of U_3O_8 , it implies that a large

Figure IV-1. Domestic uranium reserves (as of Jan 1, 1975) and projected demands.

increase in drilling activity is required. Even if the 1974 success ratio is used, 115 million feet of drilling are needed, and if the success ratio falls as the current trend suggests, a correspondingly larger drilling effort is required.

In this context it is important to note that the time it takes from initial exploration for ore until the uranium fuel is used in the reactor may range from 7 to 10 years. Approximately two years of the cycle are used from the time the natural uranium is shipped, converted to UF_6 , enriched, converted to UO_2 , fabricated into fuel, loaded in the reactor, and tested for commercial operation. Another 5 to 8 years is taken for the initial exploration, establishment of mines, shipment to mills, and milling to produce U_3O_8 . From this it is seen that the exploration for the fuel ultimately used in 1990 must be done in the early 1980's.

To meet the 1990 demand for U_3O_8 by 1982, there must be 115×10^6 feet drilled at the 1974 success ratio. Considering that in 1974 the industry drilled 22×10^6 feet,⁽³¹⁾ this implies a growth of 523% in 8 years, or a compound annual growth rate of 23% for the footage drilled. It would appear that this rate can be achieved given an assured demand, since during the period 1967-1969 the footage drilled rose from 11 to 29 million feet, at a growth rate of 38% annually. However, if the success rate falls, as the recent trend suggests, then there may have to be a greater growth of exploratory drilling. Increasing reliance must be placed on more speculative potential resources. J. A. Patterson⁽³¹⁾ writes, "Analysis of the production levels that could reasonably be attained from such resources, considering the lead time required for exploration and for construction of new mines and mills, does not indicate that the 100,000 to 150,000 tons per year production

levels required late in the century would be achieved. Therefore, evidence of additional resources is necessary to remove uncertainty about long-term uranium supply." After a discussion of positive and negative indicators which relate to the supply situation, he further states, "Balancing these factors, it seems reasonable to believe that resources can be expanded significantly if appropriate measures are taken on a timely basis. However, there is no current reason to believe that low cost resources will expand to greatly higher levels."

The foregoing discussion indicates that uranium supply probably can meet the national demands in the last decade of the century, but it will be by using higher priced uranium mined from lower concentration stocks.

For the rest of the century the northeast region will have demand for U_3O_8 as projected in Table IV-3. It is seen that by 1990 the baseline case projects a need for about 10,000 tons, which can be compared with the U.S. demand of about 86,000 tons in the ERDA revised estimate.⁽³¹⁾ Thus, the fraction of the total U.S. demand taken by the northeastern region would be about 12%.

If the total demand for nuclear power in the United States does not grow as fast as projected, it may happen that regional differences will assert themselves. Considering that the northeastern U.S. is relatively far from coal resources, whereas some other regions are not, it is possible that the northeast will consume a larger fraction of the nuclear pie, even though the pie is smaller. For the northeast this would mean greater assurance of obtaining U_3O_8 from the available stocks.

The discussion has involved domestic supply and demand for uranium; however, there is a strong international aspect to the industry which must

TABLE IV-3: Demand for U_3O_8 for "Base Case" Growth of
Nuclear Power Plants in the Northeast

Year	<u>NEW ENGLAND</u>		<u>NY POOL</u>		<u>MAAC</u>		<u>NORTHEAST</u>	
	Electric Energy (10^6 MWe)	U_3O_8 Required (Metric Tons)	Electric Energy (10^5 MWe)	U_3O_8 Required (Metric Tons)	Electric Energy (10^6 MWe)	U_3O_8 Required (Metric Tons)	Electric Energy (10^6 MWe)	U_3O_8 Required (Metric Tons)
1974	16.9	438	11.3	294	10.7	277	38.9	1010
1975	16.7	434	11.2	291	17.6	458	45.5	1183
1976	20.5	533	14.1	367	26.4	686	61.0	1586
1977	21.8	567	18.7	486	32.2	837	72.7	1890
1978	22.0	572	20.2	525	36.9	959	79.1	2057
1979	22.2	577	25.1	653	41.9	1089	89.2	2320
1980	28.4	738	25.4	660	48.1	1251	102.	2650
1981	34.7	902	26.8	697	54.1	1407	116.	3006
1982	35.0	910	32.9	855	68.9	1791	137.	3560
1983	47.9	1245	45.5	1183	92.4	2402	186.	4830
1984	60.8	1581	52.4	1360	93.1	2420	206.	5360
1985	61.2	1591	65.7	1708	110.	2870	237.	6160
1990	109.	2834	117.	3052	160.	4170	386.	10040
1995	166	4316	191.	4976	228.	5928	585.	15210
2000	244	6344	261	6786	329.	8554	834.	21680

be considered. On the demand side the annual non-communist world uranium requirements at the end of the century are projected⁽³¹⁾ to be about 200,000 tons, compared to peak production of less than 20,000 tons during the last decade. Thus, the non-communist world demand for uranium is roughly equally shared by the U.S. and foreign countries. Some purchase of U.S. supplies were made in 1974 by European companies, indicating a near-term foreign supply problem. This has tended to drive up domestic prices of U_3O_8 . It should further be noted that U.S. policy did not previously permit enrichment of uranium which came from a foreign source and was to be used domestically. In October 1974, this policy was modified so that by 1977 up to 10% of the uranium to be enriched for domestic use can come from foreign sources. This is to be increased to 15% in 1978, 20% in 1979, 30% in 1980, 40% in 1981, 60% in 1982, 80% in 1983, and from 1983 onward there is no restriction on enrichment of foreign uranium for use in domestic reactors.⁽³²⁾ Thus, the U.S. policy is to allow import of foreign uranium in the future.

Foreign countries which have strong nuclear programs or supply capabilities have tended to adopt governmental policies which discourage large scale U.S. dependence on their resources. For example, Canada has declared that she will export uranium unconditionally to 1985, conditionally from 1985-1990, but will not allow any uranium export from 1990 to 2015.⁽³³⁾ In Australia title to uranium is vested in the government, who makes all sales. Under the present Labor Government neither sales contracts nor exports have been allowed.⁽³⁴⁾ For France the known reserves appear to be insufficient, and access to outside resources is necessary.⁽³⁵⁾ Present resources in France, Niger and Gabon are approximately 10% of the world's reserves, and probably are not available for U.S. use.

Other factors which are relevant to the uranium supply situation are 1) the question of plutonium recycle, and 2) U^{235} content of "tailings" from the enrichment process.

The first of these requires a decision by the Nuclear Regulatory Commission (NRC), which must authorize the use of recycled plutonium. Plutonium is produced unavoidably in reactor fuels, and can be recovered from the spent fuel for recycle. Addition of recycled plutonium to fresh fuel reduces the need for U^{235} enrichment and thus reduces the need for uranium feed. If the NRC authorizes plutonium recycle, the demand for uranium will be reduced by about 10% in the 1990 time frame.⁽³⁶⁾

The second factor affecting demand for uranium concerns the U^{235} enrichment process. In "virgin" uranium the isotope U^{235} is 0.71% abundant. The enrichment process separates feed uranium into two product streams -- one in which the U^{235} content has been increased ("enriched uranium"), the other decreased ("tailings"). A specified enrichment can be obtained for a range of operating modes which are characterized by the amount of U^{235} left in the tailings. The higher the U^{235} content of the tailings, the higher the requirement for virgin uranium feedstock. The amount of uranium feedstock required can be estimated for various operating modes and for the projected plant enrichment capacity. The capacity for producing enriched uranium is commonly expressed in terms of "separative work units" (SWU). To carry out the enrichment process there must be provided the requisite physical structures (e.g., in a gaseous diffusion plant, barriers, heaters and pumps) and large quantities of electric energy must be consumed. By 1981 the U.S. enrichment capacity will amount to 27.7 million SWU per year. Assuming that this

capacity is fully used and that the product is enriched to 3.2% U²³⁵, the virgin feedstock required per year is given in Table IV-4.

TABLE IV-4
BASIC INPUTS AND OUTPUTS FOR U²³⁵ ENRICHMENT^(a)

<u>Separative Work Production Millions of SWU</u>	<u>Feed Available Millions of Kg</u>	<u>Operating Tails Assay % U-235</u>	<u>Product Enriched to 3.2% Millions of Kg</u>
27.7	34.3	0.20	5.8
27.7	42.1	0.25	6.6
27.7	51.6	0.30	7.5

(a) Remarks by E. B. Kiser, Ref. 37.

It may be seen that 0.20% tails requires 34,300 metric tons of feedstock to yield 5,800 MTU enriched to 3.2%, whereas 51,600 MTU of feed are needed to yield 7,500 MTU at 3.2% enrichment if the tails assay is 0.30%. The ratio of feedstock to enriched uranium is 5.91 and 6.88, respectively, for 0.20 and 0.30 percent tailings, which shows that a larger supply of ore is needed when more U²³⁵ is left in the tails, as is expected.

The goal, of course, is to select the optimum operating conditions for the enrichment plants, i.e., to meet the demand for enriched uranium at the lowest cost, taking into account possible future limits on availability of virgin uranium feedstocks. At the present time ERDA is in the process of increasing the percentage of tails which a customer can request in a transaction from 0.2% to 0.275%. The trend for the future appears to be toward 0.3% tails or thereabout.

2. Uranium Enrichment Capacity

The light water reactors operating in the United States use fuel in which the U^{235} fraction of the uranium has been enriched to about 3% from the natural value of 0.71%. This is done in three gaseous diffusion facilities owned and controlled by the U.S. Government. These plants were built in the period from 1943 to late 1955 for the purpose of making enriched uranium for nuclear weapons. Two of the facilities are operated under contract with ERDA by the Union Carbide Corporation at Oak Ridge, Tennessee, and Paducah, Kentucky, and the third by the Goodyear Atomic Corporation at Portsmouth, Ohio. They are among the largest industrial complexes in the world, and use large amounts of electricity to perform the separative work. The energy so employed amounts to approximately 5% of the electrical energy which the enriched fuel will ultimately generate in nuclear power plants.

After 1962 the military demand for enriched uranium began to decrease. The three plants, which have a combined annual capability of providing 17 million separative work units (SWU's) and which operated at that level in 1960, were only providing 6 million SWU by 1970. At that low level of output the plants required about 1,900 megawatts of electrical power. Since that time the output has recovered somewhat to about 11 million SWU in 1974. This increase reflects the shift away from military use in order to provide fuel for the nuclear power industry. At this time it is not at all clear that the peak enrichment rate can be easily achieved again for the next few years because the plants have not been able to get firm contracts for all the electrical power which is required.⁽³⁸⁾ It is expected that the full electric power level of 6,065 MWe will be achieved in 1979. In addition, two plant improvement programs are being undertaken to provide an annual capacity of

27.7 SWU by 1983, which will require a power input of 7,380 MWe. At this level of 27.7 SWU, approximately 320,000 megawatts of installed nuclear generating capacity can be serviced.⁽³⁹⁾ Under this program enriched uranium is to be stockpiled for future use, and this separative work stockpile is expected to peak in 1980-81, and then to decrease somewhat as installed reactor capacity outstrips the 1980 enrichment capacity.

It is the policy of the government to encourage private industry to enter the enrichment business by the early 1980's to provide the growing power industry with the needed capability beyond the 27.7 million SWU expected from the improved existing units.^(39,40) Interest has been expressed by several industrial groups to build enrichment plants which would be based on modern centrifuge technology⁽⁴¹⁾ as well as the gaseous diffusion method.⁽⁴²⁾ At least one centrifuge group believes that it can provide separative work more economically than can be done by the gaseous diffusion method. A major advantage of the centrifuge method is that the electric energy requirements are much smaller than for the gaseous diffusion plants, perhaps one-tenth as much, and consequently significant energy savings can be made. Additionally, it is believed that smaller plant sizes will be economically viable with the centrifuge method.

Large capital costs are required with either method. A 3.1 million SWU gas centrifuge plant is estimated to cost \$1.13 billion, compared to \$3.16 billion cost for a 9 million SWU gaseous diffusion plant expressed in 1974 dollars.⁽⁴¹⁾ Considering that as many as 12 new plants may be needed by the year 2000, each of nominal capacity 9 million SWU, to take care of projected domestic and foreign needs, it is apparent that \$30 billion of investment funds will be needed.

In addition to meeting domestic enrichment needs, it has been estimated that the United States will provide about 35% of the new foreign requirements for separative work needed in the decades of the 1980's and 1990's.⁽³⁹⁾ Thus, for the years 1975, 1980 and 1985, the percentages of the ERDA separative work commitments which are for foreign contracts are respectively 32.4, 40.9 and 36.1 percent of the total commitment.⁽⁴³⁾ It is therefore apparent that the northeastern region of the U.S., at least until the early 1980's, must compete with the other regions and foreign users for enrichment services provided by our three midwestern plants. It is possible that if the centrifuge technology proves economically viable, such an installation could be located in the northeastern region to satisfy the local market.

Because of the long lead time needed to provide a large enrichment plant, and because the present domestic expanded facilities will have been committed fully by the early 1980's, it is evident that a serious bottleneck can develop in this phase of the fuel cycle if the projected growth of the nuclear power industry materializes. It is imperative that additions to separative work capacity be started within the next year if such a bottleneck is to be averted. If financing of private enrichment facilities proves to be a hurdle, as some suggest, it may be prudent for the government to expand its existing plants to accommodate an expanded power industry.⁽⁴²⁾

The enrichment requirements of the Northeast can be estimated by assuming that a 1000 MWe LWR has a lifetime average annual fuel requirement of 116,000 kg SWU when the plant operates at 80% capacity factor.⁽⁴⁴⁾ From the Base Case Scenario of Table IX-1d, which gives the installed plant capability and capacity factors projected to the year 2000, we can estimate the separative work requirements to support the power plants. This is shown in Table IV-5. It

may be seen that by 1985 the Northeast yearly requirement is 2.14 million SWU, which, it must be recalled, must be provided as much as two years previous to 1985. Similarly, the 5.77 million SWU for the fuel used in the year 2000 must be provided some years before that date. In any event, the Northeast all by itself will need only a small fraction of the 27.7 million SWU capability projected for 1983. If it should happen that other regions of the U.S. find coal-fired plants economically more attractive than nuclear plants, this would tend to give more assurance that the 1983 national capability of 27.7 million SWU would suffice to provide the Northeast's needs.

TABLE IV-5: URANIUM ENRICHMENT REQUIREMENTS FOR THE NORTHEAST
(These data are obtained from the Base Case Scenario of Table IX-1d)

<u>Year</u>	<u>Installed Nuclear Capability (MWe)</u>	<u>Assumed Plant Capacity Factor (Average)</u>	<u>Separative Work Required (Million SWU)</u>
1975	5,195	0.575	0.43
1980	10,200	0.60	0.89
1985	23,564	0.625	2.14
1990	30,402	0.65	2.87
1995	43,922	0.65	4.14
2000	61,182	0.65	5.77

C. MANUFACTURING, CONSTRUCTION AND MANPOWER LIMITATIONS

1. Capacity for Fabrication of Components

A nuclear power plant requires several very large high quality components which need special large-scale manufacturing facilities to fabricate. Several years elapse between placing the order and delivery of the finished product to the construction site. Expansion of the manufacturing capability also requires long lead times and large capital investments.

The major components consist of the reactor pressure vessel, steam generators and pressurizer (for PWR's only), coolant water feed pumps, turbine generators, numerous specialized valves, large quantities of highest quality pipe, and reactor instrumentation and control equipment.

a) Reactor Pressure Vessels: Reactor pressure vessels are among the largest individual objects ever manufactured. A typical BWR vessel is 72 feet long, 21 feet in diameter, having a wall thickness of about 6-1/4 inches, coated inside with a stainless steel alloy, and weighing 760 tons. The vessel head weighs an additional 125 tons. PWR vessels are somewhat smaller, being typically 44 feet long by 15 feet in diameter, 11 inches in wall thickness and weighing 550 tons. Each step in the fabrication must be documented, inspected and certified, beginning with the melt at the steel mill, fabrication and heat treatment of the steel plate, and all subsequent fabrication steps.

Obviously, facilities to manufacture such objects require massive space, high capacity cranes, enormous but precise machine tools, and huge furnaces for heat treatment. Coupled with this must be sophisticated metallurgical laboratories, a skilled work force certified (qualified) to perform a given task, and a large force of trained inspectors. Such

establishments cannot readily be duplicated, and expansion of capacity must be a slow and deliberate process.

At the present time, four U.S. vendors manufacture reactor pressure vessels: Babcock & Wilcox, Chicago Bridge & Iron, CBI Nuclear, and Combustion Engineering. The U.S. capacity is estimated to be about 24 vessels per year,⁽⁴⁵⁾ which could be expanded to about 30 per year. A few vessels for U.S. reactors are being fabricated by foreign vendors. The existing capacity appears adequate to meet planned construction until about 1985, particularly in the light of announced cancellations and deferments of nuclear capacity. Beyond 1985 a substantial increase in capacity will be needed if nuclear energy is to make a substantial contribution to U.S. energy independence by the year 2000.

There appear to be two considerations regarding pressure vessel fabrication capacity which tend to impose constraints on nuclear growth:

- (i) The deferrals and cancellations which are presently occurring in nuclear construction will affect the pressure vessel industry adversely and force reduction of work staff and facilities. Recovery of capability from such cut-backs will not be easy or rapid. Thus, if there is a sudden impetus to reschedule postponed or canceled units, the procurement of pressure vessels might introduce a delay of several years.
- (ii) If, in the future, the U.S. decided on a "crash" program to accelerate nuclear construction, the growth rate would be limited over the first 15 years of the program by the ability of manufacturers to expand fabrication facilities and train qualifiable work forces.

b) Steam Generators and Pressurizers: PWR's use two or four steam generators and one pressurizer on each reactor. A steam generator serves to transfer heat from the primary (reactor coolant) loop to the secondary (steam-turbine) loop. The primary heated water passes through hundreds of small diameter, thin-walled tubes and converts into steam the secondary water surrounding the tubes. The tubes and secondary water are contained in a massive steel shell which can be 70 feet long by 22 feet in diameter and weigh as much as 720 tons. The pressurizer maintains a high enough pressure on the primary loop to prevent the heated water from boiling. The pressurizer is also a large massive object but less complicated to construct than either the reactor pressure vessel or the steam generators.

At the present time, three U.S. companies are capable of manufacturing steam generators: Babcock & Wilcox, Combustion Engineering, and Westinghouse. The annual production capability is about 40 units.⁽⁴⁵⁾ An increase in production capacity is needed to meet construction schedules in the 1980's.

Considerable and costly technical difficulty has been encountered in the performance of steam generators because of wastage and corrosion of the tubes. Leakage from primary to secondary forces a plant shutdown and the faulty tubes must be located and plugged. In a few cases, a significant fraction (20-40%) of the tubes have developed leaks and the remaining tubes show measurable deterioration. Unfortunately, the construction precludes replacing the tubes. Since the massive containment structure is built around the steam generators, major demolition and reconstruction would be required to replace the units.

Thus, the steam generator units could constrain the growth of nuclear capacity in two ways:

- (i) Existing manufacturing capability is inadequate to satisfy construction schedules in the mid-1980's and beyond.
- (ii) Manufacturers will be reluctant to expand production capabilities until the technical problem of tube wastage and corrosion is overcome and demonstrated to be solved.

There appears to be no problem in satisfying the future requirements for pressurizer units.⁽⁴⁵⁾

c) Turbine Generators: Both fossil-fueled and nuclear steam-electric plants require turbine generator sets. Turbines for the nuclear units are larger because of the lower pressure and quality of the steam. Three U.S. companies manufacture turbine generator units: Allis-Chalmers Power Systems, Inc., General Electric, and Westinghouse. Production capacity appears adequate to meet future production schedules.

d) Other Components: It appears that the U.S. industrial base for manufacturing standard and nuclear-specialized components such as pumps, valves, pipes, tanks, instrumentation, reactor control mechanisms, steel, cement, etc. is adequate to satisfy future construction schedules.

2. Skilled Construction Labor

Labor costs in the construction of a 1000 MWe nuclear power plant are in the range of \$75 million, representing some 8.4 million man-hours of effort.⁽⁴⁶⁾ Much of the work involves the highly skilled crafts, and for many tasks the craftsman must demonstrate specific experience and skills in order to "qualify" so that the completed task will be certified by an inspector.

The manpower requirements for construction of a 1000 MWe nuclear plant are listed in Table IV-6.⁽⁴⁷⁾ Probably the most critical shortage that can be anticipated is in nuclear-qualified welders, which make up about one-sixth of the construction work force. Welders are drawn from the pipe/steam fitters, ironworkers and boilermakers crafts. About 5 years of apprenticeship and training are required to train a nuclear-qualified welder. It appears that there is already a manpower shortage in this craft, although the decreased construction plans will alleviate the shortage in the immediate future. However, the cut-back in construction must be expected to disrupt the union plans for a major effort to train large numbers of welders.

The demand for manpower force for constructing nuclear plants is expected to increase from about 65,000 in 1975 to over 300,000 in 1990, a change of some 376%.⁽⁴⁶⁾

Large numbers of skilled construction workers are needed also in the supporting industries -- uranium exploration, mining and milling, enrichment facilities, fuel fabrication, etc. The overall construction force, including power plants and supporting industries, is expected to increase from about 90,000 in 1975 to about 377,000 in 1990.

3. Operating and Maintenance Manpower

Demand for highly trained manpower to operate and maintain the nuclear power plants and supporting industries is projected to increase from about 19,000 in 1975 to about 120,000 in 1990. Very likely these needs can be met provided a stable growth rate is maintained so as to attract qualified candidates into the training programs. Unfortunately, the recent deferrals and cancellations will probably disrupt the orderly development of new manpower

TABLE IV-6

Manhour Requirements for Construction
of a 1000 MW LWR Nuclear Power Plant^(a)

<u>Craft</u>	<u>Thousands Man Hours</u>	<u>Percent of Total</u>
Pipe/Steam Fitters	2,295	27.3
Laborers	1,430	17.0
Electricians	1,035	12.3
Carpenters	754	9.1
Ironworkers	700	8.3
Operating Engineers	690	8.2
Boilermakers	555	6.6
Teamsters	285	3.4
Asbestos Workers	225	2.7
Millwrights	185	2.2
Painters	120	1.4
Sheetmetal Workers	75	0.9
Concrete Finishers	50	0.6
Total	8,410	100.0

(a) Reference 47

at a critical time when training programs should be anticipating a surge in demand. Because of the lead time required to develop the skills and experience, an adequate expansion of qualified operating and maintenance manpower must remain a matter of concern.

4. Professional Manpower

The demand for engineers and scientists is expected to increase from about 30,000 in 1975 to about 110,000 in 1990. The training period for these professionals ranges from six to ten years. This anticipated demand comes at a time when university enrollment in engineering and the sciences is decreasing. Mechanical, nuclear and mining engineers are already in short supply, and there is little prospect of correcting this deficiency within the next decade. The supply of geologists and geophysicists is inadequate, and it is doubtful that the available educational system can produce the required manpower.

Unfortunately, the long training periods and the economics of society tend to force supply and demand out of phase for engineers and scientists. In a time of rising demand big shortages arise, attracting new students, but the 8-10 year lag required for training prevents a prompt adjustment. Previous experience in other fields indicates that the shortage eventually results in an oversupply of the required disciplines some 15-20 years later.

We must anticipate that the supply of engineering and scientific manpower will be marginal until at least 1990, which will preclude a substantial acceleration of new nuclear capacity much above existing plans.

