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Spent Nuclear Fuel— A Comparison of At-Reactor Basin Storage And Away-From-Reactor Storage

July 1980

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SPENT NUCLEAR FUEL -
A COMPARISON OF AT-REACTOR BASIN STORAGE
AND AWAY-FROM-REACTOR STORAGE

INTRODUCTION

A nuclear power reactor operator, confronted with rising spent fuel inventories that would soon exceed his storage capacity, has several options to remedy this situation. These options include transshipment, reracking of existing at-reactor storage basins (ARB), new ARB's, and away-from-reactor (AFR) basins. This report examines the latter two cases where a macro-economic comparison of each storage system is developed.

SUMMARY

The macro-economic comparison of the ARB and AFR spent nuclear fuel storage systems was developed using the following major assumptions: Those reactors which begin commercial operation in 1987 and after provide lifetime spent fuel storage for the entire reactor site; and nuclear waste repositories begin operation in 1997 and 2000. Based upon these assumptions and given the choice between the ARB and the AFR storage system for spent nuclear fuel, the AFR storage system proved to be significantly more economical. This analysis indicates that 46 ARB's would be needed to meet storage requirements compared to only three AFR's. As shown in Table 1, the total discounted costs associated with building new ARB's and AFR's are \$4.7 billion and \$1.2 billion respectively. This results in a total cost penalty of \$3.5 billion. This cost must be borne by the utility ratepayer.

The same licensing requirements established by the Nuclear Regulatory Commission (NRC) would apply to both Government AFR's and privately-owned ARB's. However, the total amount of manpower and other licensing resources required in the AFR licensing process would be considerably less than if it became necessary for a large number of utilities to license their own new ARB's. Furthermore, the Government is in a better position to plan for interim storage until nuclear waste repositories become available. This can be done by providing AFR storage in increments to meet the demand over time. Building ARB's could produce an excess amount of storage capacity.

TABLE 1

Economic Comparison of
ARB Storage Versus
AFR Storage
(1980 dollars)

	<u>Number of Facilities</u>	<u>Capital Cost (\$ Billions)</u>	<u>Total Cost (\$ Billions)</u>
ARB Storage System	46	1.2	4.7
AFR Storage System	3	0.5	1.2
Cost Penalty of ARB Storage System	-	0.7	3.5

DISCUSSION

Background

On April 7, 1977, President Carter announced that the United States would defer indefinitely all commercial reprocessing of spent nuclear fuel. The Department of Energy (DOE) announced its spent fuel policy on October 18, 1977, whereby, in order to avoid nuclear reactor shutdowns, the Government would provide interim storage of spent fuel pending either a final decision on reprocessing or the availability of a permanent nuclear waste repository.

As noted in President Carter's policy statement of February 12, 1980, on the radioactive waste management program, management of commercial spent fuel is primarily a responsibility of the utilities. However, a limited amount of Government storage capacity would provide flexibility to the national waste disposal program and an alternative for those utilities which are not able to provide sufficient long-term spent fuel storage capability due to technical, regulatory, or institutional reasons. It is desirable to assure that domestic utilities are able to maintain capacity for storing the full reactor core, if its discharge becomes necessary. This would avoid potential extended reactor outages and the resulting economic penalties to the energy user from purchasing replacement electric power.

DOE has solicited expressions of interest from private industry for financing and constructing AFR storage facilities. While a number of firms expressed interest, it was with the stipulation of Government financial guarantees, which could not be provided. Therefore, it was concluded that AFR facilities would have to be provided by the Government in order to be available on a timely basis.

DOE has submitted to Congress spent nuclear fuel legislation which would provide DOE with the authority to design, acquire or construct, and operate one or more AFR storage facilities; accept domestic spent fuel for storage until permanent disposal facilities are available; and accept a limited amount of foreign spent fuel to support nonproliferation policy objectives.

This report assumes that this legislation is passed, and a decision subject to the provisions of the National Environmental Policy Act is made to provide AFR capacity. New AFR's could only meet the needs after 1990 since a new AFR could not be licensed and built in time to meet near-term requirements. Existing facilities would have to be acquired to meet near-term needs. The estimated value of these facilities is currently based upon unit storage costs for a new facility. Consequently unit costs for new or existing AFR facilities are the same. Alternatives to AFR storage include transshipping fuel, reracking existing ARB's, or building new ARB's. This report compares only the latter case to AFR storage.

