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Spent Fuel Storage Requirements— The Need For Away-From-Reactor Storage

February 1979

U.S. Department of Energy
Assistant Secretary for Energy Technology

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Spent Fuel Storage Requirements— The Need For Away-From-Reactor Storage

February 1979

U.S. Department of Energy
Assistant Secretary for Energy Technology
Division of Spent Fuel Storage and Transfer
Washington, D.C. 20545

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FOREWORD

Approximately 4000 metric tonnes of spent nuclear reactor fuel is currently in storage at reactor basins around the United States. By 1988 this number will increase to over 25,000 metric tonnes, primarily from reactors already in operation. Spent fuel storage through the early 1990's is a concern regardless of the growth of nuclear power.

Although a substantial amount of the spent fuel generated can be stored at reactor sites, reactor storage capability is limited. This report analyzes storage requirements for away from reactor storage based upon a number of storage assumption variations concerning utility storage plans and reactor operations. This data will be used by the Department of Energy in planning storage requirements to implement the President's Spent Fuel Policy of October 18, 1977. Under this policy DOE would accept title and possession of U.S. and a limited amount of foreign spent fuel in return for payment of a one time storage and disposal fee. Draft Environmental Statements^{1,2,3,4} and a report on preliminary estimates of the charge for storage and disposal services⁵ have been issued for consideration in the implementation of this policy.

¹DOE/ET-0015-D - Draft Environmental Impact Statement on the "Storage of U.S. Spent Power Reactor Fuel," August 1978.

²DOE/ET-0015-DS - Draft Supplement to the EIS on "Storage of U.S. Spent Power Reactor Fuel," December 1978.

³DOE/ET-0041-D - Draft EIS on the "Charge for Spent Fuel Storage," December 1978.

⁴DOE/ET-0040D - Draft EIS on the "Storage of Foreign Spent Power Reactor Fuel," December 1978.

⁵DOE/ET-0055, "Preliminary Estimates of the Charge for Spent-Fuel Storage and Disposal Services," July 1978.

The data in this report represent information provided by utilities on their spent fuel storage capabilities and plans. Where assumptions have been made, efforts have been made to verify these assumptions with utilities. Nevertheless, utility plans and requirements will continue to be monitored and storage requirement estimates will be updated as appropriate.

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I. INTRODUCTION

The DOE spent fuel program is structured to provide away-from-reactor (AFR) storage as necessary to prevent commercial nuclear reactor shut-downs due to inadequate fuel storage capacity. Spent fuel storage is required until a disposal facility is available or until such time as reprocessing is allowed. This report analyzes the capabilities of domestic utilities for reactor basin expansions and estimates the timing and magnitude of AFR spent fuel storage requirements. It reflects the latest available data on utility expansion plans and provides a rational basis for decision making.

The impact of changes in assumptions was assessed in a sensitivity section in this report. To permit such a sensitivity analysis, a base case was identified. This case does not represent a most likely projection for AFR requirements. Instead it could better be characterized as a minimum case for planning purposes. Higher AFR requirements will result if transshipment of fuel between reactors or planned reactor basin expansion do not occur.

The data and analysis presented in this report was developed by using the DISFUL computer program written by the S. M. Stoller Corporation (SMSC) under contract to DOE. Appendix A contains a description of the program.

Unless specifically noted, the tables and data in the report are for domestic fuel only. To permit an estimation of total demand for AFR services for both domestic and foreign fuel, a section has been included which shows the projected AFR requirements for foreign fuel, which might be accepted to support U.S. nonproliferation objectives. These estimates were developed in the recent draft EIS on the storage of foreign fuel (DOE/EIS-0040D, December 1978).

II. SUMMARY

The projected AFR requirements which have been developed represent data as of December 31, 1978 on at reactor fuel pool expansion plans. The base case, which was identified for purposes of sensitivity analysis, assumes transshipments between reactor basins within the same utility. It is very likely that transshipment will not be utilized for all reactors. Hence the base case AFR requirements discussed in this report represent a minimum or lower bound for purposes of planning.

If some assumptions are varied, a wide range of AFR requirements results. The smaller the amount of fuel shipped to other reactor basins within the utilities' systems, the greater are the AFR requirements. It is also possible that some utilities may be able to expand their reactor spent fuel pools beyond the base case data. On the other hand, some utilities may not be able to expand as much as currently planned because of licensing, engineering, or institutional problems. Clearly, a number of factors exist which can influence AFR requirements.

The impact of variations in key assumptions is shown on Table 1. Figure 1 shows the base case and the range of sensitivity cases which were analyzed.