V. CONSTRAINTS ARISING FROM REGULATORY FACTORS

Regulation of the nuclear industry is in a constant state of development and change. Although it has clearly been the intent of Congress to pre-empt for the federal government most aspects of regulation, there have been increasing attempts on the part of state and local governments to play decisive roles in approving construction and operation of nuclear facilities and in regulating the transportation of nuclear materials. Such attempts to contest or by-pass federal pre-emption, whatever their benefits or lack thereof, have introduced delays in construction programs, and added to the costs of obtaining permits and approvals.

A. THE FEDERAL REGULATORY FRAMEWORK

The Atomic Energy Act of 1954⁽⁴⁸⁾ authorized and required the U. S. Atomic Energy Commission (AEC) to regulate the nuclear industry. The detailed regulations promulgated by the AEC appear in Title 10, Code of Federal Regulations (10 CFR). In January 1975, the United States Nuclear Regulatory Commission (NRC) was created⁽⁴⁹⁾ and inherited the regulatory responsibility of the AEC. NRC adopted the AEC regulations then in force and has since continued the process of modification and expansion of 10 CFR.

In 1957, the Price-Anderson Act⁽⁵⁰⁾ provided the framework for nuclear liability insurance to protect the public from losses resulting from accidents in the nuclear industry. This act was important to the development of commercial nuclear energy because it provided the needed insurance protection for the operator of a nuclear facility.

In the period 1970-1971, the regulatory responsibility of the AEC/NRC was vastly expanded by the passage and court interpretations of the National

Environmental Policy Act (NEPA).⁽⁵¹⁾ This act declared in very general and vague terms that it is the policy of the federal government to weight the environmental consequences of all its actions (including, for example, the issuance of a construction permit or operating license for a nuclear power plant). The scope of NEPA was vastly expanded by a landmark decision of a U.S. Court of Appeals,⁽⁵²⁾ the "Calvert Cliffs Decision". Under this interpretation of NEPA, the NRC is required to conduct a detailed study of the environmental impacts of a proposed nuclear plant and compare these with the impacts of alternative plants.

The Federal Water Pollution Control Act amendments of 1972⁽⁵³⁾ require the Administrator of the United States Environmental Protection Agency (EPA) to regulate the discharge of heated water from power plant condenser cooling systems. The bill provides for individual states to assume this responsibility after the passage of state legislation approved by the EPA Administrator.

The Transportation Safety Act of 1974⁽⁵⁴⁾ provides the framework for regulation of shipment of hazardous materials and prohibits any state regulation of transportation of hazardous materials unless first approved by the Secretary of Transportation.

B. UNRESOLVED FEDERAL ISSUES

Several key issues, mostly relating to the nuclear fuel cycle, are unresolved and require federal agency and/or legislative action. Delays in resolving these issues have been impeding orderly development of nuclear capacity.

1. Plutonium Recycle

As fuel is burned in a reactor, an appreciable amount of the U^{238} in the fuel is converted to various isotopes of plutonium. Part of that created is

consumed by the chain reaction and contributes to the energy extracted from the fuel. However, at the time the reactor is refueled, the spent fuel contains approximately 6 kg of fissile plutonium ($\sim 54\%$ is Pu^{239}) per metric ton of irradiated fuel. During reprocessing of the spent fuel the plutonium is chemically separated from the unconsumed uranium and the fission products. The salvaged plutonium can be combined with enriched uranium in fresh fuel to form a "mixed oxide" and recycled through the reactor. Plutonium recycle has two major advantages: 1) the recycled plutonium reduces the U^{235} enrichment requirement in fresh fuel, and 2) the plutonium is consumed to produce useful energy, rather than collecting in inventory and posing safeguard and waste management problems.

The technical feasibility of plutonium recycle has been extensively demonstrated by using test batches of mixed oxide fuels in operating reactors.⁽⁵⁵⁾ The plutonium utilization program (PUP) began in 1956 and by 1972 was considered completed. Such fuel has proved routinely successful and has posed no safety problems in the refueling and operation of reactors. Similar tests in foreign reactors gave equally successful results.

Before plutonium recycle can be used routinely in commercial reactors, the NRC must authorize its use. The decision to authorize recycle was under consideration by the AEC since about 1970. However, in 1973 final action by the AEC was delayed in order to prepare an environmental impact statement which appeared to be required by 1973 guidelines of the Council of Environmental Quality (CEQ).⁽⁵⁶⁾ A draft of the required environmental statement was issued in August 1974.⁽³⁶⁾ This document was heavily criticized by several private citizens' organizations on the basis that it failed to address

adequately the health hazards associated with plutonium and the protection of plutonium stocks against acts of terrorism. In order to consider the merit of these criticisms, the AEC delayed action and did not reach a decision on recycle before it was disbanded in January 1975.

After NRC was created, the newly formed commission ordered the preparation of a revised environmental impact statement which was not expected to be completed before 1977. Following preparation of that report, the NRC proposed holding public hearings on recycle and expected to be able to reach a final decision in mid-1978. This proposed schedule has recently been accelerated and NRC now expects to reach a decision by early 1977. (57)

The delay in a firm decision on plutonium recycle from about 1973 until 1977 has taken a heavy toll in the fuel reprocessing industry and probably has discouraged several companies from undertaking construction of new reprocessing plants. (58)

2. Uranium Enrichment Capacity

By the mid-1980's, existing U.S. capacity for enriching uranium will not be adequate to meet the needs of domestic nuclear power plants and U.S. commitments for supplying fuel for foreign reactors. For several years the Congressional Joint Committee on Atomic Energy had been urging the AEC to make arrangements with private industry to construct the next enrichment facility as a private venture. The development functions of the AEC have since been inherited by the United States Energy Research and Development Administration (ERDA). As of the present time, no firm plans have been worked out between ERDA and private industry. In order to avoid a shortage of enriched uranium in the 1980's, construction on new enrichment capacity must

begin not later than 1977, either as an addition to federally-owned facilities or as a private undertaking. A definite decision on how to proceed is urgently needed before the middle of 1976.⁽⁴²⁾

3. High-Level Radioactive Waste Management

In 1970, the AEC served notice that the high-level radioactive wastes extracted from spent fuel would have to be solidified within five years and delivered to a federal waste repository within ten years after separation.⁽⁵⁹⁾ At the time this regulation was promulgated, the AEC had identified a salt bed near Lyons, Kansas as the site for federal repository. This site was subsequently abandoned.* A new site has yet to be selected. As an interim measure, the AEC proposed constructing a "Retrievable Surface Storage Facility" (RSSF). Construction was to have begun in fiscal year 1976 but, according to an ERDA spokesman, this has been postponed pending further evaluation.⁽⁶⁰⁾ In the meantime, a prospective site for a permanent repository in New Mexico is being explored and tentative plans have been made to request funding in fiscal year 1978 to construct a mine for a test project.⁽⁶⁰⁾

The federal indecision on a waste management facility has produced major public criticism and has left the fuel reprocessing industry in a difficult quandry.

4. Extension of the Price-Anderson Act

The Price-Anderson Act⁽⁵⁰⁾, which provides the framework for liability insurance for the licensee of a nuclear facility, has played a key role in

*See discussion on page 123.

the development of nuclear energy. Under the terms of this law, the licensee of a nuclear facility must purchase \$560 million of liability insurance, partly from a private insurance pool and the balance from the federal government. The private pool initially offered \$60 million of the coverage, but this has since been increased to \$125 million. Any claims are paid first from the private pool, and only if the pool limit were exceeded would the federal insurance be drawn upon. In the 17 year history of the pool, no liability claims have been filed for off-site bodily injury or property damage arising from operation of a licensed reactor. (61)

The Price-Anderson Act was extended in 1967 and will expire in August 1977 unless Congress acts to renew it.* However, coverage of plants insured prior to August 1977 will remain in effect for the lifetime of the plant. A bill to renew the Act was passed by Congress but vetoed by the President in October 1974. The renewal of the Price-Anderson Act or an acceptable substitute for it is a critical issue for future nuclear construction. A discussion of the legislation and proposed alternatives can be found in a draft environmental statement. (62)

C. THE FEDERAL-STATE INTERFACE

The various bills cited above provide for federal sharing of regulatory responsibility with the states in certain instances. For example, the NRC can make agreements with individual states to delegate the regulation of the use and disposal of low-level radioactive materials, etc. However, it has clearly been the intent of Congress to pre-empt for the federal government those functions which relate to radiological health and safety aspects of nuclear power plants and those operations which involve interstate commerce.

* A ten-year extension of the Act to 1987 was signed by the President January 1, 1976.

The federal pre-eminence in regulating nuclear power has come under increasing challenge by individual states. In some cases, state (or local) laws or regulations have directly infringed on the responsibilities of federal agencies. In other cases, state reviews and hearings have duplicated federal procedures. Usually the utilities applying for permits to construct have found it expedient to submit to the "double jeopardy" with only meek protest and have not challenged the state's conflict with federal pre-emption.

A few notable cases are discussed below.

1. On Federal Pre-emption of Radiological Safety

In 1970, the State of Minnesota attempted to impose more stringent standards on radioactive discharges from the Monticello plant than were required by the AEC. Among other things, the state regulations would have required extra instrumentation in the reactor core. The state regulations were over-turned by the federal courts in a decision⁽⁶³⁾ which was subsequently upheld by the U.S. Supreme Court.⁽⁶⁴⁾

2. Duplicative Proceedings

The state and local governments exercise traditional rights concerning land use and site approval. Also, under the terms of the Federal Water Pollution Control Act Amendments of 1972⁽⁵³⁾ the EPA can delegate the regulation of water discharges to the states. Under the cloak of these powers many state and local hearings have duplicated the AEC/NRC reviews of radiological health and safety.

In 1970, the Maryland Public Service Commission was required to hold hearings on the Calvert Cliffs Nuclear Plant under the provisions of a state law which requires a "Certificate of Public Convenience and Necessity for Construction" of all electrical generating and transmission facilities.⁽⁶⁵⁾

Although these hearings were completed expeditiously, the testimony collected and the decision as rendered⁽⁶⁶⁾ clearly gave heavy weight to radiological factors.

Duplication of AEC hearings was largely avoided in hearings before the New York State Department of Environmental Conservation concerning the issuance of a water usage certification for the proposed Shoreham Nuclear Power Station. In this case the hearing examiner firmly resisted the efforts of intervening parties to include radiological issues.⁽⁶⁷⁾

However, the above decision did not establish a precedent for New York State hearings. A new "Siting Act" passed in 1972 requires state approval for power plant sites.⁽⁶⁸⁾ The purpose of the law is "to provide for the expeditious resolution of all matters concerning the location of major steam electric generating facilities presently under the jurisdiction of multiple state and local agencies" (emphasis added). Such hearings are conducted by the "New York State Board on Electric Generating Siting and the Environment".

In October 1974 hearings were begun on a proposal by the Long Island Lighting Company to build a nuclear power station at Jamesport, New York. The hearings are still in progress after a year and appear likely to continue for at least another year. Numerous local governments and groups of private citizens have been admitted as participants, mostly opposed to the application. From the opening day, several of the intervening parties repeatedly attempted to expand the scope to include radiological safety. According to the arguments there was a logical basis to include radiological safety, since otherwise the Board could have no basis for findings on the suitability of the proposed site. Although the Hearing Examiner ruled that the radiological

safety review was in the jurisdiction of the NRC, this ruling was overturned by an order of the New York State Public Service Commission.⁽⁶⁹⁾ The Public Service Commission in their opinion recognizes federal pre-emption of the setting of standards for radiation safety and protection and regulating the design and operation of a nuclear power plant. However, the opinion argues that such pre-emption does not bar inquiry into and discussion of radiological impacts for purposes of comparison with impacts of alternative plants. The Commission ordered the Hearing Board to obtain testimony from the applicant which references "all relevant NRC standards, regulations, generic documents and recent decisions which assess radiological health and safety impacts, and that these be related to the proposed facilities and to the findings required under Section 146 of the Public Service Law".^(68,69) "The record should be sufficient to permit the Board to evaluate and compare the impacts and risks associated with effluents from each alternative as well as the residue disposal, fuel transportation, decommissioning and security requirements of each alternative."⁽⁶⁹⁾ The Board was admonished, however, not to admit evidence which would challenge or refute NRC standards or determinations.

The Public Service Commission noted that this decision will affect other similar cases under the New York State law.⁽⁶⁸⁾ Thus it appears that in the future New York State siting hearings will plow the same ground as the NRC hearings.

In 1973, a local board of the California Coastal Zone Conservation Commission took testimony on the radiological safety aspects on proposed additions of Units 2 and 3 of the San Onofre nuclear power station. Although the Board

refused permission for the site on two purely environmental grounds, the question of radiological safety was obviously a major factor in their decision.^(70,71) Later the Commission approved a compromise siting plan, a decision which was contested in court but upheld by the California Supreme Court.⁽⁷¹⁾

Duplicative proceedings have extended even to city governments. In 1974 the Department of Water and Power of the City of Los Angeles conducted informal hearings on the radiological health and safety of a proposed nuclear power plant at San Joaquin.⁽⁷²⁾ Testimony was taken from more than sixty witnesses.

3. Conflicting Regulations

Numerous state and local regulations are in direct conflict with federal laws but remain in force because affected companies find it more expedient to submit rather than bring court action. Such conflicting regulations have been especially abundant in the transportation area.⁽⁷³⁾ A typical example can be found in regulations of the City of New York and the New York Port Authority which prohibit the use of most bridges and tunnels surrounding New York City by vehicles carrying radioactive cargoes. The regulations require that certain classes of truck shipments follow specified routes between specified hours, that prior notification of a shipment be given, and shipments must be accompanied by a police escort.

Recently the Board of Health of the City of New York has proposed promulgating a regulation prohibiting all radioactive shipments through the city.* (This has been modified to exempt certain shipments for medical applications.) If the new regulation is adopted, it is likely to be contested

*Such a regulation was adopted effective January 15, 1976. The regulation is being challenged in the courts by ERDA.

promptly by the United States Department of Justice because it will interfere with federal government shipments.

4. State Moratoria on Nuclear Plants

Nuclear moratorium bills have been introduced in the legislatures of approximately 20 states. Thus far all have been rejected. However, in April 1975 a Vermont law which closely approaches a moratorium was signed by the Governor. This law requires approval by the Vermont legislature of any proposed nuclear power plant site.

Opponents of nuclear power are attempting to create nuclear moratoria through initiative procedures in those states which provide for statutory enactments via citizens' initiative. It is likely that initiatives will qualify for 1977 ballot in at least seven states. If such initiatives are adopted, the states in question will effectively have a moratorium against the construction of new nuclear facilities for a five year period.

VI. PUBLIC ISSUES

A. THE GROWTH OF PUBLIC OPPOSITION

Since the late 1960's, there has emerged a strong public opposition to the commercial use of nuclear energy for producing electricity. In addition to individuals who have raised questions about possible hazards from low-level radiation, many environmental organizations have adopted anti-nuclear policies as part of their platforms. The latter have been concerned about siting problems, thermal pollution, the possibility of radioactive contamination of the environment from various stages of the fuel cycle. Some groups question the need for growth of electrical capacity. Skepticism about nuclear safety has increased despite the essentially perfect safety record of the nuclear industry.

In most licensing actions, the regulatory agencies have concluded that the public and ecological risks and costs from nuclear plants are smaller than for alternative means of generating electricity.⁽⁷⁴⁾ However, there are issues unique to the nuclear option (such as nuclear terrorism and international proliferation of nuclear weapons) which merit public examination.

With the passage of time the issues under public debate have changed. In some instances old issues have been laid to rest by the gradual process of public education; in other cases the regulatory structure has been modified to eliminate criticisms.

Some of the early anti-nuclear arguments concerned thermal pollution, adequacy of radiation protection standards, and the statutory conflict of interest of the AEC as both developer and regulator of nuclear energy.

It has now generally been recognized that the discharge of waste heat is a characteristic of all steam-electric generating plants and not unique to nuclear. It is true, of course, that nuclear plants require about 60% more water for condensor cooling than conventional fossil-fueled plants.* However, the regulation of water discharge by EPA and the general requirement for cooling towers or cooling ponds, lakes, canals, etc. have removed most ecological objections.

Responsibility for setting basic standards for radiation protection has been transferred from the Federal Radiation Council to EPA. EPA studies have shown that routine emissions of radioactivity from nuclear facilities represents an extremely small population radiation dose commitment compared to natural background radiation and medical radiation.⁽⁷⁵⁾ Also, the former AEC emission criteria requiring off-site doses to be "as low as practicable" relative to the upper limits defined by the standards, has been quantified to be less than 5 mRem off-site, or approximately 3.8% of natural background.⁽⁷⁶⁾

In January 1975, responsibility for licensing and regulating nuclear power was transferred to the Nuclear Regulatory Commission,⁽⁴⁹⁾ thus eliminating the "conflict of interest" charge which burdened the AEC. It remains to be seen whether the NRC can earn credibility as the public surrogate.

Public issues which are of present concern include: reactor safety (i.e., the risk of a catastrophic accident), plutonium toxicity, protection of facilities and materials against acts of terrorism or sabotage, management of radioactive wastes, and the economics and reliability of nuclear plants (see Section III, page 25).

*It should be noted that about 10% of the waste heat from a fossil-fueled plant is discharged directly to the atmosphere via the stack.

B. REACTOR SAFETY

Probably the fear of a catastrophic accident* lies at the heart of most nuclear opposition. The technical literature of the past 30 years provides a rich resource for the nuclear critic, because of the common practice of analyzing "hypothetical" events as a tool for designing systems. Such analyses have played a major technical role in identifying potential hazards and in selecting designs which eliminate such potential. However, this massive literature, used out of context, provides a ready-made source for hair-raising descriptions of what "could" happen.

Reactor safety has been constructed on the basis of making the most pessimistic (conservative) assumptions at each step of an analysis of some hypothetical event, and then applying heroic measures to deal with the extreme conditions predicted by the string of pessimistic assumptions. For example, in analyzing the "design basis accident" for a loss of coolant accident (LOCA) in a light water reactor, the safety analyst assumes that the plant is operating at a power level higher than design, that the largest diameter pipe breaks at the worst possible location, that the pipe break is instantaneous and double-ended, and that the largest unit in the emergency cooling system is inoperative at the time of the accident.

This general approach has resulted in over-design of safety systems at substantial added plant cost. Nuclear critics have viewed the multiplicity and over-design of safety systems as proofs that extreme hazards exist. On the other hand, many reactor safety experts believe that the safety criteria for contemporary plants are overly conservative⁽⁷⁷⁾ and that the number and capability of the systems could be reduced without measurable increase in public risk. These views do not evoke favorable public or regulatory response.

*It should be noted at the outset that contrary to public impression, nuclear reactors of contemporary design cannot explode like a bomb.

However, one primary goal of reactor safety research is to provide the basis for elimination of safety systems which are unnecessary.

1. The Evaluation of Risks

The quantitative evaluation of risks has presented a difficult problem for nuclear energy. In ordinary activities, statistics can be accumulated on accidents and the risks can be assessed by actuarial procedures. The concept of risk embodies two factors -- the probability of an accident, and the consequences of that accident. Thus, for example, statistics provide a reasonably accurate prediction of the number of deaths, injuries, and amount of property damage each year arising from the use of natural gas as a fuel.

In the case of commercial nuclear power, there have been no accidents which have brought death, injury or property damage to the public.⁽⁶¹⁾ Thus there are no statistics with which to work.

Over the past three years a new approach has been developed in an independent study originally commissioned by the AEC and continued under NRC sponsorship. This research, "Reactor Safety Study, an Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants", was directed by Professor Norman Rasmussen of MIT and was carried out by scientists and engineers drawn from some 17 institutions.⁽⁷⁸⁾ The study can be divided into two main parts: 1) the probability of accidents leading to some final set of conditions, and 2) the consequences (death, injury, long term health effects and property damage) from the final conditions. These factors combined yield the "risk" curves, i.e., probability vs. consequences. In general, the "final conditions" following an accident can be expressed as the quantity, composition and time dependence of uncontrolled release of radioactive materials. The probabilities

of accidents yielding a given level of radioactive release were evaluated by investigating envelopes of accident sequences. The accident consists of some class of initiating event, followed by the success or failure of each of the various safety systems which would be called upon to function, given the initiating event.

Although it was not practical to investigate every conceivable accident scenario, the accident sequences embraced broad groups of scenarios, and there is reasonable evidence that the study was exhaustive in covering all possible accident events. (It should be noted, however, that the results apply only to light water reactors of contemporary design.)

The probability of each initiating event was obtained from reactor or industrial experience. For example, an initiating event might consist of a pipe rupture. The probability of such an event can be obtained from experience with similar types of pipe in refineries and chemical plants. In each accident sequence, the probability that a required safety system would function or fail was evaluated by fault-tree methodology using industrial experience for component failure. For example, the probability that a pump will fail to start or a valve will fail to close can be obtained from industrial data. Thus, by combining the probabilities of an initiating event and each step in the accident sequence, the probability is obtained for a particular radioactive release. The consequences of each radioactive release category were evaluated for various sets of weather conditions and population distribution.

The risk results are best displayed as a set of curves showing frequency of accidents against damages. One such curve displaying the calculated risk curves for fatalities is shown in Figure VI-1. The figure compares the risk curves from 100 nuclear power plants with other risks from human activities. Figure VI-2 shows the nuclear risks compared with natural disasters.⁽⁷⁸⁾

Figure VI-1. Frequency of man-caused events involving fatalities.

Source: Reference 78.

Figure VI-2. Frequency of natural events involving fatalities.
Source: Reference 78.

The curves show that with 100 nuclear power plants operating, a nuclear accident which kills as many as 10 people can be expected about once in 25,000 years, or an accident which kills as many as 100 people can be expected about once in 80,000 years. The calculated risk of fatalities is about the same as from meteors. The risk of fatalities from other man-caused accidents (explosions, fires, dam failures, etc.) is about 10,000 times greater than nuclear accidents.

2. Public Perception of Risk

The Rasmussen Report addresses the narrow issue of the safety of the reactor complex, but it does not address other perceived risks associated with nuclear power. Thus, even if apprehension about the safety of a power plant is alleviated by the Rasmussen Report, there remain other current issues bearing on plutonium safety, the issue of toxicity, and the issue of safeguarding it against unauthorized use.

C. PLUTONIUM SAFETY

Plutonium safety has become a major public issue in recent years. Since plutonium is an inexorable component of the nuclear fuel cycle, these issues are of major importance, and must be addressed.

1. Properties of Plutonium

Plutonium is element 94, belonging to the actinide series falling in group 3b of the periodic table of the elements. In pure form, metallic plutonium is chemically reactive, and when exposed to air will react vigorously to form oxides. Although it was initially discovered in the laboratory as a nuclear reaction product, trace quantities exist in nature in uranium ore deposits, being formed from the capture of neutrons by uranium isotopes.

Fifteen isotopes of plutonium are known and their nuclear properties have been measured. All isotopes are radioactive, with half-lives varying from 20 minutes to 76 million years. Table VI-1 summarizes the radioactive decay properties.⁽⁷⁹⁾ Most of the isotopes can decay by more than one mechanism. Those which decay by spontaneous fission emit neutrons in the process, so a mass of plutonium containing a mixture of isotopes is a prolific source of neutrons. In a mass of plutonium the decay energy is mostly absorbed which heats the mass. The usual mixture of isotopes produce enough heat so that the metal feels warm to the touch.

