NUREG-0575, Vol. 1
Executive Summary
Text

final generic environmental impact statement

on

HANDLING AND STORAGE OF SPENT LIGHT WATER POWER REACTOR FUEL

AUGUST 1979

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FINAL - GENERIC ENVIRONMENTAL IMPACT STATEMENT

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U.S. Nuclear Regulatory Commission

EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

1.0 SCOPE

The Generic Environmental Impact Statement on spent fuel storage was prepared by the Nuclear Regulatory Commisson staff in response to a directive from the Commissioners published in the Federal Register, September 16, 1975 (40 FR 42801). The Commission directed the staff to analyze alternatives for the handling and storage of spent light water power reactor fuel with particular emphasis on developing long range policy. Accordingly, the scope of this statement examines alternative methods of spent fuel storage as well as the possible restriction or termination of the generation of spent fuel through nuclear power plant shutdown.

Since the Commission's directive was issued, there have been significant policy developments. In this regard, the President has stated that the U.S. should defer domestic plutonium recycle in order to search for better solutions to the proliferation problem. In light of the President's views and public comments, the NRC terminated on December 23, 1977, its proceedings on the Generic Environmental Statement on Mixed Oxide Fuel (GESMO), pending license applications, and other matters related to the reprocessing and recycle of spent light water reactor fuel. This policy decision highlights the importance of this GEIS.

On October 18, 1977, the Department of Energy (DOE) announced that the Federal Government would accept and take title to spent nuclear fuel from utilities upon payment of one time storage fees. The new policy is designed to meet the needs of nuclear reactors for both interim and permanent disposition of spent fuel. The DOE policy actions presume continued light water reactor power generation with discharge of spent fuel and government responsibility for the storage and disposition of spent fuel. Thus, these policy actions also address the issues examined in this document. However, this document does continue to serve the function of supporting the need for rulemaking for away-from-reactor (AFR) spent fuel storage facilities. In addition, DOE used this NRC statement as a source in their draft generic environmental impact statement on their announced spent fuel policy.

The storage of spent fuel addressed in this generic environmental impact statement is considered to be an interim action, not a final solution. The Commission has clearly distinguished between permanent disposal and interim storage.[1] Nonetheless, it has expressed its concern that storage of spent fuel not be used to justify retarding the development of a practicable method of permanent disposal.[2] This concern is shared by groups who have studied this situation.[3,4] The Commission is initiating a proceeding to review its basis for confidence that safe waste disposal will be available.[5] The Commission announcement of September 16, 1975, outlining this study stipulated that the Staff was to examine the period through the mid-1980's. In the absence of a national policy directed to final disposition of spent fuel, the staff extended the time period of this study to year 2000. This extension provided a conservative upper bound to the interim spent fuel storage situation at a date that constituted a practical limit to the forecasting that may logically be used as a basis for today's decisionmaking.

The study covers the following:

(1) The magnitude of the possible shortage of spent fuel storage capacity.

(2) The options for dealing with the problem, including, but not necessarily limited to:

- Permitting the expansion of spent fuel storage capacity at nuclear power plants;
- Permitting the expansion of spent fuel storage capacity at reprocessing plants;
- Licensing of independent spent fuel storage facilities;
- Storage of spent fuel from one or more reactors at the storage pools of other reactors (transshipment between reactors); and
- Ordering the generation of spent fuel be stopped or restricted (by shutting down reactors).

(3) A cost-benefit analysis of the alternatives listed in (2) above along with other reasonably feasible options, including:

- Impacts on the public health and safety and the common defense and security;
- Environmental, social and economic costs and benefits;
- Commitments of resources;
- Implications regarding options available for the intermediate and long range storage of nuclear waste materials; and
- Relationships between the local short-term uses of the environment and long-term productivity.

(4) The impacts of possible additional transportation of spent fuel that may be required should one or more of the options be adopted;

(5) The need for more definitive regulations and guidance covering the licensing of one or more of the options for dealing with the problem; and

(6) The possible need for amendments to 10 CFR 51.20(e)--the S-3 table which summarizes environmental consideration for the nuclear fuel cycle.

The scope of this study is limited to considerations pertinent to the interim storage of spent fuel. Other issues related to the "back end" of the fuel cycle, such as reprocessing and waste management, are covered elsewhere, e.g., NUREG Reports, 0002 for plutonium recycle (GESMO), 0116 and 0216 for waste management.

2.0 THE POTENTIAL MAGNITUDE OF THE SPENT FUEL STORAGE PROBLEM

The factors which affect the quantity of spent fuel requiring storage in excess of that which can be accommodated at nuclear power plants are:

- The projected generation of spent fuel--which is a function of the growth rate of nuclear power installed capacity, the assumed average annual reactor capacity factor and the reactor fuel management plans.
- The extent to which conventional spent fuel storage pools at nuclear power plants can be modified to increase the spent fuel storage capacity.
- The option of the plant owner to maintain storage reserve capacity to accommodate a full core discharge; and
- The time to develop a means for the permanent disposition of spent fuel by reprocessing or waste management.

2.1 GENERATION OF SPENT FUEL

Generation of spent fuel was projected through the year 2000 (Table ES.1) on the basis of installed reactor generating capacity (in GWe) from NRC data for reactors now operating, under construction and planned, and Energy Information Administration estimates. The staff estimated that 77,000 metric tons of heavy metal (MTHM) as spent fuel will have been discharged by year 2000 and that the total reactor storage capacity in the year 2000 will be 91,000 MTHM if full core reserve (FCR) is not maintained and 77,000 MTHM if FCR is maintained. Total storage capacity values do not indicate capacity restrictions at individual older reactors.

Table ES.1. Projected Generation of Spent Fuel

Year	MTHM-Cumulative*
1980	3,000
1985	13,000
1990	29,000
1995	50,000
2000	77,000

*Does not include ~4700 MTHM of spent fuel discharged prior to 1979 and stored AR and AFR at the end of 1978.

2.2 AT-REACTOR (AR) STORAGE CAPACITY

The spent fuel storage capacity at nuclear power plants has conventionally been designed to accommodate one full core plus one discharge, i.e., about 1-1/3 cores. The rationale was that spent fuel from a given discharge would be shipped offsite for reprocessing before the next annual discharge and capacity would be reserved to accommodate a full core if conditions made it desirable to unload the plant reactor.* However, most pools were equipped with spent fuel

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*This capacity is termed full core reserve (FCR).

storage racks which did not fully utilize the available floor space in the pool. In many cases it is now possible to increase at-reactor spent fuel storage capacity by a factor of about 3.0. This compact storage is accomplished by the replacement of existing racks with new racks designed for closer spacing of fuel assemblies and utilizing previously unused floor space. Most nuclear plants have applied to increase their spent fuel storage capacity, and a majority have already received permission to do so.

The maintenance of reserve capacity sufficient to accommodate the full reactor core in the spent fuel storage pool at a nuclear power plant is not a safety matter. However, many power plant owners may consider the maintenance of full core reserve capacity desirable for operational flexibility. Experience has shown that the capacity for fully unloading a reactor has been useful in making modifications and repairs to reactor structural components and for periodic reactor vessel inspections. Such reserve capacity is effectively unused space in the spent fuel storage pool and has the net effect of reducing the available at-reactor spent fuel storage capacity for successive spent fuel discharges.

2.3 REQUIRED AWAY-FROM-REACTOR (AFR) STORAGE

The magnitude of the projected shortfall in AR spent fuel storage capacity equates to the net requirement for away-from-reactor storage at independent spent fuel storage installations (ISFSI). Assuming no curtailment of nuclear power production, the bounding condition used to estimate the required AFR storage capacity is:

- Feasible modifications of power plant pools (compact storage of fuel).

A range or upper bound of AFR storage requirements for this bound may be established by considering (a) no full core storage reserve, and (b) maintenance of a full core reserve (FCR).

The AFR requirements* are summarized for five-year periods for these conditions in Table ES.2 below.

Table ES.2. Away-from-Reactor Spent Fuel Storage Requirements (MTHM)

	With Compact Storage	
Year	Without FCR	With FCR
1980	0	40
1985	730	1,900
1990	3,900	6,300
1995	9,700	14,000
2000	21,000	27,000

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*These include the effect of recent reactor basin storage capacity expansion applications for the Oconee Units 1 & 2 basin, for the Big Rock Point Basin and for the Hatch 1 & 2 basins.

3.0 METHODS FOR DEALING WITH THE PROBLEM OF EXTENDED SPENT FUEL STORAGE

3.1 PERMITTING THE EXPANSION OF SPENT FUEL STORAGE CAPACITY AT NUCLEAR POWER PLANTS (COMPACT STORAGE)

In its announcement dated September 16, 1975, the Commission stated its position that, in the public interest, there should be no deferral of individual licensing actions on the expansion of at-reactor spent fuel storage capacity during the period required for the preparation of this assessment. In line with this policy as of January, 1979, applications for modifications to increase storage-pool capacity at 65 operating nuclear power reactors have been received by the NRC. Such modifications have covered both the installation of newer racks with closer spacing of the spent fuel storage positions and the installation of spent fuel storage racks in previously unused spaces.

The actions can be taken without significant effect on public health and safety, and to date 39 of these applications have been approved and actions are proceeding as planned. Each of these applications was evaluated on an individual basis with findings in each case that:

- At-reactor spent fuel storage can be increased,
- The actions can be taken with no sacrifice of public health and safety, and
- The environmental impact of the proposed increased at-reactor spent fuel storage was negligible.

It should be kept in mind that increased at-reactor spent fuel storage involves only aged fuel (at least one year since discharge) which has orders of magnitude less hazard potential than fuel freshly discharged from a reactor (see Sec. 4.2).

3.2 PERMITTING THE EXPANSION OF SPENT FUEL STORAGE CAPACITY AT REPROCESSING PLANTS

There are no reprocessing plants in operation in the United States at the present time. With the NRC decision to terminate the generic study on plutonium recycle use in mixed oxide fuel (GESMO) in December, 1977 [42 FR 65334] in deference to the President's non-proliferation policy, commercial reprocessing has been indefinitely deferred in the United States. The expansion of spent fuel storage at reprocessing plants is technically feasible, but it is not considered a viable alternative for dealing with the problem of spent fuel storage because of the limited potential spaces at the remaining potential reprocessing plant, Allied General Nuclear Services at Barnwell, S.C., which has storage pool capacity for about 400 metric tons.

3.3 LICENSING OF INDEPENDENT SPENT FUEL STORAGE INSTALLATIONS (ISFSI)

This alternative represents the major means of providing interim AFR spent fuel storage.

The former Nuclear Fuel Services, Inc. reprocessing plant is now licensed and operating as an independent spent fuel storage installation. However, NFS has announced its withdrawal from the reprocessing business, and this plant is no longer receiving spent fuel from utilities for extended storage.

The General Electric Company's planned reprocessing plant at Morris, Illinois, has now been declared and licensed as an ISFSI. The initial licensed spent fuel storage capacity of about 100 MTU has been increased to about 750 MTU by installing spent fuel storage racks in its former high level waste storage pool. The plant operation as a "storage only" facility has shown that an independent spent fuel storage installation can be operated with adequate protection of the health and safety of the public.

The Department of Energy testified on January 26, 1979, before the Committee on Interior and Insular Affairs of the House of Representatives that in order to meet its deadline of 1983 for having an operational AFR facility, it is considering the NFS West Valley, the GE Morris, and the AGNS Barnwell facilities to supply storage capacity.

Currently, an increasing interest in independent spent fuel storage installations is being shown by the nuclear power industry. One architect-engineer company has submitted to NRC a standard design of such a facility, to be situated at a reactor site. The NRC staff has reviewed it and issued letters of approval for the design.

The methods of expanding spent fuel storage capacity considered in this assessment show negligible difference in environmental impact and cost with the exception that at-reactor storage pool compact storage is least costly economically, and does not require additional transportation of spent fuel. In view of this, the reference case alternative for expanded spent fuel storage assumes that most additional storage capacity will be provided by AR storage pool compact storage with additional required storage capacity being provided by away-from-reactor (AFR) at ISFSI located either at reactor sites or at separate sites using the available means of wet or dry storage discussed in this statement.

3.4 STORAGE OF SPENT FUEL FROM ONE OR MORE REACTORS AT THE STORAGE POOLS OF OTHER REACTORS (TRANSSHIPMENT)

Temporary relief for the spent fuel storage problem being faced by some of the older nuclear power plants could be alleviated in some cases by shipping spent fuel to newer plants with unused available storage capacity. However, facility operators can be expected to be reluctant to accept spent fuel that may result in prematurely filling their reactor spent fuel storage pools and potentially impacting the supply of electric power to their regions.

Currently, only one application has been approved by the NRC covering this alternative. The staff's analysis shows that intrautility transshipment, when considered in conjunction with compact storage at reactor pools, provides additional relief delaying the need for AFR storage capacity by about three to four years (see Table 3.2), depending upon whether or not full core reserve (FCR) is maintained. The staff also considered the alternative of transshipment in conjunction with compact storage at reactor pools on an unlimited basis with all the nation's reactor pools operating as a single system under a national storage allocation plan. This alternative is not considered feasible under present regulatory conditions; the staff has analyzed it solely as an emergency alternative necessary to ensure continued reactor power generation in the unlikely event that no AFR storage is made available to prevent spent fuel storage capacity shortfalls. Assuming a preemptive federal regulatory authority to allow this alternative to work, unlimited transshipment in theory could delay the need for AFR storage to the late 1990's.

3.5 ORDERING THE GENERATION OF SPENT FUEL TO BE STOPPED OR RESTRICTED (TERMINATION OF NUCLEAR POWER PRODUCTION)

The replacement of nuclear power generating capacity by coal fired plants because of filled reactor plant storage pools is technically feasible. However, the economic, social and environmental costs would be severe. Particularly in regions far removed from U.S. coal fields such as the Northeast, a conversion back to coal fired power generation would impose significant economic disadvantage which would be difficult to overcome. Even in regions that are advantageously located in relation to coal supplies, the need to raise the necessary capital for replacement coal plants could put a severe financial strain on the utilities involved.

4.0 COST-BENEFIT ANALYSES OF ALTERNATIVES

4.1 IMPACTS ON THE PUBLIC HEALTH AND SAFETY AND THE COMMON DEFENSE AND SECURITY

All of the benefits of nuclear generated power are assigned to the individual plants at the time of their licensing. Therefore, this analysis deals only with the incremental costs of the alternatives considered.

The environmental impacts-costs of interim storage of spent fuel are essentially negligible, regardless of where such spent fuel is stored.

Increased storage of aged spent fuel at either reactor or away-from-reactor sites has little relative safeguards significance. This conclusion is based upon the staff's consideration of: (1) the absence of any information confirming an identifiable threat to nuclear activities, (2) the physical characteristics and conditions of storage (which include specific security provisions) of aged spent fuel, and (3) the magnitude of the estimated consequences of certain postulated sabotage events.

Because the spent fuel involved in increased storage, regardless of where this storage takes place, is aged, and short-lived radionuclides have decayed, the consequences of credible potential accidents are orders of magnitude less than those with freshly discharged fuel.

A comparison of the impacts-costs of the various alternatives considered reduces down to a comparison of providing for the continued generation of nuclear power versus its replacement by coal fired power generation. The differences in the environmental impacts-costs, expressed in terms of potential excess mortality, of nuclear versus coal fired power generation, calculated on a per GWY basis are shown in Table ES.3.

4.1.1 Economics

The choice to construct a new nuclear power station is made on the individual economic benefit of such construction in comparison with alternative sources of power. However, in the bounding case considered in this statement where spent fuel generation is terminated, the costs of replacing existing nuclear stations (with coal fired plants) before the end of their normal lifetime makes this termination alternative uneconomical.

Table ES.3. Comparison of Potential Excess Mortality of Nuclear versus Coal Power Generation per 0.8 GWY(e)

Fuel Cycle Component	Nuclear	Coal
Resource recovery (mining, drilling, etc.)	0.32	0.3 - 8.0
Processing	0.073-1.1	10
Power generation	0.13-0.3	3 - 100
Fuel storage	∼0	∼0
Transportation	0.01	1.2
Reprocessing	0.057-0.065	--
Waste management	0.001	∼0
TOTALS	0.59-1.7	15 - 120

4.1.2 Commitments of Resources

Extended storage of spent fuel requires a minor commitment of land, water and materials of construction. Replacement of all nuclear power by the year 2000 would require a major commitment of resources, particularly coal, transportation facilities, materials of construction of new power plants and land fill sites for waste disposal. These are not all particularly strategic resources, but the magnitude of the resources needed could impose severe economic strains.

4.1.3 Implications Regarding Options Available for the Intermediate and Long-Range Storage of Nuclear Waste Materials

Extended spent fuel storage, per se, does not foreclose any options on the future storage and possible ultimate disposal of spent fuel as nuclear waste materials. Rather, storage of spent fuels for a period of time could be beneficial as it would provide time for the decay of short-lived radionuclides; subsequent storage and disposal need then only provide for the long-lived radionuclides. Nonetheless, while the feasibility of such storage may provide reassurance in the event that problems arise in the development of means for ultimate disposal, it is the Commission's view that the means for ultimate disposal should be developed without unnecessary delay.[2]

4.1.4 Relationships Between the Local Short-Term Uses of the Environment and Long-Term Productivity

For the purposes of this statement, short-term is defined as one to two decades.

In the individual licensing actions, the short-term environmental impacts of nuclear power plants are assessed to be acceptable based on their contribution to the long-term productivity of a region. The maintenance of the power base for this productivity is important, and nuclear power plants represent an option important to national productivity over the long-term.

A replacement of nuclear generating capacity by coal fired plants could meet this need. Hence, the only real option, if the power base is to be maintained, is to continue generating electricity. Replacement of nuclear with coal fired units will have a more adverse impact on the overall long-term environmental quality of the nation.

5.0 THE IMPACTS OF POSSIBLE ADDITIONAL TRANSPORTATION REQUIREMENTS

Increasing at-reactor spent fuel storage does not in itself involve any additional transportation of spent fuel.

The provisions of away-from-reactor spent fuel storage, assuming offsite locations, could involve an additional transportation step. This could be a significant incremental addition to the transportation requirements of the nuclear industry. However, the environmental impact increment from this spent fuel transportation is insignificant (see Sec. 4.2.4 and Appendix E).

6.0 THE NEED FOR MORE DEFINITIVE STANDARDS AND CRITERIA TO GOVERN THE LICENSING OF ONE OR MORE OF THE ALTERNATIVES CONSIDERED

In the judgment of the staff:

- Providing more at-reactor spent fuel storage is adequately covered by existing regulations and regulatory practices.

- There is a need for a more definitive regulatory base for new "storage only" facilities. The present regulations covering the possession of special nuclear materials in an independent spent fuel storage installation (ISFSI) lack specificity for this application. The development of a new regulation, the proposed 10 CFR Part 72, "Storage of Spent Fuel in an Independent Spent Fuel Storage Installation (ISFSI)," and its augmentation by Regulatory Guides on safety-related aspects of ISFSI licensing actions are planned to meet this need. At present 10 CFR Part 72 and Regulatory Guide 3.44, "Standard Format and Content for the Safety Analysis Report to be Included in a License Application for the Storage of Spent Fuel in an Independent Spent Fuel Storage Installation (Water-Basin Type)," have been issued for comment.

- The environmental costs of extended spent fuel storage are incrementally small, and are essentially now incorporated in the previously recognized costs assigned to the uranium fuel cycle. Consequently, no modifications to 10 CFR Part 51 §51.20(e), including the S-3 Table, indicating environmental impact summaries are necessary.

7.0 ACCIDENTS AND SAFEGUARDS CONSIDERATIONS

Restrictions on the handling of heavy loads in the vicinity of spent fuel pools imposed on individual nuclear power plants during modifications of their spent fuel storage racks limit the potential consequences of such accidents to values which are not significantly different from the consequences of spent fuel handling accidents reported in the final environmental statement (FES) for each plant.

An increase in the amount of spent fuel stored at a nuclear power plant does not significantly increase its accident potential. The additional spent fuel placed in the compact storage pool is normally aged fuel and the potentially hazardous short-lived radionuclides have decayed.

Away-from-reactor spent fuel storage at ISFSI involves shipping and storage in "storage only" type facilities.

Regarding the potential sabotage of shipments of aged spent fuel, the staff has concluded that the shipments do not constitute a serious risk to the public health and safety because of: (1) the difficulty of breaching a spent fuel cask and fragmenting the spent fuel, (2) the magnitude of the estimated consequences of successful sabotage, (3) the applicable protection measures delineated in §§ 73.37 of 10 CFR Part 73, and (4) the absence of an identifiable threat to such activities.

Based on the cumulative experience of 30 years of spent fuel shipments, both military and commercial, and extensive analyses of potential accidents, the risk to the health and safety of the public from spent fuel shipping accidents is very small.

Because of the physical characteristics and the conditions of storage that include specific security provisions, the potential risk to the public health and safety due to accidents or acts of sabotage at a "storage only" facility also appears to be extremely small.

8.0 FINDINGS

8.1 INTRODUCTION

The storage of spent fuel in water pools is a well established technology, and under the static conditions of storage represents a low environmental impact and low potential risk to the health and safety of the public. It makes little difference whether spent fuel is stored at a nuclear power plant or in an independent away-from-reactor facility designed for this purpose. This conclusion is based on existing water pool storage technology. Because of the physical characteristics of aged spent fuel, the alternative dry storage techniques expected to be available within the time frame of this study would have comparable negligible impacts.

The viable spent fuel storage methods include:

- The increase of the storage capacity at nuclear power plants by modifications to existing pools, and
- The building of additional away-from-reactor capacity at independent spent fuel storage installations (ISFSI) designed specifically for spent fuel storage. ISFSI may share a site with an existing facility such as a reactor or may be constructed on a separate site.

In addition, the unused spent fuel storage capacity at newer power plants within a utility could be used until the space was needed by these plants. This alternative was considered and it appears to delay the need for AFR storage from the early to the mid-1980's.

In the event that no relief from at-reactor storage capacity shortfalls is provided by AFR storage capacity, it appears physically possible to implement a national storage allocation plan as an emergency measure. However, such a broad increase in federal authority to regulate utilities to the exclusion of state and local authorities may not be politically acceptable.

Unlimited transshipment could potentially delay the need for operational AFR storage capacity to the late 1990's.

8.2 FINDINGS

1. The lack of sufficient spent fuel storage capacity at nuclear power plants has been alleviated by ongoing and planned modifications of at-reactor spent fuel storage pools. Modifications of at-reactor spent fuel storage pools by redesigning fuel racks and making more efficient use of available pool floor space can increase spent fuel storage capacity, on the average, by a factor of 3.0.

   As of January 1979, NRC had received applications for modifications of spent fuel storage plans at 65 power reactors. Forty applications have been approved to date.

2. Licensing reviews of these applications have shown that the modifications are technically and economically feasible and justified. Licensing of these actions is adequately covered by existing regulations and established regulatory practices. This statement supports the finding that increasing the capacities of individual spent fuel storage pools is environmentally acceptable.

   Because there are many variations in storage pool designs and limitations caused by spent fuel already in some pools, the licensing reviews must be done on a case-by-case basis. Modifications in the Technical Specifications applicable to the reactor plant involved, covering safety considerations both during the construction phase of the proposed modifications and subsequent operations, are made where necessary.

3. Table ES.2 contains upper bound requirements for AFR storage with compact storage of spent fuel at reactor pools. The reference case selected for this study is the upper bound storage capacity considering compact storage of fuel in reactor pools that has negligible environmental impact and no transshipment to offsite reactor pools. The AFR storage requirements assume that the FCR option will be selected by plant owners for operational reasons. The timing and magnitude of the AFR spent fuel storage requirements* are as follows:

Year	MTHM
1980	40
1985	1,900
1990	6,300
1995	14,000
2000	27,000

   Assuming that the national objective of an operational geologic repository for high-level nuclear wastes and possible disposal of spent fuel is attained by or before year 2000, the amount of spent fuel requiring away-from-reactor storage is not great. No more than six storage pool installations of 5000-MTHM size would be required by the year 2000. However, the effect of the announcement by the U.S. Department of Energy (DOE) of a proposed Spent Fuel Policy on October 18, 1977, has been to discourage private construction of AFR

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*These include the effect of recent reactor basin storage capacity expansion applications for the Oconee Units 1 & 2 basin, for the Big Rock Point basin, and for the Hatch 1 & 2 basins.

storage capacity since the announcement of such policy. It takes several years to license and construct new AFR capacity--about five years if new construction on a separate site is involved. The time needed to provide the required AFR storage capacity has become short. Consequently, unless some use is made of existing licensed AFR storage capacity in combination with intrautility transshipment, it is possible that individual reactor shutdowns due to shortfalls in spent fuel storage capacity at reactor storage pools will occur.

4. The storage of LWR spent fuels in water pools has an insignificant impact on the environment, whether at AR or at AFR sites. Primarily this is because the physical form of the material, sintered ceramic oxide fuel pellets hermetically sealed in Zircaloy cladding tubes. Zircaloy is a zirconium-tin alloy which was developed for nuclear power applications because of its high resistance to water corrosion in addition to its favorable nuclear properties. Even in cases where defective tubes expose the fuel material to the water environment, there is little attack on the ceramic fuel.

   The technology of water pool storage is well developed; radioactivity levels are routinely maintained at about 5×10^{-4} μCi/ml. Maintenance of this purity requires treatment (filtration and ion exchange) of the pool water. Radioactive waste that is generated is readily confined and represents little potential hazard to the health and safety of the public.

   There may be small quantities of ^{85}Kr released to the environment from defective fuel elements. However, for the fuel involved (fuel at least one year after discharge), experience has shown this to be not detectable beyond the immediate environs of a storage pool.

   There will be no significant discharge of radioactive liquid effluents from a spent fuel storage operation as wastes will be in solid form.

   This statement supports the finding that the storage of spent fuel in away-from-reactor facilities is economically and environmentally acceptable.

5. There is an increasing need for away-from-reactor spent fuel storage starting in the early to mid-1980's. This is primarily due to the older nuclear power plants where there is a limited capability for the expansion of their spent fuel storage capacity. Based on the experience to date with underwater storage, the construction and operation of "storage only" facilities is assessed to be both technically feasible and environmentally acceptable.

   The use of alternative dry passive storage techniques for aged fuel, now being investigated by the Department of Energy, appears to be equally feasible and environmentally acceptable.

6. Two existing "storage only" facilities are now licensed. One, the NFS West Valley plant under 10 CFR Part 50, and the G.E. Morris plant, under 10 CFR Part 70. However, neither of these regulations addresses the specific requirements of a spent fuel "storage only" type of facility. There is a recognized need for a more definitive regulatory basis for the licensing of future facilities of this type. Action is now underway to meet this need. The proposed 10 CFR Part 72, "Storage of Spent Fuel in an Independent Spent Fuel Storage Installation," has been issued for comment. Supporting regulatory guides are also in preparation.

7. Curtailment of the generation of spent fuel by ceasing the operation of existing nuclear power plants when their spent fuel pools become filled is found to be undesirable, and the prohibition of construction of new nuclear plants is not necessary. As shown in this statement, viable measures can be instituted to alleviate the spent fuel storage capacity shortfall. Such measures are economically and environmentally preferable to replacing nuclear generated power with coal fired power plants. The societal costs would also be significant as the excess mortality rates and environmental impacts of coal fired power generation are much higher than those for nuclear power.

8. No modification of 10 CFR 51.20(e) (the summary of environmental considerations for the uranium fuel cycle) appears necessary for spent fuel storage considerations.

References

1. Natural Resources Defense Council, Denial of Petition for Rulemaking, July 5, 1977, 42 FR 34391. Available in the NRC Public Document Room.

2. Statement of Dr. Joseph H. Hendrie, Chairman, U.S. Nuclear Regulatory Commission, before the Committee on Energy and Natural Resources, United States Senate, Thursday, May 10, 1979, pp. 6-7. Available in the NRC Public Document Room.

3. Report to the President by the Interagency Review Group on Nuclear Waste Management, Report TID-29442, March 1979, pp. 15-20. Available from the National Technical Information Service (NTIS), Springfield, Virginia 22161.

4. Letter from Irwin C. Bupp, for the Keystone Radioactive Waste Management Discussion Group, to Dr. Frank Press, Director, Office of Science and Technology Policy, Executive Office of the President, January 26, 1979, p. 6. Available in the NRC Public Document Room.