TABLE 1
IMPACT ON AFR REQUIREMENTS OF VARIATIONS
IN KEY ASSUMPTIONS

	<u>Cumulative Metric Tons of Storage Required</u>		
	<u>1983</u>	<u>1988</u>	<u>1993</u>
<u>SENSITIVITY CASES</u>			
<u>Spent Fuel Pool Expansion</u>			
1. Existing	5030	12020	24950
2. Latest Expansion Plans (Base Case)	560	3860	14020
3. Maximum	270	870	4660
<u>Transshipment</u>			
1. None	1190	6110	17340
2. Within Utility (Base Case)	560	3860	14020
3. Inter-Utility	20	140	10030
<u>Reactor Capacity Factor</u>			
1. 60%	370	2450	9540
2. 70% (Base Case)	560	3860	14020
3. 80%	800	5600	19730
<u>Discharge Capability</u>			
1. Full Core Reserve (Base Case)	560	3860	14020
2. Annual Reload Only	40	1620	8750
<u>Reactor Fuel Burnup</u>			
1. Low (Base Case)	560	3860	14020
2. High	430	2430	10800

FIGURE 1

RANGE OF AFR REQUIREMENTS
FOR SENSITIVITY ANALYSES

III. BASE CASE

A. Assumptions

There are several key variables which impact the projections for AFR storage. They include:

- o Amount of planned reactor basin expansion
- o Amount of transshipment between reactor basins
- o Reactor Capacity factor
- o Reactor Fuel burnup
- o Discharge capability philosophy (maintenance of full core reserve or annual discharge capability)

The assumptions discussed below form a base case upon which a sensitivity analysis can be done. The base case presented below doesn't represent a most likely case.

Basin Expansion

Many utilities already have expanded or plan to expand their reactor basins beyond their initial design capacity. In many cases these expansions make economic sense since they are far cheaper than the construction of new on-site basins or shipment to away-from-reactor storage. By assuming that current expansion plans occur, the projected demand for AFR storage services is reduced by about 70% from requirements based on current existing capacities.

While the sensitivity analysis addresses a theoretical maximum expansion case, it is not appropriate to use that as the base case for the following reasons:

1. Many utilities have expanded to 80 or 90% of theoretical maximum, and the marginal cost to reach absolute maximum may be much more expensive than the other options available; i.e., DOE storage or independent utility constructed storage.
2. The utilities may not be allowed to expand further due to institutional constraints such as state laws limiting fuel storage times.
3. An expansion to the absolute maximum may present licensing problems which could impact overall availability of the reactor.

Transshipment

One utility has already shipped fuel from one reactor basin to another reactor within their own system at a separate site with more available space. The base case assumes that fuel assemblies will be shipped to one intermediate site within the same utility before shipment to a Federal facility. Shipments to other utilities even within the same National Electric Reliability Council region are very unlikely due to institutional problems and the fact that other utilities also face storage problems. While an occasional exception may be made, transshipment to other utilities is not a reasonable planning assumption. If no transshipment were to occur, the AFR requirements in 1988 would be significantly higher than the base case.

Reactor Capacity Factor

A reactor capacity factor of 70% has been used in the base case. It represents a reasonable assumption for the entire study period. Capacity factors for some existing plants are lower, but improvements in reactor availability and performance are expected. Capacity factors of 60% and 80% are examined in the sensitivity section.

Fuel Burnup

Average burnups at discharge are assumed to be 31,000 MWD/MTU for PWR's and 23,000 MWD/MTU for BWR's. Reactors scheduled to come on line in the mid-80's are expected to have higher burnups. However, for the period examined, the demand for AFR services is impacted most by existing reactors.

Discharge Capability Philosophy

The maintenance of full core reserve (FCR) is assumed in the base case. Reactor fuel storage space capable of storing an entire reactor core is considered necessary by all utilities. While not a licensing or safety requirement, FCR is necessary to prevent extended reactor outages in the event a core must be discharged. Although a reactor can be quickly and safely shutdown with fuel in core, without FCR the reactor must remain shutdown while arrangements for shipping and storage are made and executed. During this time, the utility must purchase supplemental power at substantial additional cost to its customers.

For reactors with shared basins the analysis assumes that space for only one full core discharge is maintained at the site. This is considered adequate since the likelihood of needing to discharge the full core from both reactors simultaneously is low.

B. Results

The above assumptions result in the AFR requirements as shown in Table 2. Figure 2 shows both the cumulative requirements and the annual shipments to the AFR. The 1988 base requirements are only 30% of those needed without planned basin expansions and about 60% of those needed without transshipments.

TABLE 2
CUMULATIVE AFR REQUIREMENTS

<u>Year</u>	<u>Metric Tons</u>
79	70
80	80
81	200
82	340
83	560
84	810
85	1180
86	1810
87	2770
88	3860
89	5250
90	6940
91	8850
92	11310
93	14020

FIGURE 2

**AFR REQUIREMENTS
FOR BASE CASE**

C. Reactors with Near Term Storage Problems

In the base case twenty seven plants require varying quantities of away-from-reactor storage by the end of 1985. Table 3 shows the reactors that require AFR storage. Appendix B briefly summarizes the status of each.