Fission can be induced by thermal and fast neutrons in several of the isotopes, e.g., $\text{Pu}^{239,241}$. This property makes these isotopes of particular interest as reactor fuels and as weapons materials. The isotope most abundantly manufactured is Pu^{239} . This has been manufactured over the past three decades in quantities probably exceeding 1,000 tons for use in nuclear weapons. Pu^{239} is obtained in nuclear reactors by the transmutation process:

In this reaction, a neutron (n) is absorbed by a U^{238} nucleus, forming U^{239} which decays by beta-ray (β^-) emission successively to Np^{239} then to Pu^{239} . The half-lives for the decays are shown in parentheses. In a commercial nuclear power plant fuel cycle, part of the Pu^{239} which is formed participates in the chain reaction, yielding energy in the process and being destroyed to form fission products. Part of the Pu^{239} undergoes successive transmutations by absorbing additional neutrons:

Several other isotopes of plutonium are formed by other nuclear reactions.

TABLE VI-1
RADIOACTIVE DECAY PROPERTIES OF PLUTONIUM ISOTOPES^(a)

Isotope	Half Life ^(b)	Mode of Decay ^(c)	Decay Energy ^(d) (MeV)
232	36 m	EC, α	1.0, 6.58
233	20 m	EC, α	1.95, 6.3
234	9 h	EC, α	0.43, 6.19
235	26 m	EC, α	1.18, 5.85
236 ^(e)	2.85 y	α , SF	5.763, -
237 ^(e)	45.6 d	EC, α , SF	0.23, 5.65, -
238 ^(e)	89 y	α , SF	5.491, -
239 ^(e)	24,360 y	α , SF	5.147, -
240	65,800 y	α , SF	5.159, -
241 ^(e)	13 y	β^- , α	0.021, 4.893
242	379,000 y	α , SF	4.898, -
243 ^(e)	4.98 h	β^-	0.57
244	76×10^6 y	α , SF	?, -
245	10.1 h	β^-	?
246	10.85 d	β^-	0.38

(a) Reference 79.

(b) m = minutes, h = hours, d = days, y = years.

(c) Mode of decay: EC = electron capture, SF = spontaneous fission,
 α = alpha particle emission, β^- = beta particle emission.

(d) Where more than one mode of decay is possible, the decay energy for each mode is listed respectively. Spontaneous fission decay energies are not listed, but are in the range of 200 MeV.

(e) Can be fissioned by thermal neutrons.

The Pu^{239,240,241,242} which is not consumed by the chain reaction remains in the spent fuel and can be extracted at the fuel reprocessing plant and recycled into fresh reactor fuel. With each recycle the isotopic composition of the plutonium changes, because the Pu^{239,241} are preferentially consumed and the Pu^{240,242} accumulate. After several years of recycle the approximate isotopic composition in reactor fuel is that given in Table VI-2.⁽⁸⁰⁾

TABLE VI-2
APPROXIMATE ISOTOPIC COMPOSITION OF REACTOR
PLUTONIUM AFTER SEVERAL RECYCLES

<u>Isotope</u>	<u>Relative Abundance (weight percent)</u>	<u>Specific Activity Curies/gram</u>
236	~ 0.007	530
238	1.9	17
239	54.1	6.2×10^{-2}
240	25	2.3×10^{-2}
241	12	114
242	7	3.9×10^{-3}

The specific activity of this isotopic mixture is approximately 14 Curies per gram, of which Pu²⁴¹ accounts for 97% of the activity.

There has been much public concern that plutonium from commercial reactors might be diverted to weapons by nations owning the reactor or by acts of terrorists. Plutonium of the isotopic mixture shown in the table does not make good material for a bomb for several reasons. The fissile isotopes are diluted by the non-fissile 240 and 242, and the large amounts of neutrons given off in spontaneous fission of Pu²⁴⁰ and Pu²⁴² tend to cause "predetonation" of the critical assembly, thus making conditions for achieving an

explosion very difficult. However, recycled plutonium cannot be ruled out as weapons material albeit it is of extremely poor quality for this purpose.

2. Toxicity of Plutonium

Because of their radioactive decay, all isotopes of plutonium are extremely toxic substances. However, plutonium is not, as often described, the most toxic substance known to man.⁽⁸¹⁾ Like all radioactive materials used in industry and medicine, plutonium must be handled with appropriate equipment and procedures to avoid health hazards.

In general, radioactive materials present health hazards in two ways:

1) if the radiation emitted is sufficiently penetrating, e.g., gamma radiation, then unshielded material can deliver a radiation dose to the body from the outside; or 2) if the radioactive substance is trapped in the body, it will deliver a radiation dose to the surrounding tissues. Plutonium presents the second type of threat.

If plutonium is taken into the body, in some chemical forms it will be eliminated, but in other forms it will be retained more or less permanently. Since the specific activity of reactor grade plutonium is quite low, it is impractical to ingest enough plutonium to produce immediate radiation injuries. The primary hazard arises from small quantities, permanently residing in the body which, after a period of years could induce cancer. The plutonium health standards are defined in terms of "body burden".

The pathways of exposure which are of primary concern are inhalation and injection via wounds. Ingestion from food and water presents a far lesser hazard.

The inhalation hazard depends on particle size and chemical form. Particles which are too large are filtered out in the nasal passage and those

which are too small are exhaled. An intermediate range of sizes are trapped in the lungs. Soluble compounds tend to be purged, but insoluble particles will remain more or less permanently trapped in the lungs. Inhalation has been the most frequent cause of human body burden to date.

The second largest cause of plutonium exposures has been due to shop accidents in which a tool contaminated with plutonium inflicts a wound and deposits some material in the wound.

Considerable data on body burden resulting from plutonium in the food chain has been obtained as a result of atmospheric pollution from bomb tests. The data show that "fall-out" plutonium ingested with food and water is eliminated very rapidly, and the body burden via this route is 1/60,000 of that obtained through inhalation. (82)

The toxicity of plutonium was recognized as soon as its radioactive decay modes were determined by analogy to radium and other natural radioactive substances. The medical history of luminous dial painters obtained between 1925 and 1940 provided the quantitative basis for the health protection standards (83) which have remained in force since the early 1940's. The maximum permissible body burden (MPBB) is 40 nanocuries* for Pu^{239} .

Knowledge of plutonium toxicity to humans has not been obtained from direct experience, because no significant immediate or long-term health effects have been observed. This is despite the fact that many workers have accumulated body burdens of plutonium considerably in excess of the health protection standards.

* One Curie (Ci) = 3.7×10^{10} disintegrations per second (originally taken to be equal to the activity of 1 gram of pure radium).

One millicurie = 10^{-3} Ci

One microcurie = 10^{-6} Ci

One nanocurie = 10^{-9} Ci

One picocurie = 10^{-12} Ci

For the past three decades, thousands of workers have processed and fabricated hundreds of tons of plutonium for the U.S. nuclear weapons programs. In the course of this work several hundred workers have acquired measurable body burdens. In no case has any immediate effect on the health been observed following such exposures. The only pathological findings reported have been the formation after several months or years of fibrous nodules around the site of plutonium depositions in wounds. These were not unlike the fibrous nodules formed by a foreign body reaction, and were cured by excising the plutonium particles. Eight such cases have been reported.⁽⁸⁴⁾

No long-term effects have been observed among exposed workers. It should be noted, however, that medical histories of all workers have not been followed systematically after the individual terminated his employment with an AEC contractor. Efforts are being made to expand the long-term follow-up studies to include a large number of these former plutonium workers.

Detailed follow-up studies have been made on selected groups of individuals.^(84,85) Among such studies is a group of 26 individuals exposed during the 1943-45 era when material for the first nuclear weapons was being processed and fabricated under rather primitive conditions. The 26 selected individuals had the largest apparent body burdens, ranging from 0.1 to 10 MPBB. These individuals have been thoroughly examined periodically since 1953. One of the group has subsequently died from heart disease not relatable to the plutonium exposure. The surviving 25 have not shown any abnormalities after 30 years that are attributable to their plutonium body burden.⁽⁸⁴⁾

Most of the data on plutonium toxicity has been obtained from animal experiments where very large and controlled doses can be administered. As with

all forms of radiation, these experiments have shown that it is possible to induce cancer in animals from inhalation or implantation of sufficiently large quantities of plutonium compounds.⁽⁸⁶⁾ Although the use of animal data to predict the response of humans is subject to some uncertainty, the data provide a broad foundation for quantitative assessment of plutonium health effects. The experiments yield information about movement of various compounds through the system, ultimate fate of the materials, body distributions resulting from various types of introductions, as well as dose/effect data.

3. The "Hot Particle Theory"

In 1968, Geesaman⁽⁸⁷⁾ speculated that plutonium residing in the lungs as particles might be more carcinogenic than an equal amount of uniformly distributed material. A clump of Pu atoms would irradiate the neighboring cells more intensely in such a geometry. This "hot particle" hypothesis has been expanded by Tamplin and Cochran⁽⁸⁸⁾ who have concluded that the present health protection standards are 115,000 times too lax.

The "hot particle theory" has given rise to many outlandish conclusions which, although ridiculous, undoubtedly frighten the public; e.g., in a recent radio statement a spokesperson for Friends of the Earth stated: "Two tablespoons [of plutonium] released over New York City could cause millions of fatal lung cancers and require total evacuation and contamination of the city."⁽⁸⁹⁾

Aside from the problem of getting two tablespoonsful of plutonium down several million throats, the "hot particle theory" is not consistent with the extensive experimental data on animals,⁽⁹⁰⁻⁹³⁾ nor with the human medical

experience, discussed in the previous section.^(84,85) On the basis of the "hot particle" hypothesis, some 5,000 lung cancers would have been predicted for this group of 25 men (or, expressed in more practical terms, the theory predicts that all of the 25 men should have died of lung cancer long ago). B. L. Cohen⁽⁹⁴⁾ points out that a slightly different risk formula proposed by J. W. Gofman⁽⁹⁵⁾ predicts 1,500 lung cancers among the same 25 men.

It must be concluded that the hot particle theory is not valid and does not provide a realistic basis for predicting the health consequences of plutonium body burdens.⁽⁹⁰⁾

D. SAFEGUARDING NUCLEAR FACILITIES AND MATERIALS

Measures and systems which protect facilities and "special nuclear materials" (SNM)* are known as "nuclear safeguards". The United States Nuclear Regulatory Commission (NRC), formerly the AEC, is charged with the responsibility for specifying the safeguards measures to be used by domestic contractors and licensees, who are authorized to possess or handle SNM. The regulations appear in Title 10, Code of Federal Regulations, Parts 50, 70 and 73.

The "Energy Reorganization Act of 1974"⁽⁴⁹⁾ which created the NRC as successor to the AEC for regulatory matters, placed very strong emphasis on the timely development of adequate nuclear safeguards systems. The Act created within NRC an Office of Nuclear Material Safety and Safeguards, which was charged with a number of tasks including: 1) a review of safeguards regulations currently in effect and recommending changes, 2) developing contingency

* The term "Special Nuclear Materials" refers to isotopes which are fissionable, e.g., U²³³, U²³⁵, Pu²³⁹, etc. and other materials which are potential components of nuclear weapons.

plans to deal with threats, thefts and sabotage, and 3) assessing the need for establishing a security agency within NRC for performance of safeguards functions. NRC is required to provide Congress with a report by January 1976 containing recommendations on these matters. As a result of these requirements, many changes in the safeguards regulations can be anticipated in the near future.

During the period of rapid growth of commercial nuclear energy which lies ahead, the nature and quantity of the flows of SNM in industry will be undergoing substantial change. The safeguards regulations will be continually modified to anticipate these changing conditions.

Three major areas need consideration: 1) international safeguards to deter proliferation of nuclear weapons among the nations of the world, 2) protection of domestic supplies of SNM from theft and acts of terrorism, and 3) protection of nuclear facilities against acts of sabotage.

1. International Safeguards

The Atomic Energy Act of 1954⁽⁴⁸⁾ authorizes U.S. assistance to other nations in the development of peaceful applications of nuclear energy, including the sale of nuclear power plants and components to foreign countries by U.S. industry. Under the terms of this Act the United States has consummated bilateral treaties with nations receiving such assistance. These treaties provide for strict accountability for any SNM transferred to other nations, including any by-products which might result from the operation of nuclear reactors of American origin. In addition, the U.S. has cooperated fully and has provided technical assistance to the International Atomic Energy Agency (IAEA) in establishing a system of international accountability and inspection.

The opportunity to limit nuclear weapons to a small "club" of nations was probably lost in 1946 when the Baruch Plan was rejected by the USSR. However, it is dubious that even then could an effective international agreement have been consummated. Once the success of a fission had been demonstrated, it was recognized that any nation with moderate scientific and industrial resources could fabricate fission bombs after a few years of determined effort. This has been convincingly demonstrated by the USSR, the United Kingdom, France, China and India, each of whom elected to develop nuclear explosives. Of course, today many highly developed nations possess the capability and resources to make nuclear weapons on a very short time schedule should they so decide.

Probably the best that can be expected from a system of international safeguards such as is being developed by IAEA is that any nation which undertakes a large nuclear weapons production program will be unmasked in a timely manner and have to bear the burden of world criticism. This is a flimsy deterrence, but a fact of life upon which international diplomacy must be predicated.

It appears that whether or not the United States continues the development of commercial nuclear energy bears little relationship to the problem of proliferation of nuclear weapons among the other nations of the world. In fact, the bilateral treaty policy of the U.S. is probably the most effective deterrent to nuclear arms proliferation now in existence.

2. Theft of Special Nuclear Materials by Terrorists

In the mid-1960's, in anticipation of the development of a large nuclear power industry, the AEC began the process of upgrading nuclear safeguards. Civil disorder and acts of terrorism underscored the urgency for such improvements.

For security reasons much of the research and details of the safeguards systems which were deployed were highly classified. The subject of nuclear safeguards received little public notice, and even the existence of such measures was largely unknown to the general public. This situation has changed in the past few years as a result of the publication of several sensational articles which caught the public attention.⁽⁹⁶⁻¹⁰⁰⁾ In particular, two recent books have created much controversy and underscore the dilemma always faced by a democratic society in security matters, namely, "in its own best interest, how much should the public know?". One of the books, by Willrich and Taylor,⁽¹⁰¹⁾ is a technical account containing much specific detail on how a terrorist might go about stealing fissile material and what he could do with it once he had possession. The authors state that the content was based entirely on unclassified information that was already available to the public. The other book, by McPhee,⁽¹⁰²⁾ is based on essentially the same material as obtained from lengthy interviews with Taylor and is more journalistic in style.

The authors wrestle with the dilemma of the public need to know, and conclude that "the public in a democratic society has the right to know and those with the knowledge have a duty to inform".⁽¹⁰¹⁾ They decided that it seemed necessary to be quite specific in order to make the risks of nuclear terrorism credible. They believed that only following such drastic revelations would the public demand action and force the Federal authorities to take the necessary steps.

Many public officials and professionals who have been concerned with safeguards problems through the years disagree with this conclusion. They question the need for such a graphic text in order to get the necessary

safeguards measures deployed. They point out that even though the books are based on unclassified sources, the authors have supplied a very valuable service to the would-be terrorist by assembling the information from wide-flung sources and selecting the relevant facts from among hundreds of reports. One critic of the books summarizes the objections very succinctly: (103)

"Without elucidation, this reviewer would simply record here the opinion that it is both unseemly and counterproductive for a former professional in the weapons field to speculate -- however hypothetically -- on how a would-be diverter might proceed with design and fabrication of an illicit atomic bomb. Genuine concern with safeguarding against diversion of nuclear materials could surely take more constructive forms indulging in what could turn out to be self-fulfilling prophecy."

He further notes that:

".... truly constructive contributions to an effective, balanced safeguards system for the nation require competent, dedicated, and sustained hard work -- nearly always at low profile",

and that the regulatory agencies and the industry

"are in fact making great strides toward effective, stringent control of the nuclear materials which are the life blood of that industry."

Regardless of the controversy, it appears that Willrich and Taylor have achieved their objective to arouse the public, because the question of nuclear safeguards has become a central issue in the nuclear energy debate. Congress has mandated vigorous effort on the part of NRC to devise and deploy new safeguards systems.

To a large degree, the arguments about safeguards as apply to the commercial nuclear fuel cycle are at this time academic. The reason for this is that spent fuel is not being processed yet and the flow of SNM is mostly limited to experimental batches.

Nevertheless, in view of the publicity that the safeguards problem has received and the level of technical information in the public domain, it is prudent to assume that terrorist acts will be attempted at some time, and measures that will adequately frustrate the assailants must be deployed.

There is no question that safeguards measures have been upgraded and that new measures will be adopted by the NRC to provide even higher levels of security. That this problem is receiving active attention is reflected in recent remarks by NRC Commissioners^(104,105) who also take note of the dilemma concerning the public's right to know. Will not public revelation of the security details compromise the protection that is being provided? The question of public disclosure is a sensitive issue that Congress and the regulatory agencies must resolve.

3. Acts of Sabotage Against Nuclear Power Plants

Another question of public concern is the possibility of sabotage of nuclear power plants by terrorist groups or a deranged employee. Studies on the vulnerability to sabotage are being carried out by Sandia Laboratories.⁽¹⁰⁴⁾ In this regard, Commissioner Gilinsky of NRC notes:⁽¹⁰⁴⁾

"One fact that stands out is the inherent resistance of nuclear plants to sabotage which might release radioactivity. A successful attack cannot be completely ruled out, but it would require an extraordinary combination of a highly competent and determined team of saboteurs and a carefully planned and coordinated effort to simultaneously disable or destroy several separate plant components."

Already new measures are being adopted to make plant sabotage even more difficult.

4. Implications of the Military Origins of Nuclear Power

In the United States our light water reactors make use of slightly enriched uranium fuel which has been processed in uranium enrichment plants originally

built for our military weapons program. This military program made use of uranium, highly enriched in U^{235} , and plutonium for atomic weapons.* The pressurized water reactor is a direct outgrowth of the U.S. Navy nuclear submarine program, which by 1975 also included seven surface vessels with nuclear propulsion. As of mid-1975, there were 114 vessels in commission having 127 reactors, and there were 33 under construction. (106)

As a result of the military programs which originated in the early days of World War II, there have been large quantities of bomb-quality uranium and plutonium produced, and large quantities of nuclear wastes generated from both the bomb production and the nuclear navy programs.

It is apparent that even if there were no civilian nuclear power program, the current military program still carries the burdens of safeguards and disposal of wastes. Many aspects of these problems for the military are not materially different from those in the civilian power program now underway. Indeed, much of the criticism leveled at commercial nuclear power radioactive wastes cites the imperfect record of the AEC in controlling liquid radioactive wastes generated by the military program. (107)

Considering that the military applications of special nuclear materials requires that they already, without further preparation, have the capability of exploding, it would seem that terrorists now have the option of stealing or diverting the materials from the military, either here or abroad. If the civilian use of these materials is forbidden, there still remains the threat

* As noted on page 89, these authors estimate that plutonium in amounts exceeding 1,000 metric tons has been produced for the U.S. weapons program. By 1990, the amounts of plutonium accumulated from the commercial nuclear power industry will be approximately 310 metric tons with no plutonium recycle, or 42 metric tons with recycle (see Ref. 36, Vol. 1, p. S-27).

of violent groups gaining access to military or international sources of supply. It would appear that the civilian use of nuclear materials may enhance the risk, but if vigorous security programs are pursued, the incremental danger is of the same kind and magnitude as already exists with military programs. In any case, the permanent waste disposal problem must be solved for the military uses of fissionable materials.

5. Conclusions Relative to Nuclear Safeguards

The problems of international and domestic nuclear safeguards are technically complex and will require sustained effort with a high degree of sophistication. Because of public concern about these matters, the actions taken to protect nuclear facilities and materials must be revealed to the public in sufficient detail to provide reassurance that the level of protection is adequate. The balance between the public's right to know and the secrecy required for effective security must somehow be resolved.

In international matters, it appears that the proliferation of nuclear weapons to other nations is essentially independent of the development of commercial nuclear power in the United States.

The U.S. commercial nuclear fuel cycle has not yet developed to the point that it offers much opportunity for theft of SNM by terrorists. However, it is prudent to assume that terrorist attempts might be made against experimental batches of material wherever they exist. The U. S. Nuclear Regulatory Commission has been upgrading safeguards measures to deter such attempts. These improvements in security will continue.

Nuclear power plants do not make a practical target for successful acts of sabotage, and new measures are being introduced which will make sabotage even more difficult.

Aside from commercial nuclear activities, the United States has a similar safeguards problem relative to military use of atomic energy and the supporting facilities. In fact, military-related materials constitute the largest quantities of SNM by far, and will continue to comprise the largest for many years to come.

The public fear of acts of nuclear terrorism will continue to be a critical issue in every public hearing relating to the siting and construction of nuclear facilities. Unless these fears are assuaged, many projects now planned will be delayed or blocked. It is urgent that the necessary steps be taken to assure adequate protection and to win the public confidence that the protection is indeed adequate.

E. THE MANAGEMENT OF RADIOACTIVE WASTES

Concern over the management of radioactive wastes is a major public issue in the nuclear power debate. This concern arises from two factors: 1) the record in managing radioactive wastes generated by the U.S. nuclear weapons program has been marred by leaks in old tanks containing wastes stored as liquid solutions, and 2) no final decision has been made by the Federal government on procedures for permanent storage of high-level radioactive wastes generated from the nuclear fuel cycle.

The first problem begets the argument that if the AEC could not properly manage its weapons wastes, why then should it be assumed that a better record can be achieved in regard to waste from commercial nuclear exploitation. The second problem of indecision creates the general conclusion that no technically feasible methods for long-term management have been found, and that the problem might not have a practical solution.

The characterization of radioactive wastes for technical and legal purposes is complex, and no simple all-inclusive definitions have yet been adopted. Two broad categories can be recognized: 1) natural radioactivity, and 2) man-made radioactivity. The former occurs in the mining, milling, refining, enrichment and fabrication steps. The latter originates in the fission chain reaction in reactors and is associated with radioactivity collected in the waste processing systems at nuclear power plants and in the spent fuel. For purposes of this report, we shall concern ourselves only with the man-made radioactivity.

The radioactive wastes generated by the chain reaction can be divided into three broad classes: 1) low-level wastes, 2) high-level wastes, and 3) transuranic wastes (plutonium, americium, etc.). Procedures and regulatory requirements are different for each of the three classes. These will be discussed in turn in the following sections; however, a brief review of the waste streams of nuclear power plants and the characteristics and nature of spent fuel will be useful in providing a broader understanding of the situation.

1. Radioactive Wastes at the Power Plants

The bulk of the radioactivity produced in the reactor remains sealed inside the fuel elements and does not have to be dealt with at the power plant site. Nevertheless, a certain amount of radioactivity appears in the reactor coolant and subsequently must be handled locally. This originates from the neutron activation of reactor components (coolant and structural materials in the reactor core), from "tramp" uranium, and from leaking fuel elements. The "tramp" uranium is microscopic quantities of uranium on the outside of fuel elements that have defied the vigorous cleaning processes that fresh fuel receives at the fuel fabrication plant. Invariably a small percentage of the

fuel elements develop leaks, allowing gaseous fission products to escape from the fuel into the coolant.

The water used as coolant is recycled through the reactor, but a portion is by-passed for repurification through filters, gas separators and resin beds to remove dissolved salts and gases. Most of the radioactivity collecting in the coolant enters the plant waste management systems from the repurification operations. The dissolved materials are concentrated in evaporators and eventually solidified and packaged for disposal. Gaseous wastes are retained for periods ranging from 3 to 60 days to allow short-lived isotopes to decay, and are then discharged to the atmosphere through stacks. The discharge must meet the NRC regulations which limit the radiation exposures to the public to approximately 5% of natural background at the site boundary. (77)

Small amounts of radioactivity are collected from tools used in refueling, the laundering of protective clothing, and small leaks of coolant at pump seals, valve stems, etc. After all liquid waste streams have been processed through several stages of cleanup, small traces of radioactivity remain in the water. This is temporarily stored in tanks for survey, then released in controlled amounts by mixing it with the condenser cooling discharge. The liquid releases are stringently monitored and must be within NRC limits as specified in the regulations. (77)

The packaged solid wastes are shipped periodically to one of the licensed "low-level" waste disposal sites.