5. Statement of Dr. Joseph H. Hendrie, Chairman, U.S. Nuclear Regulatory Commission, before the Subcommittee on Energy and Power, Committee on Interstate and Foreign Commerce, U.S. House of Representatives, June 27, 1979. Available in the NRC Public Document Room.

FOREWORD

This Environmental Statement was prepared by the Division of Fuel Cycle and Material Safety, Office of Nuclear Material Safety and Safeguards, U. S. Nuclear Regulatory Commission (the staff), in accordance with the Commission's regulation 10 CFR Part 51, which implements the requirements of the National Environmental Policy Act of 1969 (NEPA).

The NEPA states, among other things, that the Federal Government has the continuing responsibility to use all practicable means, consistent with the other essential considerations of national policy, to improve and to coordinate Federal plans, functions, programs, and resources to the end that the Nation may:

- Fulfill the responsibilities of each generation as trustee of the environment for succeeding generations.
- Ensure for all Americans safe, healthful, productive, and esthetically and culturally pleasing surroundings.
- Attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences.
- Preserve important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment that supports diversity and variety of individual choice.
- Achieve a balance between population and resource use that will permit high standards of living and a wide sharing of life's amenities.
- Enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources.

Further, with respect to major Federal actions significantly affecting the quality of the human environment, Section 102(2)(C) of the NEPA calls for the preparation of a detailed statement on:

(i) The environmental impact of the proposed action.

(ii) Any adverse environmental effects that cannot be avoided should the proposal be implemented.

(iii) Alternatives to the proposed action.

(iv) The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity.

(v) Any irreversible and irretrievable commitments of resources that would be involved in the proposed action should it be implemented.

From time to time a generic issue must be considered in the form of a generic environmental impact statement. A public notice of intent to prepare the statement is published by the Commission. In conducting the NEPA review, the staff meets with cognizant individuals and organizations to seek new information and to ensure a thorough understanding of the issues of concern. On the basis of the foregoing and other such activities or inquiries as are deemed useful and appropriate, the staff makes an independent assessment of the considerations specified in Section 102(2)(C) of the NEPA and in 10 CFR 51.

This evaluation leads to the publication of a draft environmental statement, prepared by the NRC staff, that is circulated to appropriate governmental agencies for comment. A summary notice is published in the Federal Register of the availability of the draft environmental statement. Interested persons are also invited to comment on the draft statement.

After receipt and consideration of comments on the Draft Statement, the staff prepares a Final Environmental Statement which includes: a discussion of concerns raised by the comments; a benefit-cost analysis, which considers the environmental costs and the alternatives available for reducing or avoiding them, and balances the adverse effects against the environmental, economic, technical, and other benefits; and a conclusion. The Final Environmental Statement prepared by the staff is submitted to the Commission for its consideration.

For this Generic Environmental Statement on The Handling and Storage of Spent Light Water Power Reactor Fuel, the following comments may be made:

1. This action is administrative.

2. This action is taken in response to the Intent to Prepare Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel Federal Register, September 16, 1975 (40 FR 42801).

3. The Draft Environmental Statement was made available to the public, to the Environmental Protection Agency, and to other specified agencies in March 1978.

4. Single copies of this statement may be obtained as indicated on the inside front cover.

This project was completed with Meyer Novick as Project Leader and John P. Roberts as Project Manager. Should there be questions regarding the content of this Statement, Mr. Roberts may be contacted in care of the Director, Division of Fuel Cycle and Material Safety, or at (301)427-4205.

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GLOSSARY

AEC	Atomic Energy Commission; a former federal agency, disbanded by the Energy Reorganization Act of 1974
AFR	Away-from-Reactor (Used in reference to storage of spent fuel in structures not integral to a reactor, but which may be located on a reactor site or other nuclear facility site or on a separate site.)
ALARA	As low as reasonably achievable (applied to radiation exposures and environmental releases of radioactivity)
ANL	Argonne National Laboratory
ANS	American Nuclear Society
AR	At-Reactor
ASME	American Society of Mechanical Engineers
BNFP	Barnwell Nuclear Fuel Plant
BWR	Boiling Water Reactor
CANDU	<u>Can</u>adian <u>D</u>euterium-<u>U</u>ranium Reactor
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
Compact Storage	More storage in existing storage pools is created by providing for closer spacing of the assemblies and using pool space not previously used for spent fuel storage
DBE	Design Basis Earthquake
DOE	Department of Energy
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency

GLOSSARY (Cont'd)

FCR	Full Core Reserve
FR	Federal Register
FRC	Federal Radiation Council
Fuel Cycle	The complete sequence of operations, from mining of uranium raw material to disposal of radioactive wastes, involved in providing fuel for nuclear power plants
GESMO	Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors
GWe	Gigawatt electric
GWy	Gigawatt-year
HEPA Filter	High Efficiency Particulate Air Filter
HTGR	High Temperature Gas Cooled Reactor
ISFSI	Independent Spent Fuel Storage Installation
LWR	Light Water Reactor
mrem	Millirem
MT	Metric Ton
MTHM	Metric Tons of Heavy Metal (uranium and plutonium)
MTU	Metric Tons of Uranium
MWe	Megawatts electric
MWd	Megawatt-days
NEPA	National Environmental Policy Act
NFS	Nuclear Fuel Services
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory

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GLOSSARY (Cont'd)

person-rem	(Population rem) Sum of rem doses in a defined population or sum of doses to specific organs in a defined population
PSAR	Preliminary Safety Analysis Report
PuO_2	Plutonium Dioxide
PWR	Pressurized Water Reactor
rem	Dose of any radiation supposedly having a biological effect equivalent to one roentgen
RSSF	Retrievable Surface Storage Facility (for radioactive wastes)
S-3 Table	Summary of Environmental Considerations for Uranium Fuel Cycle; in 10 CFR 51.20(e)
SAR	Safety Analysis Report
SER	Safety Evaluation Report
SNM	Special Nuclear Material
SRP	Standard Review Plan
UO_2	Uranium Dioxide

SUMMARY

1.0 SCOPE

The Generic Environmental Impact Statement on spent fuel storage was prepared by the Nuclear Regulatory Commission staff in response to a directive from the Commissioners published in the Federal Register, September 16, 1975 (40 FR 42801). The Commission directed the staff to analyze alternatives for the handling and storage of spent light water power reactor fuel with particular emphasis on developing long range policy. Accordingly, the scope of this statement examines alternative methods of spent fuel storage as well as the possible restriction or termination of the generation of spent fuel through nuclear power plant shutdown.

Since the Commission's directive was issued, there have been significant policy developments. In this regard, the President has stated that the U.S. should defer domestic plutonium recycle in order to search for better solutions to the proliferation problem. In light of the President's views and public comments, the NRC terminated on December 23, 1977, its proceedings on the Generic Environmental Statement on Mixed Oxide Fuel (GESMO), pending license applications, and other matters related to the reprocessing and recycle of spent light water reactor fuel. This policy decision highlights the importance of this GEIS.

On October 18, 1977, the Department of Energy (DOE) announced that the Federal Government would accept and take title to spent nuclear fuel from utilities upon payment of one time storage and disposal fees. The new policy is designed to meet the needs of nuclear reactors for both interim and permanent disposition of spent fuel. The DOE policy actions presume continued light water reactor power generation with discharge of spent fuel and government responsibility for the storage and disposition of spent fuel. Thus, these policy actions also address the issues examined in this document. However, this document does continue to serve the function of supporting the need for rulemaking for away-from-reactor (AFR) spent fuel storage facilities. In addition, DOE used this NRC statement as a source in their draft generic environmental impact statement on their announced spent fuel policy.

The storage of spent fuel addressed in this generic environmental impact statement is considered to be an interim action, not a final solution. The Commission has clearly distinguished between permanent disposal and interim storage.[1] Nonetheless, it has expressed its concern that storage of spent fuel not be used to justify retarding the development of a practicable method of permanent disposal.[2] This concern is shared by groups who have studied this situation.[3,4] The Commission is initiating a proceeding to review its basis for confidence that safe waste disposal will be available.[5] The Commission announcement of September 16, 1975, outlining this study stipulated that the Staff was to examine the period through the mid-1980's. In the absence of a national policy directed to final disposition of spent fuel, the staff extended the time period of this study to year 2000. This extension provided a conservative upper bound to the interim spent fuel storage situation at a date that constituted a practical limit to the forecasting that may logically be used as a basis for today's decisionmaking.

2.0 FINDINGS

1. The lack of sufficient spent fuel storage capacity at nuclear power plants has been alleviated by ongoing and planned modifications of at-reactor spent fuel storage pools. Modifications of at-reactor spent fuel storage pools by redesigning fuel racks and making more efficient use of available pool floor space can increase spent fuel storage capacity, on the average, by a factor of 3.0.

   As of January 1979, NRC had received applications for modifications of spent fuel storage plans at 65 power reactors. Forty applications have been approved to date.

2. Licensing reviews of these applications have shown that the modifications are technically and economically feasible and justified. Licensing of these actions is adequately covered by existing regulations and established regulatory practices. This statement supports the finding that increasing the capacities of individual spent fuel storage pools is environmentally acceptable.

   Because there are many variations in storage pool designs and limitations caused by spent fuel already in some pools, the licensing reviews must be done on a case-by-case basis. Modifications in the Technical Specifications applicable to the reactor plant involved, covering safety considerations both during the construction phase of the proposed modifications and subsequent operations, are made where necessary.

3. Table 3.1 contains upper bound requirements for AFR storage with compact storage of spent fuel at reactor pools. The reference case selected for this study is the upper bound storage capacity considering compact storage of fuel in reactor pools that has negligible environmental impact and no transshipment to offsite reactor pools. The AFR storage requirements assume that the FCR option will be selected by plant owners for operational reasons. The timing and magnitude of the AFR spent fuel storage requirements* are as follows:

Year	MTHM
1980	40
1985	1,900
1990	6,300
1995	14,000
2000	27,000

   Assuming that the national objective of an operational geologic repository for high-level nuclear wastes and possible disposal of spent fuel is attained by or before year 2000, the amount of spent fuel requiring away-from-reactor storage is not great. No more than six storage pool installations of 5000-MTHM size would be required by the year 2000. However, the effect of the announcement by the U.S. Department of Energy (DOE) of a proposed Spent Fuel Policy on October 18, 1977, has been to discourage private construction of AFR storage capacity since the announcement of such policy. It takes several years to license and construct new AFR capacity--about five years if new construction on a separate site is involved.

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*These include the effect of recent reactor basin storage capacity expansion applications for the Oconee 1 & 2 basin, for the Big Rock Point basin and for the Hatch 1 & 2 basins.

The time needed to provide the required AFR storage capacity has become short. Consequently, unless some use is made of existing licensed AFR storage capacity in combination with intrautility transshipment, it is possible that individual reactor shutdowns due to shortfalls in spent fuel storage capacity at reactor storage pools will occur.

4. The storage of LWR spent fuels in water pools has an insignificant impact on the environment, whether at AR or at AFR sites. Primarily this is because the physical form of the material, sintered ceramic oxide fuel pellets hermetically sealed in Zircaloy cladding tubes. Zircaloy is a zirconium-tin alloy which was developed for nuclear power applications because of its high resistance to water corrosion in addition to its favorable nuclear properties. Even in cases where defective tubes expose the fuel material to the water environment, there is little attack on the ceramic fuel.

   The technology of water pool storage is well developed; radioactivity levels are routinely maintained at about 5×10^{-4} μCi/ml. Maintenance of this purity requires treatment (filtration and ion exchange) of the pool water. Radioactive waste that is generated is readily confined and represents little potential hazard to the health and safety of the public.

   There may be small quantities of ^{85}Kr released to the environment from defective fuel elements. However, for the fuel involved (fuel at least one year after discharge), experience has shown this to be not detectable beyond the immediate environs of a storage pool.

   There will be no significant discharge of radioactive liquid effluents from a spent fuel storage operation as wastes will be in solid form.

   This statement supports the finding that the storage of spent fuel in away-from-reactor facilities is economically and environmentally acceptable.

5. There is an increasing need for away-from-reactor spent fuel storage starting in the early to mid-1980's. This is primarily due to the older nuclear power plants where there is a limited capability for the expansion of their spent fuel storage capacity. Based on the experience to date with underwater storage, the construction and operation of "storage only" facilities is assessed to be both technically feasible and environmentally acceptable.

   The use of alternative dry passive storage techniques for aged fuel, now being investigated by the Department of Energy, appears to be equally feasible and environmentally acceptable.

6. Two existing "storage only" facilities are now licensed. One, the NFS West Valley plant under 10 CFR Part 50, and the G.E. Morris plant, under 10 CFR Part 70. However, neither of these regulations addresses the specific requirements of a spent fuel "storage only" type of facility. There is a recognized need for a more definitive regulatory basis for the licensing of future facilities of this type. Action is now underway to meet this need. The proposed 10 CFR Part 72, "Storage of Spent Fuel in an Independent Spent Fuel Storage Installation," has been issued for comment. Supporting regulatory guides are also in preparation.

7. Curtailment of the generation of spent fuel by ceasing the operation of existing nuclear power plants when their spent fuel pools become filled is found to be undesirable, and the prohibition of construction of new nuclear plants is not necessary. As shown in this statement, viable measures can be instituted to alleviate the spent fuel storage capacity shortfall. Such measures are economically and environmentally preferable to replacing nuclear generated power with coal fired power plants. The societal costs would also be significant as the excess mortality rates and environmental impacts of coal fired power generation are much higher than those for nuclear power.

8. No modification of 10 CFR 51.20(e) (the summary of environmental considerations for the uranium fuel cycle) appears necessary for spent fuel storage considerations.

References

1. Natural Resources Defense Council, Denial of Petition for Rulemaking, July 5, 1977, 42 FR 34391. Available in the NRC Public Document Room.

2. Statement of Dr. Joseph H. Hendrie, Chairman, U.S. Nuclear Regulatory Commission, before the Committee on Energy and Natural Resources, United States Senate, Thursday, May 10, 1979, pp. 6-7. Available in the NRC Public Document Room.

3. Report to the President by the Interagency Review Group on Nuclear Waste Management, Report TID-29442, March 1979, pp. 15-20. Available from the National Technical Information Service (NTIS), Springfield, Virginia, 22161.

4. Letter from Irwin C. Bupp, for the Keystone Radioactive Waste Management Discussion Group, to Dr. Frank Press, Director, Office of Science and Technology Policy, Executive Office of the President, January 26, 1979, p. 6. Available in the NRC Public Document Room.

5. Statement of Dr. Joseph M. Hendrie, Chairman, U.S. Nuclear Regulatory Commission, before the Subcommittee on Energy and Power, Committee on Interstate and Foreign Commerce, U.S. House of Representatives, June 27, 1979. Available in the NRC Public Document Room.

1.0 INTRODUCTION

In this Environmental Impact Statement the amount of spent light water reactor (LWR) fuel to be generated through the year 2000 is quantified and compared with the space available for storage. The environmental impact of solving the spent fuel storage problem, using at-reactor (AR) and away-from-reactor (AFR) storage techniques in different ways and terminating generation of spent fuel by shutting down nuclear power plants, is assessed. A cost-benefit analysis is included and conclusions and recommendations are presented.

1.1 STATEMENT OF SITUATION

From the early days of the nuclear power industry in this country, electric utilities planning to construct and operate light water nuclear power reactors contemplated that the used or spent fuel discharged from the reactors would be chemically reprocessed to recover the residual quantities of fissile and fertile materials (uranium and plutonium), and that the materials so recovered would be recycled back into fresh reactor fuel. It was also contemplated by the nuclear industry that spent fuel would be discharged periodically from operating reactors, stored in onsite fuel storage pools for a period of time (to permit radioactive decay of short-lived radioisotopes contained within the fuel, as well as thermal decay) and periodically shipped offsite for reprocessing. Typically, space was provided in onsite storage pools for about 1-1/3 full nuclear reactor cores. Assuming a 3 to 4 year reactor fuel reload cycle, the onsite storage pools were planned to hold an average of one year's discharge with sufficient remaining capacity to hold a complete core should unloading of all of the fuel from the reactor be necessary or desirable for normal maintenance or because of operational difficulties. Under normal operating conditions, about 5 years' spent fuel discharge could be accommodated before the pools were filled.

Current U.S. policy has placed a ban on the reprocessing (and recycling) of LWR fuel for an indefinite period of time. As a consequence of this policy the reprocessing part of the fuel cycle has not been a successful commercial development. For a time one such facility actually operated, the Nuclear Fuel Services (NFS) plant at West Valley, New York. However, after a shutdown for extensive alterations and expansion, the conclusion was reached that these changes were commercially impractical and the facility was not reopened for reprocessing.[1] A second facility, the General Electric Company's Midwest Fuel Recovery Plant at Morris, Illinois, never operated as a reprocessing plant and is now licensed for spent fuel storage only. A third proposed plant, the Allied-General Nuclear Service (AGNS) plant in Barnwell, South Carolina, the subject of hearings before the Commission (Docket No. 50-332 and Docket No. 70-1729), and a fourth plant, the Exxon plant proposed for construction in Tennessee, which was docketed for license review (Docket No. 50-564) have not been approved. The recent decision by the Nuclear Regulatory Commission to terminate proceedings on pending or future plutonium recycle-related license applications specifically includes both the AGNS (with the possible exception of research and development efforts related to non-proliferation objectives) and the Exxon applications [Mixed Oxide Fuel Order noticed on December 30, 1977 (42 FR 65334)].

A geologic repository is expected to be constructed by the 1990's, and the Commission has supported the position that permanent disposal of spent fuel is a viable fuel cycle alternative.[2] Thus permanent disposal is not expected to have any effect on the interim storage of spent fuel for about a decade or longer.

In response to the direction of the Commission, the staff has prepared this generic environmental impact statement on the matter of spent fuel storage capacity.[3]

In this document the magnitude of spent fuel storage capacity through the year 2000 is analyzed and an assessment made of the environmental impacts associated with the various ways of storing spent fuel. Included are the consequences of dealing with this situation by the limitation of the amount of spent fuel generated.

In the light of the national policy banning reprocessing and recycling the assumption was made, for the purpose of bounding the magnitude of the problem, that neither spent fuel reprocessing nor disposition of spent fuel as a waste would be implemented through the year 2000. This time frame was considered a practical limit to the forecasting that must serve as the basis for the current decision making actions.

1.2 SPENT FUEL STORAGE REQUIREMENTS AND ALTERNATIVES

The present policy of the United States is to store commercial reactor spent fuel without reprocessing pending the decision to reprocess it or to dispose of it directly as high level waste. While construction of a geologic repository remains a fixed national goal for high level radioactive waste from reprocessing and other radioactive wastes, it may also receive spent fuel. Pending the decision, operating reactors will continue to generate spent fuel that must be discharged from the reactor core if the reactor is to continue to produce power. Most nuclear power plants were originally designed to accommodate the equivalent of one and one-third cores of spent fuel in their onsite storage pools for single reactors and one and two-third cores for dual reactor plants. In order to maintain the capability of discharging a full core into the storage pool, full core reserve (FCR), roughly only a third of a core of spent fuel for a single reactor or two-thirds of a core for a dual reactor plant, could be stored at reactors under original design conditions. However, most reactor plants have achieved expansion of storage capacity or applied for approval for such expansion by re-racking of their spent fuel storage pools.

The maintenance of reserve capacity sufficient to accommodate the full reactor core in the spent fuel storage pool at a nuclear power plant is not a safety matter. However, power plant owners do consider the maintenance of full core reserve capacity desirable for operational flexibility. Experience has shown that the capacity for fully unloading a reactor has been useful in making modifications and repairs to reactor structural components and for periodic reactor vessel inspections. Such reserve capacity is effectively unused space in the spent fuel storage pool and has the net effect of reducing the available at-reactor spent fuel storage capacity for successive spent fuel discharges.

Installed reactor generating capacity (in GWe) was projected from NRC data for reactors now operating, under construction, and planned, and Energy Information Administration estimates through year 2000 (see App. F). The staff estimated that 82,000 metric tons of heavy metal (MTHM) as spent fuel will have been discharged by year 2000 and that the total at-reactor storage capacity in year 2000 will be 91,000 MTHM of storage capacity if full core reserve (FCR) is not maintained and 77,000 MTHM if FCR is maintained. Since these total storage capacity values include new units coming on line with storage pools, storage capacity shortfalls at older units and the need for additional storage capacity are not shown by these totals. The growth of the spent fuel storage requirements through the period 1976-2000 is examined in this statement.

Four bounding alternatives are considered in this statement.

> Alternative 1. A reference case utilizing existing (compacted) storage technologies to increase AR storage capacity and allowing free use of storage at each reactor site by reactors at that site.
>
> Alternative 2. Transshipment of spent fuel freely from facilities with full pools to pools with available storage capacity within each utility-owned reactor system, regardless of geographical location.
>
> Alternative 3. Complete and free interchange of storage space regardless of ownership or geographical location.
>
> Alternative 4. Ceasing to generate spent fuel by allowing reactor shutdown as individual reactor storage capacity is exhausted and using another energy source to generate replacement electrical power (coal is seen as this source).[4,5]

To provide an overview of the anticipated need for AFR storage, Table 1.1 has been extracted from data in Tables 3.1, 3.4 and 3.5 of Chapter 3.0. Six spent fuel storage options which were considered are summarized in Table 1.1. Storage at reactor basins with compact storage and with and without a full core reserve (FCR) is considered. Compact storage is a technique for increasing spent fuel storage capacity by reducing spacing between fuel assemblies using pool space previously unused for spent fuel and has already been employed at most operating reactors.

Table 1.1. Summary of Away-from-Reactor (AFR) Storage Requirements[a,b]

	Alternative 1		Alternative 2		Alternative 3	
	With FCR[c]	Without FCR	With FCR	Without FCR	With FCR	Without FCR
Year requiring AFR storage	1979	1980	1982	1984	1999	--
AFR requirements, 1985, MTHM	2,200	900	700	30	--	--
AFR requirements, 2000, MTHM	28,000	22,000	19,300	13,000	4,200	--

[a] 230 GWe, i.e., 230 GWe installed and 202 GWe discharging in year 2000.

[b] Does not include the effect of recent reactor basin storage capacity expansion applications for the Oconee Units 1 & 2 basin, for the Big Rock Point basin, and for the Hatch 1 & 2 basins. (See Vol. 2, Appendix F, Table F.8, footnote b.)

[c] Reference case.

The six options consider the effect on AFR storage requirements if each of the first three of the four alternatives described above are implemented for one rate of reactor installation (230 GWe by year 2000), and whether or not the full core reserve (FCR) option is exercised by utilities. These six options are also considered for a high rate of reactor installation (280 GWe by year 2000) in Appendix I.

In Chapter 4.0, the environmental impacts of the reference case are examined. The reference case consists of providing adequate storage space for the spent fuel by increasing storage at the reactor plant only. The reference case requirement for AFR storage needed with compact storage at the reactors with a full core reserve and for 230 GWe installed is shown in column 1 of Table 1.1.

1.3 SCOPE OF THIS TREATMENT

In this environmental statement, an examination is made of that part of the nuclear fuel cycle after the fuel has been removed as a power source from a nuclear reactor, and an assessment is made of the impact of storage of such spent fuel through the end of this century. In light of the status of commercial reprocessing as well as that of possible permanent disposal of spent fuel in the United States,[6,7] the staff has assumed, for purposes of bounding the spent fuel storage outlook, that neither reprocessing nor permanent disposal would be implemented before the year 2000. It is anticipated, however, that by the year 2000 disposition of spent fuel generated by light water reactors (LWR's) will be determined and whatever steps are necessary to implement these decisions will be initiated. The Department of Energy has publicly announced (October 18, 1977), a policy under which the Federal Government will accept title to spent fuel and responsibility for its final disposition.

An estimate of the amount of spent fuel to be generated during this time period as well as discussion on available storage at reactors and the amount of storage required away from reactors is included in Chapter 2.0.

A description of the four alternatives for spent fuel storage is given below and a more detailed description in Chapter 3.0.

All Alternatives

The degree of compaction for all alternatives and for all storage pools was chosen by staff to be 3; i.e., the multiple of original storage design capacity used by staff to estimate storage capacity was 3.

No further use of currently available AFR storage was contemplated by staff. This is not intended to mean that such storage could not be used. Staff estimate of the potential for licensed storage capacity is about 1000 MTHM of which about 500 MTHM is presently being used. (An additional 400 MTHM has been constructed with licensing of storage pending.) The FCR (full core reserve) requirement is based on retaining at all sites the equivalent of one full core. All estimates of storage requirements use the rate of reactor installation between 1979 and 2000 as shown in Table 1.2, (230 GWe by year 2000).

The installed reactor generating capacity (in GWe) shown is derived from estimates of the Energy Information Administration, which is charged by Congress to develop such projections, through

1995 and extrapolated to 2000 (straight line) by the staff (see App. F)[8]. The discharging GWe are based on a three-year delay from installed year (same as fuel loading date or FLD) to first discharge.

Table 1.2. Nuclear Generating Capacity Installed and Discharging Spent Fuel for Each Year, 1979-2000

Year	Capacity Installed, GWe	Capacity Discharging, GWe
1979	58	46
1980	66	48
1981	73	51
1982	80	58
1983	87	66
1984	94	73
1985	102	80
1986	110	87
1987	119	94
1988	125	102
1989	134	110
1990	142	119
1991	151	125
1992	160	134
1993	168	142
1994	177	151
1995	187	160
1996	195	168
1997	202	177
1998	212	187
1999	221	195
2000	230	202

An estimate of the amount of spent fuel to be generated during this time period, as well as a discussion on available storage at reactors is included in Chapter 2.0.

Chapter 3.0 provides the description of the four bounding alternatives for spent fuel storage.

Alternative 1 (Reference Case)

In this alternative, reactors at a given site, regardless of type, are allowed to use any space available on that site for spent fuel storage.

Alternative 2

In this alternative, reactors at any site, with common ownership, can use any spare available within that ownership.[9]

Alternative 3

In this alternative, any reactor within the U.S. could use available space at any other reactor regardless of site location or ownership.

Alternative 4 (Termination Case)

No action would be taken. Nuclear plants would be shut down as spent fuel pools become full at each nuclear plant site. Electrical power needs would be met by another source of energy (e.g., coal).[4,5]

Chapter 4.0 contains an examination of the environmental impact of taking each course of action discussed in Chapter 3.0.

Chapter 5.0 provides an assessment of the safeguards aspects of solving the problem.

Chapter 6.0 presents the economic data for each alternative.

Chapter 7.0 includes the cost-benefit analysis using the economic and environmental data developed in previous chapters.

Chapter 8.0 contains the staff findings.

Chapter 9.0 addresses the comments on the Draft Environmental Statement and the staff responses.

References

1. Letter from R. W. Deuster, President, Nuclear Fuel Services, Inc., to K. R. Chapman, NRC; subject: NFS's decision to withdraw from the nuclear fuel reprocessing business, dated September 22, 1976, Docket No. 50-201. Available in NRC PDR for inspection and copying for a fee.

2. Federal Register, Vol. 42, No. 128, Tuesday, July 5, 1977, (42 FR 34391) "Natural Resources Defense Council, Denial of Petition for Rule Making."

3. Federal Register, Vol. 40, No. 180, Tuesday, September 16, 1975, (40 FR 42801) "Spent Fuel Storage, Intent to Prepare Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel."

4. U.S. Nuclear Regulatory Commission, "Final Environmental Statement Related to Operation of Bear Creek Project," USNRC Report NUREG-0129, Docket No. 40-8452, June 1977. Available from National Technical Information Service (NTIS), Springfield, Virginia, 22161.

5. U.S. Nuclear Regulatory Commission, "Final Environmental Statement--Black Fox Station, Units 1 and 2," USNRC Report NUREG-0176, Docket Nos. 50-556/50-557, January 1977. Available from National Technical Information Service (NTIS), Springfield, Virginia 22161.

6. U.S. Nuclear Regulatory Commission, "Mixed Oxide Fuel Order," noticed December 30, 1977, 42 FR 65334.

7. Report to the President by the Interagency Review Group on Nuclear Waste Management, Report TID 29442, March, 1979.

8. Letter from John Roberts, U.S. Nuclear Regulatory Commission, to Meyer Novick, Argonne National Laboratory, dated March 30, 1979. Copy available in the NRC Public Document Room.

9. U.S. Nuclear Regulatory Commission, "Program Summary Report," Report NUREG-0380 (Brown Book) pp. 1-10 thru 1-13, February 16, 1979; "Operating Units Status Report," Report NUREG-0020-3, (Gray Book) thru December 1978; "Construction Status of Nuclear Power Plants," Report NUREG-0030-03, (Yellow Book) thru February 1979. Available from National Technical Information Service (NTIS), Springfield, Virginia, 22161.