There is the possibility that other reactors may have storage problems due to potential restrictions by states. One example is the Calvert Cliffs reactor in Maryland where there currently exists a law which prohibits expansion to provide spent fuel storage beyond 1981. Other states are also considering laws restricting the amount or timing of fuel storage at reactors in their state.

TABLE 3

REACTORS REQUIRING AFR STORAGE

<u>Reactor</u>	<u>Year of First Shipment to AFR To Maintain FCR</u>
Oconee 1, 2, 3	1978*
San Onofre	1978**
Humboldt Bay	1979
Brunswick 1	1980
Brunswick 2	1981
McGuire 1	1981
Nine Mile Point 1	1981
Diablo Canyon 1	1982
Robinson 2	1982
Diablo Canyon 2	1982
Yankee-Rowe	1982
Hatch 1, 2	1983
Prairie Island 1, 2	1983
Zimmer 1	1984
Oyster Creek	1984
Fort Calhoun	1984
Rancho Seco	1984
Arkansas 1, 2	1985
McGuire 2	1985
Maine Yankee	1985
Susquehanna 1	1985
Trojan	1985

*Currently operating without FCR, plan Transshipment to regain FCR.

**San Onofre is presently shipping to GE at Morris, Ill.

IV. SENSITIVITY ANALYSIS

This analysis examines the impact of variations of key storage assumptions. As the results indicate, a significant spread of AFR requirements can arise as these assumptions are changed.

Reactor Basin Capacities

Two variations from the base case were analyzed. The first is the use of current pool capacity. The second is the assumption that the maximum estimate for basin expansion is used. In the latter case the utility-maximum storage capability is utilized if one was provided. If one was not available, a contractor-generated maximum storage capability is utilized. These estimates have been individually reviewed with the utilities to obtain their comments on them, and only where they indicated that they were not committed to an alternative have the maximum estimates been used. Figure 3 and Table 4 show the impact of these assumptions of the base case.

TABLE 4

CUMULATIVE AFR REQUIREMENTS (METRIC TONS)

	<u>1983</u>	<u>1988</u>	<u>1993</u>
Current pool status	5030	12020	24950
Base case expansion	560	3860	14020
Maximum Estimate	270	870	4660

FIGURE 3

**IMPACT OF BASIN EXPANSION VARIATIONS
ON AFR REQUIREMENTS**

Transshipment

If no transshipment is assumed, AFR requirements increase. Likewise, if transshipment* to another utility within the same NERC region is permitted, the demand for AFR services is reduced significantly in the near-term. Two important comments should be made about the latter case. First, the institutional and regulatory problems with wholesale transshipment to other utilities are a serious impediment to this activity. Second, it represents merely a delaying technique and eventually all utilities will begin to face storage problems and AFR shipments will increase dramatically as evidenced in Table 5 and Figure 4.

TABLE 5
CUMULATIVE AFR REQUIREMENTS (METRIC TONS)

	<u>1983</u>	<u>1988</u>	<u>1993</u>
No transshipment	1190	6110	17340
Base Case (Intra-utility shipments)	560	3860	14020
Shipments within NERC Region	20	140	10030

*In this analysis it is assumed that unlimited intra-utility shipment take place prior to inter-utility shipment. Similar to the Base Case, the inter-utility shipment case is limited to transferring fuel one time to another utility, i.e., once a shipment of fuel is sent to another utility at its next transfer it is required to go to AFR storage.

FIGURE 4

IMPACT OF TRANS-SHIPMENT VARIATIONS
ON AFR REQUIREMENTS

Reactor Capacity Factor

As expected, discharges and AFR requirements vary with changes in capacity factor. The calculation assumes that the time between each fuel reload is variable with the reactor's capacity factor to allow equivalent burn-up. In practice the refueling time schedule for the reactor may not permit the flexibility necessary to cause the difference shown in the table. Figure 5 and Table 6 show the results of 60% and 80% capacity factors with all other base case assumptions held constant.

TABLE 6

CUMULATIVE AFR REQUIREMENTS (METRIC TONS)

<u>Reactor Capacity Factor</u>	<u>1983</u>	<u>1988</u>	<u>1993</u>
60%	370	2490	9540
70% (Base Case)	560	3860	14020
80%	800	5600	19730

FIGURE 5

**IMPACT OF CAPACITY FACTOR VARIATIONS
ON AFR REQUIREMENTS**

Fuel Burnup

If high burnups were assumed, spent fuel discharges would decrease and AFR requirements would likewise be reduced. Figure 6 and Table 7 show the results of a case with average burnups of 33,000 MWD/MTU for PWR's and 27,500 MWD/MTU for BWR's as opposed to the base case burnups of 31,000 for PWR's and 23,000 for BWR's.