The environs of nuclear power stations are routinely monitored by the licensee, but in addition various federal and state authorities conduct independent quantitative measurements of radioactivity in the air, water, soil and biota surrounding the plant. The data clearly demonstrate that power plant

operations routinely meet the criteria imposed by the conditions of the license, and in fact have been low in comparison to these criteria. (108)

2. The Nature of Spent Fuel

At the time spent fuel is normally discharged from a light water reactor, it contains approximately half of its original content of fissile material. Part of the fissile content is plutonium created while the fuel is in the reactor from the capture of neutrons by U^{238} (see page 89). Because of the value of the fissile content, the U.S. fuel cycle has always been based on the assumption that spent fuel would be reprocessed to recover the unburned uranium and plutonium for recycle. Reprocessing is not absolutely necessary. For example, the Canadians are currently storing their spent fuel with the possibility that reprocessing will be done at some later time. (109) The "throwaway" fuel cycle has also been studied for U.S. reactors. (110)

Also present in the spent fuel are fission products -- the "ashes" formed by the fissioning of uranium and plutonium. In most cases the uranium/plutonium nuclei split into two fragments, one large and one small. These fragments quickly become new atoms, undergoing several spontaneous radioactive transformations until they finally reach a stable configuration. In each of the transformations they emit beta particles and gamma rays. The nuclides thus formed (approximately 200 species of isotopes in various concentrations) have half-lives which range from small fractions of a second to millenia.

The radiations which are emitted are degraded in surrounding materials to form heat. The heat thus liberated must be removed; otherwise the fuel will rise in temperature and finally reach its melting point.

In addition to the fission products, the fuel contains several isotopes of plutonium and other transuranic elements formed by successive neutron capture. Also, the material in the fuel cladding contains some activation products which are radioisotopes formed by neutron capture.

Thus, the fuel contains three categories of radioactivity which behave somewhat differently as time goes by. Figure VI-3 shows how each of these components decays with time, the decay characteristics being determined by the concentrations and half-lives of the isotopes in the mixtures.⁽¹¹¹⁾ From the figure it can be seen that the fission products constitute most of the activity and that they decay to about 1% of their original strength after about 150 days. The transuranic (actinide) component decays very rapidly to a few percent of its initial strength within a month or two, after which the remaining activity decays very slowly with a time constant measured in millenia. The activation products, which are the smallest component, have mostly disappeared after a year or so.

As the radioactivity decays away, so does the heat production. Table VI-3 summarizes the rate of heat production in the fuel following reactor shutdown. (See also Figure VI-4.)

TABLE VI-3
FISSION PRODUCT "AFTERHEAT" PRODUCTION IN SPENT FUEL
(The data apply to the full fuel loading of a
1000 MWe (3030 MWth) Light Water Reactor)

Time after Reactor Shutdown	Fuel Irradiation Time		
	<u>1 day</u>	<u>30 days</u>	<u>∞</u>
	(MWth)		
1 second	167	177	183
10 seconds	142	152	158
1 minute	95	105	111
1 hour	23.0	33.0	38.8
1 day	2.8	10.1	15.8
30 days	0.6	1.2	5.7

Figure VI-3. Decay of radioactivity with time in spent fuel.

Figure VI-4. Decay of "afterheat" with time in spent fuel.

It can be seen from the table that after one month the decay heat has decreased to about 3% of its initial value at reactor shutdown.

Each year about one-third of the fuel in a commercial LWR is discharged and replaced by fresh fuel. Thus, under normal circumstances a fuel assembly will remain in the reactor for about three years.

Because of the decay heat production and the intense gamma radiation, the unloading process is carried out underwater at all times. The spent fuel is conveyed from the reactor to a storage basin through a canal. Normally the fuel remains in the storage basin for several months to allow the short-lived radioactivity to decay. After this cooling off period the fuel is loaded into massive shielded casks and shipped to a reprocessing center.

In the reprocessing plant the fuel is dissolved, the unburned uranium and plutonium are recovered for recycle, and the fission products are removed. Eventually the fission products, which constitute the "high-level" radioactive waste, must be converted to a solid form approved by the NRC, and remanded to the custody of the federal government for permanent storage.

Several prominent gaps exist in the fuel cycle as described above, which will now be discussed.

3. Spent Fuel Storage at the Power Plant

The NRC requires each power plant to have storage basins with at least enough capacity to accept a full core loading. As a practical matter, considerably more than the minimum required capacity is always provided. Normally, during each annual refueling campaign only one-third of the core is discharged.

It had been anticipated that the discharged fuel would be shipped to a reprocessing center within a year. However, at the present time no commercial

reprocessing plants are operating. Consequently there has arisen the need for interim storage capacity which had not been anticipated. This need will continue for several years until the backlog of spent fuel can be processed.

As of January 1975, 927 metric tons uranium (MTU) of discharged fuel was in storage at reactor sites. Ten power plants had already accumulated enough discharged fuel in their storage basins so that they no longer had enough reserve capacity for discharge of the entire core.⁽¹¹²⁾ By the end of 1976 at least four reactors will have insufficient storage capacity to permit scheduled refueling unless more capacity is made available.

Various measures can be taken to provide the required interim storage capacity. These include increasing the capacity of on-site basins, and increasing receiving basin capacity at the reprocessing plants. Even though the reprocessing plants are not yet in operation, they do have licensed receiving basins and licensing procedures are underway to expand the approved capacities.⁽¹¹²⁾ Projected storage capacities at reprocessing plants and annual reprocessing capabilities are given in Table IV-4.

If such a schedule is partially implemented to the point where there is 1280 MTU storage away from the reactor sites, and the AGNS facility provides processing capability of 750 MTU/yr by July 1, 1976, increasing to 1500 MTU/yr on July 1, 1977, there will be no need during the decade to increase storage capacity at individual reactors. On the other hand, if storage at reactor sites was increased by 50%, and only the NFS storage were increased to 260 MTU, then not until 1978 would there be any plants without full core storage capacity. At that time four plants would be without the desired capability. Probably a combination of the two storage processing scenarios will develop

TABLE VI-4
Projected Spent Fuel Storage Capacity
at Reprocessing Plants and Annual Reprocessing Capacity
(Data from Ref. 112)

Storage Basin Capacity (MTU) ^a at End of Year	1974	1975	1976	1977-84
Allied-General Nuclear Services	0	360	360	360
Nuclear Fuel Services, Inc.	112	193	260	370
Gen. Electric Nuclear Energy Div.	90	90	660	660
Total	202	643	1280	1390

Reprocessing Capacity (MTU/yr)	1974	1975	1976	1977	1978	1979	1980-84
Allied-General Nuc. Serv.	0	0	317 ^b	1125	1500	1500	1500
Nuclear Fuel Serv., Inc.	0	0	0	0	0	336 ^b	600
Total	0	0	317	1125	1500	1836	2100

^a Metric tons uranium	^b Schedules might be delayed.
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over the next few years. It is obvious, however, that this problem must be closely watched and that suitable storage and processing capacity be provided as the industry grows. A new survey is underway by ERDA which will provide more precise data by January 1976. (113)

4. Reprocessing of Spent Fuel

The Nuclear Fuel Services plant at West Valley, New York provided the reprocessing for the nation's commercial reactors until late 1971, when the plant was shut down for expansion of its capacity and to improve its ability to limit radioactive emissions to small fractions of statutory amounts. This

plant is scheduled to start operation again in 1979. A second facility built by General Electric Co. (GE) in Morris, Illinois, developed basic design troubles resulting from a new method of reprocessing the material. It is not clear whether this facility will be redesigned, or whether it will be abandoned as too costly to revamp. A third reprocessing plant is being built by Allied General Nuclear Services (AGNS) near Barnwell, South Carolina. At the present time it is scheduled to begin operation in mid-1976, which represents a two year delay over the originally planned startup time. This plant is experiencing licensing delays which might force further postponement of its commissioning date.

The reprocessing capability projected in Table VI-4 will not be adequate to meet reprocessing needs and clean up the backlog. About ten reprocessing plants having a 2000 MTU annual capacity will be needed before the year 2000.⁽⁵⁸⁾ Private industry has been backing away from entering the reprocessing business because the economic viability of such plants has not been demonstrated. Capital investment in each plant is large, even though it represents only about 1.7% of the cost of the power plants it services.⁽¹¹⁴⁾ It has been estimated that between 1975 and 1985 \$2.4 billion capital investment is needed for building adequate reprocessing capacity.⁽¹¹⁴⁾ In order to keep pace with the supply of discharged fuel, at least two additional plants should already be under construction. Obviously there will be a shortage of reprocessing capacity for many years into the future.

5. The Management of Radioactive Wastes

a) Low-Level Wastes - A 1000 MWe nuclear power plant, including all its supporting fuel cycle activities, generates about 10 curies per year of solid radioactive waste dispersed in filter elements, cleaning

materials, contaminated tools and equipment, etc. This radioactivity is dispersed in about 20,000 cubic feet of solid waste.⁽¹¹⁵⁾ The quantity generated at the power plant site is about 4,000 cubic feet for a BWR and about 1,000 cubic feet for a PWR.⁽¹¹⁶⁾ These low-level wastes require less than 0.1 acre of land per year for disposal.⁽¹¹⁵⁾

Low-level solid wastes are buried in shallow trenches in their containers at designated burial grounds. At the present time there are six such sites located in the states of Washington, Nevada, Illinois, Kentucky, South Carolina and New York. The burial sites are licensed by the states and are operated under state supervision. The state governments have responsibility for permanent surveillance of the sites and to prevent their future use for other purposes. The commercial burial sites have been chosen and authorized after appropriate studies have been made of site topography, meteorological, geographic and hydrological factors. The intent is to insure that the water table is sufficiently low and that the soil clay is effective in keeping the radioactivity from leaching into the ground water and migrating from the site. Monitoring wells at the site are periodically sampled to detect whether any migration has occurred. Seepage of trace amounts of radioactivity have been detected in the ground water at two of these sites. The position taken by the public health authorities in these states (Kentucky and New York) is that the observed levels have no public health significance, but that the situation should be closely monitored.⁽⁶⁰⁾

b) Gaseous and Liquid Wastes - Gaseous and liquid wastes released at power plant sites have been discussed in Section VI-E-1 (page 105).

When the fuel is dissolved at the reprocessing plant, gaseous fission products trapped in the fuel pellets are released, some of which are eventually released to the atmosphere. The principal components are tritium and Kr⁸⁵. Maximum radiation exposure from these emissions at the plant boundaries is projected to be less than 1% of natural background radiation. More detailed data on release rates and radiation doses to individual organs can be found in Table F-6, page F-24 of Ref. 44.

Of the reprocessing plants, only the NFS plant is designed to allow liquid emissions. The liquid effluent contains tritium and dissolved salts of Ru¹⁰⁶, Cs¹³⁷ and Sr⁹⁰. The operations prior to shutdown in 1971 resulted in the off-site release of radioactive liquids at a level of about 5% of the 10CFR20 limits of 170 mRems, resulting in an estimated population dose within a 50 mile radius of 50 man-rems.⁽¹¹⁷⁾ Plant modifications now being made will greatly reduce this dose when the plant resumes operation in 1979. The modifications are designed to meet the new NRC criteria⁽⁷⁶⁾, which allow no more than 5 mRems at the site boundary.

c) High Level Wastes - The fission products separated from spent fuel at the reprocessing plant are defined as "high-level radioactive wastes". Also, for purposes of permanent disposal, waste containing significant contamination of isotopes of the actinide elements (plutonium, americium, etc.) are required to be stored by methods similar to high-level wastes, even though the level of radioactivity might be thousands or even millions of times smaller.

The fission product waste stream contains a mixture of isotopes of almost all of the chemical elements. This waste stream contains about 99.9% of the radioactivity produced in the reactor and is intensely radioactive. Concentrations of radioactivity can be as high as 2,500 curies per liter of liquid. Details of the chemical and physical properties of the high-level waste streams can be found in an excellent review article by K. J. Schneider.⁽¹¹⁸⁾

The total quantity of commercial high-level wastes is still quite small, being only that generated by Nuclear Fuel Services, Inc. prior to their suspension of operations in 1971. Spent fuel in storage prior to reprocessing is not considered high-level waste because the radioactivity is immobilized in the fuel elements; although, of course, either the spent fuel elements themselves or the waste extracted in reprocessing must ultimately be placed in permanent storage.

It has always been the U.S. policy that high-level wastes would be segregated from the environment and stored in a form and place that would provide a high degree of assurance that they would remain segregated.

Initially, after separation from the spent fuel, the high-level wastes are stored in double-walled stainless steel tanks. A federal regulation published in 1970⁽¹¹⁹⁾ requires that this liquid waste must be converted to solid form within five years and transferred to a federal repository within ten years of its separation from the irradiated fuel. Technology has been developed for converting the partially aged liquid wastes into solidified glasses, or calcined or ceramic concentrates. In the form of solids with very low rates of leaching, the appropriately encapsulated material may be transported safely to the designated waste repository.

For a 1000 MWe PWR, the high-level solid wastes average about 3 cubic feet of volume per metric ton of fuel. This material has an initial activity of 4.4 megacuries and generates heat at a rate of 20 kilowatts. The activity decreases to 0.31 megacurie and 1.1 kW in 10 years, and to about 0.034 megacurie and 1.1 kW in 100 years. These figures are for fuel that has been enriched to 3.3% uranium-235 and that has been irradiated in the reactor for 33,000 megawatt days thermal per ton, with an assumed waiting period of 150 days before solidification. A PWR of 1000 MWe capacity has 108 tons of fuel, one-third of which is discharged each year. Thus, about 100 cubic feet of solid waste is generated annually, which corresponds to the volume of a cube 4.8 feet on edge. This means that the volume of solid material to be permanently stored is not very large in terms of physical size. Nevertheless this quantity of high-level waste corresponds initially to very formidable amounts both of radioactivity (158 megacuries), and of heat production (0.72 megawatts), which must be shielded and cooled.

Aside from commercial nuclear power, the United States has accumulated some 90 million gallons of aqueous high-level wastes from production of materials for the defense programs. Most of this is still stored as liquid solutions in large tanks at federal sites near Hanford, Savannah River, and Idaho Falls. Several of these tanks, dating back to the Manhattan Project and the early years of the AEC, have developed leaks. In some cases substantial quantities of the waste emptied into clay beds under the tanks before the leaks were detected. Surveillance of the affected ground and surrounding aquifers demonstrates that the radioactivity is immobilized in the clay. Nevertheless, these incidents

proved to be a serious embarrassment to the AEC, and are often cited as examples of poor management of radioactive wastes. It should be noted, however, that these bad examples are not relevant to the commercial wastes, since federal regulations specifically prohibit the use of tanks of the type that leaked. Commercial wastes in liquid form must be stored in double-walled containers which permit the timely detection of a leak from the inner vessel. Also, the period that wastes can be stored as liquids is limited to five years. (119)

d) Federal Repositories for High-Level Wastes - In the mid-1950's the National Academy of Sciences was commissioned by the AEC to examine the problem of disposal of radioactive wastes and to recommend suitable sites for permanent storage. In 1957 the Academy recommended that bedded salt deposits would constitute a suitable geological formation for a permanent repository. (120) Such formations underlie large regions of the United States and are known to have been tectonically stable for geologic ages approaching 500 million years. Their very existence is proof of their isolation from aquifers. Furthermore, salt (NaCl) is a relatively good heat conductor, thus precluding any anomalous buildup of heat in the repository, and not subject to large buildup of stored energy from radiation damage.

The bedded salt concept was investigated and developed by Oak Ridge National Laboratory, using an abandoned salt mine near Lyons, Kansas. The investigation included a large scale experiment involving the emplacement in a prototype arrangement in the salt of extremely radioactive spent fuel elements from a research reactor. These were left in place

for a period of some 18 months while extensive measurements were taken on heat flow, mechanical and chemical effects, radiation damage, etc. (121) Equipment was designed and built for handling of containers and emplacing them in the salt bed. At the end of the program the radioactive materials used for the tests were retrieved and shipped back to the storage site at Idaho Falls.

The results of the experiments were reviewed by the National Academy of Sciences and judged satisfactory. (122) The committee of the Academy concluded:

"1. The use of bedded salt for the disposal of radioactive wastes is satisfactory. In addition, it is the safest choice now available, provided the wastes are in an appropriate form and the salt beds meet the necessary design and geological criteria.

"2. The site near Lyons, Kansas, selected by the AEC is satisfactory, subject to the development of certain additional confirmatory data and evaluation."

The AEC decided to proceed with the Lyons, Kansas site as a demonstration Waste Repository, and issued the final environmental statement in June 1971. (123) Funding was budgeted for subsequent years to purchase and develop the site. However, early in 1972 the AEC announced that it was abandoning plans to use the Lyons site on the basis that it was not suitable. Rejection was ascribed to complications caused by the presence of several old oil wells that had been drilled through the formation and a nearby sluice mining operation in the same salt formation.

The sudden cancellation of the Lyons project created an unexpected void in planning. To fill this void, the AEC proposed building temporary "Retrievable Surface Storage Facilities" (RSSF) to accommodate waste

until a suitable permanent site was located and developed. In September 1974 the AEC issued a draft environmental statement for the RSSF, and in January 1975 the budget proposal of ERDA sent to Congress contained a line item for the construction of an RSSF at a site to be designated. In April 1975 this request was withdrawn by ERDA pending completion of an environmental impact statement of broader scope. A spokesman for ERDA states: "The RSSF as a concept is therefore dormant, but is not dead." (60)

In the meantime, the geological site evaluation program has located a site in New Mexico which appears promising. If subsequent surveys are favorable, ERDA will request funds in January 1977 for construction of a mine and a test project. (60)

It is clear that no immediate definite repository for high-level wastes now exists. This has given rise to public criticism that the fuel cycle is not closed. Nuclear opponents argue that the technical difficulties of permanent storage are insoluble, and the concept of a permanent retrievable storage implies perpetual stewardship -- a condition that contemporary society cannot guarantee. This condition of perpetual stewardship centers about the permanent storage of long-lived radioactivity. It is argued that it is unethical to burden future generations with this problem since they had no hand in producing the radioactivity. Plutonium-239 has a half-life of 24,400 years, which implies that for hundreds of thousands of years, or more, there will be significant activity in the stored plutonium wastes.

The time scales involved and the relative toxicity of the wastes when compared to natural uranium ore containing 1.4% of U_3O_8 are shown

in Fig. VI-5, ⁽¹¹¹⁾ which was based on work by Kubo and Rose. ⁽¹²⁴⁾ Relative toxicity as used here is defined as a ratio: the volume of water required to dilute a certain mass of a substance to its maximum permissible concentration (MPC), divided by the volume of water required to dilute an equal mass of uranium ore containing 1.4% of U_3O_8 to its MPC.

Present practice is to remove 99.5% of the uranium and plutonium from the spent reactor fuel at the reprocessing plant. It may be seen that after perhaps 600 years, when the Cs^{137} and Sr^{90} have essentially disappeared, the predominant toxicity problem is that of the actinides, including residual plutonium and other transuranic elements. At this time the waste would be approximately 10,000 times more toxic than the 1.4% uranium ore, and approximately 200 times more toxic than pitchblende ore. After 24,000 years the toxicity would be about 10 times that of pitchblende or about 500 times that of 1.4% uranium ore.

As discussed by Kubo and Rose, it is feasible by chemical means to separate out the actinides from the wastes to a greater degree than is currently practiced so that there is removed 99.9% of the uranium, plutonium and neptunium, as well as 99.0% of the americium and curium. These transuranic elements can then be transmuted by neutron irradiation in a reactor to shorter lived activities. In this manner the long-lived activities can be reduced by a factor of between 10^2 and 10^4 , as shown by the lower curve in Fig. VI-5. At such a level the material would then be much less toxic than pitchblende ore, or about 10 times more toxic than 1.4% uranium ore. This process can be carried out for a relatively minor cost addition to the whole fuel cycle, and would not be economically limiting. In this way, the problem of storage of wastes which are

Figure VI-5. Relative toxicity of reactor wastes during the time span from 1 year to 10 million years.

The upper solid curve is for wastes which have 99.5% of the U and Pu removed (present practice). After about 600 years, when Sr^{90} and Cs^{137} have mostly decayed, the main contribution is from the actinides. The lower solid curve is for a feasible case where more actinides are removed and then transformed by neutron capture in a reactor to less toxic materials, resulting in long-term wastes which are less toxic than pitchblende.

toxic for millenia is transformed to a problem of storage for several hundred years. This has importance in relation to the time scales involving the stability of human institutions which, in the main, have not proved to be permanent for millenia. The combination of such a transmutation scheme, plus storage in appropriate isolated geologic strata for a few hundred years, suggests that the ethical problem need never arise, if indeed society actually perceives such a problem to exist.

e) The Politics of High-Level Waste Storage - It is instructive to examine the history relating to the abandonment of the Lyons, Kansas site as the initial federal repository. In the absence of almost absolute assurance of safety, similar pressures might be expected in the future for any site selected to be the permanent radioactive waste repository for the nation.

The official AEC announcement of the abandonment of Lyons listed technical reasons for the decision -- the presence of old oil wells at the site and nearby sluice mining in the same salt bed. Yet, both of these factors had been under investigation for some time.⁽¹²⁵⁾ The concept of waste storage in bedded salt strata had been endorsed (see page 119) by the National Academy of Science.⁽¹²⁰⁾ For the Lyons site, in particular, extensive geophysical surveys had been conducted by the AEC to insure that all existing wells had been located. Plans had been developed for cleaning out each well and replugging, using multiple layers of cements developed to be compatible with surrounding strata. No solutioning of the salt deposit from leakage through wells had been detected in the extensive corridors of the abandoned mine.

The residents of Lyons were familiar with the plan, well informed on the results of the research, and overwhelmingly in favor of the project.* The local Congressman, supported by the Governor and both the U.S. Senators, originally had urged the AEC to adopt the Lyons site and to seek Congressional authority and funding. (126)

Near the site a salt mining operation had been conducted for many years by injecting fresh water through wells and removing salt solution. The mine operator believed that more water had been injected than had been extracted, implying an accumulation of water somewhere in the bed. This discrepancy could not be confirmed, since the metering instruments in the mine were not of sufficient accuracy. Plans had been made to investigate this situation thoroughly and to take such corrective action as might prove necessary. This was not expected to be of great difficulty. (125) A further contention which emerged was that eventually the land above the sluicing operation would subside, and form a lake near the repository which might pose a threat of water infiltration from above. However, if formed, such a lake would be some distance from the repository and isolated by a 500 foot thick layer of impermeable shale. Not all geologists were firmly of the opinion that this would be a permanently secure barrier because it was conjectured by some from Kansas that heat flowing from the repository might buckle the shale layers and admit surface waters.

It may be that the technical reasons for abandoning the Lyons site were not necessarily compelling, yet sufficient doubt had been raised

* This opinion is based on personal discussions by one of the authors (Vance L. Sailor) with several Lyons citizens in 1971 and 1975, and the enthusiastic endorsement of the Lyons Chamber of Commerce.

because of the presence of water in the vicinity that absolute guarantees could not be provided by the AEC as to permanent inviolability of the repository.