AFR Requirements

The following presents a list of assumptions used to determine AFR storage requirements. This study includes only the domestic spent fuel storage requirements shown in DOE's planning base published in DOE/NE-0002 (Reference 1). DOE's planning base assumes maximum reracking of existing ARB's, no transshipment of fuel, maintenance of full core reserve (FCR) within the ARB's, and operation of nuclear reactors at a 70 percent capacity factor.

For this study additional assumptions were added to DOE's planning base case. Reactors which begin commercial operation in 1987 and after were assumed to provide lifetime spent fuel storage for the entire site. In addition, the Tennessee Valley Authority (TVA) will also provide lifetime storage for each of their reactor sites. Six reactor sites do not contribute to the AFR requirements for various reasons. See Appendix A for a list of these sites. Finally, the Three Mile Island (TMI) site was assumed to provide lifetime storage. The incident which caused TMI-2 to be shutdown for an extended period removed the site from AFR requirement consideration. Using these assumptions, a reactor-by-reactor analysis (Reference 2) of DOE's planning base was performed to determine an adjusted AFR storage requirements schedule. To determine the final adjusted storage requirements, repository receiving rates were incorporated into the requirements projections. The first repository is assumed to be available to receive spent fuel in 1997 and the second in 2000. Appendix B contains the detailed repository receiving rates. Table 2 presents the results of the above analysis.

TABLE 2

Storage Requirements

Year	Cumulative AFR Storage Requirements (MTU) ¹	Annual Adjusted AFR Storage Requirements (MTU) ²	Cumulative Adjusted AFR Storage Requirements (MTU) ²	Cumulative Amount Shipped to Repository (MTU) ³	Final Adjusted Storage Requirements (MTU)
1979	81	77	77	0	77
1980	127	38	115	0	115
1981	186	51	166	0	166
1982	280	86	252	0	252
1983	378	90	342	0	342
1984	530	144	486	0	486
1985	755	217	703	0	703
1986	1,046	283	986	0	986
1987	1,487	433	1,419	0	1,419
1988	1,981	484	1,903	0	1,903
1989	2,524	532	2,435	0	2,435
1990	3,265	704	3,139	0	3,139
1991	4,254	839	3,978	0	3,978
1992	5,511	943	4,921	0	4,921
1993	6,987	1,147	6,068	0	6,068
1994	8,694	1,375	7,443	0	7,443
1995	10,751	1,643	9,086	0	9,086
1996	13,218	1,851	10,937	0	10,937
1997	16,021	2,066	13,003	900	12,103
1998	19,151	2,178	15,181	2,700	12,481
1999	22,576	2,333	17,514	4,500	13,014
2000	26,168	2,406	19,920	7,200	12,720
2001	30,006	2,490	22,410	10,800	11,610
2002	34,081	2,611	25,021	16,500	8,521
2003	38,319	2,649	27,670	24,300	3,370

¹ Obtained from Reference 1.² Obtained using assumptions stated in this report.³ See Appendix B.

AFR Costs

Table 2 shows that in 1999 the final adjusted storage requirement is 13,014 MTU. This is the maximum amount of spent fuel that requires AFR storage. After 1999 the final adjusted storage requirements decrease because the annual repository receiving rates exceed the annual adjusted AFR storage needs. Assuming that a new AFR has a capacity of 5000 MTU, only three new AFR's must be built to satisfy the needs.

AFR costs can be calculated using the following equations:

$$(1) \text{ Total Cost} = (\text{AFR capacity}) \times \left(\frac{\text{Unit Cost}}{\text{Total}} \right) \times \left(\frac{\text{Number of AFR's}}{\text{of}} \right)$$

$$(2) \text{ Capital Cost} = (\text{AFR capacity}) \times \left(\frac{\text{Unit Cost}}{\text{Capital}} \right) \times \left(\frac{\text{Number of AFR's}}{\text{of}} \right)$$

The unit total cost is \$154,000/MTU and the unit capital cost is \$59,000/MTU. All unit costs were obtained from DOE/SR-SF-2002 (Reference 3) and escalated to 1980 dollars. AFR costs were discounted back to 1980 and are shown in Table 3.