2.0 SPENT FUEL PRODUCTION ANALYSIS

In this chapter analyses are made of the projected generation rate of spent fuel through the year 2000. Section 2.1 and Appendix G provide descriptive material and background information on nuclear fuel in general, and spent fuel in particular.

2.1 DESCRIPTION OF LWR FUEL THROUGH ITS CYCLE OF USE

2.1.1 General Description of Fuel

Nuclear fuel for commercial power reactors is made of short cylinders (pellets) of high-fired ceramic uranium dioxide (UO_2). Depending upon the specific reactor design, these pellets are in the order of 0.75 to 1.25 cm in diameter and about 1.5 cm long. Typically a 366 cm-long stack or about 250 of these pellets are loaded and hermetically sealed into a zirconium alloy tube. This unit is called a fuel rod. The high-fired ceramic fuel pellets are hard, strong, and insoluble in water. The fuel rod (Figure G.1 in Appendix G)* is a strong but flexible structure and the zirconium alloy cladding is resistant to water corrosion.

Fuel rods are assembled into bundles in a square array, each spaced and supported by grid structures and corner tie rods. The fuel bundle is generally called a fuel assembly. The assembly has a bottom fitting in the form of an extension nozzle and a top fitting as a handle. The nozzle fits into the reactor core supporting grid and conducts coolant water to the fuel, and the handle permits the remote manipulation of the fuel assembly into and out of the reactor as well as into and out of fuel transfer casks and fuel storage facilities. Although largely similar in design, fuel assemblies used in PWRs and BWRs differ generally in size and the quantity of fuel contained. Components of the fuel assembly are also resistant to water corrosion.

Typically, a General Electric BWR assembly (Figure G.2) consists of a 7 x 7 (49 total) or 8 x 8 (64 total) array of individual fuel rods. Its overall dimensions are approximately 14 cm square by 435 cm long. Each assembly contains about 200 kilograms of uranium in the form of uranium dioxide (UO_2). PWR reactors use larger, but similarly designed, fuel assemblies. The Westinghouse PWR assembly is a square array of 14 x 14, 15 x 15 or 17 x 17 rods, with a pattern of positions within the array for internal control rods. These assemblies are about 21 cm square by 420 cm long. The Combustion Engineering and Babcock & Wilcox PWR fuel assemblies are similar to Westinghouse models. A typical PWR fuel assembly contains about 450 kilograms of uranium in the form of uranium dioxide. Typical design characteristics of fuel assemblies manufactured by the various suppliers are given in Appendix G, Tables G.1 through G.4.*

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*More detailed information concerning nuclear fuel, including appropriate tabular material and illustrations, is provided in Appendix G.

After irradiation, an LWR fuel assembly normally shows no outward physical change. While externally the spent fuel is little changed from new fuel, after irradiation within the fuel rods some of the UO_2 pellets may have been fractured due to thermal stresses and the composition has changed dramatically. Whereas new fuel is relatively innocuous and can be handled and shipped as a standard commercial product, spent fuel is highly radioactive and produces considerable heat. For these reasons spent fuel must be cooled and shielded. With time, cooling and some shielding requirements decrease as a result of the natural radioactive decay process.

The nuclear reactions within the fuel produce a number of radioactive and non-radioactive nuclides. These new nuclides are contained in the structural matrix of the fuel, in the annular region within the rod surrounding the fuel pellets, and in the hardware components of the fuel assembly. Details concerning the characteristics of this spent fuel are provided in Section 2 of Appendix G.

2.1.2 Design Bases of Existing Technology for Storing Spent Fuel at Reactor Sites

Light water reactors now operating or under construction typically have spent fuel storage facilities which were designed to contain a full core plus the spent fuel removed from the reactor during one year of operation. Most BWR fuel management plans are based on replacing the core approximately every four years, 1/4 core discharged as spent fuel per year; PWR plans are based on 1/3 core replacement per year. The average spent fuel storage space in currently operating reactors and in those that will be in operation by 1985 will accommodate at least four PWR cores and 3.75 BWR cores for single reactor sites, assuming no physical expansion of AR storage capacity. In this analysis of the spent fuel storage requirements, it is assumed that all reactors utilize reracking to expand capacity within the limits of existing pool design to attain three times the design capacity of each pool. Pools with substantially larger capacities might be constructed in the future.

Both fission and radioactive decay must be considered in spent fuel storage basin design. The spacing of spent fuel assemblies within fixed racks must be engineered to make sure that the array of fuel assemblies does not represent a configuration that could initiate self sustaining nuclear fission (become critical). This is achieved by insuring that the criticality factor, k_{eff}, is less than 0.95, assuming the most reactive composition of the fuel. Water serves to shield workers from radiation emanating from the stored fuel, and is used to remove heat generated by radioactive decay. About 97% or more of each assembly's radioactive decay energy present at reactor shutdown is dissipated within one month after the shutdown.

Spent fuel storage facilities must be capable of accommodating spent fuel transfer operations underwater, for example, transfer from within containment to the storage basin, or transfer from the storage basin to a shipping cask. Under all such operating conditions proper shielding and cooling are features of the design.

The structural integrity of spent fuel storage basins is assured by engineering design which includes the effects of location, size, and capacity.

2.1.3 Design Assumptions of Existing Technology for Storing Spent Fuel Away-from-Reactors

Spent fuel reprocessing facilities also have capacity for storing spent fuel. Three such facilities now exist. Their names, locations and capacities are:

Name	Location	Spent Fuel Storage Capacity[a]
NFS	West Valley, N. Y.	260 MTU
GE Morris	Morris, Ill.	750 MTU[b]
AGNS	Barnwell, S. C.	400 MTU

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[a] Licenses for storage at these installations are expressed in terms of the uranium content of the spent fuel.

[b] Expansion proposed to increase capacity to 1850 MTU (proceeding indefinitely suspended).

No spent fuel reprocessing is now being conducted at any of these plants. NFS and GE Morris are operating storage pools but NFS (with 170 MTU of capacity filled) is no longer receiving spent fuel for storage, GE Morris management has committed only to receive up to about 350 MTU of spent fuel, and AGNS is not licensed.

The three existing AFR storage pools discussed in this section were designed based on principles similar to those of reactor pools. There are fuel-handling differences between reactor pools and existing AFR pools. (See App. A for a discussion of reprocessing). Furthermore, these AFR pools will handle spent fuel assemblies of different design from PWR's and BWR's, and from various cask types, so the design of the handling facilities must have greater flexibility than those for reactors. The staff has not included the existing pool capacity in the analysis of future storage availability.

2.2 SPENT FUEL STORAGE REQUIREMENTS

2.2.1 Demand for Storage Capacity, 1976-2000

The annual demand for spent fuel storage depends on the number of reactors discharging fuel and their individual fuel usage rates in the year under consideration. The assumptions made for rates of reactor installation are described in Section 1.2 and Appendix F of this statement. Appendix F describes the methods used to estimate future spent fuel discharges and AR storage space requirements. The use of these models and assumptions[1] (assumptions were required for reactors beyond the 46 GWe now discharging fuel) creates a fuel discharge schedule as shown in Table 2.1.

At end of year 1978, about 4250 MTHM of spent fuel were in storage at reactors. About 170 MTHM of spent fuel were in storage at the West Valley NFS facility and 310 MTHM at the Morris, Illinois, GE facility. The total AFR storage was 480 MTHM. The facility at Barnwell, South Carolina, is not licensed.

Table 2.1 shows that by 1986 annual discharges will approach the 2700-MTHM level and will increase to at least 5800 MTHM at the projected rate of reactor installation (230 GWe) by the year 2000.

Table 2.1. Annual and Cumulated Schedules of Spent Fuel Discharge

Year	GWe Capacity Discharging	Annual Discharge, MTHM	Cumulative Discharge,[a] MTHM
1979	40	1,420	-
1980	48	1,520	2,900
1981	51	1,640	4,600
1982	58	1,850	6,400
1983	66	2,100	8,500
1984	73	2,300	11,000
1985	80	2,440	13,000
1986	87	2,650	16,000
1987	94	2,840	19,000
1988	102	3,050	22,000
1989	110	3,300	25,000
1990	119	3,600	29,000
1991	125	3,720	32,000
1992	134	3,950	36,000
1993	142	4,200	41,000
1994	151	4,380	45,000
1995	160	4,620	50,000
1996	168	4,840	54,000
1997	177	5,100	60,000
1998	187	5,460	65,000
1999	194	5,730	71,000
2000	202	5,800	77,000

[a] Does not include about 4700 MT of spent fuel discharged prior to 1979 and stored AR and AFR at the end of 1978.

2.2.2 Storage Capacity through 2000

The capacity for storage of spent fuel at operating reactors is documented.[2] Present design and construction practices were assumed to continue for storage pools at all reactors under construction or in planning. These practices are discussed in detail in Section 3.1 and Appendix B of this statement. Appendix F shows the detailed methods used to determine AR storage capacities.

Table 2.2 shows the storage capacity in metric tons of heavy metal (MTHM) as related to year and installed nuclear generating capacity expressed as gigawatts electric (GWe). The storage capacity is the total annual storage capacity for all U.S. reactors. Some of this is now being used to store spent fuel (about 4250 MTHM).

Table 2.2 indicates total reactor basin storage (with compact storage) of 91,000 MTHM without FCR and 77,000 MTHM with FCR by the year 2000.

The value given in the second column of Table 2.2 is the storage capacity at reactor plants that are operating, under construction, or planned through the year 2000.[2-4] The average storage capacity of these reactors was assumed to continue to be about four cores (360 MTHM).

Table 2.2. At-Reactor Storage Capacity--Reference Case--
With and Without FCR

Year	Installed Capacity, GWe	Maximum Basin Storage Capacity, MTHM Without FCR	Maximum Basin Storage Capacity, MTHM With FCR
1979	57	26,000	22,000
1980	64	30,000	25,000
1981	71	33,000	27,000
1982	78	35,000	28,000
1983	85	38,000	31,000
1984	92	40,000	33,000
1985	100	43,000	36,000
1986	108	46,000	38,000
1987	116	50,000	41,000
1988	124	52,000	44,000
1989	132	56,000	47,000
1990	140	59,000	50,000
1991	149	62,000	53,000
1992	158	65,000	55,000
1993	167	68,000	58,000
1994	176	71,000	60,000
1995	185	75,000	64,000
1996	194	78,000	67,000
1997	203	81,000	69,000
1998	212	84,000	71,000
1999	221	87,000	74,000
2000	230	91,000	77,000

References

1. "Nuclear Engineering International," Supplement--Power Reactors 1975, April 1975. Available at technical public libraries.

2. U.S. Nuclear Regulatory Commission, "Operating Units Status Report" (Gray Book), NUREG-0020, through January 1979. Available from National Technical Information Service (NTIS), Springfield, Virginia 22161.

3. U.S. Nuclear Regulatory Commission, "Construction Status of Nuclear Power Plants" (Yellow Book), NUREG-0030, through April 1979. Available from National Technical Information Service (NTIS), Springfield, Virginia 22161.

4. U.S. Nuclear Regulatory Commission, "Program Summary Report" (Brown Book) USNRC Report NUREG-0380, February 16, 1979. Available from National Technical Information Service (NTIS), Springfield, Virginia 22161

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3.0 DESCRIPTION OF ALTERNATIVES

This chapter describes the alternatives considered by the staff in analyzing several aspects of the spent fuel storage situation. The alternatives considered are chosen to bound the examination, since large numbers of variations within these alternatives are conceivable. In fact, at present, on a case-by-case basis, a number of interim storage actions are under consideration or are being implemented, such as compact storage at existing reactor storage pools, AFR storage (at GE Morris), compact storage of reactor pools at constructed but as yet unlicensed reactors, and in three cases, transshipment of spent fuel from one reactor to another reactor for storage has been requested with one approval already granted. Thus, any one of the bounding alternatives developed in this statement is unlikely to be the precise answer to the spent fuel storage program. However, the alternatives do scope the program and in subsequent chapters the total impacts, costs, and benefits of their implementation are examined and evaluated.

Also, for each of the first three alternatives described below (not including the cessation of reactor operations), a reference level of reactor installation rate (230 GWe installed by 2000) and whether or not full core reserve (FCR) capability is used are considered. This makes a total of two options (or cases) within three alternatives, or six total cases for which AFR storage requirements are documented. In Appendix I these six total cases are also included for a high reactor installation rate (280 GWe installed by year 2000). In all cases, expansion of reactor storage basins by a factor of three times present design is assumed. Cases with FCR assume one FCR per site. All alternatives assume that no final disposal site would be available by 2000 and that no reprocessing or recycling of LWR fuel will occur by that time.

The alternatives are:

Alternative 1: Assumes no offsite transshipment of spent fuel; utilizes existing storage technologies to increase at-reactor (AR) storage capacity and allows use of all storage space at each reactor site by reactors at that site. This alternative with FCR is the Reference Case in this statement.

Alternative 2: Transshipment of spent fuel freely from facilities with full pools to pools with available storage capacity within each utility-owned generating system, regardless of geographical locations.

Alternative 3: Complete and free interchange of available storage space, by transshipment, regardless of ownership or geographical locations.

Alternative 4: Ceasing to generate spent fuel by allowing reactor shutdown as individual reactor storage capacity is exhausted. This implies that other energy sources (such as coal) would be used to generate replacement electrical power.

3.1 SCOPE OF SPENT FUEL STORAGE REQUIREMENTS

3.1.1 Spent Fuel Storage Requirements

Spent fuel storage requirements are listed for Alternative 1 (230 GWe installed by 2000) in Table 3.1. In the Reference Case of Alternative 1 full core reserve (FCR) is maintained and there is no transshipment offsite; i.e., only at-site storage is allowed, but total storage capacity usage at site, regardless of reactor type is permitted. All storage space as originally designed has been expanded (as by reracking) to reflect experience effected to date for present reactors and by a factor of 3 for future reactors. The latter value reflects the present experience as an average value. .

Table 3.1. Away-from-Reactor (AFR) Storage Requirements with No Transshipment, 230 GWe Installed in Year 2000, With FCR (Reference Case) and Without FCR

Year	Installed Generating Capacity,[a] GWe	Pool Capacity, MTHM	Full Core Reserve, MTHM	Cumulated Discharges,[a] MTHM	AFR Capacity Required (MTHM)	
					With FCR[b,c,d]	Without FCR[c,d]
1979	57	26,000	4,700	1,400	40	0
1980	64	30,000	5,200	2,900	140	20
1981	71	33,000	6,000	4,600	310	110
1982	78	35,000	6,400	6,400	520	240
1983	85	38,000	6,700	8,500	880	360
1984	92	40,000	7,100	11,000	1,500	550
1985	100	43,000	7,400	13,000	2,200	920
1986	108	46,000	7,900	16,000	2,900	1,400
1987	116	50,000	8,400	19,000	3,800	2,000
1988	124	52,000	8,600	22,000	4,800	2,800
1989	132	56,000	8,900	25,000	5,900	3,600
1990	140	59,000	8,900	29,000	6,800	4,300
1991	149	62,000	9,100	32,000	8,000	5,300
1992	158	65,000	9,600	36,000	9,200	6,300
1993	167	68,000	10,000	41,000	11,000	7,600
1994	176	71,000	11,000	45,000	12,000	8,900
1995	185	75,000	11,000	50,000	15,000	10,000
1996	194	78,000	11,000	54,000	17,000	12,000
1997	203	81,000	12,000	60,000	19,000	14,000
1998	212	84,000	13,000	65,000	22,000[e]	16,000[e]
1999	221	87,000	13,000	71,000	25,000	19,000
2000	230	91,000	14,000	77,000	28,000	22,000

[a] Does not include ∿4700 MTHM in storage as of December 31, 1978, both AR and AFR.

[b] Reference Case.

[c] Includes ∿4300 MTHM in AR storage as of December 31, 1978.

[d] Does not include the effect of recent reactor basin storage capacity expansion applications for the Oconee Units 1 & 2 basin, for the Big Rock Point basin, and for the Hatch 1 & 2 basins. (See Vol. II, Appendix F, Table F.8, footnote b.)

[e] AFR storage is a maximum and may be overstated in 1997-2000; see Section 3.1.1 for explanation.

This situation closely resembles the current status of reactor storage and bounds the capability of the existing and planned nuclear reactor system in the U.S. to store spent fuel if no transshipment is allowed. The potential for use of existing AFR storage (as at GE Morris) is not contemplated in the results shown in Table 3.1. The present unused capacity of the Morris facility as racked is about 350 MT. This capacity approximates the need for AFR storage (from Table 3.1) without FCR through 1983 and through 1981 with FCR. Application to expand the storage capacity at this AFR facility by an additional 1100 MT has been made (proceeding indefinitely suspended).

The third column of Table 3.1 shows the capability of the entire reactor system to store spent fuel. In Alternative 1 (the reference case), however, the useable space for each reactor is restricted to that available on site. This results in a need for about 2000 MT of AFR storage in 1985 (with FCR).

If AR capacity is filled and there is no AFR capacity available, then the reactors involved in loss of spent fuel storage space would shut down. The extent of this loss of generating capacity is summarized in Table 3.2 below for Alternatives 1 and 2 with and without FCR for each year and cumulated through year 2000.

Table 3.2. Generating Capacity (GWe) Running Out of Spent Fuel Storage Capacity Each Year, 1979 Through 2000, With and Without FCR, for Alternatives 1 and 2

	GWe with FCR[a]				GWe without FCR[a]			
	Alternative 1		Alternative 2		Alternative 1		Alternative 2	
Year	Cumulated	Each Year	Cumulated	Each Year	Cumulated	Each Year	Cumulated	Each Year
1979	3	3	0		0	0	0	
1980	4	1	0		3	3	0	
1981	6	2	0		4	1	0	
1982	7	1	2	2	4	0	0	
1983	14	7	8	6	4	0	0	
1984	19	5	11	3	9	5	2	2
1985	21	2	13	2	12	3	2	0
1986	24	3	16	3	17	5	7	5
1987	26	2	19	3	19	2	5	-
1988	28	2	21	2	22	3	11	6
1989	31	3	22	1	25	3	17	6
1990	32	1	22	0	25	0	14	-
1991	36	4	24	2	28	3	13	-
1992	40	4	41	17	30	2	14	-
1993	45	5	46	5	37	7	23	9
1994	52	7	50	4	40	3	29	6
1995	63	11	50	0	48	8	33	4
1996	69	6	54	4	60	12	36	4
1997[b]	78	9	60	6	61	1	50	14
1998	88	10	86	26	69	8	52	2
1999	94	6	112	26	84	15	70	18
2000	96	2	132	20	89	5	82	12

[a] Does not include the effect of recent reactor basin storage capacity expansion applications for the Oconee Units 1 & 2 basin, for the Big Rock Point basin, and for the Hatch 1 & 2 basins.

[b] Generating capacity is a maximum and may be overstated for years 1997-2000; see Section 3.1.1 for explanation.

Alternative 1 includes no offsite shipment of spent fuel from one reactor basin to another. Alternative 2 includes intrautility shipment from one reactor basin to another offsite. For both Alternatives 1 and 2, AFR storage requirements are assumed to be met by independent spent fuel storage installations (ISFSI) as needed. These ISFSIs may be centralized regional installations or at-reactor-site installations serving a single utility's nearby reactors. For the years 1997 through 2000, the model used understates the available storage capacity. For these years, postulation of a total of 28 unnamed and unsited reactors was required to reach the projected 230 GWe installed. Both Alternatives 1 and 2 would have required siting and assigning ownership of these reactors. Since prediction of sites and ownership of these unnamed reactors coming on line during 1997-2000 would be completely speculative, the staff chose to allow the model to tabulate only those reactors for which siting and ownership information was available today. Hence, the potential understatement of storage capacity in those last years and greater increase in the fallout of generating capacity in those years, particularly for Alternative 2 with FCR. The maximum increase of storage capacity in those years is given in Table 3.3.

Table 3.3. Cumulated Increase in Storage Capacity in Years 1997-2000 from Unnamed, Unsited Reactors

	Number of Plants		Cumulated Increase in Storage Capacity (MTHM)	
Year	BWR	PWR	With FCR	Without FCR
1997	2	4	2,000	2,700
1998	3	4	4,400	5,900
1999	3	5	7,000	9,500
2000	2	5	9,300	13,000

3.1.2 Compact Storage

3.1.2.1 Compact Storage at Power Plants (AR Storage)

There are a number of options available for increasing spent fuel pool storage capacity. To some degree, each plant is different and each plant operator may choose one or more of the following options:

- Fill unused pool area with existing type racks or racks of different designs;

- Replace nonfuel racks (such as control rod racks) with racks which can accept fuel (store control rods as required in other pool areas, aisle spaces, dryer-separator pool, or support from the pool walls or railings);

- Replace old racks with racks of closer spacing:

  . Spaced closer by allowing k_{eff} (see Appendix D) to increase above the original design value but still within specifications;

  . Spaced closer by use of neutron absorbing materials in the rack construction; and

- Combinations of the above.

A decision on the method used to increase pool storage capacity would have to be based on a number of general considerations as well as considerations specific to the design and current status of the reactor and the spent fuel storage pool involved. These considerations are discussed in more detail in Appendix D.

In addition to the above, but not presently approved, storage capacity could also be increased by double stacking the fuel assemblies in two-tier racks or by disassembling some spent fuel assemblies and storing the pins in compacted form in special containers or in unused positions in other spent fuel assemblies.

One of the major considerations in compact storage is that the pool design including fuel assembly spacing must be such that the storage facility is always subcritical by a safe margin, even under accident conditions. The current requirement that k_{eff} must be 0.95 or less for spent fuel rack designs is given in NUREG-75/087, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants - LWR", Section 9.1.2. Past design practice used spacings which allowed calculated k_{eff} values of 0.90 or less, using less sophisticated computational techniques and hence a greater error allowance. For example, with current computational design dependent techniques, it has been shown in the case of PWR plants that spacing can be reduced from about 20 inches to about 12 to 14 inches without exceeding the specified k_{eff} limit.

The fuel storage pool racks for BWR plants are spaced closer together than for PWR's because the BWR fuel elements are smaller and contain less fuel (about 1/2 that of the PWR). Further reduction of spacing in BWR pools would be more difficult. If the matrix of the BWR storage rack were brought closer together than the original design, the calculated k_{eff} would become greater than allowable. The only alternative left for closer packed arrays in BWR pools is the use of neutron absorbing materials as part of the rack construction. The materials which are in use are stainless steel, Boral (a mixture of B_4C in aluminum), boron carbide plates and stainless steel alloyed with a small amount of boron.

Neutron absorber materials may also be used in the construction of spent fuel racks for PWR plants. This would provide even greater compact storage than discussed above. Spacing could be reduced to as close as 11 to 12 inches, giving as much as a threefold increase in capacity for PWR pools. The use of modified storage racks to expand pool capacity in existing plants is particularly advantageous and has proved feasible.

Spacing of racks for criticality control is not the only major consideration in planning for compact storage at existing plants. Other factors that must be taken into account are maintenance of adequate pool water cooling capacity, radiation protection, and pool water cleanup capacity; meeting seismic design requirements with the new pool arrangement; and ensuring the protection of the public and workers during structural modifications of storage pools already containing spent fuel and during normal operating and credible accident conditions after pool modifications are completed.

It appears from experience with some 39 application approvals to date that these potential problems usually can be overcome and that compact storage is a viable option for increasing the storage capacities at most reactors.

Compact storage plans for reactor storage pools of many operating reactors and reactors under construction have been defined and are at various stages of implementation.

As of December 31, 1978, all of the 69 then-operating reactors (50 GWe) except four (1.27 GWe) had either been licensed to expand their design spent fuel storage capability by an average factor of about three or were seeking such licensing. The four are Robinson-2, San Onofre-1, Big Rock

Point,* and Humboldt Bay. Of these four reactors, Robinson-2 is licensed to ship spent fuel to Brunswick, where a pool expansion for both PWR and BWR assemblies has been licensed. San Onofre-1 is at a site where two other similar reactors are being constructed, the first of which will have sufficient storage capacity.available in 1980 to accommodate the next reload from San Onofre-1.

Examples of pool expansion at existing reactors are as follows:

- The fuel storage pools for the Commonwealth Edison Company's Dresden (BWR) Units 2 and 3 were originally designed to store 1160 fuel assemblies, or sufficient capacity to store approximately 1.6 cores each. Planned changes will increase the capacities to 7560 fuel assemblies (approximately five cores for the site).
- Reduced fuel assembly spacing without employing neutron absorber materials such as Boral or boron/stainless steel is planned for Sacramento Municipal Utility District's Rancho Seco (PWR) plant. The original spent fuel pool had a capacity for 244 fuel assemblies or approximately 1.4 cores. The capacity has been expanded to 579 fuel assemblies or approximately 3.3 cores. The new storage rack design employs square fuel guides fabricated from 14-gauge stainless steel (0.078 inches) with a 15-inch center-to-center spacing.
- The Boston Edison Company has increased the capacity of the spent fuel storage pool at Pilgrim 1 (BWR) by replacing the existing spent fuel storage racks with anodized aluminum fixed-absorber racks which have a reduced center-to-center spacing. The neutron absorber material would consist of a minimum of 35% by weight of natural B_4C in a type 1100 aluminum alloy matrix (Boral). This change has increased the capacity from 900 assemblies or approximately 1.6 cores to 2320 assemblies or approximately 4.3 cores.

At the present time, licensing credit for the use of soluble neutron absorbers in the storage pool water is not acceptable to the Nuclear Regulatory Commission and to date no known applications have included credit for this method.

Selected examples of how pool storage capacity for PWR and BWR plants were increased and detailed discussions of the factors involved in the applicable guidelines and requirements are given in Appendix D.

3.1.2.2 Compact Storage at Existing Reprocessing Plants (AFR Storage)

Increased fuel storage capacity can be achieved at some existing reprocessing plant storage pools by methods similar to those described in Section 3.1.2.1 for reactor stations. Planning for compact storage at reprocessing plants would have to take into consideration any plant-specific design peculiarities, as well as any special conditions resulting from the current use of the pool. An example of an increase in storage capacity at a reprocessing plant is given in Appendix D. The licensed storage capacity at the GE Morris facility has been increased to 750 MT with compact storage of spent fuel in existing basins. Recent reviews funded by NRC indicate that compact storage for the West Valley facility could present structural difficulties.[1]

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*In April 1979, an application for a license amendment to expand storage capacity to 441 assemblies (88 MTHM) was received.

3.1.2.3 Summary

Compact storage is a means of increasing spent fuel storage capacity at existing storage facilities, both at reactors and at some existing reprocessing plant storage pools, which is implementable with today's technology. The rapidity with which increased storage capacity can be achieved by using this alternative makes it attractive. Fifty-five individual license amendments have been applied for to modify pools by this means. Of these, 54 were for reactor pools--40 have been approved and 14 applications are outstanding. The remaining application, also approved, was for the GE Morris pool.

3.1.3 Volume Expansion of Existing Reactor (AR) and Reprocessing Plant (AFR) Pools

3.1.3.1 Description

Allowable construction practices for storage pools are discussed in Appendix L. The addition of space to a fuel pool storage facility by extending the pool or connecting in a second pool is difficult at reactors. As noted, any action that requires a penetration of the pool liner is normally avoided. This is particularly true for operating plants with fuel already stored in the pool. Consequently an add-on section to an existing pool appears to be an unlikely alternative.

However, storage pools at some existing reprocessing plants have gates which permit add-on sections to their pools to be isolated from existing spent fuel storage locations until construction is completed. The designs of both GE Morris and the Barnwell FRSS will permit the building of additions to existing pools.[2,3] General Electric has made application to NRC for an add-on section to the existing storage pool to increase storage capacity to a licensed 1850 MT.

A potential option in some nuclear power plants is to build an additional storage pool in an adjacent building. In at least one existing PWR plant, the fuel and auxiliary building is located at the station such that sufficient space is available outside the building to construct an additional storage facility. An addition of this sort would not require interruption of operations in the fuel and auxiliary building until the connection between the two buildings was made. It may be possible that the same crane could be used for both facilities. Transfer of spent fuel between the two storage pools would have to be accomplished by a transfer cask. The add-on facility is not a practical consideration where the existing pool is elevated in a building or the building arrangement does not provide reasonable access between the existing facility and the available space for a new facility.