TABLE 7
CUMULATIVE AFR REQUIREMENTS (METRIC TONS)

	<u>1983</u>	<u>1988</u>	<u>1993</u>
Base Case	560	3860	14020
Higher Burnups	430	2700	10800

FIGURE 6

IMPACT OF FUEL BURNUP VARIATIONS
ON AFR REQUIREMENTS

FIGURE 7

IMPACT OF DISCHARGE CAPABILITY VARIATIONS
ON AFR REQUIREMENTS

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Summary of Sensitivity Variations

Table 9 shows the results of variations in single parameters of the base case. Figure 8 shows the range of AFR requirements resulting from these sensitivity analyses.

TABLE 9
IMPACT ON AFR REQUIREMENTS OF VARIATIONS
IN BASE CASE ASSUMPTIONS

	<u>Cumulative Metric Tons of Storage Required</u>		
	<u>1983</u>	<u>1988</u>	<u>1993</u>
<u>SENSITIVITY CASES</u>			
<u>Reactor Basin Expansion</u>	560	3860	14020
1. Existing	5030	12020	24950
2. Latest Expansion Plans	560	3860	14020
3. Maximum	270	870	4660
<u>Transshipment</u>			
1. None	1190	6110	17340
2. Within Utility	560	3860	14020
3. Inter-Utility	20	140	10030
<u>Capacity Factor</u>			
1. 60%	370	2450	9540
2. 70%	560	3860	14020
3. 80%	800	5600	19730
<u>Discharge Capability</u>			
1. Full Core Reserve	560	3860	14020
2. Annual Reload Only	40	1620	8750
<u>Burnup</u>			
1. Low-Base Case	560	3860	14020
2. High	430	2430	10810

FIGURE 8

RANGE OF AFR REQUIREMENTS
FOR SENSITIVITY ANALYSES

V. AFR REQUIREMENTS FOR FOREIGN FUEL

Predicting the exact quantity of foreign spent fuel that may be sent to the U.S. under the October 1977 offer is not currently possible because it will depend upon a number of variables. Therefore, a range of effects spanning the minimum and maximum quantities of spent fuel that might reasonably be expected to be sent to the United States will be described. Further discussion of the possible quantities, benefits and impacts resulting from the storage of foreign fuel in the U.S. can be found in DOE's Draft Environmental Impact Statement on the storage of foreign fuel (DOE/EIS-00400, December, 1978).

In the following sections, three conceptual levels of foreign fuel deliveries (Option 1, 2 and 3) that might be involved in the implementation of the President's offer to store foreign spent fuel under this policy are described. These options (Table 10) represent progressively larger increments of fuel that might be received, each increment from an additional category of countries. This breakdown is provided so that the nonproliferation benefits of different types of offers may be analyzed. Derivation of the annual and cumulative amounts of spent fuel for Option 3 appearing in Table II-1 have been predicated upon a fixed percentage of projected spent fuel that will be discharged up to the year 1995. These amounts from Option 3 countries are assumed to be conservative figures that would be the upper bound of our policy at this time. Further, the amounts describing discharges of countries in the other options (1 and 2) are

TABLE 10
Foreign Spent Fuel Delivered to United States

FY	Countries in Sensitive Regions (Option 1)		Nonproliferation Benefits - Low Option (Option 2)		Nonproliferation Benefit - High Option (Option 3)	
	Total		Total		Total	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1983	110	110	220	220	541	540
1984	50	160	125	340	417	960
1985	65	225	95	435	443	1400
1986	70	295	140	575	620	2020
1987	80	375	115	690	540	2560
1988	90	465	195	885	440	3000
1989	95	560	210	1095	480	3480
1990	110	670	220	1320	530	4010
1991	115	785	230	1550	600	4610
1992	120	905	240	1795	660	5270
1993	130	1035	250	2045	750	6020
1994	135	1170	265	2310	830	6850
1995	145	1315	285	2595	900	7750
1996	150	1465	305	2900	970	8720
1997	160	1625	330	3230	1080	9800
1998	170	1795	350	3580	1170	10,970
1999	180	1970	375	3955	1260	12,230
2000	190	2160	400	4355	1350	13,580

lower amounts that demonstrate an acceptance by U.S. of spent fuel on a more case-by-case basis. Figure 9 shows the AFR requirements for both foreign and domestic fuel.

1. Option 1 - Countries in Sensitive Regions

Under Option 1, the U.S. would accept spent fuel on a case-by-case basis only from countries located in sensitive regions where the protracted storage of even this material might be judged inappropriate or troublesome in terms of nonproliferation concerns. As used in this analysis, the term "sensitive regions" means areas of the world in which international tensions are high, and a risk of violent conflict may occur. The term also applies to areas in which a country's nuclear power program may represent an additional source of international tensions. In most of these instances, the U.S. acceptance of fuel would be limited to countries that have agreements for cooperation with the U.S. for peaceful use of nuclear energy. However, in some cases, the U.S. might accept spent fuel from the other nations.