TABLE 3

AFR Costs

<u>Number of AFR's</u>	<u>Capital Cost (\$ Billions)</u>	<u>Total Cost (\$ Billions)</u>
3	0.5	1.2

ARB Requirements

If there were no AFR's for storage of spent fuel, then utilities would have to build their own ARB's for storage. As stated in a previous section, all reactors which start operation in 1987 and after would provide lifetime storage capacity on-site. Those reactors which start up before 1987 and require additional storage capacity must build new ARB's. The assumptions concerning TVA, TMI, and the six reactor sites of Appendix A which were used to determine AFR requirements were also used in developing the ARB requirements. Each ARB will provide lifetime storage for the entire reactor site and will consist of three types. A 500 MTU capacity ARB will be built for sites having one reactor on a site. An 1100 MTU capacity and 1900 MTU capacity ARB will be built for sites having two and three reactors per site respectively. The demand schedule for ARB's is based on a reactor-by-reactor analysis.

Consistent with the assumption of maintaining FCR at existing ARB's, new ARB's will start up in the year that FCR is scheduled to be lost at an existing ARB on site. The date that FCR is lost was determined using DOE's planning base case. Each ARB can be designed, licensed, and built in 7 years (Reference 4). Thus a decision to build an ARB must be made 7 years before the scheduled startup date. However, if a utility decided to build an ARB today, then it would not begin operation until 1987. Consequently, those reactors that lost FCR before 1987 will start up in 1987. In addition, it was assumed that utilities do not commit or expend funds on a new ARB within 7 years of scheduled repository startup. The repository startup dates are the same as previously stated. Table 4 shows the projected ARB requirements and Appendix C provides more detailed information.

TABLE 4

ARB Startup Schedule

<u>ARB Startup Date*</u>	<u>Number of ARB's</u>
1987	13
1988	1
1989	4
1990	5
1991	2
1992	2
1993	4
1994	7
1995	6
1996	2
1997 and beyond	<u>0</u>
Total	46

*A decision to build an ARB must be made
7 years before indicated date.

ARB Costs

The equations for calculating ARB costs are similar to the AFR cost equations, and they are given below:

$$(3) \text{ Total Cost} = \sum (x)(a_x)(c_x)$$

$$(4) \text{ Capital Cost} = \sum (x)(b_x)(c_x)$$

where x = ARB Capacity and can be 500, 1100, or 1900 MTU

a_x = Unit Total Cost for an ARB of x capacity

b_x = Unit Capital Cost for an ARB of x capacity

c_x = Number of ARB's of x capacity

The unit total costs for a 500, 1100, and 1900 MTU capacity ARB are \$348,000/MTU, \$201,000/MTU, and \$149,000/MTU, respectively. The unit capital costs for a 500, 1100, and 1900 MTU capacity ARB are \$87,000/MTU, \$51,000/MTU, and \$38,000/MTU, respectively. All ARB sizes and costs were obtained from DOE/SR-SF-2002; and the costs were escalated to 1980 dollars. ARB costs were discounted back to 1980 and are shown in Table 5.

TABLE 5

ARB Costs

<u>Number of AFR's</u>	<u>Capital Cost (\$ Billions)</u>	<u>Total Cost (\$ Billions)</u>
46	1.2	4.7

AFR-ARB Comparison

Table 6 shows the impact of the ARB and AFR systems. A total of 46 ARB's must be designed, licensed, and built in order to satisfy the spent fuel storage needs of the U.S. nuclear power reactors considered. The capital and total discounted costs involved are \$1.2 billion and \$4.7 billion, respectively. The number of AFR's that must be designed, licensed, and built is considerably less. Only three new AFR's are needed to satisfy storage requirements. The capital and total discounted costs involved are \$0.5 billion and \$1.2 billion, respectively.