It is also feasible to construct a spent fuel storage facility on a reactor plant site but separated from and not a part of the existing structures. Such a facility would be considered an AFR. This concept is described in Section 3.1.4.3.

3.1.3.2 Summary

Expansion of pool volume at existing nuclear power plants is an option with limitations in application. The staff will perform detailed safety and environmental reviews of pool volume expansion if a license for such a modification is requested by a utility.

Expansion of pool volume at reprocessing plant pools equipped with pool isolation gates is considered feasible.

3.1.4 Wet Storage Facilities (AFR)

3.1.4.1 Introduction

The construction of new independent spent fuel storage installations (ISFSI) may provide expanded storage capacity for reactor spent fuel. Additional water filled spent fuel storage pools can be constructed to provide storage space in excess of several thousand MTHM of spent fuel. This is far greater than the capacities of current reactor site storage pools.

Presently, spent fuel storage is licensed by the NRC at two pools functioning as ISFSI's, though their original purpose may have been different. The pool at the GE Morris facility is one example.

All of the commercial LWR spent fuel storage operational experience is with wet storage. Regulatory Guide 3.24, "Guidance on the License Application, Siting, Design, and Plant Protection for an Independent Spent Fuel Storage Installation,"[4] has provided recommended criteria and requirements for ISFSIs but is being updated by a series of guides. Pertinent sections of 10 CFR Parts 19, 20, 30, 40, 51, 70, 71, 73, now apply to spent fuel storage installations.

These regulations cover the possession of special nuclear materials, but were promulgated to cover such possession incidental to manufacturing type operations. These regulations do not specifically cover spent fuel storage only type operations under static storage conditions. In addition, the pertinent requirements of 10 CFR Part 70 are worded in general language and require interpretations in specific licensing actions. In recognition of the need for a more definitive regulation base for storage only type activities, a proposed new rule 10 CFR Part 72, "Licensing Requirements for Storage of Spent Fuel in an Independent Spent Fuel Storage Installation," was issued for comment in October 1978.

3.1.4.2 Concepts

The design of a pool type ISFSI would be similar to that of spent fuel pools at reprocessing plants. In addition to the required pools, the designs would include spent fuel cask receiving, handling, and unloading equipment; pool water cooling and treatment systems; a heating, ventilation, air conditioning (HVAC) system; a radioactive waste treatment and handling system; cask maintenance shops; personnel support systems; and the necessary buildings to house this equipment.

The function of the pool is to serve as a radiation shield as well as a heat sink for the heat generated by radioactive decay of spent fuel. Supporting equipment and systems ensure the safe operation of the pool with respect both to the public and operational personnel. The person-rem dose to the public from effluents and the operating occupational dose will be maintained as low as reasonably achievable, and is expected to be a small fraction of 10 CFR Part 20 requirements.

Detailed considerations of a model ISFSI are provided in Appendix H.

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3.1.4.3 Design Criteria

An ISFSI is described as a "self-contained installation for storing spent fuel." It differs from reactor pools only in that it operates independently. An ISFSI is presently licensed under 10 CFR Parts 30, 40, and 70. (It is reviewed under Part 70, since a facility meeting the requirements of Part 70 automatically satisfies the requirements of a Part 30 and 40 license.) Part 72, which has been issued for comment, specifically covers the licensing aspects of AFR storage installations, where spent fuel is kept for an extended period of time. As with other major nuclear installations, an environmental impact review is required in addition to a license review for an ISFSI.

Regulatory Guide 3.24[4] addresses the design criteria for an ISFSI. Regulatory Guide 3.24 is being updated with the preparation of a series of guides. One of these, Regulatory Guide 3.44, has been issued for comment. Design standards must assure safe plant operation. An ISFSI may contain in excess of 10^9 curies of long-lived fission products, therefore the design of systems, structures, and components must provide for the confinement of radionuclides. In general, the safe storage of irradiated fuel depends on maintaining the integrity of the fuel cladding as the primary barrier to the release of radionuclides. Protection of the pool structure and the purity of the cooling water are the primary means of maintaining cladding integrity. Experience to date indicates that under the proper storage conditions, LWR spent fuel can be stored under water for long periods without serious degradation of the fuel cladding.[5,6] (See App. H.)

A proposed design for an independent spent fuel storage facility suitable for construction on an existing reactor site has been approved by the NRC. This design, described in the Stone and Webster Engineering Corporation report number SWECO-7601,[7] has a maximum fuel storage capacity of approximately 1300 metric tons of spent fuel (as UO_2 of either PWR or BWR fuel).

Any license application by a utility to construct such a facility would be supported by additional information and detailed drawings on a site-specific basis as well as a safety analysis report as necessary for the NRC to perform its statutory review to ensure the health and safety of the public and the protection of the environment.

3.1.5 Dry Storage Facilities (AFR)

3.1.5.1 Introduction

Dry storage of LWR spent fuel assemblies, i.e., storage outside a water environment, has not been employed by the U.S. nuclear industry for LWR spent fuel. However, preliminary conceptual studies indicate that dry storage is feasible, provided the fuel has first been stored in water for about five years or more so that the decay heat generation rate is low. For some applications, particularly if extended storage is expected, dry storage may have economic advantages over water pool storage.

3.1.5.2 Concepts

Much of the concept development work for dry storage was originally done in conjunction with the storage of solidified high level waste. Fission products are the major sources of heat and radiation for both spent fuel and high level waste. With the appropriate adjustment for density of the radiation sources, heat removal and shielding requirements for storage of high level waste are approximately the same as those required for storage of spent fuel assemblies for equivalent

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times after discharge from a reactor. Technology and conceptual designs developed for one may be, in part, applicable to the other.

The various concepts that have been studied for dry storage of spent fuel and high level waste include:

- Retrievable surface storage facility (RSSF) - shielded, sealed cask
- Retrievable surface storage facility (RSSF) - air cooled vault
- CANDU shielded, sealed storage cask
- Dry caisson storage
- Air cooled storage racks.

3.1.5.2.1 *RSSF Sealed Cask*

The RSSF sealed cask is a concept which had previously been developed for interim surface storage of solidified high level wastes, prior to permanent placement in geologic formations or other suitable facilities.[8] In this concept solidified high level waste is contained in stainless steel canisters approximately 30 cm in diameter and 3 meters in length. Such a canister, which is roughly the same volume as a PWR fuel assembly, would contain the high level waste resulting from processing about three metric tons of spent fuel. Assuming that high level wastes are stored for ten years at reprocessing plants prior to placement in an RSSF, a typical heat generation rate is about five kilowatts per canister. This is comparable to a typical BWR fuel assembly about three months after reactor discharge.

The shielded, sealed storage cask design is for aboveground waste storage and is illustrated in Figure 3.1. A stainless steel canister of high level waste is to be sealed into a carbon steel cask approximately 48 cm o.d. x 38 cm i.d. x 3.2 m long. This cask is contained within a concrete gamma-neutron shield approximately 2.5 m o.d. x 0.8 m i.d. x 3.5 m long. A 15-cm airflow annulus remains between the carbon steel cask outer diameter and the concrete inner diameter. This assembly constitutes a completely passive system. Heat is removed from the assembly by natural convection.

The Department of Energy has initiated a research and development study[9] of cask storage at its Nevada Test Site with both PWR and BWR spent fuel in storage casks.

3.1.5.2.2 *RSSF-Air Cooled Vault*

An alternative dry storage concept for the RSSF is an air-cooled vault, illustrated in Figure 3.2. The high-level waste canisters would be sealed in 1.3 cm thick carbon steel overpacks. The overpacked canisters would be positioned as shown by lowering them through access openings in the concrete deck. Natural-draft air circulation would provide adequate heat removal. Air-cooled vault storage for non-LWR spent fuel is practiced at the Idaho National Engineering Laboratory.[10]

3.1.5.2.3 *CANDU Spent Fuel Storage*

In Canada, consideration has been given to the application of similar concepts for the storage of spent fuel from their CANDU reactors.[11] Figure 3.3 is a schematic drawing of a CANDU fuel assembly. It is approximately 50 cm long. Figure 3.4 illustrates the storage of about 4.4 MT

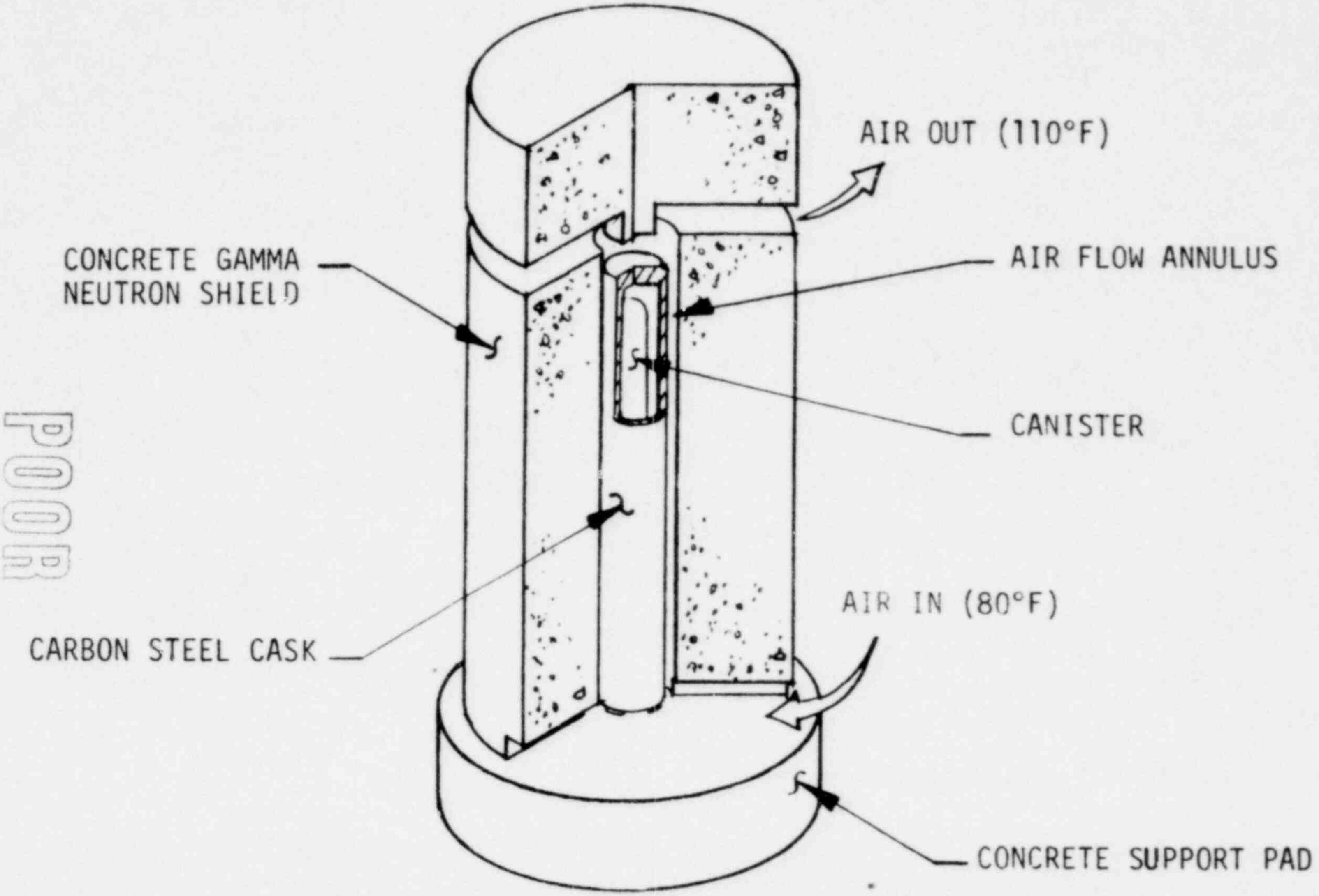

Figure 3.1 Shielded Sealed Storage Cask Concept for High-Level Waste. (After Fig. 8 in Nelson and Wodrich, "Retrievable Surface Storage Facility for Commercial High Level Waste," in Nuclear Technology, 24:391-397, December 1974. Used with permission of the publisher.)

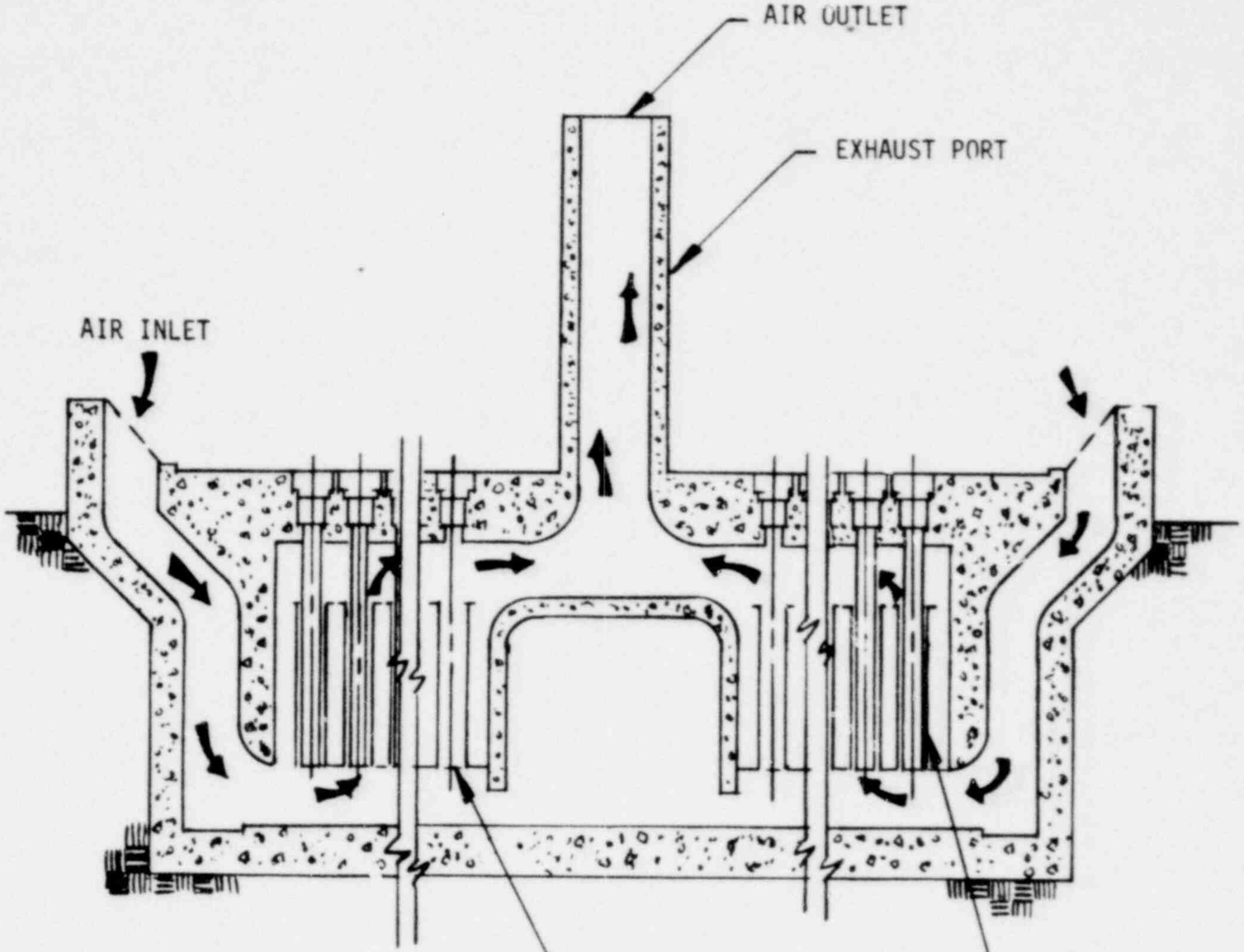

Figure 3.2 Air Vault Concept for High Level Waste. (After Fig. 4 in Nelson and Wodrich, "Retrievable Surface Storage Facility for Commercial High Level Waste," in Nuclear Technology, 24:391-397, December 1974. Used with permission of the publisher.)

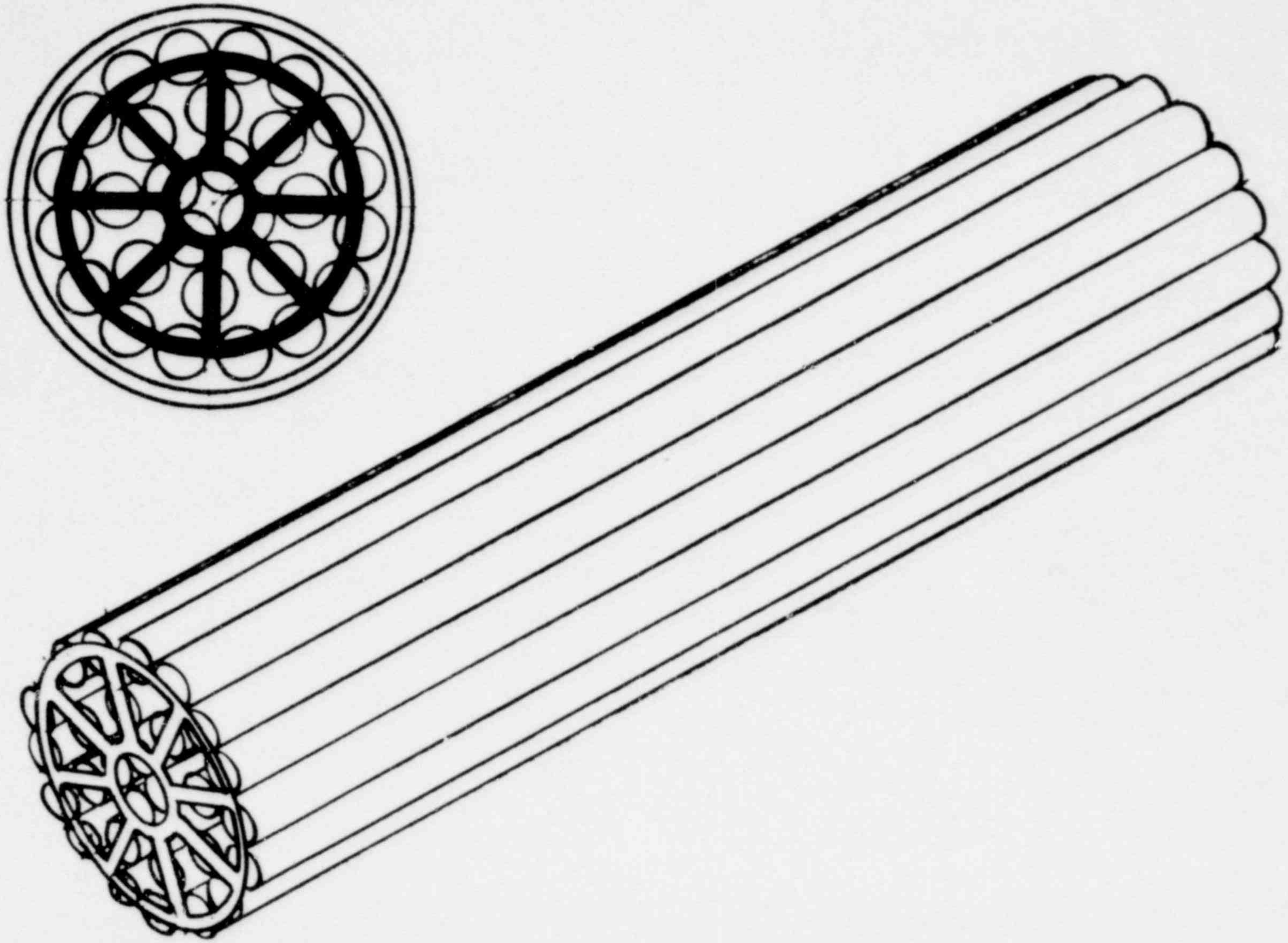

Figure 3.3 CANDU Fuel Assembly. (After Fig. 2 in Morgan, "The Management of Spent CANDU Fuel," in Nuclear Technology, 24:409-417, December 1974. Used with permission of the publisher.)

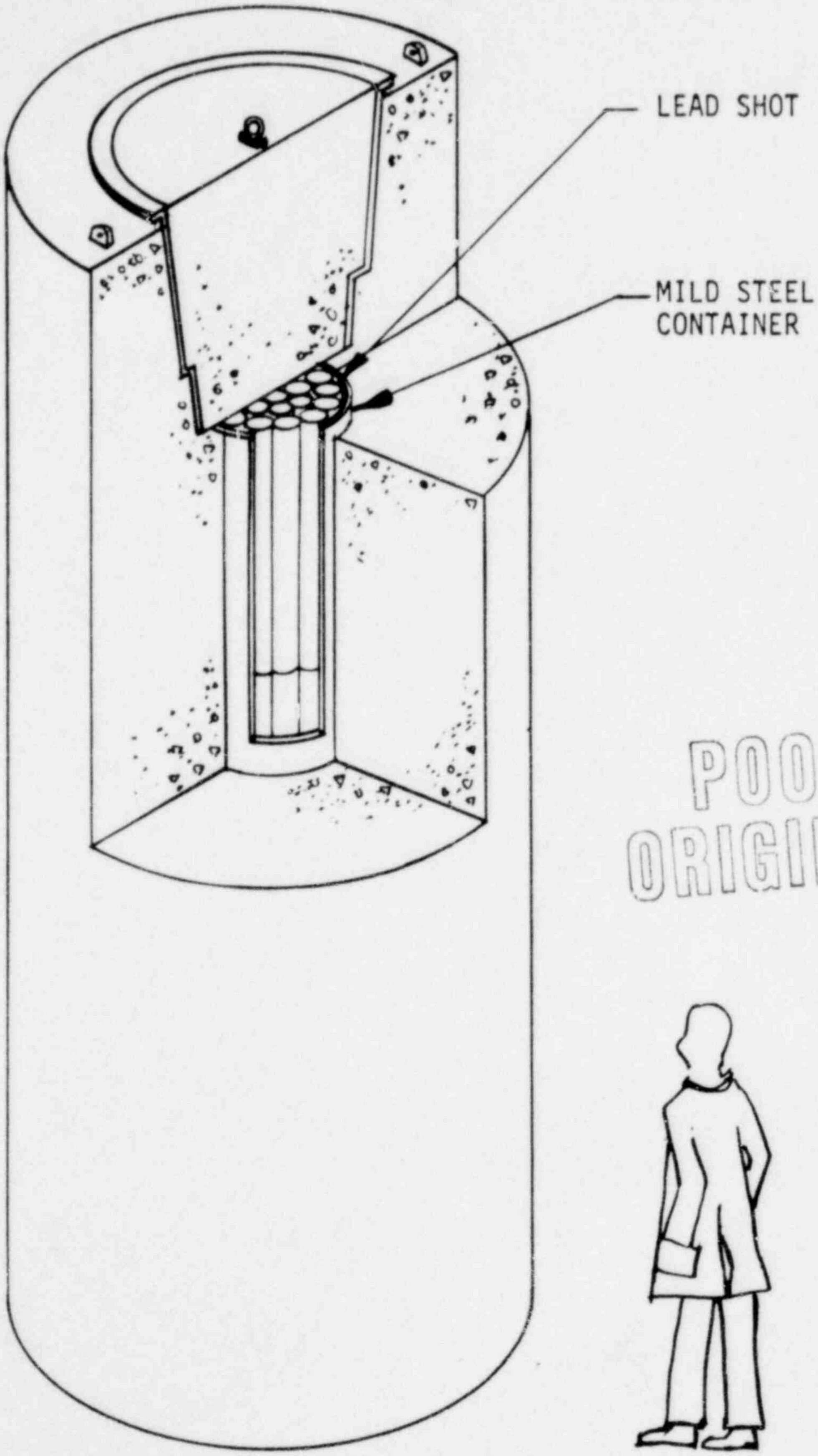

Figure 3.4 Shielded Sealed Storage Cask Concept for CANDU Fuel. (After Fig. 5 in Morgan, "The Management of Spent CANDU Fuel," in Nuclear Technology, 24:409-417, December 1974. Used with permission of the publisher.)

of such spent fuel assemblies in a shielded, sealed storage cask. It has been assumed that the fuel would be aged for five years prior to storage in this cask. Use of spent fuel in dry storage testing of this design has been initiated at the Whiteshell Nuclear Research Establishment, Manitoba.[12]

Figure 3.5 illustrates another dry storage concept proposed for spent CANDU fuel that is similar to the RSSF air cooled vault concept. In this concept, it is assumed that the fuel assemblies are loaded into aluminum pipe. The pipe is then filled with molten zinc or aluminum to form a solid casting.[11] Cooling is achieved by the natural circulation of air.

3.1.5.2.4 *Dry Caisson Storage*

This concept for dry storage of spent light water reactor fuel was under study by the Atlantic Richfield Company[13] and utilized the shielding and heat transfer qualities of the earth. Similar approaches are being used at the Idaho Nuclear Engineering Laboratory for the storage of Peach Bottom (HTGR) spent fuel[10] and after study[9] by the Department of Energy at the Nevada Test site for LWR spent fuel on a small research and development basis.

The Atlantic Richfield concept is illustrated schematically in Figure 3.6. One PWR fuel assembly or three BWR fuel assemblies are sealed in a mild steel overpack approximately 40 cm in diameter. The overpack is stored inside a well casing or caisson, which may range from 50 to 100 cm in diameter. Caisson diameters in excess of the minimum required to accommodate the internal container may be employed to reduce heat flux into the earth. The depth of approximately 7.5 m is established to provide adequate shielding.

The minimum spacing between caissons depends on the heat generation rate of contained fuel, maximum allowable material temperatures, and the thermal conductivity of the soil. Figure 3.7 shows temperature distributions for a heat generation rate of 1.5 kW per caisson 7.5 m apart in dry soil.

In the design of this particular concept it is assumed that fuel would be received after two to three years of storage in a spent fuel storage pool. A spent fuel assembly or assemblies are placed in an overpack, welded shut, tested for integrity of the seal, and cleaned of surface contamination. The encapsulated assembly or assemblies are then conveyed in a shielded transporter to a previously prepared caisson and lowered into it. A high-density shield plug is next lowered into place and then a cover placed on the caisson and locked in place.

Each caisson would be provided with probes to monitor radioactivity, temperature, and possibly tracer gases such as helium. The rate of heat evolution is measured before each assembly is placed in a caisson. After placement, the caisson temperature rise would be monitored intermittently. The temperatures of selected caissons is monitored continuously to verify expected trends. Maximum temperatures are expected about one year after insertion. The soil near and between caissons would also be monitored at selected locations. Radiation and temperature monitors and/or alarms would be placed at strategic locations in the storage area.

At this time, no unusual factors which would preclude an acceptable design have been identified and it is the staff opinion that an adequate dry caisson storage design can be developed for LWR spent fuel.