In the spring of 1970 a Congressman representing a district 200 miles from Lyons launched an attack on the Lyons plan. A special study of the project was ordered by the Governor from the Kansas State Geological Survey. This study restated the known problems and focused on heat flow and other aspects, noting that complete information did not exist. Questions were also raised by the Advisory Council on Ecology in their report to the Governor. In 1971 the Governor of Kansas withdrew his support, despite an active lobbying effort by the local citizens to keep the project alive. In the face of the opposition by the Governor, and evidently lacking unequivocal proof of its contentions, the AEC abandoned the project.

The abandonment decision has had very far-reaching consequences which have been extremely costly; e.g., completion of the reprocessing stage has been impaired, large expenditures must be made to find a new site, and the negative decision without a viable immediate substitute has been widely interpreted as proof of insurmountable obstacles inherent in the concept of safe and permanent disposal. This has undermined public confidence in nuclear energy.

f) Tailings from Uranium Milling Operations - Another issue which has appeared recently is the presence of radioactivity in tailings from uranium mines and mills. The physical volume of the residues from these installations is the largest generated in the entire fuel cycle. Small concentrations of uranium, and its decay products thorium and radium,

remain in the tailings. Thorium-230 decays into radium-226, which then gives rise to gaseous radon-222. The latter diffuses out of the tailings into the air, and much smaller amounts of particulate thorium and radium may become windborne.

According to H. F. Soule⁽⁶⁰⁾ the tailings piles at mills are not an environmental problem if they are kept wet to prevent wind erosion and diked to prevent water from running off. Radon gas in excess of normal background is not noticeable at distances of 1/4 to 1/2 mile from such piles. Since the tailings piles are located in uninhabited regions, the local concentrations of radon gas pose no immediate health hazard. However, in the past such tailings were used for construction fill for houses in the Grand Junction, Colorado area. This ill-advised practice required corrective action to eliminate a possible health hazard to inhabitants of the buildings. Proper stabilization of the tailings piles, or other effective measures, must be assured to sequester the alpha-particle emitters from the biosphere, and their use in construction must be prohibited. The question of who should bear the cost of these measures has been a subject of controversy between the states involved and the AEC, EPA and ERDA. The Atomic Energy Act of 1954⁽⁴⁸⁾ did not authorize AEC control over the tailings; however, the AEC has been criticized for not aggressively seeking to control the problem.

F. CONCLUSIONS

The future development of nuclear energy is in serious jeopardy because of problems with public perception of the hazards associated with the operation of reactors and the nuclear fuel cycle. By comparison with other current

technologies, it appears that from the technical point of view the public safety has been protected to an extremely high degree, and that this level of safety can reasonably be assured for the future. Unfortunately, public education on these complex technical issues has not been successful thus far, and the built-up fear of radiation overwhelms objective assessment of the facts. Indecision by regulatory authorities on several major issues, particularly waste management, has aggravated the situation and invites public criticism. If our society is to make effective use of the nuclear option, progress must be made by working towards a consensus on what is an acceptable level of risk, by introducing improved solutions to the problems, and by educating the public that this has occurred.

VII. BREEDER REACTORS

A. THE BREEDING CYCLES

Contemporary light water reactors derive their energy from only a small part of the uranium in the fuel. The fission chain reaction is primarily sustained by the U^{235} isotope which must be enriched from its natural abundance of 0.7% to a level of 2-3% in order for an LWR to operate. The uranium found in nature is mostly (99.3%) U^{238} . The LWR can burn only a very small amount of U^{238} via the formation of Pu^{239} from neutron capture in U^{238} (see page 89 for reaction which produces plutonium). Thus, the modern nuclear power plant can unlock only a small fraction of the total energy potential of virgin uranium. A more advanced concept, the breeder reactor, can burn up to about 70% of the U^{238} .

The breeder reactor, fueled initially by enriched uranium, can produce plutonium faster than it consumes U^{235} . In subsequent loadings the reactor can be fueled with a mixture of plutonium and uranium, thus eliminating the need for U^{235} enrichment. At each subsequent loading, the breeder produces more plutonium than it consumes. The surplus plutonium would then be available for fueling new breeder reactors or for fueling conventional LWR's.

When breeder reactors come into common use, the demand for uranium feedstock will greatly decrease, because the breeder will derive about 100 times as much energy from the original uranium as is now possible.

It should be noted that a second breeding cycle is possible in which thorium is converted to U^{233} by the reaction:

The U^{233} so produced is fissionable just as are U^{235} , Pu^{239} and Pu^{241} . Since thorium is more abundant in the earth's crust than uranium, the $Th^{232} - U^{233}$ breeding cycle affords an enormous energy reserve for the future. In general, the $Th^{232} - U^{233}$ cycle can be substituted for the $U^{238} - Pu^{239}$ cycle. However, the thorium cycle has not been as thoroughly developed at the present time.*

The most favorable breeding chain reaction utilizes "fast" neutrons, i.e., the neutrons emitted in the fission event are not slowed down (not moderated). In principle, breeding can take place with moderated neutrons in some reactor systems, but the time required to double the fuel is very long, which tends to make the economics less favorable. The requirement for "fast" neutrons means that water cannot be used as a coolant. Instead, some heavy material must be used which does not produce appreciable moderation. The breeder reactor presently under intensive development in several countries is cooled by liquid metallic sodium. These reactor characteristics yield the common name for such a system, the liquid metal fast breeder reactor (LMFBR). Other breeder concepts in earlier stages of development are the gas-cooled fast reactor (GCFR) and the molten salt breeder reactor (MSBR).

Many small sodium-cooled reactors have been built and operated successfully over many years. The technology has been thoroughly tested and has reached a high state of development. (127)

B. THE STATUS OF BREEDER REACTORS

The United States had been at the forefront in the development of LMFBR, but in the last decade has lost the leadership.

The USSR has operated a series of demonstration LMFBR's of successively larger sizes, including the BOR-60 for a period of more than 5 years, and the

* Probably the "best" economic utilization of the thorium cycle will prove to be for the combination of gas-cooled fast breeder reactors and HTGR's.

BN-350 (350 MWe) for two years. The BN-600 (600 MWe) is almost completed.⁽¹²⁸⁾

The French demonstration LMFBR, "PHENIX", reached criticality in August 1973 and full power in March 1974. It has operated remarkably well, achieving a plant availability factor of > 80% in its first nine months of operation at full power.⁽¹²⁸⁾ The next plant, "SUPER-PHENIX" (1200 MWe), is in the final states of design.⁽¹²⁹⁾ France has signed an agreement for the construction of an experimental fast breeder in Brazil.⁽¹³⁰⁾

The British prototype, 250 MWe fast breeder reactor (PFR), began operation in 1974, but its operation has been limited by problems in pumps and heat-exchangers.⁽¹²⁸⁾

The West German prototype fast reactor (SNR-300) has been under construction since 1973 and is scheduled for operation in 1979.

At the present time the first United States demonstration LMFBR, the Clinch River breeder reactor (CRBR), is scheduled to begin operation in 1983.⁽¹³¹⁾ This target date appears optimistic, since NRC hearings for the construction permit will probably not begin before the end of 1976. Spirited opposition by intervenors is anticipated, and it appears likely that the hearings might last for two or three years. If so, the completion date could be as late as 1985.

C. TIME SCALE FOR COMMERCIAL BREEDERS IN THE U.S.

In view of the present status of the U.S. LMFBR program, it appears unlikely that a full-scale commercial LMFBR could begin operating before 1990. Probably a more realistic date for the commissioning of the first commercial breeder in the United States is 1995-2000. If, for some reason, the public policy should change to make the breeder development an urgent goal, it is possible that the first commercial plants could be ready by 1990. A similar

date could probably be met if the United States decided to buy French or Soviet breeders.

Because of the above considerations, it is highly unlikely that breeder reactors will play a significant role in the energy resources of the Northeast before the year 2000. Despite the apparent long time scale for exploitation of breeders, serious regional planning is needed now to insure availability of suitable sites for breeder power plants. The "power park" concept is particularly appropriate for breeders, because of the economic and technical advantages of having several reactors and their complete fuel cycle facilities located on a common site. In the Northeast the opportunities for such sites are rapidly disappearing. Careful planning now could avoid great expense and other difficulty in 20 years.

VIII. COMPARISONS BETWEEN NUCLEAR AND FOSSIL-FUELED POWER PLANTS

It is sometimes useful to compare the characteristics of alternative methods for generating electricity. To be meaningful, such a comparison should embrace the entire energy system, including the fuel cycle and residuals. Considerable progress has been made on quantifying the many factors that describe direct and external costs. However, only primitive methods have been devised for the reduction of externalities to a common base.

In the case of the Northeast there appear to be only three viable alternatives for large base-loaded generating plants: 1) coal, fueled by eastern coal deposits; 2) oil, fueled by imported residual fuel oil, and 3) nuclear, light water reactors. Long term irreversible shortages preclude domestic natural gas as a possible choice. The high temperature gas cooled reactor (HTGR) appears to be unavailable for the foreseeable future (see page 24), and the breeder reactor will not be available for large scale exploitation for at least two decades. Other systems such as fusion, solar and wind are not yet practical and cannot be made practical for large scale application before the end of the century.

Quantitative results from a recent assessment⁽¹³⁷⁾ comparing the costs and benefits of coal, oil and nuclear (LWR) systems are summarized in Table VIII-1. The plants are located at the average "Middletown, U.S.A." site; thus various entries should have to be modified to apply to a specific site. The data are normalized to equivalent plants of 1000 MWe net capacity, and based on an average plant capacity factor of 0.75. The characteristics are representative of contemporary units and current practices in fuel extraction, processing and waste disposal. The economic data are based on 1974 costs escalated to 1980.

TABLE VIII-1

COMPARISON OF ALTERNATIVE METHODS OF GENERATING ELECTRICITY

The data, taken from Ref. 132, compare equivalent plants of 1000 MWe (net) capacity and their supporting fuel cycles. An average plant capacity factor of 75% was assumed.

<u>Item</u>	<u>Coal</u>	<u>Oil</u>	<u>Nuclear</u>
EFFICIENCIES			
1. Net electrical energy output (billion kWh/year)	6.57	6.57	6.57
2. Power plant heat rate (Btu/kWhe, net)	8900	8830	10850
3. Power plant thermal efficiency (kWe/kWt, %)	38	39	32
4. Efficiency of complete system (kWe consumer/kWht input, %)	35	35	28
CONSUMPTION OF NON-RENEWABLE FUEL RESOURCES			
5. Power plant fuel consumption (annual)	2,300,000 tons	10,000,000 bbls	132 MTU ^(a)
6. Fraction of reserves consumed (annual)	0.000006	0.0001	0.0002
CONVENTIONAL COSTS (mills/kWhe, expressed in 1980 dollars)			
7. Plant	7.8	7.2	11.7
8. Operation and maintenance	0.8	0.6	0.8
9. Fuel	9.8	27.4	6.0
10. Total	18.4	35.2	18.5
11. Selected abatement costs	4.7	2.0	0.6
OCCUPATIONAL HEALTH AND SAFETY			
12. Occupational health (MDL/yr) ^(b)	600	U ^(c)	480
13. Occupational fatalities (deaths/year)	1.1	0.17	0.1
14. Occupational non-fatal injuries (#/yr)	46.8	13.1	6-7
15. Total MDL/year (fatalities + injuries)	9250	1725	900-1000

(a) MTU = metric tons (2204 lbs) uranium. Only about 1.3 tons are actually consumed; the remaining 99% is available for recycle or use in breeders.

(b) MDL - Man days lost

(c) U = Unevaluated

TABLE VIII-1 (cont'd)

<u>Item</u>	<u>Coal</u>	<u>Oil</u>	<u>Nuclear</u>
PUBLIC HEALTH AND SAFETY			
16. Routine pollutant release (MDL/yr)	U	U	180-210
17. Transportation accidents-fatalities (deaths/yr)	0.55	U	0.009
18. Transportation accidents-injuries (#/year)	1.2	U	0.08
19. Transportation accidents-total MDL/yr (fatalities + injuries)	3500	U	60
ENVIRONMENTAL DEGRADATION, LAND			
20. Land use, inventory (acres)	22,400	1,600	1,000
21. Land use, consumption (acres/year)	740	small	12
ENVIRONMENTAL DEGRADATION, AIR			
22. SO ₂ releases, w/o abatement (tons/year)	120,000	38,600	3,600
23. SO ₂ releases, with abatement	24,000	21,000	720
24. NO _x releases, w/o abatement (tons/year)	27,000	26,000	810
25. Particulate releases, w/o abatement (tons/year)	270,000	26,000	8,000
26. Particulate releases, with abatement (tons/yr)	2,000	150	60
27. Trace metal releases (tons/year)	0.5 Hg	1500 V	small
28. Radioactivity releases (Curies/yr)	0.02	0.0005	250-500 x 10 ³
29. Thermal discharge, power plant stack (billion kWh/yr)	1.64	1.71	0
ENVIRONMENTAL DEGRADATION, WATER			
30. Cooling water use ^(d) (billion gal/yr)	263	263	424
31. Process water use (billion gal/yr)	1.46	1.75	0.095
32. Radioactivity releases (Curies/yr)	0	0	500-1000
33. Other water polluted (billion gal/yr)	16.8	7.9	small
34. Thermal discharge, power plant (billion kWh/yr)	9	9	14

(d) Mostly non-consumptive use. Consumptive water use (evaporation) by natural draft wet cooling tower is 0.3 gal/kWh of rejected heat. Thus, using Item 34, consumptive use is 2.7 billion gals/year for coal and oil and 4.2 billion gals/year for nuclear.

Comments on a few specific items in Table VIII-1 follow.

Item 1: It should be noted that a 1000 MWe power plant is a large facility. About five such plants would meet the 1975 base-load requirements for New York City. The retail value of the electricity produced in a year (6.57×10^9 kwh) would have been about \$240 million based on the average sales price of electricity in the Northeast of approximately 4 cents/kwh (assuming a 9% transmission and distribution loss).

Item 4: The efficiency of the complete system takes into account energy consumed in the fuel cycle -- mining, processing, transportation and disposal of wastes. The nuclear datum includes the energy expended in the uranium enrichment process.

Item 5: In order to provide 132 metric tons of uranium for input into the enrichment stage, some 70,000 to 100,000 short tons of ore must be mined. In 1973, about 60% of the ore came from open pit mines.

Item 6: The remaining resources of each fuel include only "proven reserves" accessible with current extraction economics and technologies. The resource base for coal is estimated at $200-400 \times 10^9$ short tons. The petroleum resource base includes 90×10^6 bbls of which 30% is domestic, 46% Venezuelan, and 24% African.

Item 9: Fuel costs are based on 1974 data escalated at a rate of 8% per year, levelized over a ten year period to 1980. It should be noted that the fuel costs cited are for "Middletown, U.S.A.". Since these costs are sensitive to geographical location, they would require substantial corrections to apply to the Northeast, particularly New England and eastern New York. In these regions the high cost of transportation would increase the cost of coal substantially.

Items 12-15: Occupational fatality and injury rates assume that 50% of the coal is extracted from underground mines.

Item 16: The public health impacts from coal- and oil-fired plant air emission were unevaluated in the table based on Ref. 132. A recent assessment⁽¹³³⁾ yields the following estimates (normalized to 1000 MWe):

	Excess Deaths	Excess Disabilities
	(Data Rounded)	
Coal	15-125	200-300
Oil	2-100	85-190

The excess deaths and disabilities are mostly among the higher age groups and do not include malignancies. An upper limit can be set on public health effects from routine emissions of radioactivity from a 1000 MWe LWR which is of the order of one excess malignancy every 12 years.

Item 21: Consumptive land use is defined as land disturbed by surface mining or inundated by disposal of fuel cycle residuals.

Items 22-27: Releases of air pollutants for the nuclear system include coal-generated electricity for the uranium enrichment step.

An attempt has been made to reduce the entries in Table VIII-1 to a common base, i.e., dollar costs.⁽¹³²⁾ The costs can be divided into two general categories, conventional and non-conventional. The conventional costs include direct costs for plant, operation and maintenance, fuel and abatement. Non-conventional costs include health, injuries, fatalities and environmental impacts. It is recognized that conversion of non-conventional costs to dollar values is subject to considerable uncertainty.⁽¹³²⁾

The cost data are summarized in Table VIII-2. It can be seen from the table that for all three alternatives, the non-conventional costs are small

in comparison with the conventional, i.e., in the range from about 1 to 3%. Conventional costs with abatement are least for the nuclear. Because of the high cost of fuel, the oil costs are almost double the nuclear. Coal with abatement is about 20% higher than nuclear. Note that this difference would be greater in New England and eastern New York because of the high cost of transporting coal. The non-conventional costs of oil and nuclear are about the same, except the public health and safety have been omitted from the oil evaluations. Non-conventional costs from coal appear at least 3 times the nuclear.

The data indicate that on the basis of conventional costs, occupational and public health and safety and environmental impact, the nuclear system is the least costly and damaging choice of the three viable alternatives.

TABLE VIII-2

COMPARISON OF CONVENTIONAL COSTS AND SOME
EVALUATED NON-CONVENTIONAL COSTS OF ALTERNATE ENERGY SYSTEMS

(The data are from Ref. 132)

Basis: Annual operation of one 1000 MWe Power Plant and Sup-
porting Fuel Cycle (6.57 billion kWh) 1980 dollars.

		<u>Coal</u>	<u>Oil</u>	<u>Nuclear</u>
Conventional Costs	(\$10 ⁶ /yr)			
Capital Plant		51	47	77
Fuel Cycle		64	186	39
O&M		<u>5.4</u>	<u>4.0</u>	<u>5.2</u>
Rounded Totals		120	231	121
Abatement Costs	(\$10 ⁶ /yr)			
Cooling Towers		3.6	5.9	2.4
Sulfur/SO ₂ Removal		25.9	4.9	NA
Strip-mined Land Reclamation		0.1	NA	S
Near-Zero Radwaste		<u>NA</u>	<u>NA</u>	<u>1.2-1.8</u>
Rounded Totals		30	11	3-4
Conventional and Abatement	(\$10 ⁶ /yr)	150	242	125
Abatement Component	(%)	20	5	3
Safety	(\$10 ⁶ /yr)			
Occupational ^a		0.46	0.086	0.05
Public ^b		<u>0.18</u>	<u>U</u>	<u>0.003</u>
Subtotal		0.64	> 0.086	0.053
Health	(\$10 ⁶ /yr)			
Occupational		0.03 ^c	U	0.024 ^d
Public		<u>U</u>	<u>U</u>	<u>0.01^e</u>
Subtotal		> 0.03	U	0.034
Total Human Health & Accident Costs	(\$10 ⁶ /yr)	> 0.67	> 0.086	0.087

TABLE VIII-2 (cont'd)

		<u>Coal</u>	<u>Oil</u>	<u>Nuclear</u>
Environmental Effects	(\$10 ⁶ /yr)			
Water Base		0.4	0.4	0.6
Air Base		0.8	0.6	S
Land Base		0.2	S	S
Subtotal		1.4	1.0	0.6
Total Human & Env. Effects	(\$10 ⁶ /yr)	2.1	1.1	0.7
Percent of Conv.	(%)	3	1	0.9

Key: U = unevaluated; NA = not applicable; S = small

Footnotes: (a) Conventional injuries in routine industrial accidents, including fatal and non-fatal injuries; 1 death = 6,000 MDL = \$300,000.

(b) Conventional injuries in accidents in transportation of fuels; 1 death = 6,000 MDL = \$300,000.

(c) Coal workers' pneumoconiosis (CWP)

(d) Radiological health effects, including lung cancers among uranium miners.

(e) Radiological health effects from routine emissions.

IX. SCENARIOS

As noted in preceding sections, plans for construction of electric generating plants of all types have been severely curtailed since mid-1974. These postponements and cancellations have been primarily the consequence of problems which utilities have been encountering in raising capital funds; although to some degree the reduced construction schedules can be attributed to downward revisions in demand-growth forecasts.⁽¹³⁴⁾ Whether or not the predictions for greatly reduced demand-growth rates will prove valid over the next several decades is a question of great importance, because of the long lead time to emplace new generating units. Shortages and increased costs of natural gas and No. 2 fuel oil for space heating, and increased electrification of transportation could reverse the trend of the past 1-1/2 years and result in a return to a very rapid growth in demand for electricity.

In devising scenarios for the future role of nuclear power in the Northeast, it is necessary to project two factors -- the total capacity added each year, and the fraction that is nuclear. Large uncertainties exist in both projections. Some realistic upper and lower limits can be placed on the projections, e.g., constraints based on lead times, ability of nuclear component supply industry to expand, projects already underway, etc.

From such considerations we have prepared three scenarios which we believe will bracket the realistic range of possibilities:

- A) The "Base Case Nuclear Scenario" reflects present planning of the utilities;
- B) the "Nuclear Moratorium Scenario" describes the situation imposed by a suspension in all new nuclear construction beginning in 1977, and
- C) the "Maximum Nuclear Growth Scenario" defines a plausible upper limit.

The details of these scenarios are described below and the projections are tabulated. It will be noted that the three cases are essentially identical until after 1985, since for the next decade the die is already cast as far as nuclear capacity is concerned.

The annual nuclear net electric energy production assumes an average 57.5% plant capacity factor for 1975, increasing by 0.5% per year to 65% in 1990, and remaining at 65% thereafter.

A. BASE CASE NUCLEAR SCENARIO

The "base case" scenario corresponds to the "present" plans of the utilities, taking into account announced revised planning up to about August 31, 1975. For the most part the projected capacity through 1985 is based on plants whose location, size and targeted completion date have been announced. The details of individual plants can be found in Tables II-2 and II-3 (pages 15 and 20).

Beyond 1985, the scenario adopts the power pool projections as far as they go and then extrapolates to 2000 using the total capacity given in Ref. 2 and assuming the same mix of nuclear as for the preceding decade. In arriving at these projections, the three sub-regions have been treated separately and then combined to yield the values for the whole Northeast. Thus, the "Base Case Nuclear Scenario" postulates that:

- 1) Present plans of each power pool (or utility) will materialize.
- 2) After 1985 capacity additions will be made at the rate given in Ref. 2.
- 3) The nuclear share of new capacity will be: 76.4% in NEPOOL after 1985, 86.4% in NYPP after 1990, and 54.4% in Mid-Atlantic after 1985.

- 4) The annual total net electric energy production assumes a 57.5% average plant capacity factor for 1975, increasing by 0.5% per year, reaching 65% in 1990, and remaining at 65% thereafter. It is further assumed that on the average new additions produce no electricity during year in which commercial operation is achieved.

Projected nuclear additions, total installed nuclear capacity and annual nuclear electric energy production are given in Tables IX-1a, b, c and d for each sub-region and for the Northeast. The data are plotted in Figure IX-1.

B. NUCLEAR MORATORIUM SCENARIO

Various citizens' campaigns are underway to impose nuclear moratoria. Generally, these would impose a suspension of nuclear construction for a period of approximately five years. Other factors, e.g., regulatory constraints, fuel contracting difficulties, etc. might prove to have a similar effect.

We have assumed the following conditions:

- 1) Duration of Moratorium: 5 years
- 2) Starting Date: January 1, 1977
- 3) Nature of Moratorium: No new Construction Permits issued between January 1, 1977 and December 31, 1981.

It is the opinion of the authors that the nuclear manufacturing and construction industries could not survive a 5-year suspension in business, and that these capabilities could not recover before the end of the century.

Therefore, we assume:

- 4) That no new nuclear units would be commissioned by the year 2000.