These cost estimates are conservative at best due to the additional assumptions added to DOE's planning base. However, a total cost penalty of \$3.5 billion

still exists. This penalty represents a cost that must be passed on to the utility ratepayer. AFR's are significantly more economical than ARB's.

DOE has made a commitment that Government-owned AFR's would be licensed and regulated by the NRC. Both AFR's and ARB's would be subject to the same licensing procedures. However, the total amount of manpower and other licensing resources required to license three AFR's would be considerably less than the amount needed to license 46 ARB's. As many as 13 ARB's would have to be licensed in 1 year.

As shown in Appendix C, the 46 ARB's provide storage capacity for 42,200 MTU of fuel. This is in excess of the maximum amount of spent fuel that requires storage. Table 2 shows this amount to be 13,014 MTU. Each utility is faced with a major decision concerning the amount of ARB storage capacity to be provided. They must know with confidence when permanent nuclear waste repositories are to be available. However, the Government is in a better position to plan for interim storage of spent fuel. This can be done by providing AFR storage in increments to meet the demand over time. Implementation of the spent fuel storage policy would provide an economically feasible alternative to help alleviate utility uncertainty and would be an important first step in closing the back end of the fuel cycle.

TABLE 6

Economic Comparison of
ARB Storage Versus
AFR Storage
(1980 dollars)

	<u>Number of Facilities</u>	<u>Capital Cost (\$ Billions)</u>	<u>Total Cost (\$ Billions)</u>
ARB Storage System	46	1.2	4.7
AFR Storage System	3	0.5	1.2
Cost Penalty of ARB Storage System	-	0.7	3.5

Sensitivity Analysis

Two sensitivity cases to the reference case were considered:

1. Delay repository startup

2. Build smaller ARB's

1. A delay in repository startup changes the number of AFR's and ARB's required to meet storage needs. It is assumed here that the first repository starts operation in 2000 and the second in 2003. Table 7 shows the storage needs in this case. The maximum final adjusted storage requirement occurs in 2002 and is 20,521 MTU. This would require five AFR's. In addition to the 46 new ARB's in the reference case, nine other ARB's are required. The ARB startup schedule for these nine is shown in Table 8. Appendix D contains the detailed information on the additional nine ARB's.

TABLE 7

Storage Requirements With a
Delay in Repository Startup

<u>Year</u>	<u>Annual Adjusted AFR Storage Requirements (MTU)</u>	<u>Cumulative Adjusted AFR Storage Requirements (MTU)</u>	<u>Cumulative Amount Shipped to Repository (MTU)</u>	<u>Final Adjusted Storage Requirements (MTU)</u>
1999	2,333	17,514	0	17,514
2000	2,406	19,920	900	19,020
2001	2,490	22,410	2,700	19,710
2002	2,611	25,021	4,500	20,521
2003	2,649	27,670	7,200	20,470

TABLE 8ARB Startup Schedule with a Delay
in Repository Startup

<u>Year</u>	<u>Number of Additional ARB's</u>
1997	5
1998	3
1999	1
2000 and beyond	<u>0</u>
Total	9

The economic comparison for this case is shown in Table 9. A capital cost penalty of \$0.7 billion and a total cost penalty of \$3.7 billion exist. A comparison to the reference case indicates that delays in the repository startup dates will increase the total cost penalty.

TABLE 9Economic Comparison of
ARB Storage Versus AFR Storage
with a Delay in Repository Startup
(1980 dollars)

	<u>Number of Facilities</u>	<u>Capital Cost (\$ Billions)</u>	<u>Total Cost (\$ Billions)</u>
ARB Storage System	55	1.3	5.3
AFR Storage System	5	0.6	1.6
Cost Penalty of ARB Storage System	-	0.7	3.7

2. A utility, when faced with the decision to build an ARB, may not decide to build lifetime storage as the reference case assumes. This case assumes smaller sized ARB's are built. ARB size is based on the cumulative amount of fuel to be stored to maintain FCR at the existing ARB up to and including 1997. If the requirement is 500 MTU or less, then a 500 MTU capacity ARB is built. An 1100 MTU capacity is built for requirements in the 501-1100 MTU range. A 1900 MTU capacity ARB is built for storage requirements above 1100 MTU. Appendix E shows that forty 500 MTU ARB's and six 1100 MTU ARB's are needed. No 1900 MTU ARB's are built.