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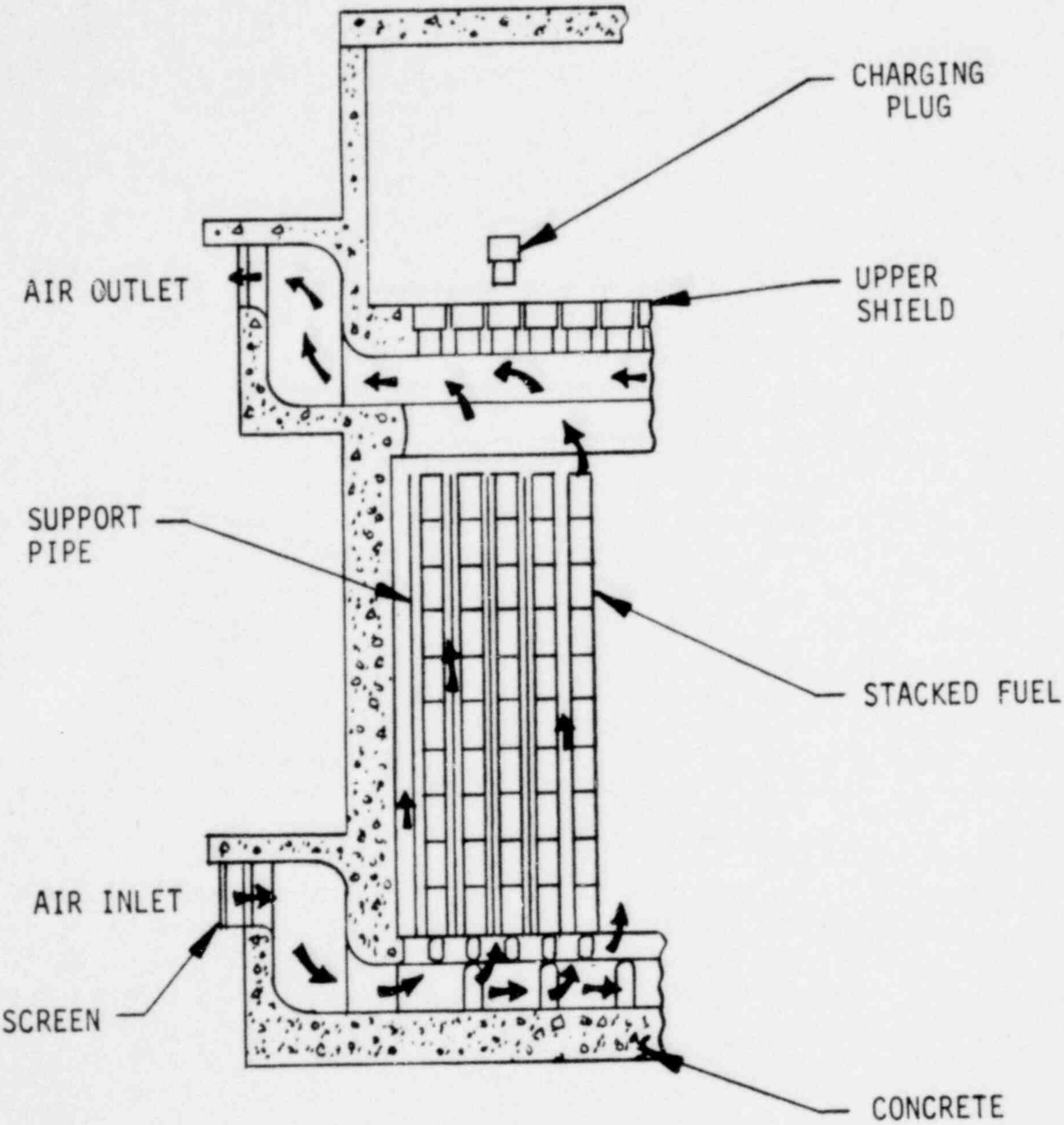

Figure 3.5 Air Vault Concept for CANDU Fuel. (After Fig. 8 in Morgan, "The Management of Spent CANDU Fuel," in Nuclear Technology, 24:409-417, December 1974. Used with permission of the publisher.)

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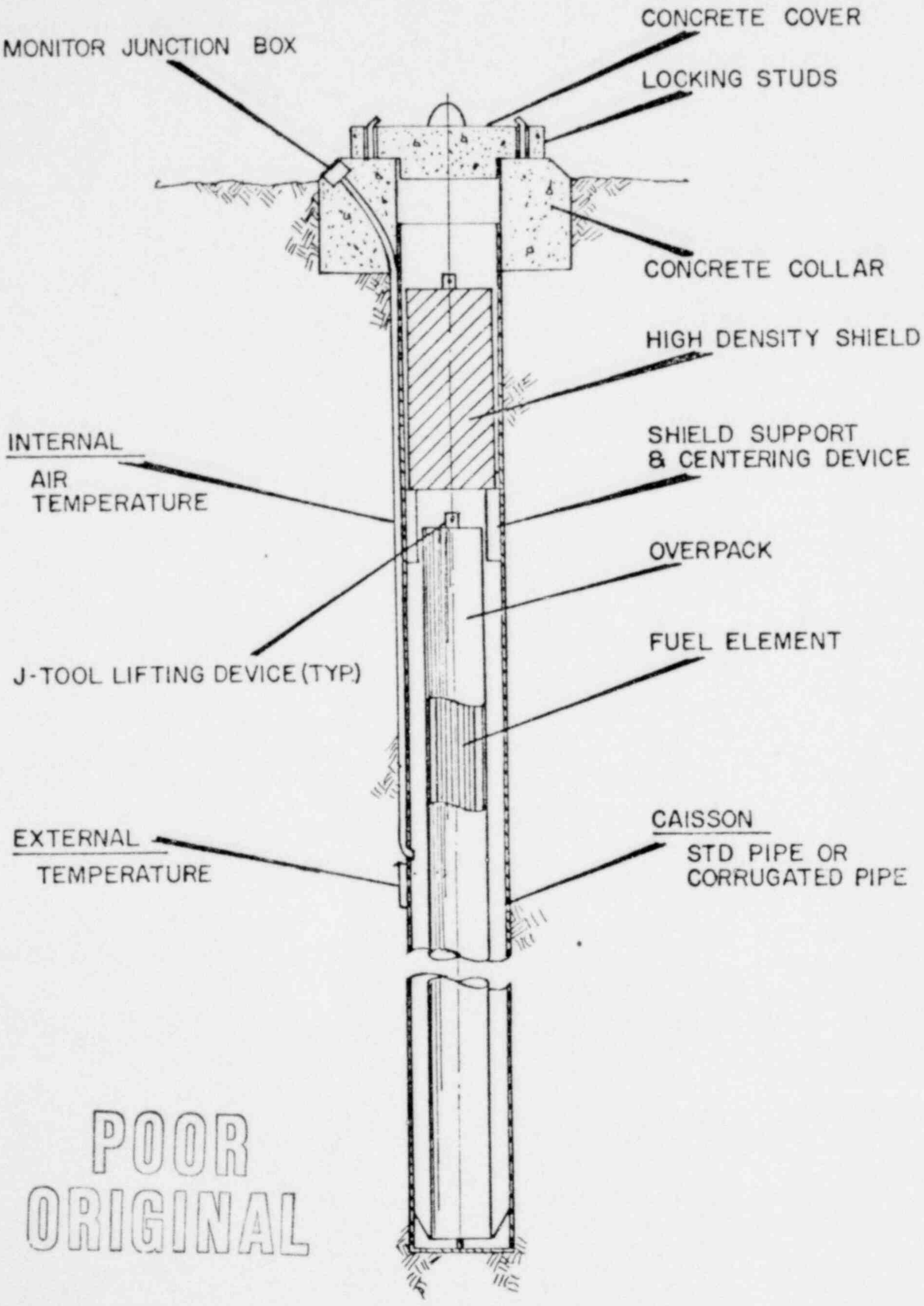

Figure 3.6 Spent Fuel Storage Caisson.

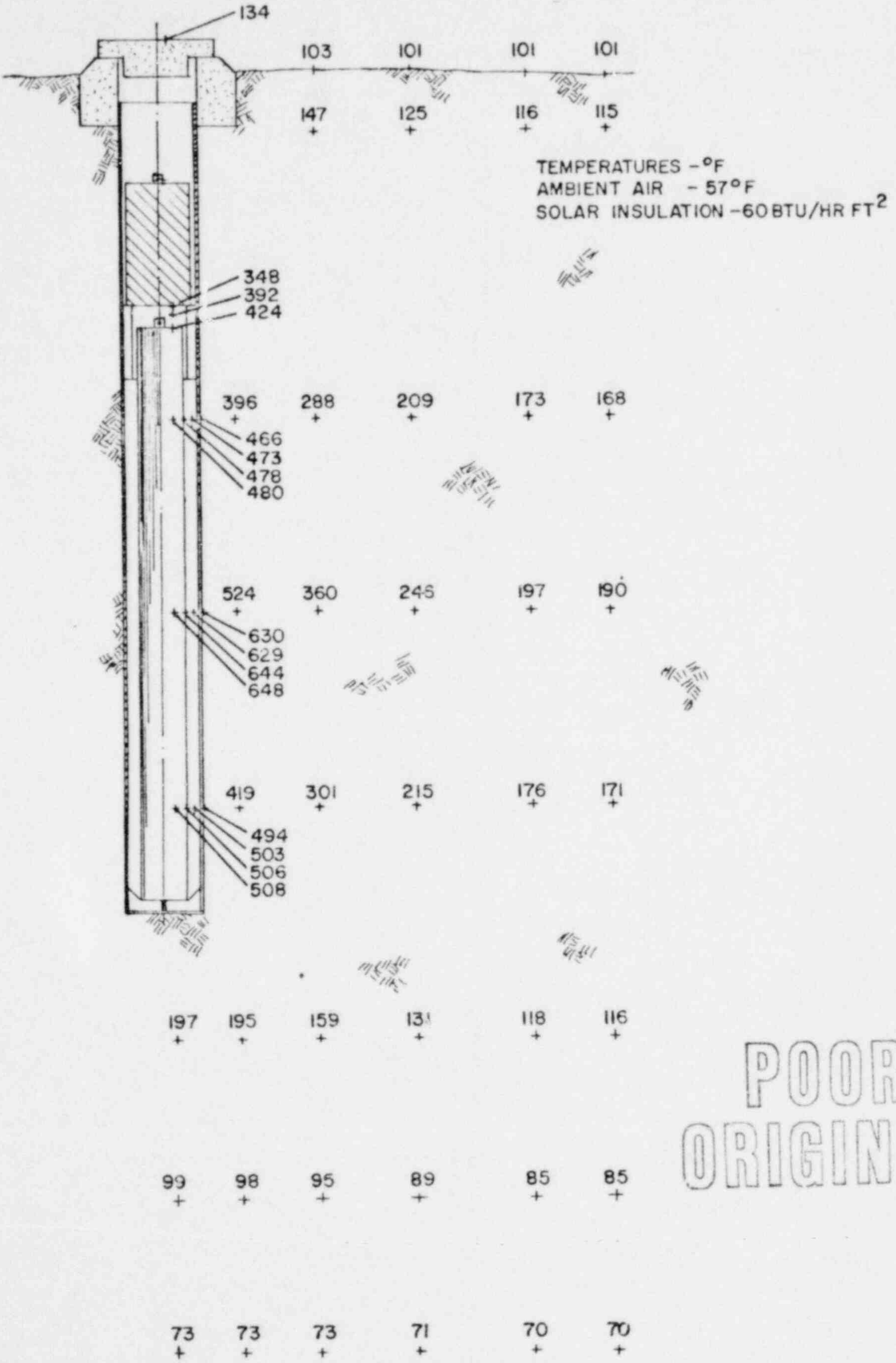

Figure 3.7 Caisson Temperature Distribution at 42 Weeks for 1.5 kW Heat Load (higher loads are possible).

3.1.5.2.5 Air-Cooled Storage Racks

All of the previously discussed dry storage concepts have assumed encapsulation of the spent fuel elements into containers. It may also be feasible to store dry spent fuel without sealing the fuel in canisters. For example, one concept would utilize closely spaced storage racks within an enclosed building.[14] The building could be partially or totally underground to provide shielding. Forced once-through air circulation, estimated to be about 150,000 cfm for a 1500-MTU facility, with filtered exhaust is assumed to provide adequate cooling. A reliable backup system for the primary ventilation system would be required. Damage to storage building structures, rather than fuel cladding temperature effects, would be the limiting factor for safety concerns. Contamination control would also be a major safety concern. For example, it may be necessary to mechanically or chemically clean the surface of incoming spent fuel before storage. Because of the absence of a moderator (water), fuel spacing in storage racks would not be limited by criticality criteria as in a storage pool; however, close spacing of dry fuel requires assurance there are no possible modes of accidental flooding of the storage area. Finally, some means of handling ruptured fuel elements must be provided.

3.1.5.3 Design Criteria

The design of dry storage facilities will be subject to siting and licensing procedures prior to operation. Currently there are no regulations or guides referring explicitly to dry storage facilities. All general requirements of 10 CFR Parts 20, 30, 40, 70, 71 and 100 where applicable would apply. Licensing would be based on 10 CFR Part 70 until such time as the proposed 10 CFR Part 72, which will cover both wet and dry storage, is implemented. Regulatory policy and guidelines will be developed as plans for dry storage emerge.

3.1.6 Use of Existing Government Facilities to Store Spent Fuel (AFR)

The possibility of using Federal facilities to store spent fuel from commercial reactors has been studied. Either existing storage facilities could be used or a new facility could be constructed specifically for such fuel.

3.1.6.1 Existing Spent Fuel Storage Facilities

Currently, the only Federal facility that has a spent fuel storage facility that is similar to commercial ones is the Savannah River Plant. This storage pool has a capacity of less than 100-MT which is used for storage of DOE development program fuels. There is no uncommitted space that could be used for commercial fuels. Use of existing Federal fuel pools consequently does not appear to be possible.

3.1.6.2 Possibility of New Facilities

In October 1977, the Department of Energy announced a Spent Fuel Storage Policy for nuclear power reactors. Under this policy, as approved by the President, U.S. utilities will be given the opportunity to deliver spent fuel to U.S. Government custody in exchange for payment of a fee. Under this policy, spent fuel transferred to the U.S. Government would be delivered at the user's expense to a U.S. Government-approved storage site.[15]

If this policy is implemented, spent fuel storage could be accommodated in either centralized large ISFS facilities owned or operated by the U.S. Government or decentralized storage in Government-approved decentralized small privately-owned ISFS facilities.

Two bills have been introduced in the House of Representatives to implement this policy. One, H.R. 2586, was introduced on March 1, 1979, and the other, H.R. 2611, was introduced on March 5, 1979. Identical bills have been introduced in the Senate.

The staff has estimated that with reasonably high prices ($1,000 per acre), the land cost for a 1000-MT storage basin would be about 3% of the capital cost, and for a 2000-MT facility, less than 3%. The contribution of Federal land would not significantly reduce the overall facility capital or operating costs.

3.1.7 Transportation Requirements for Away-from-Reactor Storage

Three parameters influence the transportation requirements for the transfer of spent nuclear fuels from reactors to independent spent fuel storage facilities. These parameters are:

- The availability of AFR storage facilities,
- The availability of and need for the transfer of spent fuel, and
- The availability of spent fuel transportation casks. At any given time one of these parameters will be limiting.

As indicated in Section 2.1.3, three facilities now exist for AFR storage of spent fuel. Of these three, two are relatively small and will have only limited impact on the overall spent fuel storage problem and the licensing proceeding for the GE Morris Plant proposed expansion to 1850 metric tons has been suspended indefinitely.

Table 3.1 indicates the amount of spent nuclear fuel which will require transfer away from reactors under various assumptions. The basis for this analysis is the reference case (230 GW in year 2000) with a full core reserve at each reactor site.

The present practices of handling, storing and transporting spent nuclear fuel are reviewed in Appendix B. Table B.3 provides detailed information on currently available spent nuclear fuel transportation casks. Approximately 14 truck and 6 rail casks were licensed and available for the transport of spent nuclear fuel by the latter part of 1978. In addition, six truck casks were under construction.

There are a number of factors that influence the estimated transportation capacity of a given fleet of spent fuel casks. These factors include:

- Type of casks, rail or truck
- Mix of fuel, BWR and PWR
- Regulatory restrictions such as State and local routing requirements and special train requirements
- Shipping distances

- Individual facility limitations such as special cask loading and unloading procedures

A conservative estimate of the annual transportation capacity of currently available casks would be about 1500 metric tons of spent fuel. Thus, for the reference case until the late 1990's, no additional casks will be needed beyond those presently certified or under construction (see App. B, Table B.3). Thus, the possibility of a transportation "bottleneck" due to an inadequate number of casks in the 1990's is not foreseen, assuming casks are used to capacity. Moreover, there is no indication that industry cannot provide additional casks if needed.

The provisions of AFR spent fuel storage, depending upon where such facilities are located, could involve an additional transportation step. This could be a significant incremental addition to the transportation requirements of the nuclear industry. However, the overall environmental impacts of spent fuel transportation is essentially insignificant.[16]

Ultimately, all spent fuel will either be sent to permanent disposal or to be reprocessed. The transportation steps involved for disposal are no more than those required for immediate reprocessing. For later reprocessing a transportation step must be added unless the AFR storage site was located at the reprocessing facility.

3.1.8 Implementation of Reference Case Technologies

The various storage technologies examined above appear feasible and indeed some are already in use. Discussion of these is not meant to exclude new designs. New ideas and techniques will continue to be developed. For example, applications for stacked (double tier) storage of spent fuel at the LaCrosse plant pool and for storage of spent fuel assemblies with added fuel inserted at the Yankee Rowe plant pool have been received. At this time, however, the technologies examined seem likely, with perhaps some variations, to be those implemented in spent fuel storage through the end of the century.

3.2 TRANSSHIPMENT

A possible option for storing spent fuel discharged by LWR's involves transfer of the fuel from the storage pool of one reactor to that of another reactor at a different site, both reactors belonging to the same owner (Alternative 2), or transfer to the pool of any other reactor in the U.S. which has available storage space (Alternative 3). A few of the LWR's presently in operation have filled or are about to fill their spent fuel storage pools. LWR's that have recently begun operations or that are scheduled for operation in the next decade will temporarily have available spent fuel storage space. Spent fuel transshipment involves the movement of spent fuel from nuclear generating plants with full storage pools to those nuclear plants with available storage space. In this section transshipment in conjunction with compact storage at reactor storage pools will be analyzed as an independent alternative.

Spent fuel transshipment as an option to ameliorate the storage problem, in which only the parameters of spent fuel discharge rate and availability of storage space for the total reactor population are considered (Alternative 3), oversimplifies this alternative. Irregularities of timing, transport and space within this "average" are not accounted for, nor are conditional relationships between these elements. It would be unrealistic to think that a utility with some excess storage space would prematurely fill up its pool with spent fuel from another utility. Moreover, legislative action to date by various states and cities could limit the practical application of such unlimited transshipment. To more realistically assess the contribution of transshipment as a potential solution, the following option has been investigated:

- Shipment between pools at different sites belonging to the same utility (Alternative 2).

A second option has also been investigated:

- Unlimited shipment between pools belonging to different utilities (Alternative 3).

For the reasons stated above, unlimited shipment of spent fuel between reactors of different utilities is not considered to be practical under normal conditions. However, in the event of an emergency situation, such as an imminent threat of reactor shutdown due to storage capacity shortfall, the Federal Government, by preemption of all regulatory authority, could potentially direct establishment of a national storage allocation plan utilizing all reactor storage pools as a single system. On this basis, projections of such an option are shown in Table 3.4 and Table 3.5.

3.2.1 Common Features of the Three Transshipment Modes

3.2.1.1 Facilities for Spent Fuel Handling

The basic equipment necessary to handle spent fuel is a holding pool or shielded cell and devices to manipulate a cask and fuel elements. For Alternative 1 it is assumed that movement take place within reactor sites regardless of the reactor types. Transfer of fuel between different operating reactor types on different sites is possible and has been approved in one case (fuel transfer between H. B. Robinson and Brunswick 1 & 2); however, the overall contribution in comparison with transshipment among like reactors is expected to be small. The most likely transshipment among reactors of differing types will occur when a utility has an operating reactor of one type with excess spent fuel and a reactor under construction of a different type. If the new reactor pool is constructed early, it may be able to readily receive the fuel from the operating reactor. Such cases are assessed as Alternative 2; i.e., transshipment among all reactors belonging to the same owner.

3.2.1.2 Transportation of Spent Fuel

Spent fuel transshipment creates no new transportation considerations except increased volume. Transport requirements, technology, and availability considerations are discussed in Appendix B.

3.2.1.3 Safety Analysis

Fuel transshipment does not generate new safety problems. However, the staff will perform site specific analyses on case-by-case actions to verify this conclusion.

3.2.1.4 Regulatory Aspects

Any reactor receiving spent fuel from another reactor will require an amendment to its operating license. NRC will perform a safety evaluation and appraise the environmental impact of such an

Table 3.4. Fuel Usage Summary Report with Full Core Reserve (MTHM)

Year	Annual Discharges	Cumulated Discharges (3)	Alt. 1 AFR Req., No Transshipment (2,4,5,6,9,10)	Alt. 2 AFR Req., Intrautility Transshipment (4,5,6,7,8,10)	Alt. 3 Storage Reserve Unlimited Transshipment (1,4,5,6,10)	Gigawatts Discharging (11)
1979	1420	1,420	-40		16,000	46
1980	1520	2,940	-140		17,000	48
1981	1640	4,580	-310		18,000	51
1982	1850	6,430	-520	-30	18,000	58
1983	2090	8,530	-880	-190	18,000	66
1984	2290	10,820	-1,500	-520	18,000	73
1985	2430	13,260	-2,200	-700	18,000	80
1986	2640	15,910	-2,900	-1,200	18,000	87
1987	2840	18,750	-3,800	-1,500	18,000	94
1988	3050	21,800	-4,800	-2,200	18,000	102
1989	3290	25,100	-5,900	-2,700	18,000	110
1990	3600	28,700	-6,800	-2,800	17,000	119
1991	3720	32,420	-8,000	-3,100	16,000	125
1992	3950	36,380	-9,200	-4,100	15,000	134
1993	4200	40,580	-11,000	-4,900	13,000	142
1994	4370	44,950	-12,000	-6,200	11,000	151
1995	4620	49,580	-15,000	-7,300	9,900	160
1996	4840	54,420	-17,000	-8,800	8,000	168
1997	5100	59,520	-19,000	-11,000	5,200(12)	177
1998	5460	64,980	-22,000	-13,000	2,300	187
1999	5720	70,710	-25,000	-16,000	-860	195
2000	5790	76,510	-28,000	-19,000	-4,200	202

1 Assumes all spent fuel storage space would be available to any reactor requiring it.

2 Assumes reactors requiring storage could use only that space available at that reactor or at its site.

3 Does not include ∼4700 MTHM in storage, both AR and AFR, at end of December 1978.

4 Includes ∼4700 MTHM in storage at end of December 1978.

5 Negative numbers mean AFR storage required. Positive or no number means no AFR storage required.

6 For sites with multiple reactors, spent fuel storage from installation of the second or additional reactors is not made available until fuel loading date has occurred.

7 Assumes all reactors within a given utility system can be used to store spent fuel from any reactor within that same utility system.

8 Includes only those reactors presently operating, planned, or under construction.

9 Reference case.

10 Does not include the effect of recent reactor basin storage capacity expansion applications for the Oconee Units 1 & 2 basin, for the Big Rock Point basin and for the Hatch 1 & 2 basins. (See Vol II, Appendix F, Table F.8, footnote b.)

11 Corresponding installed GWe are 230 in year 2000.

12 Includes effect of additional storage from unnamed and unsited reactors.

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Table 3.5. Fuel Usage Summary Report without Full Core Reserve (MTHM)

Year	Annual Discharges	Cumulated Discharges (3)	Alt. 1 AFR Req., No Transshipment (2,4,5,6,9,10)	Alt. 2 AFR Req., Intrautility Transshipment (4,5,6,7,8,10)	Alt. 3 Storage Reserve Unlimited Transshipment (1,4,5,6,10)	Gigawatts Discharging (11)
1979	1420	1,420			21,000	46
1980	1520	2,940	-10		23,000	48
1981	1640	4,580	-110		24,000	51
1982	1850	6,430	-240		24,000	58
1983	2090	8,530	-360		25,000	66
1984	2290	10,820	-550	-20	25,000	73
1985	2430	13,260	-920	-30	26,000	80
1986	2640	15,910	-1,400	-210	26,000	87
1987	2840	18,750	-2,000	-320	27,000	94
1988	3050	21,800	-2,800	-610	26,000	102
1989	3290	25,100	-3,600	-980	27,000	110
1990	3600	28,700	-4,300	-1,300	26,000	119
1991	3720	32,420	-5,300	-1,600	25,000	125
1992	3950	36,380	-6,300	-2,000	24,000	134
1993	4200	40,580	-7,600	-2,500	23,000	142
1994	4370	44,950	-8,900	-3,300	22,000	151
1995	4620	49,580	-10,000	-4,300	21,000	160
1996	4840	54,420	-12,000	-5,300	19,000	168
1997	5100	59,520	-14,000	-6,900	17,000(12)	177
1998	5460	64,980	-16,000	-8,700	15,000	187
1999	5720	70,710	-19,000	-11,000	12,000	195
2000	5790	76,510	-22,000	-13,000	9,800	202

1 Assumes all spent fuel storage space would be available to any reactor requiring it.

2 Assumes reactors requiring storage could use only that space available at that reactor or at its site.

3 Does not include ∼4700 MTHM in storage, both AR and AFR, at end of December 1978.

4 Includes ∼4700 MTHM in storage at end of December 1978.

5 Negative numbers mean AFR storage required. Positive or no number means no AFR storage required.

6 For sites with multiple reactors, spent fuel storage from installation of the second or additional reactors is not made available until fuel loading date has occurred.

7 Assumes all reactors within a given utility system can be used to store spent fuel from any reactor within that same utility system.

8 Includes only those reactors presently operating, planned, or under construction.

9 Reference case.

10 Does not include the effect of recent reactor basin storage capacity expansion applications for the Oconee Units 1 & 2, for the Big Rock Point basin and for the Hatch 1 & 2 basins. (See Vol. II, Appendix F, Table F.8, footnote b.)

11 Corresponding installed GWE are 230 in year 2000.

12 Includes effect of additional storage from unnamed and unsited reactors.

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action. Currently, the staff has not identified any generic problems associated with this alternative.

3.2.2 Consideration of the Transshipment Options

Assumptions used in this analysis are expressed before the three options are considered. Nuclear power reactors that would be operating during the 1979-2000 period are listed in Appendix F. This study considers a period beginning in 1979 for all alternatives and it was assumed that the capacity of the spent fuel storage pools at these reactors would be the same as of December, 1978. It was also assumed that no storage was available at fuel reprocessing plants or at new storage facilities.

When identifying specific transshipment actions it was assumed that a utility would try to solve each year's storage problem as it occurs. No claim is made that this is the optimal approach or that this is the approach that a specific utility may use.

Spent fuel discharges were based on analysis of the data on page 3-6 of NUREG-0020, which analysis showed that the reactors, after an initial core discharge period of five years for BWR's and four years PWR's, discharge one-third of their cores per year for PWR's and one-fourth per year for BWR's.

Consideration was also given to the transportation requirements (specifically, spent fuel transport casks) for the transshipment modes (see App. E). Both rail and truck shipments could be used for the movements, but to maximize these requirements, it was assumed that all shipments would be made by truck.

3.2.2.1 Alternative 2

The scope and magnitude of spent fuel storage requirements for Alternative 2 are detailed for the reference case reactor generating capacity (230 GWe in 2000), and with and without FCR in Tables 3.4 and 3.5. In these tables AFR requirements for Alternatives 1 and 3 are also shown for easy comparison. The list of reactors[17,18] which were used as the basis for the analysis is given in Appendix F. This alternative (Alt. 2) contains all of the basic assumptions of Alternatives 1 (and 3) but allows transshipment between reactors having the same owner, regardless of geographic location.

The effect of intrautility transshipment is to reduce the need for AFR Storage from Alternative 1 in 1985 by 67% with FCR and 97% without FCR for the 230-GWe by year 2000 reactor installation rate. Without FCR, the reduction in AFR due to intrautility transshipment is, for year 2000, 30% with FCR, and 40% without FCR.

The effect of unlimited transshipment (Alt. 3) is to reduce the need for AFR storage through year 2000 for the reference case by 85% from 28000 MT to 4200 MT). There is excess AFR storage capacity in year 2000 of about 10,000 MT if no FCR is required for the reference case. Without inclusion of assumed reactors (see Table 3.3) the available storage is about 3000 MT less than requirements.

Nuclear generating capacities under Alternatives 1 and 2 (both with and without FCR) that would become unavailable because of filled spent fuel storage pools are shown in Table 3.2 for the period 1979-2000.

In Table 3.2, it is shown that transshipment (intrautility) markedly reduces the amount of generating capacity (GWe) which attains filled-pool status through 1997. The generating capacity (GWe) in years 1998, 1999, 2000 is maximized and probably overstated because 28 unsited reactors are not included in the tabular data for Alternatives 1 and 2, since utility ownership and specific sites are not established.

However, even without FCR and transshipment, some capacity starts to fill pools in 1984. The use of transshipment postpones the occasion of filled pool status, for the United States, for three to five years.

3.2.2.2 Situation with Unlimited Spent Fuel Transshipment

In evaluating spent fuel transshipment between reactors belonging to different utilities (complete transshipment), it is assumed that any such transshipment would take place with storage capacity allocated on a national basis by a Federal regulatory agency having full authority to work with utilities owning nuclear power plants to prevent widespread at-reactor storage capacity shortfalls. It is unlikely such an emergency situation would be allowed to develop. However, lead times to expand existing storage facilities are measured in months and to complete new facilities may require up to about five years. Thus an emergency situation is possible. Any storage commitment made by one utility to another would likely be temporary in nature; that is, any storage commitment would be to provide relief for a limited duration. This policy is assumed since any long term commitment by a utility to store spent fuel belonging to another utility could result in advancing the ultimate fill date of its own reactor pools. Thus, a long term storage commitment would be unacceptable to any utility and undesirable because it could place that utility's reactors in the position of having to shut down due to lack of adequate pool space.