Projected nuclear additions, total installed nuclear capacity, and annual nuclear electric energy production are given in Tables IX-2a, b, c and d for each sub-region and the Northeast as a whole. The data are plotted in Figure IX-2.

C. MAXIMUM NUCLEAR GROWTH SCENARIO

It is conceivable that some factors in the energy situation might stimulate nuclear growth, e.g., another boycott on imported oil, shortages of domestic natural gas, a lag in increased coal production, etc. In such an event, the growth of nuclear power would be constrained by the ability of the nuclear component supply industries to expand capacities to meet the increased orders. Since the industries involved require large specialized manufacturing facilities and highly skilled labor, the response time to accommodate expanded orders will be long. The components and special skills include pressure vessel fabrication, mining and milling of ore, steel production, U²³⁵ enrichment, pipe production, training of welders and pipe fitters, etc. We estimate that, given the economic motivation to increase manufacturing capacity, the nuclear industry would require a minimum of 15 years to double its capacity over present planning. This factor would set an upper limit on growth; however, as will be seen, our postulated maximum growth scenario does not approach this constraint.

It is likely that lead times could be reduced from present schedules, and thus advance the commissioning dates for plants presently in the pipeline. Consideration of critical paths during the construction phase indicates that the acceleration in schedule for plants in the pre-construction phase or already under construction would be slight; however, units which are "planned" for after ~ 1990 could be advanced by several years.

In devising the maximum growth scenario, we have not considered the problem of capital construction financing. We tacitly assume that, given sufficient motivation to step up the pace of electrification, the means for raising the construction funds would be found.

Based on these considerations, we have postulated the following maximum growth scenario:

- 1) That beginning in 1982, the total electric energy generated in each sub-region will grow at 1.25 times the rates projected by each power pool. These rates are summarized in the following table:

	<u>GROWTH IN ANNUAL ELECTRIC ENERGY GENERATION</u>		
	<u>New England</u>	<u>New York</u>	<u>Mid-Atlantic</u>
	<u>(percent per annum)</u>		
Base Case	6.08	4.39	5.02
Maximum Growth (1.25 x Base Case)	7.60	5.49	6.28

- 2) The nuclear component of the difference between the Base Case and the Maximum Growth Scenario is 75% for New England, 85% for New York, and 55% for Mid-Atlantic.

Projected nuclear additions, total installed capacity and annual nuclear electric energy production are given in Tables IX-a, b, c and d for each sub-region and the Northeast. The data are plotted in Figure IX-3.

D. COMPARISON OF THE THREE SCENARIOS

For convenience, the three scenarios for each sub-region are plotted on the same graph in Figures IX-4 through 7. The most impressive feature is the long delay between the start of a scenario and the time at which its effects become markedly apparent. Between 1990 and 2000 the three cases diverge widely, although the Maximum Growth Case is only 40% greater than the Base Case by the year 2000.

F. ENERGY EQUIVALENTS OF OTHER FUELS

In the generation of electricity, nuclear energy replaces either residual fuel oil or bituminous coal. An important consideration for the energy

balance of the region is how much oil or coal would be replaced by the nuclear generation under each scenario.

At the present time modern fossil-fueled steam electric generating plants operate at about the highest efficiency* possible within the constraints of existing materials for fabricating boiler tubes. Most modern large fossil-fueled steam plants have the following efficiencies: (135)

	<u>Oil-fired</u>	<u>Coal-fired</u>
Net efficiency	0.366	0.386
Heat rate	9319	8838

The net efficiency is the fraction of the energy content of the fuel which appears as electric energy at the plant output terminals. The heat rate is the number of Btu's required to make 1 kwh of electricity. For convenience, the following table lists various conversion factors and units:

1 kwh (kilowatt hour) = 3412.8 Btu (British Thermal Unit)

1 MWh (megawatt hour) = 1000 kwh = 3.4128×10^6 Btu

1 bbl (42 gallons) residual oil = 6.29×10^6 Btu

1 ton bituminous coal = 26.2×10^6 Btu
(this value is characteristic of Appalachian coal;
Western coal has a lower heating value)

* Although a large fraction of the "heat content" of the fuel is lost and must be discharged to the environment as waste heat, the steam cycle is actually quite efficient from the viewpoint of extracting "available work". The "available work" is the useful mechanical energy that an ideally perfect heat engine could extract when operating between the flame temperature of the fuel and the outdoor air or water temperature. Only about 1-1/2% of the "available work" is lost with the rejected waste heat.

By way of example, calculate how many barrels of oil are required to deliver one million (10^6) MWh of electric energy to the transmission line:

$$\begin{aligned}\text{No. of bbls per million MWh} &= \frac{\text{Btu per } 10^6 \text{ MWh}}{\text{net efficiency} \times \text{Btu's per bbl}} \\ &= \frac{3.4128 \times 10^{12}}{0.366 \times 6.29 \times 10^6} \\ &= 1.482 \times 10^6 \text{ bbls}\end{aligned}$$

Thus, 1,482,000 bbls of residual oil are needed to send out one million MWh of electric energy. A similar calculation for coal yields: 337,460 tons of bituminous coal must be burned to send out one million MWh of electric energy.

The oil and coal equivalents of the nuclear electric energy are given in: Tables IX-4a .. d, Base Case Scenario

IX-5a .. d, Nuclear Moratorium Scenario

IX-6a .. d, Maximum Nuclear Growth Scenario

F. ECONOMIC CONSEQUENCES OF THE NUCLEAR MORATORIUM SCENARIO

During the first half of 1975, the weighted average production costs of electricity in the Northeast were (see page 26):

Nuclear:	12.69	mills/kwh	
Oil:	19.31	"	"
Coal:	19.78	"	"

The datum for oil is that listed in the footnote of page 26, which is the experience of a large modern base-loaded oil-fired plant operated in a system

with no competing nuclear plants (and hence having a capacity factor limited by forced outages and system demand), located on the sea coast with off-shore unloading facilities. This datum appears to be more representative than the average value 34.20 for oil-fired units derived from Ref. 12, which included peaking units.

In general, the electricity generated by nuclear units will substitute for that which would otherwise be generated by oil or coal. The 1975 production cost differential (oil or coal minus nuclear) is approximately 6.75 mills/kwh.

We shall assume that all costs escalate at a rate of 8% per annum, and hence that the differential escalates at the same rate. Thus, for example, in 1985 the differential will have escalated to:

$$6.75 (1.08)^{10} = 14.57$$

This result is consistent with, although slightly smaller than, the differentials predicted in "Study '74" (page 41), "Study '75" (page 40), and in the projections of the Philadelphia Electric Co. (page 42).

The incremental energy difference between the Base Case and the Nuclear Moratorium Scenarios is combined with the above differential to obtain the annual incremental cost of the moratorium scenario. The results are given in Table IX-7 and Figure IX-8.

Under the scenario assumptions, the effects of the moratorium first appear in 1983. The incremental costs increase rapidly thereafter, reaching > \$4 billion/year by 1990 and ~ \$30 billion/year by 2000. Cumulative incremental costs through the year 2000 are in the range of \$160 billion. If reckoned at 10%, the 1975 present value would be \$23 billion.

The long delay in the consequences and the potential magnitude of the economic impacts underscore the importance of thorough evaluation of all

factors before an irreversible moratorium decision be made. A more rigorous assessment than done here should include impacts on employment and industry, differences in regional air pollution burdens, etc.

It should be noted that the cost differential used here favoring nuclear over coal is consistent with results of L.F.C. Reichle who estimates⁽¹³⁶⁾ that by 1985-95, on a 10-year levelized basis, a nuclear station will generate electricity at a cost of 35 mills/kwh, whereas an equivalent eastern coal-fired unit will generate at 59 mills/kwh. The method used previously would predict for 1990 a differential of

$$6.75(1.08)^{15} = 21.4 \text{ mills/kwh}$$

which compares favorably with Reichle's differential of 24 mills/kwh.

A recent paper by L. J. Perl⁽¹³⁷⁾ also suggested that there would be a cost advantage for nuclear compared to coal on the basis of reasonable differentials for fuel and capital costs. A spot check by Electrical World⁽¹³⁸⁾ of U.S. utilities indicates that New England and California utilities see significant advantages for nuclear over coal; however, for plants near coal fields, coal competes favorably.

TABLE IX-1a: BASE CASE NUCLEAR SCENARIO (NEW ENGLAND)

Projections through 1985 are based on mid-1975 plans of NEPLAN.⁽⁶⁾ Extrapolations beyond 1985 are explained in text. The installed nuclear capability is for year-end and is the "winter capability". It is assumed that new units produce no electric energy in year of commissioning.

Year	Nuclear Additions (Nominal) (MWe)	Installed Nuclear Capability (MWe)	Assumed Plant Capacity Factor ^a (Average)	Annual Energy Production (Million MWh)
POWER POOL PLANS ^b				
1974	---	3,317 ^c	0.58 ^c	16.87 ^c
1975	830	4,223	0.575	16.7
1976	---	4,229	0.58	20.5
1977	---	4,249	0.585	21.8
1978	---	4,249	0.59	22.0
1979	1,156	5,399	0.595	22.2
1980	1,200	6,549	0.60	28.4
1981	---	6,549	0.605	34.7
1982	2,380	8,879	0.61	35.0
1983	2,300	11,179	0.615	47.9
1984	---	11,179	0.62	60.8
1985	1,200	12,329	0.625	61.2

SCENARIO EXTRAPOLATION

1990	(8,600) ^d	20,900	0.65	109
1995	(10,200) ^d	31,100	0.65	166
2000	(14,600) ^d	45,700	0.65	244

^a The average plant capacity factor is a scenario assumption.

^b Ref. 6

^c Actual

^d Installed during a 5 year period ending with the indicated year.

TABLE IX-1b: BASE CASE NUCLEAR SCENARIO (NEW YORK)

Projections through 1985 are based on mid-1975 plans of N. Y. Power Pool. Extrapolations beyond 1990 are explained in the text. The installed nuclear capability is for the year-end and is the "summer capability".

Year	Nuclear Additions (Nominal) (MWe)	Installed Nuclear Capability (MWe)	Assumed Plant Capacity Factor ^a (Average)	Annual Energy Production (Million MWh)
1974	---	2,218 ^c	.58 ^c	11.3 ^c
1975	821	2,774	.575	11.2
1976	873	3,647	.58	14.1
1977	---	3,909	.585	18.7
1978	820	4,821	.59	20.2
1979	---	4,821	.595	25.1
1980	---	5,049	.60	25.4
1981	1,100	6,149	.605	26.8
1982	2,300	8,449	.61	32.9
1983	1,200	9,649	.615	45.5
1984	2,350	11,999	.62	52.4
1985	---	11,999	.625	65.7
1986	1,200	13,199	.63	66.3
1987	2,600	15,799	.635	73.5
1988	1,300	17,099	.64	88.6
1989	3,900	20,999	.645	96.7
1990	2,600	23,599	.65	117.4

SCENARIO EXTRAPOLATION

1995	(10,000) ^d	33,600	.65	191.4
2000	(12,150) ^d	45,750	.65	261.0

^a The average plant capacity factor is a scenario assumption.

^b The additions are for a 5-year period.

^c Actual

^d Installed during a 5 year period ending with the indicated year.

TABLE IX-1c: BASE CASE NUCLEAR SCENARIO (MID-ATLANTIC)

Projections through 1994 correspond to MAAC⁽⁸⁾ plans with account taken of other utilities in Pennsylvania which are not a part of MAAC. Extrapolation to 1995 and 2000 are explained in text. The installed nuclear capability is for year-end "maximum dependable capacity."⁽⁹⁾ It is assumed that new units produce no electric energy in year of commissioning.

Year	Nuclear Additions (Nominal) (MWe)	Installed Nuclear Capability (MWe)	Assumed Plant Capacity Factor ^a (Average)	Annual Energy Production (Million MWh)
POWER POOL PLANS ^b				
1974	2,878 ^c	3,498 ^c	---	10.671 ^c
1975	1,697	5,195	0.575	17.6
1976	1,090	6,285	0.58	26.4
1977	845	7,130	0.585	32.2
1978	905	8,035	0.59	36.9
1979	1,115	9,150	0.595	41.9
1980	1,050	10,200	0.60	48.1
1981	2,687	12,887	0.605	54.1
1982	4,252	17,139	0.61	68.9
1983	---	17,139	0.615	92.4
1984	2,997	20,136	0.62	93.1
1985	3,428	23,564	0.625	110.3
1986	1,160	24,724	0.63	130.1
1987	3,428	28,152	0.635	137.6
1988	---	28,152	0.64	157.9
1989	---	28,152	0.645	159.2
1990	2,250	30,402	0.65	160.4
1991	2,300	32,702	0.65	173.2
1992	2,650	35,352	0.65	186.3
1993	1,900	37,252	0.65	201.4
1994	2,700	39,952	0.65	212.3

SCENARIO EXTRAPOLATION

1995	3,970	43,922	.65	228.0
2000	(17,260) ^d	61,182	.65	329.0

^a The average plant capacity factor is a scenario assumption.

^b Ref. 8 and private communication with MAAC non-member Penn. utilities.

^c Actual

^d Installed during a 5 year period ending with the indicated year.

TABLE IX-1d: BASE CASE SCENARIO (NORTHEAST)

These data are obtained by summation
of corresponding entries in Tables IX-1a, b and c.

Year	Nuclear Additions (Nominal) (MWe)	Installed Nuclear Capability (MWe)	Assumed Plant Capacity Factor ^a (Average)	Annual Energy Production (Million MWh)
POWER POOL PLANS ^b				
1974	2,878 ^c	9,033 ^c	---	38.84 ^c
1975	3,347 ^c	12,197	.575	45.5
1976	1,963	14,162	.58	61.0
1977	845	15,288	.585	72.7
1978	1,725	17,105	.59	79.1
1979	2,271	19,370	.595	89.2
1980	2,250	21,798	.60	101.9
1981	3,787	25,585	.605	115.6
1982	8,932	34,467	.61	136.8
1983	3,600	37,967	.615	185.8
1984	5,347	43,314	.62	206.0
1985	4,628	47,892	.625	237.0

SCENARIO EXTRAPOLATION ^b				
1990	(27,038) ^d	74,901	.65	386
1995	(33,720) ^d	108,622	.65	585
2000	(44,010) ^d	152,632	.65	834

^a The average plant capacity factor is a scenario assumption.

^b NEPLAN plans extend to 1985, NYPP to 1990, and MAAC to 1994.

^c Actual

^d Installed during a 5 year period ending with the indicated year.

TABLE IX-2a: NUCLEAR MORATORIUM SCENARIO (NEW ENGLAND)

This scenario assumes that no new nuclear plants will be built by the year 2000, except those having NRC Construction Permits issued on or before December 31, 1976. Because of long lead times in plant construction, departures from Base Case do not appear until 1983.

Year	Nuclear Additions (Nominal) (MWe)	Installed Nuclear Capability (MWe)	Assumed Plant Capacity Factor ^a (Average)	Annual Energy Production (Million MWh)
1974				
1975				
1976				
1977				
1978		(SAME AS BASE CASE UNTIL 1983)		
1979				
1980				
1981				
1982				

1983	---	8,879	0.615	47.9
1984	---	8,879	0.62	48.3
1985	---	8,879	0.625	48.6
1990	---	8,879	0.65	50.6
1995	---	8,879	0.65	50.6
2000	---	8,879	0.65	50.6

^a The average plant capacity factor is a scenario assumption

TABLE IX-2b: NUCLEAR MORATORIUM SCENARIO (NEW YORK)

This scenario assumes that no new nuclear plants will be built by the year 2000, except those having NRC Construction Permits issued on or before December 31, 1976. Because of long lead times in plant construction, departures from Base Case do not appear until 1982.

Year	Nuclear Additions (Nominal) (MWe)	Installed Nuclear Capability (MWe)	Assumed Plant Capacity Factor ^a (Average)	Annual Energy Production (Million MWh)
1974				
1975				
1976				
1977		(SAME AS BASE CASE UNTIL 1982)		
1978				
1979				
1980				
1981				

1982	---	6,149	.61	32.9
1983	---	6,149	.615	33.1
1984	---	6,149	.62	33.4
1985	---	6,149	.625	33.7
1990	---	6,149	.65	35.0
1995	---	6,149	.65	35.0
2000	---	6,149	.65	35.0

^a The average plant capacity factor is a scenario assumption.

TABLE IX-2c: NUCLEAR MORATORIUM SCENARIO (MID-ATLANTIC)

This scenario assumes that no new nuclear plants will be built by the year 2000, except those having NRC Construction Permits issued on or before December 31, 1976. Because of long lead times in plant construction, departures from Base Case do not appear until 1984.

Year	Nuclear Additions (Nominal) (MWe)	Installed Nuclear Capability (MWe)	Assumed Plant Capacity Factor ^a (Average)	Annual Energy Production (Million MWh)
1974				
1975				
1976				
1977				
1978		(SAME AS BASE CASE UNTIL 1984)		
1979				
1980				
1981				
1982				
1983				
1984	1,837	18,976	0.62	93.1
1985	---	18,976	0.625	104.0
1990	---	18,976	0.65	108.0
1995	---	18,976	0.65	108.0
2000	---	18,976	0.65	108.0

^a The average plant capacity factor is a scenario assumption.

TABLE IX-2d: NUCLEAR MORATORIUM SCENARIO (NORTHEAST)

This scenario assumes that no new nuclear plants will be built by the year 2000, except those having NRC Construction Permits issued on or before December 31, 1976. Because of long lead times in plant construction, departures from Base Case do not appear until 1982.

Year	Nuclear Additions (Nominal) (MWe)	Installed Nuclear Capability (MWe)	Assumed Plant Capacity Factor ^a (Average)	Annual Energy Production (Million MWh)
1974				
1975				
1976				
1977		(SAME AS BASE CASE UNTIL 1982)		
1978				
1979				
1980				
1981				

1982	6,632	32,167	0.61	137
1983	---	32,167	0.615	173
1984	1,837	34,004	0.62	175
1985	---	34,004	0.625	186
1990	---	34,004	0.65	194
1995	---	34,004	0.65	194
2000	---	34,004	0.65	194

^a The average plant capacity factor is a scenario assumption.

TABLE IX-3a: MAXIMUM NUCLEAR GROWTH SCENARIO (NEW ENGLAND)

Projections through 1982 are identical to the Base Case. Beyond 1982 the total electric energy production is assumed to grow at the rate of 7.6% per year, and the nuclear production is assumed to be 75% of the incremental growth over the Base Case.

Year	Nuclear Additions (Nominal) (MWe)	Installed Nuclear Capability (MWe)	Assumed Plant Capacity Factor ^a (Average)	Annual Energy Production (Million MWh)
1974				
1975				
1976				
1977				
1978	(SAME AS BASE CASE UNTIL 1983)			
1979				
1980				
1981				
1982				

1983	2,537	11,416	0.615	47.9
1984	1,268	12,684	0.62	62.0
1985	1,269	13,953	0.625	69.5
1990	(11,378) ^b	25,331	0.65	131
1995	(16,408) ^b	41,739	0.65	219
2000	(23,670) ^b	65,409	0.65	346

^a The average plant capacity factor is a scenario assumption.

^b Total additions for a 5 year period ending with year indicated.

TABLE IX-3b: MAXIMUM NUCLEAR GROWTH SCENARIO (NEW YORK)

Projections through 1982 are identical to the Base Case. Beyond 1982 the total electric energy production is assumed to grow at the rate of 5.49% per year, and the nuclear production is assumed to be 85% of the incremental growth over the Base Case.

Year	Nuclear Additions (Nominal) (MWe)	Installed Nuclear Capability (MWe)	Assumed Plant Capacity Factor ^a (Average)	Annual Energy Production (Million MWh)
1974				
1975				
1976				
1977				
1978	(SAME AS BASE CASE UNTIL 1983)			
1979				
1980				
1981				
1982				

1983	2,016	10,465	0.615	45.5
1984	3,165	13,630	0.62	56.4
1985	816	14,446	0.625	74.7
1990	(12,685) ^b	27,131	0.65	140
1995	(17,041) ^b	44,172	0.65	232
2000	(22,890) ^b	67,062	0.65	356

^a The average plant capacity factor is a scenario assumption.

^b Total additions for a 5 year period ending with year indicated.

TABLE IX-3c: MAXIMUM NUCLEAR GROWTH SCENARIO (MID-ATLANTIC)

Projections through 1982 are identical to the Base Case. Beyond 1982 the total electric energy production is assumed to grow at the rate of 6.28% per year, and the nuclear production is assumed to be 55% of the incremental growth over the Base Case.

Year	Nuclear Additions (Nominal) (MWe)	Installed Nuclear Capability (MWe)	Assumed Plant Capacity Factor ^a (Average)	Annual Energy Production (Million MWh)
1974				
1975				
1976				
1977				
1978	(SAME AS BASE CASE UNTIL 1983)			
1979				
1980				
1981				
1982				

1983	200	17,339	0.615	92.4
1984	3,197	20,536	0.62	94.2
1985	3,626	24,162	0.625	112.5
1990	(14,971) ^b	39,133	0.65	206
1995	(20,300) ^b	59,433	0.65	316
2000	(27,527) ^b	86,960	0.65	464

^a The average plant capacity factor is a scenario assumption.

^b Total additions for a 5 year period ending with year indicated.

TABLE IX-3d: MAXIMUM NUCLEAR GROWTH SCENARIO (NORTHEAST)

Projections through 1982 are identical to the Base Case. Beyond 1982 the three sub-regions are assumed to grow as indicated in Tables IX-3a, b and c. These data are the summation of the other three tables.

Year	Nuclear Additions (Nominal) (MWe)	Installed Nuclear Capability (MWe)	Assumed Plant Capacity Factor ^a (Average)	Annual Energy Production (Million MWh)
1974				
1975				
1976				
1977				
1978		(SAME AS BASE CASE UNTIL 1983)		
1979				
1980				
1981				
1982				

1983	4,753	39,220	0.615	185.8
1984	7,630	46,850	0.62	212.6
1985	5,711	52,561	0.625	256.7
1990	(39,034) ^b	91,595	0.65	477
1995	(53,749) ^b	145,344	0.65	767
2000	(74,087) ^b	219,431	0.65	1,166

^a The average plant capacity factor is a scenario assumption.

^b Total additions for a 5 year period ending with year indicated.

TABLE IX-4a: BASE CASE SCENARIO (NEW ENGLAND)

Annual Equivalents of Nuclear Electric Energy Expressed in
Btu, Barrels of Residual Oil and Tons of Bituminous Coal.

Year	Nuclear Electric Energy Production Million (10 ⁶) MWh	Electric Energy in Thermal Units Trillion (10 ¹²) Btu	Residual Fuel Oil Replacement Million (10 ⁶) bbl ^a	Bituminous Coal Replacement Million (10 ⁶) tons ^b
1975	16.7	57.0	24.7	5.64
1980	28.4	96.9	42.1	9.58
1985	61.2	208.9	90.7	20.65
1990	109	372	162	36.8
1995	166	567	246	56.0
2000	244	833	362	82.3

^a The efficiency for base-loaded oil-fired plants is taken to be 0.366, and it is assumed there are 6.29×10^6 Btu/42 gal barrels of residual fuel oil.

^b The efficiency for base-loaded coal-fired plants is taken to be 0.386, and it is assumed there are 26.2×10^6 Btu/ton.

TABLE IX-4b: BASE CASE SCENARIO (NEW YORK)
Annual Equivalents of Nuclear Electric Energy Expressed in
Btu, Barrels of Residual Oil and Tons of Bituminous Coal.