The economic comparison for this case is given in Table 10. Building smaller ARB's result in lower capital and total costs than the reference case. However, even though the resulting cost penalties are lower, they still are significant. In addition, the above assumption to provide storage only until 1997, which is when the first repository starts up is not completely realistic. Thirteen reactor sites have to make a decision in 1980 to build an ARB. This is 17 years before a repository begins receiving fuel and would require the utility to know with confidence today that a repository would be in operation in 1997. If this date were missed, then additional storage capacity would have to be added.

TABLE 10

Economic Comparison of
ARB Storage Versus AFR Storage
Based on Smaller Sized ARB's
(1980 dollars)

	<u>Number of Facilities</u>	<u>Capital Cost (\$ Billions)</u>	<u>Total Cost (\$ Billions)</u>
ARB Storage System	46	1.1	4.1
AFR Storage System	3	0.5	1.2
Cost Penalty of ARB Storage System	-	0.6	2.9

REFERENCES

1. DOE/NE-0002, "Spent Fuel Storage Requirements--The Need for Away-From-Reactor Storage," January 1980.
2. DOE/SR-0004, "Appendices for Department of Energy Study on Spent Nuclear Fuel Storage," Volume II, March 1980.
3. DOE/SR-SF-2002, "Spent Fuel Storage Costs--Reracking, AR Basins, and AFR Basins," January 1980.
4. "Spent Fuel Management Program Study, Summary Option Paper," Prepared by the Division of Fuels, Tennessee Valley Authority, May 1979.
5. DOE/NE-0007, "Proposed Rulemaking on the Storage and Disposal of Nuclear Waste--Statement of Position of the United States Department of Energy," April 1980.

Appendix A

Six Reactor Sites Given Special Consideration*

1. Dresden-1
2. Big Rock Point
3. LaCrosse
4. Humboldt Bay
5. North Anna-3, 4
6. WNP-1, 2, 3, 4, 5

*These sites do not contribute to storage needs for one or more of the following reasons: The reactors are shutdown or will be shutdown shortly; or the utilities have announced changes in reactor plans.

Appendix B

Repository Receiving Rates* (MTU)

<u>Year</u>	<u>Repository</u>		<u>Annual</u> <u>Capacity</u>	<u>Cumulative</u> <u>Capacity</u>
	<u>#1</u>	<u>#2</u>		
1	900	0	900	900
2	1,800	0	1,800	2,700
3	1,800	0	1,800	4,500
4	1,800	900	2,700	7,200
5	1,800	1,800	3,600	10,800
6	3,900	1,800	5,700	16,500
7	6,000	1,800	7,800	24,300

*Obtained from Reference 5.

Appendix C *

ARB Requirements

<u>ARB Startup Date</u>	<u>Size of ARB (MTU)</u>	<u>Number of ARB's</u>	<u>Applicable Reactors</u>
1987	500	3	Robinson-2 Palisades Oyster Creek
	1,100	7	Brunswick-1,2 Turkey Point-3,4 Surry-1,2 Arkansas Nuclear One-1,2 Peach Bottom-2,3 North Anna-1,2 St. Lucie-1,2
	1,900	3	Oconee-1,2,3 San Onofre-1,2,3 Millstone-1,2,3
1988	500	1	Maine Yankee
1989	500	2	Fort Calhoun-1 Fitzpatrick
	1,100	2	Calvert Cliffs-1,2 Indian Point-2,3
1990	500	3	Cooper Monticello Vermont Yankee
	1,100	2	La Salle-1,2 Limerick-1,2
1991	500	2	Connecticut Yankee Yankee-Rowe
1992	500	1	Trojan
	1,100	1	Zion-1,2
1993	500	1	Summer
	1,100	3	Perry-1,2 Beaver Valley-1,2 Prairie Island-1,2

ARB Requirements (continued)