The offer would apply to fuel that had cooled sufficiently to allow safe transport. For these cases, the U.S. would not insist that the sending countries would build up substantial local spent fuel storage capability. Under this option a few countries might wish to

FIGURE 9
AFR REQUIREMENTS
FOR COMBINED DOMESTIC AND FOREIGN FUEL

avail themselves of the United States spent fuel storage offer as a way of demonstrating their respective intentions to observe nonproliferation obligations, and in so doing, contribute to mutual confidence and a reduction of hostility and suspicion.

Precisely which countries or regions may at any given time be covered under this option or what quantities of spent fuel may be involved during a given period is difficult to specify. However, the quantities of spent fuel likely to exist in such circumstances are modest.

2. Option 2 - Low Option

Under Option 2, the U.S. would accept spent fuel on a case-by-case basis from the countries covered in Option 1 and in a limited number of other situations where there is a nonproliferation benefit and the countries have no ready alternative solutions for spent fuel disposition that are acceptable from a nonproliferation standpoint. Illustrative nonproliferation benefits may include adherence to the Nuclear Non-Proliferation Treaty, (NPT) adherence to the Tlatelolco Treaty, or acceptance of full-scope safeguards on nuclear facilities. Countries that play a key role in evolving useful international fuel cycle arrangements or that agree to renegotiate their agreements for cooperation with the United States to include the conditions established in the Nuclear Non-Proliferation Act of 1978 might also be given preference. The United States might also give preference to countries

which do not undertake reprocessing or that suspend new conventional reprocessing activities, or that avoid entering into major new commercial reprocessing contracts with third countries. Illustrative evidence that a country has no ready solution to spent fuel disposition could include: 1) a temporary shortage of local spent fuel storage capacity; 2) an inability to dispose of spent fuel domestically, e.g., on geologic or demographic grounds; or 3) unavailability of planned spent fuel storage in another country. In general, countries located outside of sensitive regions as defined in Option 1 would be expected to make good faith efforts to establish or expand local spent fuel storage capacity.

3. Option 3 - High Option

The U.S. would accept spent fuel from countries in sensitive regions (Option 1 countries) from other presumably smaller countries with clearly identifiable storage problems (e.g., Option 2 countries), and from some of the larger, industrialized, nonnuclear-weapons states. In each instance, action would be taken on a case-by-case basis when U.S. nonproliferation interests are served and there is an apparent need for the action. This option includes: 1) cases in which reprocessing is likely to be a probable alternative to storing fuel in the United States; 2) cases in which U.S. acceptance would be offered under terms that would encourage the sending country to develop alternatives to national reprocessing, including investigation

of multinational or national storage facilities; and 3) a larger number of cases in which nonproliferation treaty adherence or similar actions might be encouraged. Option 3 differs from Option 2 by expanding the scope of the offer to include a very few nonnuclear-weapon countries with larger nuclear power programs. In no instance would the U.S. offer extend to all the spent fuel generated in large nuclear power programs but only to specific amounts of spent fuel to which the needs and nonproliferation benefits described above are relevant.

Many of the observations applicable to the spent fuel storage situations discussed under Option 2 apply here. While some of the countries included in Option 3 may be considering acquiring their own reprocessing capabilities, the U.S. offer to accept their spent fuel may assist in deferring new investments.

APPENDIX A

DISFUL COMPUTER PROGRAM DESCRIPTION

The DISFUL computer program and its associated data base have been developed by the S. M. Stoller Corp. (SMSC) under contract to DOE to analyze spent fuel shipping and storage requirements for various storage scenarios, including different combinations of transshipment patterns (i.e., shipments between reactor pools), pool expansions and away-from-reactor storage requirements. In addition, yearly fuel discharges are estimated based either on the utility's estimate* or on a calculated value based upon an input capacity factor. The current DISFUL program can handle up to 250 reactors in 75 utilities, for a study period of 25 years commencing 1977. The utilities are further categorized as being located in one of the nine regions defined by the National Electric Reliability Council. DISFUL can account for transshipment from utility to utility within a given NERC region.

The analysis starts with an assumption as to how the reactor spent fuel storage pools will be expanded. DISFUL permits three different patterns of pool expansion (Expansion Options):

1. Maintenance of present pool capacity as of 12/31/78
2. Expansion of the pools according to current utility plans as of 12/31/78

*As given in the utilities' responses to the Moss Committee questionnaire of November 1977.

3. Expansion of the pools to the maximum estimate (as given in the data base) in a selected year (1981) or at startup, whichever is later.