This mode of transshipment would increase the fuel transport case requirement by the utility because of such shipments. However, broadening the scope of transshipment has again resulted, as shown in Table 3.4, for the reference case, in no requirement for AFR storage prior to 1999 if unlimited transshipment were allowed.

3.2.2.3 Cask Availability

As a result of this analysis cask availability was not found to be limiting (see App. E).

3.2.3 Summary

The objective of this discussion was to investigate the extent to which transshipment could contribute to solving the spent fuel storage problem. Transshipment was examined in detail in two cases (Alt. 2 and 3).

The effects of transshipment on AFR requirements are shown in Table 3.4 for comparison with the reference case. Table 3.4 also contains comparative data for Alternatives 1, 2, and 3. AFR requirements for the reference case are reduced by 30% (in year 2000) if transshipment between reactors having common ownership is allowed, and the year of first AFR need is postponed from 1979 to 1982. If unlimited transshipment is permitted, AFR requirements in year 2000 are 85% less than those for the reference case, and the year of first AFR need is postponed from 1979 to 1998, again compared to the reference case of Alternative 1.

Transshipment between commonly-owned reactors, since it is shown to be licensable (as in the Robinson-2 to Brunswick application), could be a temporary solution to pressing fuel storage problems. However, expansion and use of the GE Morris AFR facility would extend the year of first reactor shutdown due to filled pools for the reference case to 1984 (from 1980).

Transshipment in conjunction with compact storage at reactor spent fuel storage pools can serve to postpone and reduce the total AFR capacity needed to forestall at-reactor storage capacity shortfalls. In 1996, as Table 3.4 illustrates, the need for AFR storage in Alternative 1 with no offsite reactor-to-reactor transshipment would be in excess of three large (about 5000-MT capacity) ISFSI for 17,000 MT, while for Alternative 2 with such transshipment there is a need for only about two large ISFSI for 8800 MT. Beyond 1996 the maximum need for AFR storage for these alternatives is shown but this could be reduced by projected but unnamed reactors with undesignated ownership and sites. For Alternative 3, where lack of AFR storage is assumed to result in a national storage allocation plan sanctioned and regulated by the Federal Government, AFR storage need would be for only one large ISFSI for 4200 MT in year 2000. (Since Alternative 3 treats the nation's reactor pools as a single storage system, the uncertainty arising beyond 1996 for Alternatives 1 and 2 does not pertain.) Beyond year 2000 the further discharge of spent fuel is assumed to be accommodated; that is, a system to accomplish ultimate disposition of spent fuel is assumed to be operational.

3.3 TERMINATION CASE

3.3.1 Nuclear Technology

All reactors presently operating, except three (see Sec. 3.1.2.1 for details) are either licensed for expansion of their existing spent fuel storage capacity, or have requested a license for such expansion. The average degree of compaction is three times (3x) their initial design capacities. As shown in Table 2.1, extension of time before the pools become full ranges from 10 to 16 years. Even if existing AFR storage is used, reactor shutdowns would occur prior to year 2000 for Alternative 1.

Since it seems unlikely that new reactors would be put into service if this situation developed, under this alternative, nuclear generated electricity would need to be replaced by an alternative source or the electrical demand reduced. To analyze the impact of this possibility (see Chap. 4), it is assumed that all nuclear plants on line by 1985 will continue to operate until their pools are full, and that no new nuclear generation capacity will come on line after 1985.

3.3.2 Modification of Fuel Management Practices to Reduce Spent Fuel Generation

Consideration has been given to changing fuel management practices so that more of each fissile nuclide would be burned per unit mass of fuel. Such a practice can extend the time a fuel element stays in the core, thereby decreasing the frequency of discharges. The objective of in-core fuel management is to minimize the fuel cycle cost while meeting the requirements of safe and reliable power production. Because of the latter requirement, fuel management is not only an operating parameter but also a design parameter. This implies that modification of current fuel management practices in order to reduce the spent fuel discharge rate will be constrained by design considerations.

The most important fuel management parameter affecting the rate of spent fuel discharge is the average discharge burnup of the fuel. The burnup is a measure of the fuel utilization, which is conventionally expressed in terms of thermal megawatt days per metric ton of uranium ($MW_{th}D$).*

The average discharge burnup can be expressed as:

Burnup = (specific power) x (capacity factor) x (fuel lifetime in the core)

The specific power is a fixed parameter for a given reactor, typically 26 MW_{th}/MTU for BWR's and 38 MW_{th}/MTU for PWRs with older plants being 19 MW_{th}/MTU for BWRs and 28 MW_{th}/MTU for PWRs. Reduction of the capacity factor is equivalent to reducing the power plant electrical output which is the same as reducing generation to decrease discharge frequency. The only free parameter that can be changed by modified fuel management is fuel lifetime in the core. Since the fuel discharge rate is inversely proportional to the fuel lifetime or the discharge burnup, it is theoretically possible to reduce the spent fuel discharge rate by increasing the average discharge burnup. A few possibilities are discussed below.

3.3.2.1 Increased Burnup

A higher burnup can be achieved by increasing the feed ^{235}U enrichment to compensate for increasing ^{235}U depletion and fission product poisoning. However, the peak discharge burnup is limited by original design for fuel performance. The fuel performance reliability is directly related to the peak discharge burnup level (i.e., specific power and irradiation time).

The utilization of fuel at a significantly higher burnup level would require a stronger cladding (either a high-strength material or an increased cladding thickness) to maintain the fuel rod integrity during the longer fuel life. More generally, safety analysis, licensing pr and economics of design and manufacture standardization favor continuation of proven fuel designs and burnup levels. Hence, changes in the fuel design to accommodate a higher burnup and subsequent modification of the fuel management strategies will not be realized in a short time frame.[19] Furthermore, an increased burnup requires an increased ^{235}U enrichment to provide additional available reactivity for a longer fuel life and increased reactivity control margins. The increased enrichment of the fuel would require a reevaluation of the safety analysis.

3.3.2.2 Improved Burnup by Increased Uniformity of Consumption Rate

Incentives exist to maintain the spatial power distribution within the core in a uniform condition. This practice extends the life of the fuel, so it is a concept of management which already is incorporated in reactor operation procedures. It also serves to decrease discharge

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*The energy produced by the fission of one gram of fuel is approximately 1 $MW_{th}D$ (82×10^6 Btu). Hence, a burnup of 10,000 MWD/MTU is equivalent to the energy released by fissions corresponding to 1% of the initial uranium loaded into the reactor.

frequency, so it is effectively a maintenance option to help resolve spent fuel storage overcrowding.

The fission power produced in the reactor is proportional to the fissile enrichment and the neutron flux. Neutron flux is lower in the core outer region due to the neutron loss by leakage. The principle of achieving a flat power distribution is to compensate the flux distribution with enrichment distribution. In addition, control rod positioning and coolant void distributions are also used to flatten the power distribution. Since flat power distribution is one of the major objectives of current fuel management practices, it appears that no additional improvement could be made to retard the spent fuel discharge rate.

3.3.2.3 Thermal Coastdown

For a given initial ^{235}U enrichment, increased burnup is limited by the reactivity requirement, and reactivity is primarily a function of fissile enrichment. However, reactivity also depends on the fuel and coolant temperatures. In the thermal coastdown mode of operation, the reactor continues to operate in a gradually reduced thermal power output by utilizing the increased reactivity value due to the reduced fuel and coolant temperatures. The coastdown capability of the nuclear power plant is currently being used, depending on each utility's own need and on economic considerations (savings due to extended fuel life vs. replacement power cost for the reduced power operation). Typically, a two-month power coastdown could be considered feasible. Such a coastdown operation could increase the discharge burnup by about 10% and hence postpone spent fuel discharging.

Thermal coastdown lowers the plant capacity factor achievable and the stretchout operation could conflict with the refueling shutdown period desired to meet load demand. The use of coastdown operation will depend on each utility's need and operating strategies. However, such practices will not significantly impact the resolution of the problem.

3.3.2.4 Summary

There appear to be no marked benefits to be achieved in terms of relieving the spent fuel storage problem by modified fuel management schemes without considerable changes in practices already in economic balance. Indeed, there may be distinct disadvantages. Little realistic relief consequently seems possible by these techniques.

3.3.3 Replacement Power for LWR-Produced Electricity

In this statement coal-fired plants are assumed to replace nuclear electric power generating capacity for the termination alternative. Each type is assumed to operate at a capacity factor of 60%. This choice is dictated by the lack of the alternative energy sources to accomplish this task.[20,21] A similar approach has been taken by a recent Ford Foundation study covering this same time frame.[21] This position is supported by the National Energy Plan[22] which contains a strong regulatory program that would prohibit all new utility and industrial boilers from burning oil or natural gas except under extraordinary conditions. This plan is supported by the National Energy Act of 1978.

The extent that conservation or utilization of alternative sources of energy production reduce the need for projected nuclear power or coal power would result in a proportional decrease in the environmental impacts of nuclear and coal power fuel cycles. It should be noted, however, that some of the proposed alternative power sources may have significant impacts.[16] Also, the extent to which they would be feasible (as in the case of solar energy conversion, which is projected to contribute no more than about 1% to electrical energy production by the year 2000[17]) is speculative.

None of this, however, affects the finding that additional spent fuel storage is environmentally acceptable.

Present practice consists of operating nuclear power plants as baseload facilities at the highest practicable capacity factor. When the fuel storage capacity is exhausted, the plant will have to be shut down. The installed nuclear generating capacity projected through the year 2000 is given in Table 1.2. The reduction in nuclear plant capacity due to the filling of spent fuel storage pools and the termination of the operation of nuclear plants is listed in Table 3.2.

In the discussion of environmental impacts an examination is made of the effects of the shutdown reactors based on the installed capacity, and the replacement of this lost generating capacity with some other fuel cycle.

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4.0 ENVIRONMENTAL IMPACTS

In this chapter the incremental ecological, health, and social impacts associated with the alternatives of the termination case and the reference case storage solution are discussed. The termination alternative provides for the shutdown of nuclear power plants when their storage pools are filled; the reference case provides for expanded interim storage of spent fuel pending reprocessing or disposal.

4.1 ECOLOGICAL IMPACTS

The ecological impacts of the uranium fuel cycle have been extensively described elsewhere.[1-6] As previously discussed in this Statement, the previously published documents all assume that spent fuel is temporarily stored at the reactor and is actually stored and/or reprocessed at "away-from-reactor" (AFR) facilities. This document treats a series of options (Section 3) for the disposition of spent fuel.

The alternatives discussed below assume that electrical energy demand for the remainder of the century requires the projected capacity, and thus any loss of nuclear generating capacity in one utility grid will be replaced by increased capacity of other types (e.g., fossil fuel) in order to maintain the utility grid generating capacity (see Sec. 7.4.1.2).

Several storage techniques for maintaining continued operation of nuclear power plants are considered, including compact storage (Sec. 4.1.1.1), AFR wet storage (Sec. 4.1.1.2), and AFR dry storage (Sec. 4.1.1.3). Their collective contribution defines the reference case alternative (Table 3.1).

The termination alternative considered assumes a shutdown of operating nuclear power plants when their present onsite spent fuel storage capacities are saturated and that coal fired power plants will come on line as replacements. Both the environmental impacts of existing reactors in safe shutdown condition (Section 4.1.2.1) and the construction and operational impacts of the replacement coal fired units (Section 4.1.2.2) are considered.

4.1.1 Reference Case Storage

4.1.1.1 Compact Storage

Increasing the number of assemblies stored in existing nuclear power plant fuel pools will not cause any new environmental impacts. The amount of waste heat emitted by the plant will increase slightly (less than one percent), resulting in no measurable increase in impact upon the environment.

4.1.1.2 Wet Storage Facilities

A fuel receiving and storage facility at an AFR storage installation requires approximately 600 acres of land, over half of which serves as a buffer zone and is undisturbed or slightly disturbed. Facility construction requires the removal of existing vegetation in the immediate construction area and excavation for building foundations. Earth-moving operations expose soils to erosion and the creation of dust.

Intrinsic to removal of vegetation is the destruction of the habitat requirements of a portion of the terrestrial animals in the affected area. Following such disturbance, some of the less mobile life forms perish, while more mobile species, such as birds and the large and intermediate-sized mammals, migrate to the less disturbed adjacent habitats. This may create increased competition for resources in the surrounding habitat. Some increase in road kills may occur as a result of increased vehicular traffic. Various measures, such as dust-control procedures, topsoil stockpiling, revegetation, etc., are usually implemented either to reduce initial impacts or to facilitate rapid recovery.

Depending upon facility location and the type of cooling used, aquatic habitats may be impacted by the construction of intake and outfall structures. Construction runoff may cause additional impacts to nearby aquatic areas; however, techniques are available to reduce concentrations of suspended solids in runoff to acceptable levels. Additional aquatic impacts may occur as a result of sanitary waste disposal. Operation of a storage only facility, based on the Barnwell Fuel Receiving and Storage Station, will require approximately 400 gpm of water for dissipation of heat generated by the spent fuel.

Minor impacts to the terrestrial environment might occur from the transfer of heated water or water vapor to the environment. Drift from cooling towers may adversely affect local vegetation. Some local fogging and increased humidity may occur. All of these ecological impacts are of relatively limited importance or can be reduced at reasonable costs. NRC has precedence for the treatment of mitigative measures for similar kinds of impacts in the various licensing actions.

4.1.1.3 Dry Storage

Dry storage technology has been utilized for some years for high level radioactive waste in solid form at the Idaho National Engineering Laboratory (INEL)[7] and provides a good example of the impacts of this technology. Above and below ground dry storage areas are utilized at the INEL. Below-ground dry storage is also provided for HTGR spent fuel at INEL.[8] The land area committed to this purpose must be considered indefinitely lost to other uses. The construction and operation of the facility involve excavation and replacement of soil. Occasional dust and soil erosion problems have been encountered. Soil disposal areas have been contoured to conform to existing topography and reseeded so that the visual and erosion impacts are reduced. Fences have been constructed to exclude grazing animals. The heat generated by spent fuel in a dry storage situation may result in above normal temperatures in soils immediately surrounding the storage area. In areas immediately adjacent to pad floors or vault walls some soil sterility may occur. While a potential for leaching of radioactive materials from these facilities exists, the integrity of the containers, coupled with the sorbtive capacity of most soils for waste contaminants, provides assurance that groundwater supplies will not be impacted. Thus the spent fuel storage facility does not appear to have any ecological impact on the surface or groundwater environment.

The statements relating to the ecological impacts included in Section 4.1.1.2 above for wet storage applies as well to dry storage technology.

4.1.2 Termination Case

4.1.2.1 Shutdown of Nuclear Facilities

In the termination alternative it is assumed that no action is taken to alleviate the shortage of spent fuel storage capacity before the year 2000. Since this alternative assumes that no nuclear plants are licensed after 1985, all installed nuclear generating capacity will have been retired due to saturated onsite spent fuel storage pools before year 2000. After its spent fuel storage pool is filled, each reactor will have to be placed in a safe shutdown condition, but the operation of the cooling system must be continued to remove decay heat from any spent fuel in the core and in the storage pool.

The land use impacts of the plant should remain unchanged while it is maintained in a safe shutdown condition. Typically, all plant structures will remain, and the exclusion area will have to be maintained. The possibility of controlled public access to the exclusion area via leased agricultural use or limited recreational use would have to be considered on a case-by-case basis.

Water use will continue because of the need to disperse the heat produced by the spent fuel. The rate of heat production by spent fuel is a small fraction of that produced by an operating power plant. All impacts associated with the water makeup facility (entrainment and impingement if from surface water, or drawdown of the water table if from wells) will be greatly reduced compared to those impacts during reactor operation. Similarly, the impacts associated with heat dispersion (fogging, drift, etc.) will be significantly less than those of the operating facility.

4.1.2.2 Replacement with Coal-Fired Facilities

At present and through the year 2000, the only large scale economically feasible replacement fuel is coal.[9] It is assumed that most of the coal will be burned in conventional, dry bottom, pulverized-coal burners, with some burned in cyclone furnaces. The two combustion systems are nearly equal in all impacts except the cyclone furnace requires approximately 98% as much coal as a pulverized burner to produce 1,000 MWe;[9] the cyclone furnace yields 0.1% of the ash as particulates leaving the stack, compared with 0.4% for a pulverized-coal burner, when each is equipped with an electrostatic precipitator;[9] and the cyclone furnace produces more NO_x than does a pulverized coal burner because of the higher operating temperature of a cyclone furnace.

Other alternative combustion modes (e.g., fluidized-bed combustion, conversion to synthetic natural gas, or liquifaction prior to combustion) have not been considered because of uncertainties in economics, state of development during the next three decades, and impacts associated with these advanced technologies.

It is assumed that the boilers will deliver steam at supercritical pressure, 3500 pounds per square inch gauge, superheated to 1000°F with 1000°F reheat, which allows operation at the upper range of efficiencies for the replacement coal fired facilities.[9] The plant capacity is assumed to be 1000 MWe net.

Finally, it is assumed that the majority of the replacement plants will have to be built near the sites of the shutdown reactors to maintain utility load balancing. From an environmental point of view, the site selection process for these 1,000-MWe coal fired generating plants should be quite similar to site selection for the nuclear facilities. As a result, the probable sites for the coal fired plants will resemble, ecologically, the proposed and alternative sites discussed in the environmental impact statements (EIS) for the individual reactors, and nearly all site-specific impacts of construction and operation of the coal fired facilities will be similar to the nonradiological impacts analyzed in the EIS's for the nuclear plants replaced. The major exceptions expected will be the site-specific impacts associated with airborne combustion emissions and the transportation requirements of coal-burning plants (see App. C). It is not feasible to consider these site-specific impacts in this document. A regional analysis of these impacts has been published elsewhere.[9]

4.1.2.2.1 *Construction Impacts*

Because the coal fired power-generating facilities are assumed to be located on or near the sites of the nuclear facilities to be replaced, the site-specific construction impacts are assumed to be comparable to those discussed in the environmental impact statements for the individual nuclear stations.

The relative magnitudes of the construction impacts for the coal fired generating stations compared with those for the nuclear generating stations can be estimated by comparing the relative size of the various components of the two types of stations (Table 4.1).

The building that houses a typical coal fired boiler is comparable in size to the building housing the reactor core and primary coolant containment and related safety devices of a nuclear plant. The steam distribution lines and controls, the turbine, and the generator will be similar regardless of the source of the energy used to produce the steam. Therefore, the areal extent of the power-generating facility structures for a coal fired plant is equivalent to those for a nuclear plant.

A coal-fired power plant requires a continuous supply of fuel (7,000 to 13,000 tons of coal per day per 1,000 MWe delivered at 100% capacity). The staff has assumed that the necessary railroad sidings will be long enough to hold a train containing approximately one day's supply of coal (130 cars of 100-ton capacity or 240 cars of 55-ton capacity). A train to deliver nuclear fuel requires only a few cars, so extensive sidings are not needed. To maintain a steady input of coal, the utility must stockpile coal onsite. Based on 1,750 tons per acre-foot,[9] a 100-day reserve supply would require a stockpile volume of 400 to 740 acre-

Table 4.1. Approximate Areas Required by 1000-MWe Power Generating Stations

Nuclear[*]		Coal Fired[**]	
Component	Area, sq. ft	Component	Area, sq. ft
Power Generating		Power Generating	
Reactor	50×10^3	Boiler	50×10^3
Turbine/generator	50×10^3	Turbine/generator	50×10^3
Subtotal	100×10^3	Subtotal	100×10^3
Fuel handling		Fuel handling	
Railroad siding	5×10^3	Railroad siding	100×10^3
		Coal stockpile	100×10^3
Subtotal	5×10^3	Subtotal	200×10^3
Waste handling (exc. heat)		Waste handling (exc. heat)	
Spent fuel storage	50×10^3	Slag storage	100×10^3
		Ash ponds	200×10^3
		Scrubber sludge storage	100×10^3
Subtotal	50×10^3	Subtotal	400×10^3
Waste heat disperal		Waste heat disperal	
Cooling towers	$1,000 \times 10^3$	Cooling towers	$1,000 \times 10^3$
UHS	45×10^3		
Subtotal	$1,045 \times 10^3$	Subtotal	$1,000 \times 10^3$
Total	$1,200 \times 10^3$	Total	$1,700 \times 10^3$
Area permanently disturbed[***] (200 acres)	9×10^6	Area permanently disturbed[***] (300 acres)	13×10^6
Construction area	13×10^6	Construction area	20×10^6

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[*] Data are staff approximation based on "Bailly Generating Station, Nuclear-1, Final Environmental Statement," "Skagit Nuclear Power Project, Final Environmental Statement," and "Black Fox Station, Units 1 & 2, Final Environmental Statement."

[**] "The Environmental Effects of Using Coal for Generating Electricity (Draft)," U.S. Nuclear Regulatory Commission, NUREG-0252, March 1977.

[***] Includes access roads, parking lots, landscaping between buildings, etc., not included in the rest of the table.

feet (at 100% capacity), although mine-mouth plants may stockpile only about half this amount.[10] Typically, this stockpile will cover an area much larger than the area of the structures housing the boiler and generator combined.

Several waste streams at a coal fired plant lead to temporary storage areas on the site. These include slag from the boiler, ash captured by precipitators (generally as a slurry), and scrubber sludge. For quantities involved see Appendix C, Table C.4. These wastes are transported to some ultimate disposal area. This waste disposal could create heavy truck traffic, noise and dust, and would require large land sites for disposal. On the other hand, a nuclear power plant will produce spent fuel as a waste product. The spent fuel is stored temporarily in the onsite fuel pool. Its eventual shipment offsite involves only minor truck or rail traffic.

For the purposes of this analysis, it has been assumed that over the range of energy to be dissipated as waste heat by a 1,000-MWe power plant, the area covered by the cooling towers is about the same for both nuclear and coal plants. The total area directly affected by the construction of a coal fired plant will be approximately one and a half times that affected by construction of a nuclear plant (see Table 4.1). Assuming that the onsite biota are distributed reasonably uniformly, it may be concluded that approximately one and a half times as many plants and animals will be lost due to construction. With appropriate mitigative measures, the ecological impacts from the construction of coal fired plant land uses are generally expected to be acceptable.

4.1.2.2.2 *Operational Impacts*

Assuming approximately 30% thermal efficiency,[11] existing nuclear power plants produce 2.3 GW of waste heat per gigawatt of electric power produced. On the other hand, coal fired power plants, with about 36 to 40% thermal efficiencies, produce about 1.5-1.8 GW of waste heat per gigawatt of electric power. Therefore, the replacement of nuclear-based electric generating capacity by coal fired steam plants could result in up to 35 percent reduction of waste heat. Because of regulations and standards covering the allowable temperature difference of blowdown to ultimate receiving water bodies, the majority of this waste heat for either type of plant would probably be dissipated to the atmosphere. Questions of global thermal balance including the effect of the additional production of CO_2 from replacement coal plants are beyond the scope of this impact statement.

A major public concern with nuclear power has been the routine release of radioactive substances to the atmospere. This concern implicitly includes the erroneous assumption that coal fired plants do not release radioactive substances. However, a portion of the ash content of domestic coal is uranium and thorium.[12] Some radioactive ash particles can be expected to be emitted with the stack gas of coal fired plants. In some cases the total quantity of radioactive substances released in the stack gas of a coal fired boiler may exceed that normally released by a nuclear reactor.[13,14] Martin et al. have compared a hypothetical 1,000-MWe coal plant (based on the Widows Creek 1960-MWe TVA plant) with two then existing nuclear reactors (Connecticut Yankee, 462-MWe PWR; Dresden-1, 200-MWe BWR), and have concluded that downwind exposure to radioactive materials is greater from a coal plant than from a modern PWR, but less than that from a BWR.[14] It should be recognized, however, that emissions from BWR's, even with potentially higher exposure dose rates, are well below those specified by regulation. In addition, since the above study was made, BWR's have improved their waste gas treatment system by the addition of charcoal decay tanks to reduce radioactive releases. In addition, emission controls on modern coal plants have been greatly improved over Widows Creek.

The burning of coal produces a variety of air pollutants, including SO_2, NO_x, particulates, and trace elements, in varying amounts depending on the source of coal. There are state-of-the-art control devices, particularly scrubbers and precipitators, that effect a considerable reduction in these pollutants in the stack gas, but none is 100% effective. For the termination case, in the year 2000 the following total magnitudes of these pollutants would be reached: for SO_2, 600-1200 kilotons/yr; for NO_x, 750 kilotons/yr; for particulates, 40-60 kilotons/yr; and for trace elements such as zinc, 100-425 tons/yr; and cadmium, 2-14 tons/yr (derived from data in Reference 9). The projected growth of their emission rates from 1976-2000 is given in Appendix C, Figures C.1 through C.5. These airborne pollutants are known to have adverse impacts on human health, crops, and real estate.[9,15]

The fuel requirements of a coal fired plant necessitate a high volume of rail traffic into the plant. There will be several adverse impacts associated with this heavy train traffic. Local surface transportation will be disrupted; there will be considerable noise generated by such heavy trains; and finally, fugitive dust from the coal and emissions from the diesel engines of the trains will contribute to the reduction in air quality attributable to the plant. By contrast, for a nuclear plant seven rail cars equipped to handle 100-ton casks or the equivalent truck capacity would be needed to remove the spent fuel elements for the annual refueling, and about 10 trucks would be required to deliver the required reload fuel.

4.1.2.3 Fuel Cycle Considerations

Domestic coal on the average ranges from about 8,000 to 14,000 Btu per pound.[9] Each power-generating station rated at 2,500 MWt (1,000 MWe) and operating at a capacity factor of 0.6 would have to consume between 4,300 and 7,700 tons of coal per day. The total annual coal consumption to replace the shutdown nuclear capacity is shown in Figure 4.1.[9]

Figure 4.2 shows the acreage that would have to be disturbed annually by strip mining to meet this coal production schedule.[9] An estimated average of 95 acres per gigawatt-year would be disturbed by coal mining, for a total of from 9,000 to 60,000 acres disturbed for the nuclear-generated power to be replaced by year 2000.

Current estimates for reclamation of coal strip mine disturbed land are approximately $5,000 per acre.[16] Underground mining by conventional or advance techniques may reduce the total acres disturbed. However, any potential ecological benefits of underground mining over surface mining are more than offset by health and safety considerations: "The accidental fatality rate for underground coal mining is higher than for any other occupation...."[9]

Delivered coal is not the raw coal produced at the mine. Various processes collectively referred to as benefaction are utilized to reduce impurities in the coal.[9] The magnitude

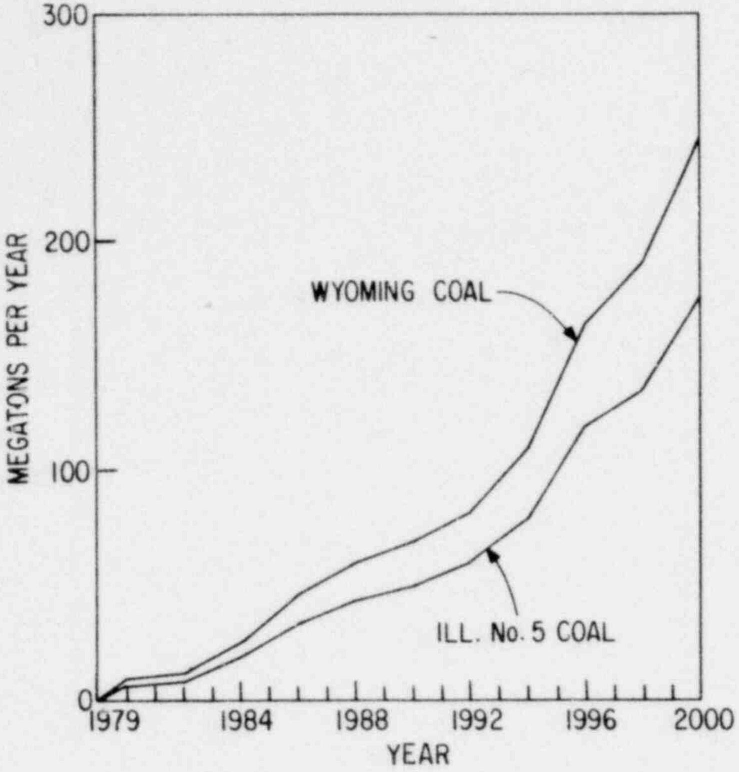

Figure 4.1. Annual Coal Requirements.