Year	Nuclear Electric Energy Production Million (10 ⁶) MWh	Electric Energy in Thermal Units Trillion (10 ¹²) Btu	Residual Fuel Oil Replacement Million (10 ⁶) bbl ^a	Bituminous Coal Replacement Million (10 ⁶) tons ^b
1975	11.2	38.2	16.6	3.78
1980	25.4	86.7	37.6	8.57
1985	65.7	224.2	97.4	22.17
1990	117.0	399.0	173.0	39.5
1995	191.0	652.0	283.0	64.5
2000	261.0	891.0	387.0	88.1

^a The efficiency for base-loaded oil-fired plants is taken to be 0.366, and it is assumed there are 6.29×10^6 Btu/42 gal barrel.

^b The efficiency for base-loaded oil-fired plants is taken to be 0.386, and it is assumed there are 26.2×10^6 Btu/ton.

TABLE IX-4c: BASE CASE SCENARIO (MID-ATLANTIC)

Annual Equivalents of Nuclear Electric Energy Expressed in
Btu, Barrels of Residual Oil and Tons of Bituminous Coal.

Year	Nuclear Electric Energy Production Million (10 ⁶) MWh	Electric Energy in Thermal Units Trillion (10 ¹²) Btu	Residual Fuel Oil Replacement Million (10 ⁶) bbl ^a	Bituminous Coal Replacement Million (10 ⁶) tons ^b
1975	17.6	60.1	26.1	5.94
1980	48.1	164.2	71.3	16.23
1985	110.3	376.4	163.5	37.22
1990	160	546	237	54.0
1995	228	778	338	76.9
2000	329	1123	488	111.0

^a The efficiency for base-loaded oil-fired plants is taken to be 0.366, and it is assumed there are 6.29×10^6 Btu/42 gal barrels of residual fuel oil.

^b The efficiency for base-loaded coal-fired plants is taken to be 0.386, and it is assumed there are 26.2×10^6 Btu/ton.

TABLE IX-4d: BASE CASE SCENARIO (NORTHEAST)
Annual Equivalents of Nuclear Electric Energy Expressed in
Btu, Barrels of Residual Oil and Tons of Bituminous Coal.

Year	Nuclear Electric Energy Production Million (10 ⁶) MWh	Electric Energy in Thermal Units Trillion (10 ¹²) Btu	Residual Fuel Oil Replacement Million (10 ⁶) bbl ^a	Bituminous Coal Replacement Million (10 ⁶) tons ^b
1975	45.5	155.3	67.4	15.35
1980	101.9	347.8	151.0	34.39
1985	237.0	808.8	351.2	79.98
1990	386	1317	572	130.2
1995	585	1996	867	197.4
2000	834	2846	1236	281.4

^a The efficiency for base-loaded oil-fired plants is taken to be 0.366, and it is assumed there are 6.29×10^6 Btu/42 gal barrels of residual fuel oil.

^b The efficiency for base-loaded coal-fired plants is taken to be 0.386, and it is assumed there are 26.2×10^6 Btu/ton.

TABLE IX-5a: NUCLEAR MORATORIUM SCENARIO (NEW ENGLAND)

Annual Equivalent of Nuclear Electric Energy Expressed in
Btu, Barrels of Residual Oil and Tons of Bituminous Coal.

Year	Nuclear Electric Energy Production Million (10 ⁶) MWh	Electric Energy in Thermal Units Trillion (10 ¹²) Btu	Residual Fuel Oil Replacement Million (10 ⁶) bbl ^a	Bituminous Coal Replacement Million (10 ⁶) tons ^b
1975	16.7	57.0	24.7	5.64
1980	28.4	96.9	42.1	9.58
1985	48.6	165.9	72.0	16.40
1990	51	173	75	17.1
1995	51	173	75	17.1
2000	51	173	75	17.1

^a The efficiency for base-loaded oil-fired plants is taken to be 0.366, and it is assumed there are 6.29×10^6 Btu/42 gal barrels of residual fuel oil.

^b The efficiency for base-loaded coal-fired plants is taken to be 0.386, and it is assumed there are 26.2×10^6 Btu/ton.

TABLE IX-5b: NUCLEAR MORATORIUM SCENARIO (NEW YORK)

Annual Equivalents of Nuclear Electric Energy Expressed in
Btu, Barrels of Residual Oil and Tons of Bituminous Coal.

Year	Nuclear Electric Energy Production Million (10 ⁶) MWh	Electric Energy in Thermal Units Trillion (10 ¹²) Btu	Residual Fuel Oil Replacement Million (10 ⁶) bbl ^a	Bituminous Coal Replacement Million (10 ⁶) tons ^b
1975	11.2	38.2	16.6	3.78
1980	25.4	86.7	37.6	8.57
1985	33.7	115.0	49.9	11.37
1990	35	119	52	11.8
1995	35	119	52	11.8
2000	35	119	52	11.8

^a The efficiency for base-loaded oil-fired plants is taken to be 0.366, and it is assumed there are 6.29×10^5 Btu/42 gal barrels of residual fuel oil.

^b The efficiency for base-loaded coal-fired plants is taken to be 0.386, and it is assumed there are 26.2×10^5 Btu/ton.

TABLE IX-5c: NUCLEAR MORATORIUM SCENARIO (MID-ATLANTIC)
Annual Equivalents of Nuclear Electric Energy Expressed in
Btu, Barrels of Residual Oil and Tons of Bituminous Coal.

Year	Nuclear Electric Energy Production Million (10^6) MWh	Electric Energy in Thermal Units Trillion (10^{12}) Btu	Residual Fuel Oil Replacement Million (10^6) bbl ^a	Bituminous Coal Replacement Million (10^6) tons ^b
1975	17.6	60.1	26.1	5.94
1980	48.1	164.2	71.3	16.23
1985	104.0	354.9	154.1	35.10
1990	108	369	160	36.4
1995	108	369	160	36.4
2000	108	369	160	36.4

^a The efficiency for base-loaded oil-fired plants is taken to be 0.366, and it is assumed there are 6.29×10^6 Btu/42 gal barrels of residual fuel oil.

^b The efficiency for base-loaded coal-fired plants is taken to be 0.386, and it is assumed there are 26.2×10^6 Btu/ton.

TABLE IX-5d: NUCLEAR MORATORIUM SCENARIO (NORTHEAST)
Annual Equivalents of Nuclear Electric Energy Expressed in
Btu, Barrels of Residual Oil and Tons of Bituminous Coal.

Year	Nuclear Electric Energy Production Million (10 ⁶) MWh	Electric Energy in Thermal Units Trillion (10 ¹²) Btu	Residual Fuel Oil Replacement Million (10 ⁶) bbl ^a	Bituminous Coal Replacement Million (10 ⁶) tons ^b
1975	45.5	155.3	67.4	15.35
1980	101.9	347.8	151.0	34.39
1985	186.0	635.0	275.7	62.77
1990	194	662	288	65.5
1995	194	662	288	65.5
2000	194	662	288	65.5

^a The efficiency for base-loaded oil-fired plants is taken to be 0.366, and it is assumed there are 6.29×10^6 Btu/52 gal barrels of residual fuel oil.

^b The efficiency for base-loaded coal-fired plants is taken to be 0.386, and it is assumed there are 26.2×10^6 Btu/ton.

TABLE IX-6a: MAXIMUM NUCLEAR GROWTH SCENARIO (NEW ENGLAND)

Annual Equivalents of Nuclear Electric Energy Expressed in
Btu, Barrels of Residual Oil and Tons of Bituminous Coal.

Year	Nuclear Electric Energy Production Million (10^6) MWh	Electric Energy in Thermal Units Trillion (10^{12}) Btu	Residual Fuel Oil Replacement Million (10^6) bbl ^a	Bituminous Coal Replacement Million (10^6) tons ^b
1975	16.7	57.0	24.7	5.64
1980	28.4	96.9	42.1	9.58
1985	69.5	237.2	103.0	23.45
1990	131	447	194	44.2
1995	219	747	325	73.9
2000	346	1181	513	116.8

^a The efficiency for base-loaded oil-fired plants is taken to be 0.366, and it is assumed there are 6.29×10^6 Btu/42 gal barrels of residual fuel oil.

^b The efficiency for base-loaded coal-fired plants is taken to be 0.386, and it is assumed there are 26.2×10^6 Btu/ton.

TABLE IX-6b: MAXIMUM NUCLEAR GROWTH SCENARIO (NEW YORK)
Annual Equivalents of Nuclear Electric Energy Expressed in
Btu, Barrels of Residual Oil and Tons of Bituminous Coal.

Year	Nuclear Electric Energy Production Million (10 ⁶) MWh	Electric Energy in Thermal Units Trillion (10 ¹²) Btu	Residual Fuel Oil Replacement Million (10 ⁶) bbl ^a	Bituminous Coal Replacement Million (10 ⁶) tons ^b
1975	11.2	38.2	16.6	3.78
1980	25.4	86.7	37.6	8.57
1985	74.7	254.9	110.7	25.21
1990	140	478	207	47.2
1995	232	792	344	78.3
2000	356	1215	528	120.1

^a The efficiency for base-loaded oil-fired plants is taken to be 0.366, and it is assumed there are 6.29×10^6 Btu/42 gal barrels of residual fuel oil.

^b The efficiency for base-loaded coal-fired plants is taken to be 0.386, and it is assumed there are 26.2×10^6 Btu/ton.

TABLE IX-6c: MAXIMUM NUCLEAR GROWTH SCENARIO (MID-ATLANTIC)

Annual Equivalents of Nuclear Electric Energy Expressed in
Btu, Barrels of Residual Oil and Tons of Bituminous Coal.

Year	Nuclear Electric Energy Production Million (10 ⁶) MWh	Electric Energy in Thermal Units Trillion (10 ¹²) Btu	Residual Fuel Oil Replacement Million (10 ⁶) bbl ^a	Bituminous Coal Replacement Million (10 ⁶) tons ^b
1975	17.6	60.1	26.1	5.94
1980	48.1	164.2	71.3	16.23
1985	112.5	383.9	166.7	37.96
1990	206	703	305	69.5
1995	316	1078	468	106.6
2000	464	1584	688	156.6

^a The efficiency for base-loaded oil-fired plants is taken to be 0.366, and it is assumed there are 6.29×10^6 Btu/42 gal barrels of residual fuel oil.

^b The efficiency for base-loaded coal-fired plants is taken to be 0.386, and it is assumed there are 26.2×10^6 Btu/ton.

TABLE IX-6d: MAXIMUM NUCLEAR GROWTH SCENARIO (NORTHEAST)

Annual Equivalents of Nuclear Electric Energy Expressed in
Btu, Barrels of Residual Oil and Tons of Bituminous Coal.

Year	Nuclear Electric Energy Production Million (10^6) MWh	Electric Energy in Thermal Units Trillion (10^{12}) Btu	Residual Fuel Oil Replacement Million (10^6) bbl ^a	Bituminous Coal Replacement Million (10^6) tons ^b
1975	45.5	155.3	67.4	15.35
1980	101.9	347.8	151.0	34.39
1985	256.7	876.1	380.4	86.63
1990	477	1628	707	161.0
1995	767	2618	1137	258.8
2000	1166	3979	1728	393.5

^a The efficiency for base-loaded oil-fired plants is taken to be 0.366, and it is assumed there are 6.29×10^5 Btu/42 gal barrels of residual fuel oil.

^b The efficiency for base-loaded coal-fired plants is taken to be 0.386, and it is assumed there are 26.2×10^5 Btu/ton.

TABLE IX-7

It has been assumed that the 1975 production cost differential of 6.75 mills/kwh between nuclear and oil/coal will escalate at the rate of 8% per annum. The "Energy Increment" is the difference in annual electric production by nuclear plants for the BASE CASE and NUCLEAR MORATORIUM SCENARIOS. The annual incremental cost represents the extra production cost required to compensate for lost nuclear capacity with coal/oil.

Year	Energy Increment (Base Case minus Moratorium) (billion kwh/year)	Annual Incremental Cost (<u>\$ billion</u>)	Cumulative Incremental Cost (<u>\$ billion</u>)	Present Value in 1975*	
				Annual Increment Cost (<u>\$ billion</u>)	Cumulative Incremental Cost (<u>\$ billion</u>)
1982	0	0	0	0	0
1983	13	0.162	0.162	0.076	0.076
1984	31	0.418	0.580	0.177	0.253
1985	51	0.743	1.323	0.286	0.539
1986	74	1.165	2.488	0.408	0.948
1987	99	1.683	4.171	0.536	1.484
1988	128	2.350	6.521	0.681	2.165
1989	158	3.133	9.654	0.825	2.990
1990	192	4.111	13.765	0.984	3.974
1991	225	5.204	18.969	1.133	5.106
1992	262	6.545	25.514	1.295	6.401
1993	301	8.118	33.632	1.460	7.861
1994	344	10.021	43.653	1.639	9.500
1995	391	12.301	55.954	1.828	11.328
1996	434	14.747	70.701	1.993	13.321
1997	480	17.616	88.317	2.164	15.485
1998	530	21.004	109.321	2.346	17.831
1999	583	24.952	134.273	2.533	20.364
2000	640	29.587	163.860	2.731	23.095

*Present value calculated on the basis of 10% discount rate/year.

Figure IX-1. Base case nuclear scenario.

Figure IX-2. Nuclear moratorium scenario.

Figure IX-3. Maximum nuclear growth scenario.

Figure IX-4. Comparison of scenarios (New England).

Figure IX-5. Comparison of scenarios (New York).

Figure IX-6. Comparison of scenarios (Mid-Atlantic).

Figure IX-7. Comparison of scenarios (Northeast).

Figure IX-8. Cumulative incremental costs of the nuclear moratorium scenario.

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XI. ACKNOWLEDGEMENTS

The authors are indebted to Dr. Philip F. Palmedo of BNL and the staff of the Energy Policy Analysis Group for many useful comments and suggestions. Our special gratitude belongs to Mrs. Dorothy Thompson of the BNL Department of Applied Science for her untiring and cheerful labor on the manuscript.

It is impractical to list all of the individuals who contributed data, directed documents to our attention, and suffered through lengthy telephone conversations to answer our many questions. To them, we must express our appreciation collectively.

APPENDIX A

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APPENDIX A

A brief operating history follows for each nuclear power station in operation in the Northeast as of July 1975.* Many of the units experienced significant delays in their commissioning. The reasons for such delays were varied, e.g., late delivery of components by vendors, labor disputes, licensing delays, technical problems requiring modifications, retrofitting during construction to meet changes in regulations, etc. We have made no attempt to chronicle these delays, but instead begin our history with the date of commissioning. The operating data are through December 31, 1975.

The following definitions apply:

- Maximum Dependable Capacity - the dependable main-unit capacity (gross or net), winter or summer, whichever is smaller. The maximum dependable capacity often differs from the unit Design Electrical Rating, which is a nominal value, because the turbine generator output may vary during the year with the temperature of the condenser cooling water. The net maximum dependable capacity is the gross electrical output as measured at the output terminals of the turbine generator during the most restrictive seasonal conditions (usually summer), less the normal station service loads.
- Net Electrical Energy Generated (Output) - the gross electrical output of the unit measured at the output terminals of the turbine generator, minus the normal station service loads. We shall express this in units of million megawatt hours (10^6 MWh).
- The capacity factor is the net energy actually produced, divided by the net energy that would have been produced if the plant had operated 100% of the time at the maximum dependable capacity.
- The unit availability factor is the quotient of the time that the unit actually was operated with the turbine generator on-line during a given period, expressed as a percent.

* Millstone Point 2, which began commercial operation December 26, 1975, has not been included.

SECTION 1: NEW ENGLAND

Yankee-Rowe has been in commercial operation since July 1, 1961, and was the second commercial plant in the United States. This was the first of a series of "Yankee" plants for New England built under a cooperative arrangement by New England utilities. Yankee-Rowe is owned by the Yankee Atomic Electric Company and operated by the New England Electric System (NEES). The pressurized water reactor system and turbine generators were supplied by Westinghouse. The architect/engineer and constructor was Stone and Webster.

The plant is located on the Deerfield River in Northwestern Massachusetts near Rowe. An operating summary from Ref. A-1 follows*:

Years of Operation: 14.5

Maximum Dependable Capacity (net): 175 MWe

Cumulative Electric Energy Production (net): 16.0×10^6 MWh

Cumulative Capacity Factor: 71.8%

Cumulative Unit Service Factor: 79.5%

Although this is a small plant by contemporary standards, it has achieved a remarkably good operating record over its relatively long history, despite the fact that it was a pioneering plant which from time to time required long shutdowns for evaluation inspections and installing improved reactor components. (A-2) During the first six months of 1975 the total cost of producing electricity (including capital investment, fuel and operating expenses) averaged 9.25 mills per kwh. (A-3)

A good discussion of the plant configuration and a summary of its early operating history can be found in Ref. A-4.

* Data through end of December 1975.

Connecticut Yankee began commercial operation on January 1, 1968. The plant is second in the "Yankee" series of New England utilities, owned by the Connecticut Yankee Atomic Power Company and operated by Connecticut Light and Power Co. (a subsidiary of Northeast Utilities). The pressurized water reactor system and turbine generator was supplied by Westinghouse and Stone and Webster was the architect/engineer and constructor.

The plant is located on the east bank of the Connecticut River at Haddam Neck, a few miles north of East Haddam, Connecticut. An operating summary from Ref. A-1 follows*:

Years of Operation: 8.0

Maximum Dependable Capacity (net): 540 MWe

Cumulative Electric Energy Production (net): 30.1×10^6 MWh

Cumulative Capacity Factor: 79.9%

Cumulative Unit Service Factor: 80.5%

For the moment, this plant is the world leader among nuclear units in terms of total energy produced. (A-5) Connecticut Yankee also bears the distinction of producing the lowest cost electricity in New England (aside from hydro units). For the 17 month period, January 1, 1974 - May 31, 1975, the production costs averaged 6.6 mills/kwh, (A-6) including capital investment, fuel and operating costs. During this same period in the same utility, fuel costs alone for oil-fired plants averaged 21.1 mills/kwh.

The plant has experienced relatively few operational problems, most having been associated with the steam turbine unit which has required several modifications. The longest shutdown was for a 5-month period in 1973

* Data through end of December 1975.

for replacement of the low pressure turbine spindles and work on the steam generators.

A considerable amount of radiological and ecological data have been obtained in the vicinity of the plant, particularly on Connecticut River ecosystems. No significant adverse effects have been observed^(A-7) from the thermal plume or from entrainment in the cooling water intakes.

Connecticut Yankee would have to be rated as one of the most successful nuclear units built to date, both in terms of technical performance and economics.

Millstone Point 1 began commercial operation in March 1971. The plant is owned and operated by the Northeast Nuclear Energy Co., a joint venture of Connecticut Light and Power Co., Hartford Electric Light Co. and Western Massachusetts Electric Co. (all subsidiaries of Northeast Utilities). The boiling water reactor system was supplied by General Electric, and the architect/engineer and contractor was EBASCO.

The plant is located on the coast of Long Island Sound at Millstone Point, a few miles southwest of New London, Connecticut. Millstone Point is the site of famous granite quarries which produced high grade millstones during the colonial days and has furnished quality stone for many public buildings in the eastern United States. It has recently become recognized that this quarry is effectively a low grade bed of thorium ore, and that buildings constructed from the stone display very high levels of radiation originating from the thorium decay products contained therein. For example, some interior regions of Grand Central Station have radiation levels as high as 525 mrem/year, or more than four times natural background radiation levels. (A-8) Background radiation in the vicinity of the quarries has always been abnormally high. When the power plant started operation, the quarries were flooded with water, thus shielding the radiation from the stone surfaces. As a consequence, the overall radiation level in the local area has actually decreased since the nuclear plant was commissioned.

An operating summary from Ref. A-1 follows*:

Years of Operation: 4.8

Maximum Dependable Capacity (net): 652 MWe

*Data through end of December 1975.

Cumulative Electric Energy Production (net): 16.0×10^6 MWh

Cumulative Capacity Factor: 55.0%

Cumulative Unit Service Factor: 65.2%

During the 17-month period from January 1, 1974 to May 31, 1975, the average cost of production was 9.2 mills/kwh. (A-6)

This unit experienced a lengthy shutdown (5 months) beginning in September 1972, which was the consequence of an intrusion of salt water into the reactor coolant resulting from a leak in the condenser tubing. It should be noted that the condensed steam, which in BWR's contains some radioactivity, forms a partial vacuum. This pressure differential causes the condenser cooling water to leak into the steam condensate and precludes the leakage of radioactivity outward from the condensate into the cooling water discharge. The salt water intrusion incident caused corrosion damage from the presence of chloride ions in the reactor coolant. This forced the replacement of several internal components of the reactor system. (A-9)

Some difficulty has been experienced with formation of cracks in the stainless steel core spray sparger and piping of the reactor coolant system. The former caused a 3-month shutdown in 1973, and the latter has necessitated replacement of some pipe sections, but without long shutdowns. These are apparently generic problems of contemporary BWR's. The causes and procedures for avoidance are presently under intensive investigation.

Vermont Yankee began commercial operation on November 29, 1972. The plant is the third in the "Yankee" series being owned by Vermont Yankee Nuclear Power Corp., a subsidiary of several New England utilities. It is operated by the Central Vermont Public Services Corp. The boiling water reactor and turbine generator were supplied by General Electric. EBASCO was the architect/engineer and constructor.

Vermont Yankee is located on the west bank of the Connecticut River just north of the Vermont-Massachusetts boundary, near Vernon, Vermont. During periods of minimum flow of the Connecticut River and/or in warm seasons, the plant is required to use cooling towers. At other times it uses once-through cooling. The towers are evaporative, mechanical draft. The power needed to run the fans reduces the net output by several megawatts.

An operating summary from Ref. A-1 follows*:

Years of Operation: 3.1

Maximum Dependable Capacity (net): 504 MWe

Cumulative Electric Energy Production (net): 8.3×10^6 MWh

Cumulative Capacity Factor: 57.2%

Cumulative Service Factor: 73.8%

A variety of teething problems have been experienced during the three year operating history which at various times have imposed regulatory limits on power output. Most recently an 80% of maximum power limitation was in effect for several months due to excessive vibration of internal components (LPRM). This was corrected in August 1975 and the plant returned to 100%

* Data through the end of December 1975.

capacity. In 1974 a lightning strike on the off-gas stack induced failures in the gas rad-waste processing system.

During the first six months of 1975 the total production costs (capital carrying charges, fuel, operating and maintenance) averaged approximately 15.7 mills/kwh. (A-3)

Pilgrim 1 began commercial operation on December 9, 1972. The plant is owned and operated by the Boston Edison Company. The boiling water reactor was supplied by General Electric. Bechtel was the architect/engineer and constructor. The plant is located on the coast of Cape Cod Bay 5 miles to the east of Plymouth, Massachusetts. An operating summary taken from Ref. A-1 follows*:

Years of Operation: 3.0

Maximum Dependable Capacity (net): 670 MWe

Cumulative Electric Energy Production (net): 9.5×10^6 MWh

Cumulative Capacity Factor: 49.8%

Cumulative Unit Service Factor: 66.1%

In October 1973, the plant output was reduced to 50% of capacity to avoid excessive wear in fuel channels caused by vibrations which had been observed in similar reactors. The station was out of service from December 28, 1973 until March 20, 1974 for modifications to eliminate the vibration problem and to install a new type of fuel. During most of 1975 the output was restricted to between 60-80% of maximum capacity in order to remain below authorized limits for radioactive iodine emission arising from seal leakage in recirculation pumps. Repairs to the seals will be made during a scheduled refueling in January 1976.