In each case, spent fuel pools for reactors not yet in operation are assumed to be ready during the initial loading and pre-startup testing period, that is in the calendar year preceding the start of commercial operation of the plant; thus they are available for storage of assemblies from other reactors. For Option 3, pool expansion is to the maximum in year 1981 or in the year before startup, whichever is later; prior to 1981, expansion is assumed to be according to utility plans.

One of two possible estimates is utilized as the maximum. Either a utility-provided maximum storage capability or an SMSC-generated maximum storage capability is utilized depending upon whether or not the utility has provided a maximum estimate. These estimates have been individually reviewed with the utilities to obtain their comments on them, and only where they indicated that they were not committed to an alternative have the maximum estimates been used.

Some examples of alternative commitments are:

1. Carolina Power and Light has indicated that the costs associated with making the necessary structural modifications to Robinson 1 to enable it to expand further are prohibitive. It would require

shutting the plant down and purchasing replacement power while equipment was relocated from under the fuel pool floor to enable supports to be placed to carry the load of a more densely packed fuel pool.

2. Maine Yankee can get only an additional 185 spaces by going to more closely spaced racks. The marginal cost for this modification would cause them to consider other alternatives, such as a separate at reactor storage pool, before re-racking for such a small gain in storage capability.

The result of this portion of the calculation is the fuel pool capacity of each reactor as a function of time.

The next step in the analysis is the determination of when shipment away from the reactor's own storage pool is required. This is set in DISFUL according to one of three different shipment options:

1. Maintenance of full core discharge capability
2. Maintenance of normal yearly discharge capability
3. Shipment of assemblies stored a given number of years after discharge.

Under the third Shipment Option, assemblies will be shipped before they are stored for the specified number of years if failure to do so will

violate the normal yearly discharge criterion. For the same Shipment Option, if assemblies older than the specified number of years are present in the storage pool at the beginning of the study period, they are shipped off-site immediately.

The assemblies comprising a given shipment are always the oldest in the pool (at discharge, assemblies are '0' years old).

For the purpose of determining how many assemblies will be in the pool as a function of time, it was assumed (for reactors with a pre-1977 startup date) that the number of assemblies already discharged, as given in the data base, includes the 1977 discharge. For reactors starting up in 1977 or later, the first discharge was assumed to occur in the year following startup, with annual discharges thereafter.

The size of the annual discharge is, on option, set by the utility estimate entered in the data base, or calculated as a function of capacity factor. If the calculated value is used, it is found, assuming uniform fuel batches at equilibrium, from

$$\text{ASSEMBLIES DISCHARGED} = \frac{\text{THERMAL POWER} \times 365.25 \times \text{CAPACITY FACTOR}}{\text{MTU/ASSEMBLY} \times \text{AVERAGE DISCHARGE BURNUP}}$$

In general, PWR's are assumed to have average burnups at discharge of 31,000 MWD/MTU, while the corresponding values for BWR's is

23,000 MWD/MTU. Other specific and lower values have been entered for 14 currently operating reactors; these are listed in Table A-1.

TABLE A-1

BURNUPS USED IN CALCULATIONS
OF YEARLY DISCHARGE BATCH SIZE

<u>Reactor</u>	<u>Average Burnup at Discharge, MWD/MTU</u>
Connecticut Yankee	20,000
Big Rock Point	11,025
Palisades	24,000
La Crosse	16,800
Oconee 1,2,3	27,000
Ft. Calhoun	27,700
Humboldt Bay	17,500
Brown's Ferry 1,2,3	20,900
Vermont Yankee	20,900
Yankee Rowe	16,540

The third Option used in the analysis is the type of transshipment permitted. There is in DISFUL a choice of four such options, each of which describes the action that may be taken before final shipment to a Federal Facility such as an Interim Spent Fuel Storage Facility or Spent Fuel Repository.

1. No transshipment permitted (i.e., storage within a reactors own pool only).
2. Unlimited intra-utility shipment (i.e., storage in any pool in the same or affiliated utility. This makes maximum use of all available storage within a given utility's plants).

3. Limited intra-utility shipment (assemblies may be shipped to one intermediate site in the same or affiliated utility before shipment to a Federal Facility).
4. Limited inter-utility shipment (assemblies may be shipped from one utility to one other utility in the same NERC region before shipment to a Federal Facility. Each of the utilities is considered as a single storage unit in this scenario).

The analyses for Transshipment Options 1 and 2 are similar; in each case, the available pool capacity, defined as the total capacity reduced by the requirement for either full core or normal yearly discharge capability, is compared with the amount to be stored including the current year's discharge. If the available capacity is exceeded, the oldest assemblies are shipped to a Federal Repository. In Option 1, this comparison is done for each reactor and its pool individually. For Option 2, pool capacities and reactor discharges are summed for the utility, and then shipments are determined as in 1. The age and number of assemblies in each shipment is calculated, as is the impact on the Federal Storage Facility attributable to each source reactor or utility.