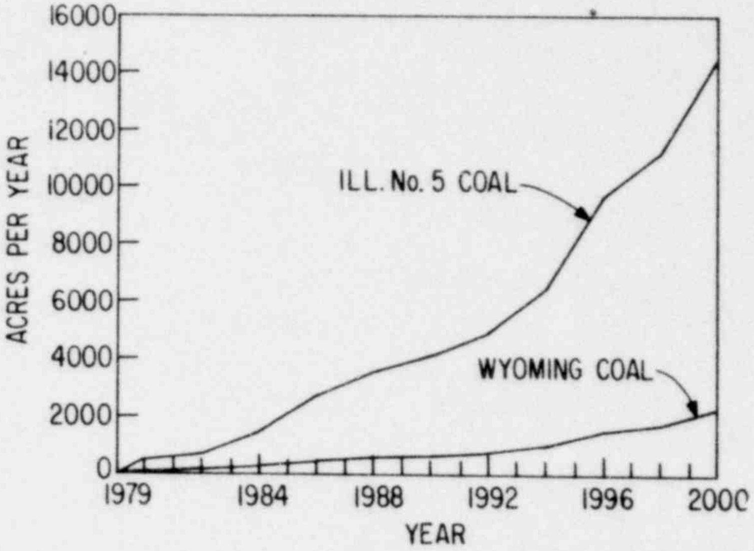

Figure 4.2. Acres Disturbed by Surface Mining.

of this waste production would reach about 50 megatons/yr in year 2000 and its projected growth from 1979-2000 is shown in Appendix C, Figure C.8.

The wastes (gob) produced during benefaction are commonly rich in pyrites (sulfides of iron), trace elements, and heavy metals. The pyrites release sulfuric acid when exposed to normal rock weathering processes, so runoff water from the gob disposal area may be extremely acidic. The runoff water may also carry high concentrations of trace elements and heavy metals. The exact magnitude of the gob volume, acid released, and metals carried in runoff is highly variable and depends on the composition of the coal and benefaction technology employed. Similarly, uranium must pass through milling, enrichment, and fabrication processes. Although uranium milling is analogous to the benefaction of coal, its impacts are more similar to the impacts of milling metals, such as copper. A generic environmental impact statement on uranium milling is now in preparation. The draft statement has been circulated for comment.

Because only a small fraction of the ore is uranium, "the amount of solid tailings is roughly equal to the ore feed rate plus part of the reagents used in the process ...".[16] The tailings may be acidic or alkaline, depending upon the milling process, and will typically be fine particles.

The coal fuel cycle produces ultimate by-products that require ultimate disposal. The burning of coal produces cinders or slag that must be stored temporarily onsite prior to being transported to the ultimate disposal site. The predicted slag production reaches 1.8-3 megatons/yr in year 2000 based on information in Reference 9 and its growth from 1979-2000 is shown in Appendix C, Figure C.9.

Each year the precipitators and scrubbers for a 1,000-MWe plant at 60% capacity could produce 400-650 tons of fly ash and 70-400 kilotons of wet lime-SO_2 residue. The total expected production of collected fly ash and scrubber sludge in year 2000 reaches about 7-12 kilotons/yr and 7-33 megatons/yr respectively and their growth from 1979-2000 is shown in Appendix C, Figures C.10 and C.11. These wastes would require temporary onsite storage (covering as much acreage as the boiler and turbine buildings combined) and then would be transported to some unspecified ultimate disposal site.

4.2 HEALTH IMPACTS

When one examines the human health impacts associated with the alternatives discussed in this environmental impact statement, it appears that there is little incremental impact associated with the reference case spent fuel storage solution. This is due to the relatively inert conditions of spent fuel in storage. Also, increased storage of spent fuel at any facility simply results in the retention of older fuel that would otherwise have gone to reprocessing or disposal. Volatile and non-volatile radionuclides with short half-lives will have decayed to negligible levels. Consequently, the radiological and heat load impacts of this older fuel are factors of ten lower than that of the less cooled fuel and result in a small incremental impact to health and safety. Thus, environmental and health impacts of spent fuel storage are dominated by new spent fuel, and whether older fuel is present or is disposed of has little impact on the health and safety posture as a whole. The principal health impact is associated with incremental radiation dose. This subject is treated separately in Section 4.2.1. Section 4.2.5 treats the impacts associated with the termination case alternative of substituting coal fired power generation for nuclear energy.

4.2.1 Reference Case Storage Alternative

4.2.1.1 Normal Operations

The calculated health effects of the nuclear fuel cycle are summarized in Table 4.2.[17] In addition to the indicated potential excess mortality, there could be increases in morbidity due primarily to the incidence of nonfatal cancers.[17] For persons employed by the nuclear industry, the incremental incidence of nonfatal cancers and benign thyroid nodules could possibly be approximately one case per gigawatt-year.[17] For the general public, the incremental increase in morbidity could be about 0.5 case of a nonfatal cancer per gigawatt-year due to the entire nuclear fuel cycle.

Table 4.2. Summary of Excess Mortality Due to Civilian Nuclear Light-Water Reactor Power, per 0.8 Gigawatt-Year Electric

Fuel Cycle Component	Occupational		General Public		
	Accident	Disease	Accident	Disease	Totals
Resource recovery (mining, drilling, etc.)	0.2	0.038	∿ 0	0.085*	0.32
Processing	0.005***	0.042	**	0.026-1.1	0.073-1.1
Power generation	0.01	0.061	0.04	0.016-0.20	0.13-0.3
Fuel storage	**	∿ 0	**	∿ 0	∿ 0
Transportation	∿ 0	∿ 0	0.01	∿ 0	0.01
Reprocessing	**	0.003	**	0.059-0.062	0.057-0.065
Waste Management	**	∿ 0	**	0.001	0.001
Totals	0.22	0.14	0.05	0.18-1.3	0.59-1.7

*These effects indicate that 4060 Ci of ^{222}Rn released from mining the uranium to produce 0.8 GWy(e) would result in 0.085 excess deaths over all time.

**The effects associated with these activities are not known at this time. While such effects are generally believed to be small, they would increase the totals in this column.

***Corrected for factor of 10 error based on referenced value (WASH-1250).

The radiological impact from spent fuel storage is as follows:

- Population dose due to the release of ^{85}Kr from leaking fuel elements
- Occupational exposure of plant personnel incurred while working in the vicinity of the spent fuel storage pool, e.g., changing water purification filters and ion exchange resins.

These types of impacts are generic to spent fuel storage operations regardless of whether such fuel is stored at a nuclear power plant or at an AFR storage facility.

For the "aged" fuel involved in relatively long time storage, ^{85}Kr leakage rates are too low to be detected. However, for the final GESMO, Chapter IV-K, Extended Spent Fuel Storage, a conservative release rate of 1 Ci/MT-year was used. (Based on experience at the GE Morris Operation,[18] this figure could be high by a factor of 10^6). The resultant population dose factors were:

United States = 0.004 man-rem/MT-yr.
Foreign = 0.02 man-rem/MT-yr.

Occupational dose rates, based primarily on at-reactor experience, used in final GESMO were 20 man-rem per 1,000 MT-yr.

The above figures are applicable to conventional water basin storage pools. The figures for the various types of passive dry storage systems under development are expected to be comparable or less. Based on these figures, the calculated doses due to all spent fuel in storage are shown in Table 4.3. Note that the population doses are not corrected for ^{85}Kr decay.

Table 4.3. Radiological Doses from Spent Fuel Storage

Year	MT Fuel in Storage	Occupational Dose Total Body, man-rem	Population Dose, Skin, man-rem	
			U.S.	Foreign
1980	7,600	160	33	150
1985	18,000	360	77	350
1990	33,400	670	140	660
1995	54,300	1,100	230	1,100
2000	81,200	1,600	350	1,600

4.2.1.2 Compact Storage

For the majority of the facilities treated under this alternative, design, construction, and operating data were available. For the rest it was assumed that current practices in these areas would be continued at least through 1986, and that the 1,000-MWe hybrid model power plant as used in GESMO would be used after 1996. Spent fuel is considered stored at the bottom of large pools of filtered, deionized water.

The water serves as a coolant to remove decay heat of the spent fuel, and as a radiation shield for the stored spent fuel. The occupational radiation exposure results from the radioactivity in the water and the required operational activities. The spent fuel contributes a negligible amount to dose rates in the pool area because of the depth of water shielding the fuel.

Radioactivity in the pool water comes from introduction of reactor coolant water into the pool during refueling, the dislodging of crud from the surface of the spent fuel assemblies during handling of the assemblies, and the leakage of fission products from defective spent fuel elements. The rate of introduction of reactor coolant water into the pool with compact storage should not change because the proposed modification does not involve a change in the refueling procedures. Although the proposed modification will increase the total number of assemblies that can be stored in the pool, it is not expected that there would be a significant increase in the number of times the assemblies are handled before shipment offsite. Also, any significant removal of crud from the surface of an assembly would occur during the initial fuel handling when the assembly is transferred from the core to the storage pool. Therefore, there should not be a significant increase in crud introduced to the pool water due to the proposed modification. Experience with spent fuel stored at the GE Morris Plant and at the NFS, New York Plant has indicated that there is little or no leakage of radioactivity from spent fuel which has cooled several months. There should not be a significant increase in leakage activity from spent fuel to the pool because of the proposed modification.

The pool cleanup system serves to clarify and remove the radioactive materials from the pool water. Pool water treatment technology is well developed, and it is not uncommon to find fuel pool water with radioactivity content comparable to the 10 CFR Part 20 limits for occupational uses. Water carried out of the fuel pool by mechanical means or seepage is collected in sumps and recycled through a radwaste cleanup system. Small amounts of pool water eventually reach the environment but only after several levels of radwaste treatment, so that the quantities of radioactivity released are insignificant.

The only gaseous radionuclides released to the atmosphere in significant quantities are the noble gases, principally krypton-85. Some radiation reaches the environment in the form of direct radiation from the fuel within the pool and from the transportation of intermediate level wastes to the final disposal site. Direct radiation in the vicinity of the spent fuel storage pool is extremely low, in the order of one to two millirem per hour. If this were the only contribution to the occupational dose, that dose would be quite small. However, the occupational dose is dominated by the exposures involved in handling and moving the fuel, in handling radwaste, and in decontaminating tools during which time the dose rates are higher. In all other respects, the FCR and no-FCR alternatives proved to have nearly identical radiation impact. However, the additional handling, due to more fuel at the AFR storage involved, in the FCR alternative results in somewhat higher occupational doses than would be true for the no-FCR alternative.

4.2.1.3 "Away-from-Reactor" Storage

At the moment, independent spent fuel storage installations (ISFSI) comprise two licensed fuel pools, the GE installation at Morris, Illinois, and the NFS installation at West Valley, New York, and one facility undergoing licensing, the AGNS facility at Barnwell, South Carolina. These are relatively small facilities with a maximum total capacity of less than 1,000 tonnes. An ISFSI design of about 1100 metric tons pool capacity to be situated at a reactor site and to utilize some reactor facilities, such as electricity, water, and waste processing systems, has been reviewed by the NRC staff.[19] Such an ISFSI, designed to receive spent fuel from several neighboring reactors of a utility, would have reduced transportation (comparable to offsite reactor transshipment) compared to a large regional ISFSI. However, for the purposes of bounding the impacts of this alternative, large ISFSIs with total capacities of the order of 6,000 tonnes in multiple units of about 500 tonnes each were assumed.[20] In effect, each independent unit is the size of the currently projected larger fuel pools at reactors and is designed, built, and operated in very much the same manner. Thus, the majority of the radiological impact considerations (including cask handling) are essentially identical. However, in this case, transportation of spent fuel to the facility, assumed to be 1000 miles away, constitutes a major pathway of dose to the environment.[21] The storage of much larger quantities of spent fuel at these facilities would raise the quantities of noble gases released to the atmosphere per storage facility. Also, the much increased fuel load tended to increase the handling dose, thus raising the occupational exposure; while the more specialized design of these facilities resulted in a lowering of radionuclides released to the aquatic environment.

4.2.2 Safety and Accident Considerations

To be a potential radiological hazard to the general public, radioactive materials must be released from a facility and dispersed offsite. For this to happen:

- The radioactive materials involved must be available in a dispersable form,
- There must be a mechanism available for the release of such materials from the facility, and
- There must be a mechanism available for offsite dispersion of such released material.

Although the inventory of radioactive materials contained in 1000 MTHM of aged spent fuels may be in the order of a billion curies or more, very little is available in a dispersable form; there is no mechanism available for the release of radioactive materials in significant quantities from the facility; and the only mechanism available for offsite dispersion is atmospheric dispersion. Increased spent fuel storage with AR or AFR storage normally involves only aged fuel. The underwater storage of aged spent fuels is an operation involving an extremely low risk of a catastrophic release of radioactivity.

The radioactive materials present in a spent fuel storage installation are:

- The spent fuel in storage
- Impurities in the pool water
- The "crud" deposits on the surfaces of the fuel pins and fuel assembly structural components
- Airborne radioactivity, primarily due to entrainment in evaporating pool water
- Impurities removed from the pool waters by filtration and ion exchange treatment
- Wash solutions generated during shipping cask cleanup and miscellaneous decontamination operations
- Dry materials such as contaminated protective clothing, blotting paper, cleaning materials and ventilation system filters.

4.2.2.1 Composition of Spent Fuel

The spent fuel in storage is highly radioactive, with a total inventory of radionuclides in the order of 106 curies per metric ton of contained uranium. The gross radioactivity in curies per metric ton of uranium as a function of time since discharge from a reactor (decay time) is shown in Table 4.4. The decay times were chosen to represent:

Days		Event
0	-	At time of discharge from reactor.
120	-	Typical short storage time of AR spent fuel.
365	-	Nominal decay time for acceptance of spent fuel at an AFR (proposed 10 CFR Part 72).
3,650	-	Time when only long-lived activity remains.

Note that from a gross radioactivity standpoint, the fission product nuclides are predominant throughout the life of spent fuels in storage, but that 96.8% of this activity decays away in the first 120 days and 98.7% is gone in 365 days.

The fission product radionuclides are , emitters, and only those few that enter into biological processes are of major concern. For freshly discharged fuels at a reactor, a principal concern is the 8-day ^{131}I which is absorbed by plants, animals and humans, particularly in natural iodine deficient inland locations. However, since the quantity of ^{131}I present in discharged fuel is reduced by a factor of over a billion times in the first 365 days of decay, it is not a major concern for the storage of spent fuels in an AFR storage facility.

Those fission product nuclides of primary concern under conditions of long term spent fuel storage are ^{85}Kr and ^{134}Cs-^{137}Cs and possibly ^{129}I. These nuclides are present in significant quantities, are soluable in water and biologically mobile. Cesium enters the muscle tissue of animals and man. The isotope ^{129}I has a low specific activity, 1.4 dpm per gram of iodine in the environment where the background radio of ^{129}I to ^{127}I ranges from 4.8×10^{-10} to 3.1×10^{-9}. Thus, to receive a dose of the same order as that natural dose from ^{40}K in the thyroid would require ^{129}I to ^{127}I ratios about 10,000 times background.[22] However, because of its 17-million year half-life, its release to the environment should be minimized.

Table 4.4. Radioactivity Present in Spent Fuels,*
megacuries per metric ton of uranium**

Decay time - days after discharge	0	120	365	3,650
Fission product nuclides***	180	5.84	2.36	0.326
Actinides and their daughter elements***	49.8	0.191	0.167	0.105
Light elements & fuel element construction materials***	0.189	0.046	0.011	0.002

*See Appendix G for tabulation of nuclides present
**Based on metric tons of uranium charged to a reactor
***Source - ORIGEN code - Reference PWR
- Power - 37.5 MW/MTU
- Burnup - 33,000 MWd/MTU
- Plant capacity factor = 80%

Many of the actinides and their daughter elements are also short lived; 99.6% decay away in 120 days. Of those present in aged spent fuel stored in an AFR storage facility, the plutonium isotopes present the most significant potential hazard.

Of the materials of fuel element construction and surface crud deposites, the most significant radionuclide is cobalt-60.

The only way in which the radionuclides in spent fuel could be made available for dispersal is by physical rupturing of fuel pins. As fuel assemblies must be handled under water to provide the necessary protective shielding, a rupture of fuel pins would allow the escape of free gases, primarily ^{85}Kr, and contact of the fuel material by the pool waters. However, as corrosion rates of ceramic fuel materials are low, the only observable effect might be a slight increase in the ^{137}Cs content of the pool waters.

4.2.2.2 Krypton-85

The principal radioactive gas which could escape from defective fuel elements in storage is ^{85}Kr. The evidence to date indicates that the free gases present in fuel pin void spaces leak out rather quickly from defective fuel elements in the reactor and upon discharge, but that the gases which are contained within the fuel pellet matrix have an extremely low diffusion rate and hence a low leak rate. Experience at the NFS West Valley reprocessing plant with chopping fuel, in preparation for dissolution, showed the the release of krypton from spent fuel was marginally observable on their krypton stack monitor; almost all of the krypton was retained in the fuel until its dissolution. This experience indicates that even the rupture of a number of fuel elements in the storage pool would not cause a release of ^{85}Kr in sufficient quantities to be measurable offsite.

4.2.2.3 Cesium-134/137

Stable cesium is rare geologically and in the biosphere but radioactive cesium from weapons testing fallout is widely distributed throughout the biosphere. Cesium-137 is important as it is readily absorbed from the food intake by both animals and man. However, the cesium in spent fuel is strongly bound within the fuel matrix even when the fuel pellets are exposed to the pool water. The dissolution rate of cesium is very low and decreases sharply with time. The cesium concentration in pool waters is readily controllable by circulation through an ion exchange resin bed.

4.2.2.4 Pool Water Activity

The fuel pellets are sintered ceramic cylinders which have a very low solubility in water, and the contained radioactivity is tightly bound within the fuel material. In addition, the fuel material is hermetically sealed within highly corrosion resistant zirconium alloy (or stainless steel) cladding tubes with welded end closures. The only mechanism available under normal operating conditions for radionuclides in spent fuel to become available for dispersal is through the corrosion of defective fuel pins by the pool waters. Experience at pools where aged fuel has been stored (GE Morris Operation and NFS West Valley) has shown that the activity level of the pool water does show an increase when more fuel is added to a pool but that the activity decreases rapidly with time. The apparent explanation is that only the fuel directly exposed by a cladding defect is available for attack and only for a relatively short time.

A Zircaloy-clad fuel bundle containing two failed rods was placed in a closed can after burnup of 1900 MWD/MTU. After nine years, the radioactive content of the water inside the can had risen to only 1 mCi ($\sim$ 5 ppm of ^{137}Cs).[23]

NFS reported[24] an experienced pool water impurities composition of 76% ^{137}Cs; 6% ^{134}Cs; 6% ^{124}Sb; 6% ^{144}Ce and 1% ^{90}Sr. GE Morris Operation has also identified ^{60}Co as a minor contaminant in pool waters. Because of the direct relationship between pool water activity levels and occupational exposures, there is an incentive to keep pool water activity levels under control at all times; values in the range of 10^{-4} to 10^{-3} μCi/ml are common.

4.2.2.5 Surface Crud Deposits

Crud deposits have been observed on the surfaces of fuel pins and fuel assembly hardware, particularly on the inner lower nozzle surfaces. The thickness of these crud layers varies from almost nil up to about 150 microns.[25] Surface appearance varies from a dense black for PWR fuels to an orange-red for some BWR fuels, dependng upon reactor primary coolant circuit characteristics. These crud layers are oxides of iron, nickel, and copper and mixed oxides.

These crud deposits slough off during shipping and are the principal source of contamination of cask coolants. A small fraction also apparently becomes either dissolved or suspended in the pool waters, e.g., ^{60}Co. However, based on visual observations at the NFS West Valley plant, most of the crud deposits remained on the fuel assembly until it was chopped up prior to reprocessing.

4.2.2.6 Airborne Radioactivity

Airborne radioactivity within a spent fuel storage facility is a function of: the pool water activity, care used in handling fuel, frequency of fuel transfer operations and good housekeeping practices. Based on G.E. experience, the airbone activity levels are a factor of 10^{-8} less than the pool water activity and are routinely less than 1% of the occupational exposure limits in 10 CFR Part 20, Appendix B, Table I.

4.2.2.7 Pool Water Purification System

Spent fuel storage pools are serviced by a pool water cleanup system consisting of filters and ion exchange units, and the necessary pumps, tanks and piping. These systems may contain concentrations of radionuclides as much as 100 times that of the pool waters, enough to require local shielding and carefully controlled operating procedures. However, the inventory of radionuclides available for disposal is limited to that contained in a spent filter or ion exchange unit at the time of replacement. As these are wetted materials, spills could cause a local decontamination and cleanup problem but the materials involved are readily contained.

4.2.2.8 Decontamination Solutions

Shipping casks represent the major source of contaminated wash solutions. During shipment some of the surface crud on fuel assemblies can become dislodged and become a source of contamination to the cask cavity. On receipt at the storage installation, the water in the cask cavity is sampled for radioactivity and, if necessary, flushed out before the cask is opened. The wash waters generated are collected in the onsite low level waste system for treatment prior to disposal.

Wash solutions from plant decontamination operations are also collected in the low level waste system for treatment prior to disposal.

The GE Morris Operation has a somewhat unique system, different from that described above. This facility has a vault which is embedded in rock for their collection of low level wastes. This vault was originally intended for the collection of low level wastes from the reprocessing plant and is designed for relatively long period onsite storage to take advantage of radioactive decay before final treatment and disposal. It is not anticipated that a storage only facility would be equipped with such a vault, but would more likely use relatively small volume tankage behind shielding for the collection of low level wastes prior to treatment.

4.2.2.9 Dry Waste Materials

A spent fuel storage operation also generates dry radioactive waste materials. These consist of contaminated protective clothing, blotting paper, and cleaning mops and plastic sheeting. Such materials are normally collected in plastic bags and packaged in drums prior to disposal. The contained radioactivity in such drums is normally in the order of 200 μCi/drum. This activity adheres to the materials involved and is not in a readily dispersable form.

4.2.2.10 Release Mechanisms

As underwater storage is a low temperature, low pressure environment, there is no driving force for the sudden release of a major fraction of the radioactive materials contained in the stored spent fuel even under abnormal operating conditions. Small quantities of radioactive materials could be released inside the facility during an inadvertent venting of a shipping cask while it is being prepared for unloading or a spill of low level waste materials in the waste handling and treatment system.

4.2.2.11 Offsite Dispersal Mechanisms

Again, because of the absence of high temperatures or pressures in an under water spent fuel storage operation, the only mechanism for offsite dispersal of released radioactive materials is atmospheric conditions.

4.2.3 Accidents and Natural Phenomena

For an accident to represent a potential radiological hazard to the general public, the same conditions apply - radioactive materials must be released from the facility and dispersed offsite. For this to happen:

- The radioactive materials involved must be rendered into a dispersable form,
- These must be released from the facility, and
- The conditions must be present for dispersion offsite of such released materials.

A range of potential accidents and natural phenomena events have been analyzed.

4.2.3.1 Accidents Resulting in Rupturing of Fuel Pins

Both NFS and AGNS included in their safety analysis reports (Docket Nos. 50-201 and 70-1729 respectively) an under water fuel drop accident in which it was assumed that all of the fuel pins in a fuel assembly were ruptured. Because of the age of the spent fuel, very little ^{131}I remains and with a decontamination factor of 100 for an under water release, a negligible amount of ^{131}I would be available for dispersion offsite. The NFS calculated release rates for an assembly exposed for 33,000 MWD/MTU and cooled for a minimum of 120 days were:

Nuclide	Release Rate -- Ci/Sec From Fuel	 From Pool
^{85}Kr	5.5×10^{-4}	5.5×10[illegible]
^{131}Xe	9.2×10^{-7}	9.2×10^{-7}
^{129}I	3.7×10^{-10}	3.7×10^{-12}
^{131}I	2.9×10^{-7}	2.9×10^{-9}

With ground level release dispersion factors in the order of 10^{-4} to 10^{-7} sec/m^3 at most sites, site boundary concentrations would be a small fraction of the 10 CFR Part 20, Appendix B, Column II, limits.

4.2.3.2 Low-Probability Missile Accident

An analysis has also been made of a low-probability missile accident at a storage only type of facility containing 1 year and 3 year, aged, spent fuel. The accident was defined as the penetration of the building by a tornado generated missile that lands in the storage pool. The activity in the gap between the fuel and the fuel cladding is released from the fuel pins ruptured by the impact of the missile. The missile evaluated was a 13.5-inch-diameter by 35-foot-long utility pole, travelling at 144 mph.

Assuming that the missile entered the pool at an optimum angle, a 45 foot row of fuel assemblies could be impacted if the missile was not deflected from its course of travel. Assuming a uniform storage array of 40 BWR assemblies and 27 PWR assemblies, a total of 20 MT of fuel could be impacted. It was assumed that 10% (a high figure) of the contained ^{85}Kr is in the fuel cladding gap and hence available for release. Similarly, 1% of the ^{129}I is also assumed present in the gap. However, iodine is soluble in water and an under-water release would be subject to a decontamination factor of at least 100. On this basis the source terms for spent fuel exposed to an average of 28,000 MWd/MTU shown in Table 4.5 were calculated.

Assuming an atmospheric dispersion factor (χ/Q) of 10^{-4} sec/m^3 for a ground level release and a site boundary distance of 275 meters, the calculated dose rates are shown in Table 4.6.

The calculated doses shown in Table 4.6 are obviously quite small and are a fraction of the average annual natural background dose of greater than 0.1 rem.

Table 4.5. Calculated Source Terms for Low-Probability Missile Accident Analysis - Away-from-Reactor Storage Pool

Radionuclide	Inventory Ci/MT* 1 yr decay	Inventory Ci/MT* 3 yr decay	Fraction in Gap**	Release Fractions***	Curies Released per MTU 1-yr old fuel	Curies Released per MTU 3-yr old fuel	Curies Released per 20 MT of Fuel 1 yr old	Curies Released per 20 MT of Fuel 3 yr old
^{85}Kr	9.6×10^{3}	8.4×10^{3}	0.1	0.1	9.6×10^{2}	8.4×10^{2}	1.9×10^{4}	1.7×10^{4}
^{129}I	3.1×10^{-2}	3.1×10^{-2}	0.01	0.01	3.1×10^{-6}	3.1×10^{-6}	6.2×10^{-5}	6.2×10^{-5}

Bases:

*28,000 (average) MWd/MTU burnup, ORIGEN Code calculation.

**^{85}Kr = 10%; ^{129}I = 1%

***^{85}Kr = 100%; ^{129}I = 1% of gap activity

Table 4.6. Calculated Site Boundary Dose Rates for Low-Probability Missile Accident at Away-From-Reactor Storage Pool

Radionuclide	Ci Released 1 yr decay	Ci Released 3 yr decay	Exposure at Site Boundary, Ci-sec/m^3 1 yr decay	Exposure at Site Boundary, Ci-sec/m^3 3 yr decay	Dose Conversion Factor, Rem/Ci-sec/m^3	Critical Organ Dose, rem 1 yr decay	Critical Organ Dose, rem 3 yr decay
^{85}Kr	1.9×10^{4}	1.7×10^{4}	1.9	1.7	3.0×10^{-2}	5.7×10^{-2}**	5.1×10^{-2}**
^{129}I	6.2×10^{-5}	6.2×10^{-5}	6×10^{-9}	6×10^{-9}	4.6×10^{6}	2.9×10^{-2}***	2.9×10^{-2}***

*50-year commitment

**Skin

***Thyroid

4.2.3.3 Fires and Explosions

Fires and explosions could be the driving force for the dispersion of radioactive materials in finely divided forms. However, there is no need for the use of explosive materials in an AFR storage facility and normal operating procedures limit the accumulation of combustible materials such as paper. Such materials are used for routine decontamination operations, but as soon as used, these materials must be properly bagged to prevent a further spread of contamination. Serious fires and explosions are not considered credible in an AFR storage facility.

4.2.3.4 Criticality Accident

Assuming the fuel storage design was adequate, a criticality accident in a spent fuel pool could conceivably approach the power levels (less than 1,000 kW) of a "swimming pool" type of research reactor.[26] As proven by the operation of such reactors for many years, conditions did not generate enough energy to disperse any radioactive materials to the atmosphere from under more than 12 feet of water.