<u>ARB Startup Date</u>	<u>Size of ARB (MTU)</u>	<u>Number of ARB's</u>	<u>Applicable Reactors</u>
1994	500	4	Zimmer-1 Fermi-2 Duane Arnold Rancho Seco-1
	1,100	3	Byron-1,2 Braidwood-1,2 Midland-1,2
1995	500	1	Waterford-3
	1,100	5	Quad Cities-1,2 D.C. Cook-1,2 Nine Mile Point-1,2 Susquehanna-1,2 Salem-1,2
1996	1,100	2	Dresden-2,3 Marble Hill-1,2
1997 and beyond		0	
Totals			
	500 MTU	18	
	1100 MTU	25	
	1900 MTU	3	
		<u>46</u>	
Total Capacity: 42,200 MTU			

* This appendix was developed using the assumptions stated in this report and in no way does it represent policies or schedules established by the utilities that own and operate the above reactors.

Appendix D *

ARB Requirements With a Delay in Repository Startup**

<u>ARB Startup Date</u>	<u>Size of ARB (MTU)</u>	<u>Number of ARB's</u>	<u>Applicable Reactors</u>
1997	500	1	Crystal River
	1,100	4	McGuire-1,2 Hatch-1,2 Seabrook-1,2 Comanche Peak-1,2
1998	1,100	2	Grand Gulf-1,2 Point Beach-1,2
	1,900	1	Palo Verde-1,2,3
1999	1,100	1	South Texas-1,2
2000 and beyond		0	
Totals			
	500 MTU	1	
	1100 MTU	7	
	1900 MTU	$\frac{1}{9}$	

Total Capacity: 10,100 MTU

* This appendix was developed using the assumptions stated in this report and in no way does it represent policies or schedules established by the utilities that own and operate the above reactors.

** This is in addition to Appendix C

Appendix E *

ARB Requirements Based on Smaller Sized ARB's

<u>ARB Startup Date</u>	<u>Cumulative Amount of Fuel to be Stored to Maintain FCR at Existing ARB through 1997 (MTU)</u>	<u>Size of ARB (MTU)</u>	<u>Number of ARB's</u>	<u>Applicable Reactors</u>
1987	374	500	8	Robinson-2
	382			Palisades
	281			Oyster Creek
	429			Turkey Point-3,4
	447			Surry-1,2
	367			Arkansas Nuclear One-1,2
	479			North Anna-1,2
	282			St. Lucie-1,2
	872	1,100	5	Brunswick-1,2
	799			Peach Bottom-2,3
	943			Oconee-1,2,3
	511			San Onofre-1,2,3
	561			Millstone-1,2,3
	211	500	1	Maine Yankee
	109			Fort Calhoun-1
1989	225	500	4	Fitzpatrick
	375			Calvert Cliffs-1,2
	370			Indian Point-2,3
	208	500	4	Cooper
1990	140			Monticello
	135			Vermont Yankee
	476			Limerick-1,2
	553	1,100	1	La Salle-1,2
1991	143	500	2	Connecticut Yankee
	57			Yankee Rowe
	159	500	2	Trojan
1992	293			Zion-1,2
1993	104	500	4	Summer
	392			Perry-1,2
	110			Beaver Valley-1,2
	113			Prairie Island-1,2

ARB Requirements Based on Smaller Sized ARB's (continued)

<u>ARB Startup Date</u>	<u>Cumulative Amount of Fuel to be Stored to Maintain FCR in Existing ARB through 1997 (MTU)</u>	<u>Size of ARB (MTU)</u>	<u>Number of ARB's</u>	<u>Applicable Reactors</u>
1994	98 137 60 80 209 207 154	500	7	Zimmer-1 Fermi-2 Duane Arnold Rancho Seco-1 Byron-1,2 Braidwood-1,2 Midland-1,2
1995	61 125 163 59 198 123	500	6	Waterford-3 Quad Cities-1,2 D.C. Cook-1,2 Nine Mile Point-1,2 Susquehanna-1,2 Salem-1,2
1996	90 62	500	2	Dresden-2,3 Marble Hill
1997 and beyond			0	

Totals	
500 MTU	40
1100 MTU	6
1900 MTU	0
	<u>46</u>

Total Capacity: 26,600 MTU

* This appendix was developed using the assumptions stated in this report and in no way does it represent policies or schedules established by the utilities that own and operate the above reactors.