Transshipment Option 3 permits one intermediate site before shipment to a Federal Repository; that site is chosen as the pool in the same utility having the maximum available capacity. When it becomes necessary for any pool to ship fuel, the oldest fuel in the pool is chosen. If the fuel

originated from the reactor at the site, it is shipped to another pool in the same utility (chosen as before). If the oldest fuel originated at another reactor, it is shipped to the Federal Repository. Of course, when there is no space available for transshipped fuel, then all fuel is shipped to the Federal Repository. Fuel characteristics of shipments under this system are all completely defined, with origin, age and present site of all assemblies known at all times.

The assumption made under Transshipment Option 4 is that maximum use is made of a utility's pools before shipment to a single intermediate destination (another utility) is permitted, i.e., there is unlimited intra-utility shipment prior to the limited inter-utility transfer.

The same criteria for choice of destination and fuel to be shipped are applied here as in Option 3, except that they are applied to utilities.

The same criteria for choice of destination and fuel to be shipped are applied here as in Option 3, except that they are applied to utilities rather than individual reactors.

Table A-2 compares the nuclear electric power growth utilized in the DISFUL data base with other recent projections of nuclear power growth. The commercial operation dates for reactors with limited work authorization and construction permits are based on an SMSC percentage of completion model. For reactors that do not have CP's or LWA's the commercial operation data is based on the utility estimate. As can

be seen from Table A-1, the DISFUL data base case lies between current utility and the DOE-Energy Information Service low-growth scenario.

TABLE A-2
GROWTH OF NUCLEAR POWER

Year	<u>1983</u>	<u>1988</u>	<u>1993</u>
+ Utility Plans	112.5	176.2	252.5
* SMSC % of Completion Model (Reference Case)	95.8	167.5	181.6
+ DOE Energy Information Service Low-Growth Scenario	82.5	130	192.5

+ Includes continued growth, i.e., addition of new plants not yet committed.

* Operating and committed plants only.

APPENDIX B

Reactors With Near-Term Problems

Oconee 1 & 2 - Duke Power Co.

The Oconee 1, 2 reactors share a fuel pool with a capacity of 306 fuel assemblies. Since their full core size is 177 fuel assemblies and 194 assemblies are in residence, they are operating without full core reserve. Oconee has had a program of transfer of fuel to the Oconee 3 pool and plans to transfer fuel subsequently to McGuire and the other units on its system. NRC licensing hearings for the McGuire transfers are now in progress.

Based upon the assumptions in the base case, shipment of fuel to an AFR would be required in 1978, subsequently the reactors ship to McGuire or other units on the Duke system. In practice the Oconee units will operate temporarily without full core reserve before transferring fuel to McGuire or other reactors on Duke's system.

Duke is also considering expanding the Oconee fuel pools, although the racks currently in place are welded to fixtures on the floor and walls and makes interplant transfer the preferred alternative.

Oconee 3 - Duke Power Co.

The Oconee 3 pool capacity was expanded in 1976 to 465 fuel assemblies. The situation at Oconee 3 is similar in most respects to Oconee 1 and 2 and it is also operating without FCR currently, before shipping to other plants on the Duke system.

San Onofre-1 - Southern California Edison

San Onofre-1 has a fuel pool with a capacity of 216 fuel assemblies. Currently 58 fuel assemblies are in residence. In this analysis, it would require shipment to AFR storage in 1978 and 1979. Thereafter, it would ship to San Onofre 2 or 3. In fact San Onofre is shipping fuel to the GE facility at Morris, Illinois for interim storage. Also the contracted shipment occurs in 1979. San Onofre-1 cannot be expanded because of seismic and structural limitations.

Humboldt Bay - Pacific Gas & Electric

In this analysis Humboldt Bay would require shipments to an AFR starting in 1979. Humboldt Bay is presently shut down because of licensing problems and it is not expected to start up for at least a year.

Brunswick 1 & 2 - Carolina Power & Light Co.

The Brunswick Units (BWR's) require AFR storage in 1980 and 1981 respectively. These units have had their pools expanded to store both BWR and PWR type fuel. The Robinson plant is presently shipping fuel to the Brunswick Pool (see discussion below). The storage requirements indicated in this analysis for Brunswick are for BWR type fuel and assume only the BWR portion of the pools as described below is available for BWR fuel storage.

The capacity of Brunswick-1 pool is 1098 BWR assemblies and 128 PWR assemblies. It is estimated that 114 PWR assemblies are in residence to meet the case criteria of full core reserve at Robinson. The Brunswick-2 pools were expanded to accommodate 990 BWR fuel assemblies and 176 PWR fuel assemblies. It is estimated that as of the end of 1978, 283 BWR assemblies were in residence and 42 PWR assemblies. Brunswick 1 & 2 pools have been expanded to their structural limit.

McGuire-1 - Duke Power Co.