During the first six months of 1975, the average production cost was 18.7 mills/kwh. (A-3)

* Data through the end of December 1975.

Maine Yankee began commercial operation on December 28, 1972. This plant, the fourth of the "Yankee" atomic power plants of the New England utilities, is owned by the Maine Yankee Atomic Power Co. and operated by the Central Maine Power Co. The pressurized water reactor was supplied by Combustion Engineering with Stone and Webster serving as architect/engineer and constructor.

The plant is located on an island in Back River, 3.9 miles south of Wiscasset, Maine. An operating summary based on Ref. A-1 follows*:

Years of Operation: 2.9

Maximum Dependable Capacity (net): 790 MWe

Cumulative Electric Energy Production (net): 11.9×10^6 MWh

Cumulative Capacity Factor: 56.6%

Cumulative Unit Service Factor: 74.8%

Early in its operating history Maine Yankee experienced some difficulty with leaks in the fuel cladding, which caused a loss of approximately five months of operating time for unscheduled refueling. From start of operation until the end of July 1975, the station output was restricted by temperature limitations on condenser discharge water. The addition of the diffuser systems in August 1975 has removed this constraint and allowed the plant to operate at full power.

During the last five months of 1975, the total cost of producing electricity was 10.3 mills/kwh. (A-10) This compares with a 12-month total average cost of 27 mills/kwh for all oil-fired units in the same system. (A-10) During the period from January 1 through July 31, 1975, when operating at about 75-85% of capacity, the costs averaged 15.0 mills/kwh.

* Data through the end of December 1975.

SECTION 2: NEW YORK

Indian Point 1 began commercial operation on February 19, 1963. The plant was shut down October 30, 1974 pending installation of an emergency core cooling system. No decision has been made on whether to carry out these modifications or to decommission the plant. The owner/operator is Consolidated Edison Company of New York, Inc., who also served as architect/engineer and constructor. The pressurized water reactor was supplied by Babcock & Wilcox. The plant is unique in that it is equipped with two oil-fired superheaters. An operating summary follows:*

Years of Operation: 11.6

Rated Capacity (net): 265 MWe

Cumulative Electric Energy Production (gross): 13.6×10^6 MWh

Cumulative Capacity Factor: 45.6%

Cumulative Unit Service Factor: 57.3%

The plant is located on the east bank of the Hudson River about 3 miles southwest of Peekskill, New York.

This was the first commercial nuclear power plant in the United States to receive a construction permit, which was issued in 1956. This must be regarded as a developmental unit, and for the first portion of its operational history it was used to investigate the practicality of using the thorium fuel cycle which had special reactor physics interest. The initial core (Core A) consisted of uranium oxide of 93% U^{235} enrichment, mixed with thorium oxide. During operation some of the thorium was converted to fissionable U^{233} (see Page 128). This core performed quite well, reaching a burnup of

* Data provided by Con Edison

15,700 MWd/tonne, and provided a variety of useful data for future reactor fuel cycles. Subsequent fuel loadings (Core B) have been more typical of PWR's, being uranium oxide of about 4% U²³⁵ enrichment.

The plant has sustained many long shutdowns associated with pump seal problems, tube failures in the oil-fired superheater units, steam generator leaks and failure of a feedwater pipe connection. The latter failure proved difficult to repair because of its inaccessibility in a high radiation area, forcing a shutdown from December 1972 until January 1974. Following this repair, the plant operated for only 10 months until its present shutdown.

Production costs of Indian Point 1 have been quite high, averaging 30.7 mills/kwh over its 11.6 years of operation. This can be partly ascribed to the low average plant capacity factor, which means that the capital costs (\$126 million) must be distributed over fewer kilowatt hours of production. Also, the long shutdowns imply unusually high maintenance costs (especially the 1973 repair). Because of the small rated capacity of the plant and the large staff required to operate a nuclear unit, operational costs have been relatively high. Some of these high costs could be ascribed to the pioneering nature of the plant and the research value of the first core, which required special shutdown periods for evaluation.

Indian Point 2 began commercial operation in August 1973.* The owner/operator is the Consolidated Edison Company of New York, Inc. The nuclear steam supply system (PWR) was provided by Westinghouse. The architect/engineer was United Engineers and Constructors, and the plant was constructed by J. A. Jones and UE&C. An operating summary based on Ref. A-1 follows:†

Years of Operation: 1.5*

Maximum Dependable Capacity (net): 864 MWe

Cumulative Electric Energy Production (net): 7.6×10^6 MWh

Cumulative Capacity Factor: 64.2%

Cumulative Unit Service Factor: 76.2%

The plant is located on the east bank of the Hudson River about 3 miles southwest of Peekskill, New York, at the same site as Indian Point 1.

The plant has been restricted in operation from time to time because of fish kill problems at the condenser cooling intakes. Environmental groups have continued to exert pressures on the company by various litigation and intervention in licensing hearings. Fish problems are aggravated by the fact that the plant is located at a point in the Hudson River where the salt water/fresh water interface occurs, which proves to be particularly rich in marine biota and a key habitat in parts of the life cycle of many species of marine life. A regulatory order which requires the installation of cooling towers by May 1, 1979 is being contested by the licensee, but a petition to postpone the date to September 1, 1981 was denied by the Atomic Safety and Licensing Appeal Board. (A-11) Average production cost has been 12.4 mills/kwh.

* Con Edison lists date of commercial operation as July 1, 1974.

† Data through the end of December 1975.

In its short history, the plant has experienced the usual variety of shakedown problems, but the cumulative capacity factor appears to be slightly better than average for an immature unit.

During the first half of 1975 the production costs averaged 12.11 mills/kwh. (A-3)

Nine Mile Point 1 began commercial operation in December 1969. Niagara Mohawk Power Corporation is the owner/operator, which served as its own architect/engineer. The boiling water reactor was supplied by General Electric and the constructor was Stone and Webster.

An operating summary based on Ref. A-1 follows*:

Years of Operation: 6.0

Maximum Dependable Capacity (net): 610 MWe

Cumulative Electric Energy Production (net): 17.9×10^6 MWh

Cumulative Capacity Factor: 54.3%

Cumulative Unit Service Factor: 66.2%

The plant is located on the south shore of Lake Ontario at Scriba, New York, about 6 miles northeast of Oswego.

During a shutdown in March 1970 (3 months after commissioning) two small cracks were found in a core spray nozzle "safe end". Similar problems had occurred in similar reactors, e.g., Oyster Creek and Millstone Point 1. Exhaustive studies indicate that the cracks were caused by intergranular stress corrosion in furnace-sensitized stainless steel. All furnace-sensitized safe end attachments to the vessel were carefully inspected, and three attachments were replaced with non-sensitized 304-L stainless steel. Some pipe hangers were relocated to reduce stresses. With AEC Regulatory approval the plant was placed back in service in July 1970, but with additional surveillance requirements. Subsequent inspections have revealed no additional cracks, and all vessel penetrations appear to be in excellent condition.^(A-12) Since this initial problem no other notable operating difficulties have been encountered.

* Data through the end of December 1975.

During the period January 1974 through June 1975, the production costs averaged 11.57 mills/kwh. This can be compared with a modern oil-fired base loaded plant (Roseton) shared by Niagara Mohawk which had average production costs from August 1974 through June 1975 of 25.64 mills/kwh.^(A-12) The data for the two plants are summarized in the table below:

	Nine Mile Point 1 (Nuclear)		Roseton (Oil)	
	<u>mills/kwh</u>	<u>percent</u>	<u>mills/kwh</u>	<u>percent</u>
Capital	7.29	63.0	10.04	39.2
Operation & Maintenance	0.88	7.6	0.84	3.3
Fuel	<u>3.40</u>	<u>29.4</u>	<u>14.76</u>	<u>57.6</u>
Total	11.57	100	25.64	100

It can be seen that the fuel costs alone for the Roseton plant exceed the total production of Nine Mile Point 1.

Ginna (Robert Emmett Ginna Nuclear Power Plant, Unit 1) began commercial operation in March 1970. The plant is owned and operated by the Rochester Gas and Electric Corp. The pressurized water reactor was supplied by Westinghouse. The architect/engineer was Gilbert and the constructor Bechtel.

An operating summary based on Ref. A-1 follows*:

Years of Operation: 5.8

Maximum Dependable Capacity (net): 470 MWe

Cumulative Electric Energy Production (net): 15.9×10^6 MWh

Cumulative Capacity Factor: 67.3%

Cumulative Unit Service Factor: 74.7%

The plant is located on the south shore of Lake Ontario at Ontario, New York, 16 miles east of Rochester, New York. The plant has experienced relatively few problems in its operating history, as evidenced by the high cumulative unit availability factor.

During its early operating history, some fuel cladding leaks were detected by increases in radioactivity of the coolant. During a shutdown for refueling in April 1972, several discharged fuel elements proved to have bowed elements, and an appreciable number were found to have sections in which the fuel cladding had collapsed. (A-13) The collapsed sections varied in length from 0.5 to 4 inches. Investigation disclosed that the effect was caused by the phenomenon of fuel densification. The uranium oxide fuel pellets have initial densities (depending on manufacturer) in the range of 90 to 95% of the theoretical density of solid UO_2 . During the initial stages of irradiation of fresh fuel in the reactor, the fuel pellets slowly shrink in size (increase in density), approaching the theoretical density. (At later stages of irradiation the

* Data through the end of December 1975.

pellets swell as fission products accumulate.) The initial shrinking causes the column of fuel pellets to settle downward within the metal tube (the cladding). However, in some columns an individual pellet might stick and not settle downward, leaving a void below it. If the fuel element is not pressurized, the surrounding pressure of the coolant squeezes the cladding inward at points of voids, thus producing the "collapsed" sections.

Regulatory concern was that local voids in the fuel could result in local "hot spots" or other phenomena which could have safety implications. Subsequent investigations have shown that such effects could produce power spikes which would exceed licensed power densities in upper regions of the core. The AEC Office of Regulation required reactors using fuel subject to this phenomenon to operate at reduced power levels (in the range of 90-95% of rated capacity). Fuel fabricators have since increased the density of the fuel pellets to circumvent this phenomenon.

It should be noted that most reactors were affected by fuel densification and that the phenomenon is not unique to Ginna, except that it had the distinction of first discovering the effect*. The Ginna fuel affected in April 1972 was unpressurized, which allowed the collapse to occur and thus be detected. At the end of the refueling campaign in May 1972, the Ginna plant returned to service at 83% of rated capacity. In October 1972 the plant was shut down to remove the remaining unpressurized fuel elements.

During the first quarter of 1975 power production costs were 9.40 mills/kwh. (A-3)

* Actually the effect had been observed earlier at the Beznau reactor in Switzerland.

FitzPatrick (James A. FitzPatrick Nuclear Power Plant) began commercial operation on July 28, 1975. The owner is the Power Authority of the State of New York (PASNY) and the operator Niagara Mohawk Power Corp. General Electric supplied the boiling water reactor. Stone and Webster served as architect/engineer and constructor. An operating summary based on Ref. A-1 follows*:

Years of Operation: 0.5

Maximum Dependable Capacity (net): 410 MWe[†]

Cumulative Electric Energy Production (net): 2.2×10^6 MWh

Cumulative Capacity Factor: (Not available)

Cumulative Unit Service Factor: 71.0%

FitzPatrick is located adjacent to Nine Mile Point 1 on the south shore of Lake Ontario in Scriba, New York, approximately 6 miles east of Oswego, New York.

Preparations are being made to start warranty run at rated power. No significant operational difficulties have been reported to date, although the usual types of shakedown problems have been encountered.

* Data through the end of December 1975.

† Note that the plant is rated at 821 MWe (net), but is temporarily restricted to 50% of rated capacity until all startup testing is completed.

SECTION 3: MID-ATLANTIC

Oyster Creek began commercial operation on December 23, 1969. The owner/operator is the Jersey Central Power and Light Co. General Electric supplied the boiling water reactor; Burns & Roe served as architect/engineer and J. A. Jones was constructor. An operating summary based on Ref. A-1 follows*:

Years of Operation: 6.0

Maximum Dependable Capacity (net): 620 MWe

Cumulative Electric Energy Production (net): 22.2×10^6 MWh

Cumulative Capacity Factor: 72.5%

Cumulative Unit Service Factor: 76.0%

The plant is located about one-half mile east of Barnegat Bay, 9 miles south of Toms River, New Jersey. Oyster Creek is a notable plant, being the first large "turn-key" contract of General Electric. Although it experienced lengthy construction delays and encountered many construction problems which have since been the subject of litigation, the plant has performed quite well as evidenced by its relatively high cumulative capacity factor.

Among its operational problems have been difficulties with the turbine control valves, problems with the emergency diesel generators, and sundry problems with other valves. During the past year the unit has been experiencing condenser tube leaks which have required numerous tubes to be plugged, and has limited operation to about 80% of rated capacity. The condenser will be re-tubed in December 1975.

Power production costs averaged 14.47 mills/kwh during the first half of 1975.

* Data through the end of December 1975.

Peach Bottom 2 began commercial operation on July 5, 1974; Peach Bottom 3 on December 23, 1974. Ownership of the two units is shared by the Philadelphia Electric Co., Public Service Electric and Gas Co. of New Jersey, Delmarva Power and Light Co., and Atlantic City Electric Co. The operator is the Philadelphia Electric Co. General Electric supplied the two boiling water reactors and Bechtel was the architect/engineer and constructor.

An operating summary of the two units based on Ref. A-1 follows*:

	<u>Unit 2</u>	<u>Unit 3</u>
Years of Operation:	1.5	1.0
Maximum Dependable Capacity (net):	1051†	1035 MWe†
Cumulative Electric Energy Production (net):	8.7	5.5x10 ⁶ MWh
Cumulative Capacity Factor:	63.0%	58.7%
Cumulative Unit Service Factor:	80.7%	86.3%

The units are located on the west bank of the Susquehanna River in York County, Pennsylvania, about 18 miles south of Lancaster, Pennsylvania.

Both units use cooling towers most of the time. Both units have experienced vibrations of reactor internals (LPRM) which restricted operations to about 55% of rated capacity during most of 1975. The problem was corrected in Unit 2 during November 1975, and in Unit 3 in January 1976.

Production costs averaged 12.74 mills/kwh for the first half of 1975. (A-3)

* Data through the end of December 1975.

† The identical units both have a design capacity of 1065.

Three Mile Island 1 began commercial operation on September 2, 1974. The plant is owned jointly by the Metropolitan Edison Co., Jersey Central Power and Light Co. and Pennsylvania Electric Co. Metropolitan Edison is the operator. Gilbert Associates, Inc. was architect/engineer and the constructor was UE&C. The pressurized water reactor was supplied by Babcock & Wilcox.

The plant is located on the Susquehanna River approximately 11 miles southeast of Harrisburg, Pennsylvania. An operating summary based on Ref. A-1 follows*:

Years of Operation: 2.3

Maximum Dependable Capacity (net): 792 MWe

Cumulative Electric Energy Production (net): 7.5×10^6 MWh

Cumulative Capacity Factor: 81.4%

Cumulative Unit Service Factor: 83.7%

The unit had a remarkably smooth startup, requiring less than 3 months between initial criticality and commercial operation. During the first year of operation, the capacity factor was 84.8%, which probably is one of the best performance records ever achieved for a commissioning year by a large steam-electric generating plant, nuclear or fossil-fueled.

Production costs between January 1 and June 30, 1975 averaged 16.35 mills/kwh.

* Data through the end of December 1975.

Calvert Cliffs Unit 1 began commercial operation on May 8, 1975. The plant is owned and operated by the Baltimore Gas and Electric Company. The pressurized water reactor was supplied by Combustion Engineering. Bechtel was architect/engineer and constructor.

The plant is located in Calvert County, Maryland on the west shore of Chesapeake Bay, about 45 miles southeast of Washington, D. C. An operating summary based on Ref. A-1 follows*:

Years of Operation: 0.7

Maximum Dependable Capacity (net): 800 MWe

Cumulative Electric Energy Production (net): 4.4×10^6 MWh

Cumulative Capacity Factor: 78.8%

Cumulative Unit Service Factor: 82.7%

As indicated by the cumulative capacity factor, the plant has operated satisfactorily during its short history.

The Calvert Cliffs name became famous because of the U.S. Court of Appeals landmark decision on how the AEC in particular and federal agencies in general should implement the National Environmental Policy Act (see Ref. 52). It is somewhat ironic that the Calvert Cliffs AEC Docket should have been singled out to be the target of historical litigation between environmental groups and a federal agency. The Construction Permit was issued in July 1969 by the AEC. The Calvert Cliffs project had been the subject of very intensive programs of environmental studies prior to the enactment of the National Environmental Policy Act. (A-14,15,16) These studies, which can serve as an excellent model of marine ecology research, were conducted by the Department of Natural Resources and the Department of Chesapeake Bay Affairs of the State of Maryland,

* Data through the end of December 1975.

the University of Maryland Natural Resources Institute, and the Chesapeake Bay Institute of Johns Hopkins University. (A-14) Included were extensive hydraulic studies using a scale model of a 34-mile region of Chesapeake Bay. (A-16)

REFERENCES FOR APPENDIX A

- A-1 United States Nuclear Regulatory Commission, Operating Units Status Report, Licensed Operating Reactors, NUREG-0020-1, January 1976.
- A-2 For example, see G. Reed and E. Tarnuzzer, "Examining Yankee Plant Performance in 1965", Nucleonics, March 1966, pp. 42-7.
- A-3 Atomic Industrial Forum, Newsrelease, "Nuclear 43.6% Below Fossil Generating Costs in First Half", Sept. 15, 1975.
- A-4 "Five Case Histories: Nuclear Power Plants in Operation", Nuclear News, Vol. 12, No. 6, June 1969, pp. 41-62.
- A-5 Nuclear Engineering International, Vol. 20, No. 226, p. 146, March 1975.
- A-6 Northeast Utilities, "Report on Nuclear Power Production Costs", July 1975.
- A-7 For example, see D. Merriman, "The Calefaction of a River", Scientific American, Vol. 222, No. 5, pp. 42-52, May 1970.
- A-8 J. E. McLaughlin, "Environmental Survey at Grand Central Terminal", unpublished memo to J. H. Harley, USAEC Health and Safety Laboratory, March 2 and March 9, 1971. Credit for discovery and investigation of the relationship of the quarry and radioactivity in public buildings probably belongs to Ragnwald Muller who began work on the problem in 1969.
- A-9 Special Report: Chloride Intrusion Incident, Millstone Nuclear Power Station, Unit 1, December 11, 1972, USAEC Docket 50-245.
- A-10 Private communication from Central Maine Power Co.
- A-11 Atomic Safety and Licensing Appeal Board, Memorandum and Order, April 25, 1974, ALAB-198, Regulatory Adjudication Issuances, April 1974, RAI-74-4, pp. 475-7.
- A-12 Private communication, C. V. Mangan, Niagara Mohawk Power Corp. to V. L. Sailor, October 28, 1975.
- A-13 U. S. Atomic Energy Commission Regulatory Staff Technical Report on Densification of Light Water Reactor Fuels, November 14, 1972.
- A-14 Nuclear Power Plants in Maryland, a report of the Governor's Task Force on Nuclear Power Plants, State Office Bldg., Annapolis, Md., Dec. 1969.
- A-15 Baltimore Gas and Electric Co., Environmental Report, Calvert Cliffs Nuclear Power Plant, Nov. 16, 1970.
- A-16 C. H. Lantz, Summary Report of Calvert Cliffs Model Studies for the Baltimore Gas and Electric Co., Alden Research Laboratories, Worcester Polytechnic Institute, Dec. 1969.

APPENDIX B

ADDITIONAL DATA ON ECONOMIC ASSUMPTIONS USED FOR COST COMPARISONS BETWEEN NUCLEAR, COAL AND OIL PLANTS

In Section III.B.3 (page 38), we have summarized three studies^(4,5,25) conducted for New England and Long Island utilities comparing projected production costs for nuclear coal- and oil-fired power plants. Although the reader must refer to the original documents to obtain the many complex details on the numerous factors that were taken into account, several of the more important assumptions are summarized in Table B-1. The studies took account of long term reliability of fuel supplies, transportation costs, various escalation rates for labor, materials and equipment, etc. The data summarized in Table B-1 are for:

- Oil-fired units which can later be converted to coal
- Coal-fired units with stack gas scrubbers for sulfur removal
- Dual nuclear plants and dual or triple fossil units

The reports contain a range of sensitivity studies that calculate the impact of varying the many economic assumptions. We regret that lack of space has precluded our inclusion of a more detailed summary of these comprehensive studies.

TABLE B-1: SUMMARY OF ECONOMIC ASSUMPTIONS USED IN THE
ARTHUR D. LITTLE, INC./S. M. STOLLER CORP. COMPARATIVE
COST STUDIES CITED IN SECTION III.B.3 (PAGE 38)

<u>Item</u>	<u>"Study '73"</u>	<u>"Study '74"</u>	<u>"Study '75"</u>
Reference	4	25	5
<u>Plant Capacity (MWe net)</u>			
Nuclear	1150 (2 units)	1150 (2 units)	1150 (2 units)
Coal and Oil	800 (2 units)	800 (3 units)	800 (3 units)
<u>Service Dates</u>			
Nuclear	1981-82 & 1983-84	1981 & 1983	1983 & 1985
Coal and Oil	1981-82 & 1983-84	1981, 1983 & 1985	1983, 1984 & 1985
<u>Capital Costs (\$/kw)</u>			
Nuclear	702	765	863
Coal	588	658	697
Oil	389	464	510
<u>Fixed Charge Rate</u>			
Nuclear	14.7%	14.1%	18.2%
Coal and Oil	14.7%	14.6%	19.4%
<u>Plant Capacity Factors</u>			
Nuclear - 1st year	50%	50%	53%
2nd year	65%	65%	60%
3rd year	75%	75%	65%
following yrs.	75%	75%	70%
Coal & Oil - 1st year	50%	50%	57%
2nd year	65%	65%	64%
3rd year	75%	75%	69%
following yrs.	75%	75%	75%
<u>Heat Rates (Btu/kwh)</u>			
Nuclear	10,300	10,230	10,500
Coal	9,500	9,400	9,500
Oil	9,000	9,140	8,900
<u>Allowance for Funds During Construction (AFDC)</u>			
	8%	8%	9%
<u>Discount Factor for Present Value Calculations</u>			
	8%	9%	10.4%
<u>GNP Deflators</u>			
1973-1981	4.4%/yr.	4.4%/yr.	
Post-1981	3.1%/yr.	3.1%/yr.	
1975-1980			5.0%/yr.
Post-1980			3.5%/yr.

THE BROOKHAVEN NATIONAL LABORATORY REGIONAL ENERGY STUDIES PROGRAM

The Brookhaven National Laboratory Regional Energy Studies Program is part of a national effort supported by the U.S. Energy Research and Development Administration (ERDA) to create an energy assessment capability which is sensitive to regional conditions, perceptions, and impacts. Within ERDA, this program is supported by the Division of Biomedical and Environmental Research and includes, in addition to a concern for health and environmental impacts of energy systems, analysis of the complex trade-offs between economics, environmental quality, technical considerations, national security, social impacts, and institutional questions. The Brookhaven Program focuses on the Northeast, including the New England states, New York, Pennsylvania, New Jersey, Maryland, Delaware, and the District of Columbia. The content of the program is determined through an identification of the major energy planning issues of the region and in consultation with state and regional agencies. A major component of the program in 1976 is the Northeast Energy Perspectives Study which examines the implications of alternative energy supply-demand possibilities for the region.