McGuire-1 has storage capacity for 500 fuel assemblies. In this analysis the Oconee units ship to McGuire in the early years. In 1981 McGuire has to start shipping fuel to an AFR. The fuel being shipped is Oconee fuel. Oconee fuel is shipped off-site until 1986 when all Oconee fuel has been transferred. At that time McGuire fuel is transferred to other reactors on the Duke system. This procedure follows the criteria of shipping oldest fuel first. McGuire racks are welded to fixtures of the fuel pool and expansion would be difficult. This is similar to Oconee reactors.

Nine Mile Point-1 - Niagara Mohawk Power Co.

Nine Mile Point-1 has a capacity of 1520 fuel assemblies according to Niagara Mohawk's current plans. According to this analysis a shipment to an AFR would be required in 1981. Subsequent to that Nine Mile 2

becomes available and until 1990 shipments take place to this unit. There are possible seismic problems with further pool expansion.

Diablo Canyon- 1, 2 - Pacific Gas & Electric Co.

Based upon current plans and base case assumptions, these two units respectively will need to begin shipping in 1981 and 1982 to AFR storage. There is potential for expansion in the basin to 1400 - 1450 MTU; however, the utility does not presently have an established schedule for expansion.

Robinson - Carolina Power and Light

Carolina Power and Light has indicated that the costs associated with making the necessary structural modifications to Robinson 1 to enable it to expand further are prohibitive. It would require shutting the plant down and purchasing replacement power while equipment was relocated from under the fuel pool floor to enable supports to be placed to carry the load of a more densely packed fuel pool. Robinson is currently shipping to the Brunswick fuel pools as previously discussed.

Yankee Rowe - Yankee Atomic Electric Co.

Yankee Rowe has a capacity of 391 fuel assemblies. This capacity is exhausted when maintaining full core reserve and shipments to AFR storage begin in 1982. Basin is near maximum capacity and the marginal cost of an additional small increment of storage does not appear to be justified.

Hatch 1,2 - Georgia Power Co.

Hatch 1,2 share a pool with a capacity of 1960 fuel assemblies. This pool can be expanded but the utility has no firm plans to do so.

Shipments to AFR storage are required beginning in 1983 if full core discharge is maintained.

Prairie Island 1,2 - Northern States Power

These units share a fuel pool with a capacity of 687 fuel assemblies.

First shipment to AFR storage is needed in 1983. By 1985 Tyrone is available and shipments from these units go there.

The Prairie Island 1,2 fuel pool is capable of being expanded to somewhat less than twice its current capacity. This is under study.

Zimmer-1 - Cincinnati Gas and Electric

The current capacity of the Zimmer-1 fuel pool is 1120 fuel assemblies.

The utility could approximately double this capacity, but no schedule is presently defined for doing this. At its present capacity shipments to AFR storage would be required in 1984.

Oyster Creek - Jersey Central Power & Light

This utility has plans to expand this unit to 1796 fuel assemblies in steps between now and 1984. They are basically expanding to maintain full core reserve and according to this analysis first shipments to AFR storage will be required in 1984.

Fort Calhoun - Omaha Public Power District

Fort Calhoun has a fuel pool of 483 assemblies. The pool is expandable, but there would be a problem working around fuel in residence.

Rancho Seco - Sacramento Municipal Utility District

The capacity of the fuel pool at this reactor is 575 fuel assemblies. Based on this analysis shipments to AFR storage would be required in 1984. The utility has no current plans to further expand this unit.

Arkansas Nuclear One-1 - Arkansas Power & Light Co.

This unit has a fuel pool capacity of 590 fuel assemblies and first shipments to AFR storage are required in 1985. The utility has no current plans for further expansion.

Arkansas Nuclear One-2

This unit has a fuel pool capacity of 486 assemblies and its status is similar to ANI-1.

McGuire-2 - Duke Power Co.

Like McGuire-1 this unit has a fuel pool capacity of 500 fuel assemblies. Shipments of Oconee fuel are required from this unit to AFR storage beginning in 1985. Subsequent to this McGuire fuel is shipped to other units on the Duke system. Further expansion of basin would be difficult since racks are welded to fixtures in the basin.

Maine Yankee - Maine Yankee Atomic Power Co.

Maine Yankee has a fuel pool capacity of 943 assemblies. There are no plans to expand it further. First shipments to AFR storage are required in 1985. Main Yankee can get only an additional 185 spaces by going to more closely spaced racks. The marginal cost for this modification would cause them to consider other alternatives, such as a separate at reactor storage pool, before re-racking for such a small gain in storage capability.

Susquehanna-1,2 - Pennsylvania Power & Light Co.

Susquehanna 1,2 have mutually accessible fuel pools of 1015 fuel assemblies capacity each. First shipments are required in 1985 to AFR storage for this case. The utility has plans to expand by approximately 50%, but has no presently defined firm schedule.