4.2.3.5 High Pool Water Activity

Based on operating experience at the GE Morris Operation and the NFS West Valley Plant, spent fuel storage pool water activity should normally be maintained at less than 5×10^{-3} μCi/ml. At this concentration the dose rate on the bridge crane above the pool is less than 2 mrem/hr.

An increase in the pool water activity by a factor of ~ 10 times to about 5×10^{-2} μCi/ml would result in a dose rate of about 20 mrem/hr based on NFS experience when their pool became contaminated due to ruptured metal fuel elements from the dual purpose N-reactor at Hanford.

During a period of high pool water activity, fuel transfer activities would normally be curtailed until the pool water activity is reduced to normal operating levels.

4.2.3.6 Rupture of Waste Tank or Piping

One of the potential sources of in-plant personnel exposure is the low level waste treatment system. The backwashes from the pool water filters and demineralizers are normally piped to a collection tank prior to concentration and solidification. Activity levels in the piping and collection tanks are in the order of 0.5 to 1.0 μCi/ml. For this reason, this system is normally located behind shielding.

A break in the piping or a rupture of the collection tank might cause a leak of 100 gals. of contaminated water to the floor inside the building. The area would have to be isolated, and decontamination and cleanup action initiated.

One method of cleanup would be to absorb the spillage with vermiculite and load it into drums for disposal. If the waste treatment facility is located within a shielded cell with a HEPA filter in its exhaust air duct, and only particulates are involved, 99.9% of which would be captured on the HEPA filter, the effects of the spill would be confined to the cell. A decontamination and cleanup operation would be necessary, but this could be confined and would have a negligible effect on the rest of the installation or its environs.

If the waste treatment facility is located behind shielding but not in an enclosed cell, or the cell door was open, the airborne fraction of the spill could be distributed within the facility in a pattern depending on air flow.

With an air volume of 100,000 ft^3 or greater, the activity of the building air might be increased initially, but with circulation through a HEPA filter, this activity could be reduced to normal levels within a short time. Access to the building could be restricted for this short period of time but essential operations could be carried out under "special work permit" restrictions.

Exposure of in-plant personnel should be readily controllable by operating procedures and physical barriers. There should be a negligible effect offsite.

4.2.3.7 Lowering of Pool Water Level

A 1,000-ton-capacity storage pool is estimated to contain 1,000,000 gallons of water and be 30 or more feet deep. The water in a spent fuel storage pool serves the dual functions of heat removal and shielding. Spent fuel storage pools are normally designed with a minimum of 12 feet of water over the fuel in storage, enough to reduce the gamma dose rate from the fuel assemblies to less than 0.5 mr/hr at the pool surface.

Fuel transfer mechanisms have limit switches and mechanical stops to prevent raising a fuel element or a storage canister to less than 9 or 10 feet of the water surface.

- A loss of 5% of the water, about 50,000 gallons, would have only a negligible impact on personnel exposures,
- A loss of 25% of the water, about 250,000 gallons, would reduce the shielding over the stored fuel to about 6 feet. Under these conditions the fuel transfer bridge crane work could be carried on within the facility but this may have to be done under "special work permit" conditions.

The fall of the water level to this depth may require an emergency modification of the cooling water circuit inlet and outlet lines, such as connecting emergency supply and cutting off any bleed-off system, but this should be feasible without serious over exposure of personnel.

While the loss of all water is beyond the design basis envelope, it involves only low risks for independent spent fuel storage installations in which only aged spent fuel is stored. The major consequence of such an unlikely event would be a small skyshine dose at a site boundary. Dose rate versus distance calculations have been made for this event.[27]

The heat generation rate of spent fuel decreases rapidly with time for a short period following discharge from a reactor. For example, at one year after discharge the spent fuel heat generation rate is less than one percent of its rate when it is discharged from the reactor. At ten years its heat generation rate has decreased by another factor of ten to one-tenth of one percent.

Assuming that the spent fuel stored at an independent spent fuel storage installation is at least one year old, calculations have been performed to show that loss of water should not result in fuel failure due to high temperatures if proper rack design is employed.[28] Such design specification is included in NRC regulatory guidance now in preparation. Cooling by natural convection air currents alone should be adequate. The staff believes that such storage facilities can be designed and constructed to assure that loss of the pool water will be a highly unlikely event. Based on its safety reviews of similar facilities the staff finds that such pools can be constructed to withstand severe events and backup sources of water can be provided.

4.2.3.8 Loss of Cooling

Because there is adequate time to take corrective action in the event of a loss of cooling at an AFR storage facility, there are no special requirements placed on the design and construction of the cooling system other than the pool water be circulated in a closed loop. However, in the course of a safety review, the staff does require an adequate backup supply of water. A loss of the cooling system for a number of weeks was experienced at the GE Morris facility operating during the 1976-1977 winter with no adverse effects.

On January 16, 1977 a two hour interruption in the power supply shut down the circulating pump. The outdoor temperature was -19°F. When normal flow was reestablished, a pipe break was discovered and the system was shut down and drained. With 225 tons of fuel in storage, the GE pool reached an equilibrium temperature of 115°F over a number of weeks. The humidity in the building was uncomfortably high, but otherwise this incident had no adverse impact on either plant personnel or the general public.

NFS showed an analysis in their SAR for a planned expansion program of their pool filled with fuel (giving off 12×10^6 Btu/hr) and allowed to reach a boiling temperature. Their calculated time required to reach boiling was 48 hours for an isolated pool, and a boil off rate of 1,500 gal/hr. A comparable staff calculation for a much larger pool and more compact fuel storage but with a heat generation rate more typical of fuel placed in extended storage showed a temperature rise of about 4°F/hr. and the time to reach boiling was 33 hours.

These figures show that there is time to take corrective action even with a complete loss of cooling. If conditions preclude reactivation of the cooling system within the time allowance to reach boiling, makeup water must be provided to offset evaporation losses. A staff calculation for a pool containing 1,000 tons of fuel with a heat generation rate of 3.4×10^7 Btu/hr would require 60 gal/min to maintain the water level under boiling conditions.

To assure the availability of makeup water during an extended outage of the cooling system, there must be a reliable water source and a means of delivering water to the spent fuel storage pools should the need arise.

NFS calculated that, with a decontamination factor of 10^4, the airborne activity within the building, with the pool water boiling, would be less than the occupational exposure concentration limits shown in 10 CFR Part 20, Appendix B, Table II, Column I.

4.2.4 Considerations and Assumptions Used for Offsite Transportation Accident Analysis

All information in this section is summarized from WASH-1238, "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants."[29] The consequences of a major release of radioactive material from a spent fuel shipping cask could be severe; however, the low probability of such an occurrence during transportation makes the risk from such accidents extremely small. Spent fuel shipping casks are designed to withstand severe transportation accidents without significant loss of contents or increase in external radiation levels. The casks are protected from the damaging effects of impact, puncture, and fire by thick outer plates, protective crash frames, or other protective features designed to control damage.

Transportation accidents occur in a range of frequencies and severities. Most accidents occur at low vehicle speeds. The severity of accidents is greater at higher speeds, but the frequency decreases as the severity increases. Transportation accidents usually involve some combination of impact, puncture, fire, or submersion in water.

4.2.4.1 Estimates of Releases in Accidents

Estimates of the amount of radioactive material released and the calculated doses in the unlikely event that a shipping cask is breached are summarized herein. The consequences in terms of potential doses to humans were calculated for the estimated releases of ^{85}Kr, ^{131}I, and fission products. Normal distributions of weather and population densities for a release on land were used in the calculations.

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Table 4.7 shows the probability of a transportation accident per vehicle mile in each of the five accident severity categories. Tables 4.8 through 4.11 show the probabilities of "N" or more persons receiving doses of "D" or more millirem as a result of a release of 1.1 x 10^3 Ci of ^{85}Kr, 1 x 10^{-2} Ci of ^{131}I, and 130 Ci of gross fission products, with all of the krypton and iodine and 1% of the gross fission products being dispersed in the air. It would require an accident of the extra severe category to cause a release of this magnitude. Therefore, the total probability of "N" or more persons receiving doses of "D" or more millirem from the transportation of spent fuel would be the probabilities in Tables 4.8 through 4.11 multiplied by the appropriate probability in Table 4.7 multiplied by the distance traveled.

Table 4.7. Accident Probabilities for Truck or Rail Travel per Vehicle Mile for the Accident Severity Categories (from WASH-1238)

Minor	Moderate	Severe	Extra Severe	Extreme
2 x 10^{-6}	3 x 10^{-7}	8 x 10^{-9}	2 x 10^{-11}	1 x 10^{-13}

Table 4.8. Probability of "N" or More Persons Receiving a Dose to the Skin of "D" Millirem or More from the Release of 1,100 Curies of Krypton-85 in an Accident (from WASH-1238)

Number of People, "N"	Dose (millirem), "D"				
	1	10	100	1000	5000
1	0.9	0.5	0.1	2 x 10^{-2}	3 x 10^{-3}
10	0.6	0.2	3 x 10^{-2}	1 x 10^{-3}	
10^2	0.2	4 x 10^{-2}	2 x 10^{-3}		
10^3	7 x 10^{-2}	2 x 10^{-3}			
10^4	1 x 10^{-2}				
10^5	5 x 10^{-4}				

Table 4.9. Probability of "N" or More Persons Receiving a Dose to the Thyroid of "D" Millirem or More from the Release of 0.01 Curies of Iodine-131 in an Accident (from WASH-1238)

Number of People, "N"	Dose (millirem), "D"			
	1	10	100	1000
1	0.5	9 x 10^{-2}	1 x 10^{-2}	2 x 10^{-4}
10	0.1	1 x 10^{-2}	4 x 10^{-4}	
10^2	2 x 10^{-2}	6 x 10^{-4}		
10^3	1 x 10^{-3}			

Table 4.10. Probability of "N" or More Persons Receiving a Dose to the Lungs of "D" Millirem or More from 1.3 Curies of Gross Fission Products Which Became Airborne as a Result of an Accident (from WASH-1238)

Number of People, "N"	Dose (millirem), "D"					
	1	10	100	1000	5000	10,000
1	1	0.8	0.3	5×10^{-2}	1×10^{-2}	4×10^{-3}
10	0.8	0.3	6×10^{-2}	4×10^{-3}	3×10^{-4}	4×10^{-5}
10^2	0.4	9×10^{-2}	6×10^{-3}	1×10^{-4}		
10^3	0.1	1×10^{-2}	2×10^{-4}			
10^4	4×10^{-2}	5×10^{-4}				
10^5	4×10^{-3}					

Table 4.11. Probability of "N" or More Persons Receiving a Dose to the Whole Body of "D" Millirem or More over a Period of One Year Following the Release in an Accident of 130 Curies of Gross Fission Products Which Deposit on the Ground (80% of the dose is to the skin) (from WASH-1238)

Number of People, "N"	Dose (millirem), "D"					
	1	10	100	1000	5000	10,000
1	1	1	1	0.9	0.7	0.7
10	1	1	0.9	0.7	0.3	0.2
10^2	1	0.9	0.6	0.3	0.1	6×10^{-2}
10^3	1	0.7	0.4	9×10^{-2}	2×10^{-2}	6×10^{-3}
10^4	0.8	0.5	0.2	3×10^{-2}	9×10^{-4}	2×10^{-4}
10^5	0.7	0.4	8×10^{-2}	2×10^{-3}		

4.2.4.2 Consequences of Implementing Storage Alternatives

The severity of the consequences of a single transportation accident will not change with any of the proposed storage alternatives. However, the probability of occurrence will increase in direct proportion to the increase in distance of shipment of spent fuel for those alternatives which involve transportation for offsite storage. Specifically, those storage alternatives which involve offsite transportation are independent storage facilities, transshipment, and use of government facilities.

The estimated average distance from a nuclear power plant site to an AFR storage facility over which the irradiated fuel would be transported is 1,000 miles. From Table 4.9 and Table 4.10, the probability of 100 persons receiving a dose to the skin of 100 millirem from a release of 1,100 curies of ^{85}Kr as the result of an extra severe transportation accident is 4×10^{-11}. If the offsite storage facility was located at or near a future reprocessing plant or disposal site, this probability would be about 4×10^{-14}. However, if the offsite storage facility required an additional 1,000 miles of travel, the probability of occurrence of this accident would increase to 8×10^{-11}. Consequently, the environmental risk due to offsite transportation accidents involving spent fuel casks remains extremely small.

4.2.5 Termination Case

The termination case assumes that as nuclear power plant pools became filled with spent fuel, the plants will be shut down and the generation capacity replaced by coal plants. In addition it was assumed that no new nuclear plants would be built for start up after 1985.

The staff has made several projections of public health fatalities derived from the termination case. Table 4.12 presents a generic analysis for the whole coal fuel cycle.[17] This appears to be the best approximation of excess mortality due to substituting coal fired plants. This table corresponds to Table 4.2 for an LWR. Health effects estimates from radon have been conservatively extended into an admittedly uncertain future to incorporate periods ranging from 100 to 1,000 years. Similarly, the staff also extended health effects estimates of carbon-14 releases for 100 to 1,000 years into the future.

In this table, excess mortality is synonymous with premature death. Therefore, in the case of radiogenic cancer, for example, excess mortality does not mean more people in a given population will die, since every member of the population will die at some time from some cause. Premature death implies that some members of the population will die (statistically) at an earlier time than they would have had they not received a radiation dose.

The "excess mortality" figures represent projected deaths 90 years into the future (i.e., a 40-year environmental dose commitment period per annual fuel requirement, with a 50-year dose commitment for each of the 40 years).

4.3 SOCIAL IMPACTS

Two assumptions underlie the discussion of all the alternatives. First, analysis of the various options assumes a period of socio-political stability. This includes the assumptions that no unexpected national or international event will occur (e.g., oil embargo), the economy will be reasonably healthy, and a political atmosphere conducive to problem solving will prevail. Second, the analysis projects normal operating conditions at all generating facilities.

Table 4.12. Summary of Excess Mortality due to Coal-Fired Electric Power Production, per 0.8 Gigawatt-Year Electric

Fuel Cycle Component	Occupational		General Public		
	Accident	Disease	Accident	Disease	Totals
Resource recovery (mining, drilling, etc.)	0.3-0.6	0-7	*	*	0.3-8
Processing	0.04	*	*	10	10
Power generation	0.01	*	*	3-100	3-100
Fuel storage	*	*	*	*	*
Transportation	*	*	1.2	*	1.2
Waste management	*	*	*	*	*
Totals	0.35-0.65	0-7	1.2	13-100	15-120

*The effects associated with these activities are not known at this time but are generally believed to be small. The totals would increase only slightly if these values were included.

4.3.1 The Reference Case Storage Solution

Storing spent fuel has the advantage of resulting in confinement of perceived problems to a small area. As at a nuclear power plant, safeguards and safety measures can be developed to restrict access. The location of such a site near a community would produce social problems similar to those associated with siting of other nuclear-related facilities.

Social impacts likely associated with independent storage facilities will be similar to those occurring at power plants and are of three main types:[30] (1) impacts on socially valued aspects of the natural environment, (2) impacts on the social structure, and (3) the effects of perceived danger of accidents and radiation. Changes caused by the disruption of the environment have direct impacts upon humans. The removal of the land for the site from future development, long-term demands on the water supply, and visual intrusion of cooling towers or buildings on the natural landscape will permanently affect the relationship of the residents with their environment and the development of the area.

Areas where such facilities would be built would pay most of the resulting socioeconomic costs but receive few of the social benefits involved. Also, while certain items can be isolated and labeled as costs or benefits, other impacts cannot be quantified or are slow in developing, causing them to be unaccountable.

4.3.2 Termination Case

This social analysis is based on the phasing out of nuclear power through a one-to-one replacement of such plants with coal fired plants and past 1985 by building only coal fired plants. By hypothesizing a phased decline in nuclear generating capacity, one can explore the consequences of switching to coal.

4.3.2.1 Employment

The electric power industry is one of the nation's largest employers. Nuclear facilities require about the same labor force as do coal fired plants. Therefore, a shift to coal fired plants thus would result in no significant difference in employment.

4.3.2.2 Life Style/Quality of Life

Where people live depends upon the provisions of economic and environmental service systems. Thus, people are clustered where there is adequate employment, markets and distribution systems. Coincident with denser population there will be requirements for water, a capability for waste removal, and a capacity for home heating and cooling. In the past two decades when energy was relatively inexpensive and the price of electricity was declining, Americans developed an energy-intensive life style. The suburbs and low-density housing grew rapidly. However, with the recent increases in energy costs, the rate of suburbanization has declined.[28] The suburban development, with its predominance of single-family homes, is far more consumptive of energy than multiple dwelling units. More and more Americans are turning to either common-wall dwellings or apartments. In the future it appears that a larger proportion of homes built will be in these latter two categories. With the decline of the suburban alternative, population growth will lead also to the filling in of urban areas. It is probable that urban patterns of densely populated communities connected by transportation corridors will replace the present spread-city pattern.

Local impacts in coal mining areas and along transportation corridors could be quite significant. These include population and transportation increases with attendant local societal stresses and adjustments. For the average citizen, the most noticeable impact of the replacement of nuclear energy with coal fired or other types of power plants under the termination alternative would be higher utility bills.

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5.0 SAFEGUARDS CONSIDERATIONS

5.1 INTRODUCTION

Safeguards are defined as those measures employed to deter, prevent, or respond to (1) the unauthorized possession or use of significant quantities of nuclear materials through theft or diversion and (2) the sabotage of nuclear materials and facilities. As applied to licensees and licensed materials, the NRC safeguards program has the general objective of providing a level of protection against such acts that will ensure against significant increase in the overall risk of death, injury, and property damage to the public from other causes beyond the control of the individual.

Since the inception of the program for peaceful uses of nuclear energy in 1954, a primary concern of the safeguards program has been special nuclear materials (SNM) accountability. Starting in 1967, however, public concern and awareness regarding the physical protection of nuclear materials and facilities has been growing because of the rapid growth of the nuclear power industry coupled with the increase in terrorist activities indicated by acts of individuals or identifiable groups over the past decade or so.[1] Accordingly, in addition to the SNM accountability provisions contained in 10 CFR Part 70, the NRC publishes (in 10 CFR Part 73) specific physical protection requirements applicable to certain licensed activities. As will be addressed further in a subsequent portion of this chapter, the primary safeguards objective applicable to spent fuel storage and transportation is protection against acts of sabotage that could endanger the public health and safety by exposure to radiation.

This chapter addresses the potential security-related impacts of increased spent fuel storage at alternative locations. Since the scope of this GEIS is confined to issues pertinent to alternative storage modes, only those fuel assemblies suitable for away-from-reactor (AFR) storage, viz., "aged" assemblies, were considered in the course of this analysis. (See Sec. 4.2 regarding the safety-related impacts of the storage and transportation of aged spent fuel.)

5.2 AGED SPENT FUEL--POTENTIAL FOR MISUSE AND PHYSICAL PROTECTION

Irradiated (spent) fuel removed from light water cooled power reactors (LWRs) contains low enriched uranium, fission products, and plutonium and other transuranics. It is highly radioactive and requires heavy shielding for safe handling. Theft or diversion of spent power reactor fuel by subnational adversaries with the intent of utilizing the contained special nuclear material (SNM) for nuclear explosives is not considered credible due to (1) the unattractive form of the contained SNM, viz., it is not readily separable from the radioactive fission products, and (2) the immediate hazard posed by the high radiation levels. Sabotage of spent fuel might be within the capability of potential adversaries, however, and therefore may constitute a possible hazard to local populations.

The NRC is continuously evaluating the nature and extent of potential threats against nuclear materials and facilities. It is not possible from the available evidence to conclusively demonstrate that any imminent threat to the nuclear fuel industry actually exists. It is apparent, however, that:

- There may be people who have the skills necessary to plan and execute an operation against the industry;
- Conceivably such people could be gathered together and motivated to conduct such an operation.

There have been no deliberate acts of sabotage directed against a licensed activity which culminated in a direct or indirect danger to the public health and safety by exposure to radiation.[2] The possibility always exists that at some point in time a disgruntled employee or politically motivated group may attempt some act that would be classified as a threat to nuclear activities.

The areas of the LWR fuel cycle against which spent fuel sabotage might be directed include fuel reprocessing plants (FRPs), independent spent fuel storage installations (ISFSIs), power reactors (LWRs), and shipping packages during transportation. Given the absence of any evidence indicating the existence of a domestic threat to the nuclear power industry, it is not possible to ascertain the likelihood of a sabotage attack against these activities. Consequently, protection against such acts and their possible consequences is dictated by prudence. Although the features designed into plants and packages to prevent releases or serious consequences due to accident or natural phenomena also provide protection against sabotage, certain additional protective measures have been specified to deter attempts and mitigate the seriousness of deliberate acts.

The sections that follow address, in general, the intrinsic features of plant and package designs that protect against potential releases, the protection requirements of the regulations, and possible consequences of certain sabotage events. Away-from-reactor (AFR) storage, at-reactor (AR) storage, and spent fuel transportation activities are examined separately as a basis for comparing the security-related impacts of the storage options being considered by the staff.

5.2.1 Storage in Away-From-Reactor (AFR) Facilities

Interim storage of spent fuel at fuel reprocessing plants and at independent spent fuel storage installations (located at reactor sites, but separate from existing structures, or at separate sites) are two alternative methods for providing increased AFR storage capacity. Sections 2.1.3 and 3.1.4 describe existing and planned AFR facilities. At both FRP and ISFSI locations, aged spent fuel will likely be stored in conventional basin pools. The designs of such pools provide for protection against radioactive releases due to accidents or violent natural phenomena. The design criteria established to maintain confinement of radioactive contaminants are delineated in Appendix B (Vol. 2). In short, AFR storage facilities are designed to assure adequate margins of safety in accidents and to mitigate their consequences.

To the extent that acts of sabotage initiate sequences of events much like those initiated by accidents, the measures designed into AFR storage facilities for mitigation of consequences of such accidents also provide some protection against potential releases resulting from sabotage. The large volume of water and the substantial concrete barriers, constructed for biological shielding and earthquake resistance, provide a degree of inherent protection against explosive attacks and their consequences, but the possibility exists that potential saboteurs may be capable of overcoming the inherent protection and engineered safety features in an attempt to create a radiological hazard. For this reason, NRC regulations include requirements for the physical protection of spent fuel against sabotage.*

5.2.1.1 Safeguards Requirements for Spent Fuel at AFR Locations

Spent fuel in interim storage (i.e., prior to disposal or reprocessing) at FRPs and spent fuel storage sites must be stored in accordance with requirements for its protection against sabotage contained in Section 73.50 of 10 CFR Part 73. These regulations do not include a specific definition of a potential adversary, but have been implemented to prescribe a range of physical security measures that a licensee must follow. Principal features include protection forces (guards), physical and procedural access controls, detection aids, communication systems, and liaison with local law enforcement agencies.

Each licensee is required to prepare and submit a security plan for NRC approval. The plan contains details on how the licensee intends to implement the security provisions applicable to his site. In addition to the basic security plan, each licensee is also required to develop a guard qualification and training program and a plan for responding to safeguards contingencies as outlined in Appendices B and C of 10 CFR Part 73.

Any equipment, system, device, or material of which the failure, destruction, or release could endanger the public health and safety by exposure to radiation is considered "vital", and is subject to additional specific protective measures. The site-specific identification of vital equipment and material is a necessary part of the NRC staff's review of the security plan submitted by an applicant or licensee. Spent fuel is considered vital in this sense and is therefore required to be located in an area which is protected by at least two personnel barriers and to which access is limited and controlled. Further detail regarding the safeguards requirement applicable to the interim storage of spent fuel appears in Section 1.0 of Appendix J in Volume 2.

5.2.1.2 Environmental Effects of Sabotage

In assessing the impacts of successful malevolent acts, one can demonstrate the potential magnitude of the radiological consequences by postulating destructive acts against the stored fuel elements and analyzing the resultant effects. Radiologically, sabotage events may be similar to accidents or abnormal operations and thus the consequence estimation techniques for the effects of these latter causes also apply to some sabotage events.**

A reasonable upper bound on estimated consequences stemming from sabotage incidents can be established if (1) no limiting assumption is made with regard to the sequence or number of deliberate events or (2) no credit is taken for the effectiveness of any existing security measures. As part of broad study of adversary actions at nuclear facilities, the NRC directed a study of

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*Industrial sabotage, in the context of the nuclear industry, is defined in 10 CFR 73.2(p) and means any deliberate act which could directly or indirectly endanger the public health and safety by exposure to radiation.

**The discussion and analyses presented in Chapter 4.0, "Environmental Impacts," address potential radioactive releases, both routine and accidental, associated with AFR storage.

potential consequences associated with the successful sabotage of spent fuel at AFR storage locations.[3,4] As is discussed more fully in Section 2.0 of Appendix J (Vol. 2), a specific set of reference events was identified and analyzed to establish a quantitative estimate of potential consequences of such events in terms of loss of life, injury, and property damage. There are, of course, design variations among the several existing or proposed facilities, and the list of postulated reference events was made sufficiently broad in scope to encompass many of these variations. Nevertheless, certain of the scenarios that may be possible within the reference design cannot occur at a plant whose design is different. For example, at existing facilities (see Sec. 2.1.3) the casks are unloaded underwater, making the rupture of fuel assemblies in air inside a cask-unloading cell (CUC) impossible. The worst-case consequences presented for this range of reference events should not be inferred to represent the potential effects of sabotage at every AFR storage location.

The following events were postulated as reference events for the purpose of analyzing the sabotage consequences at present and future AFR storage facilities:

I. Damage to Fuel Assemblies in the Cask-Unloading Cell (CUC)
  - Mode 1. Mechanical damage to between 1 and 20 fuel assemblies in the air space of the CUC (normal ventilation conditions).
  - Mode 2. Same as (1) but with HEPA filtering ruptured or removed, ventilation flow maintained.
  - Mode 3. Same as (1) but with air flow from CUC discharged directly to atmosphere unfiltered at ground level.

II. Damage to Fuel Assemblies in the Spent Fuel Storage Pool (SFSP)
  - Mode 1. Explosive rupture of 1, 24, and 1000 fuel assemblies underwater in the SFSP (normal ventilation conditions).
  - Mode 2. Same as (1) but with final filters damaged, ventilation fans operational.
  - Mode 3. Same as (1) but with ventilation system turned off and openings created in opposite walls of the SFSP building.
  - Mode 4. Same as (1) but with breach in 3/16-in steel liner and 5-ft concrete floor so that contaminated pool water leaks into the ground.

Unique features of each scenario which affect the radiological source terms are explained in Section 2.0 of Appendix J. The population distribution and weather conditions assumed for the purpose of calculating the health effects approximate those of a site near Oak Ridge, Tennessee. The resultant estimates are displayed in Table 5.1. Only late fatalities are listed since for the range of events considered there were no early deaths. The quantity of radioactivity released is relatively small and widely dispersed such that the dose received by any single person due to acute exposure is far short of the threshold for observing any of the early somatic effects considered.

With regard to property damage, the calculations show that only when 20 fuel assemblies are breached in Events I.2 and I.3 is sufficient contamination released to require interdiction of land and crops and land decontamination. (Events I.2 and I.3 involve the unfiltered release from fuel assemblies ruptured in air in the Cask-Unloading Cell, elevated and ground-level releases, respectively.) Breach of a single fuel assembly does not release sufficient contamination to require such measures. The maximum predicted property damage is $150,000 (in 1974 dollars, based on the economic data for the site and the interdiction and decontamination criteria used in the Reactor Safety Study[5]). This cost is associated with the reduction of radiation dose received by the general population through chronic exposure pathways by taking the protective actions discussed above. Such actions may result in a reduction of the incidence of late fatalities of about 30% from the number expected to occur in their absence.

Table 5.1. Late Fatalities[a]

Event	Single Assembly	Intermediate Release[b]	Maximum Release[c]
Cask Unloading Cell			
Mode 1	5.60×10^{-7}	1.12×10^{-5}	1.12×10^{-5}
Mode 2	5.22	74.1	74.1
Mode 3	4.75	65.4	65.4
Spent Fuel Storage Pool			
Mode 1	3.72×10^{-8}	8.92×10^{-7}	3.72×10^{-5}
Mode 2	3.72×10^{-8}	8.92×10^{-7}	3.72×10^{-5}
Mode 3	4.00×10^{-8}	9.59×10^{-7}	4.0×10^{-5}
Mode 4[d]	3.73×10^{-8}	8.92×10^{-7}	3.72×10^{-5}

[a] Weather conditions for a day in September used. The spent fuel assemblies are assumed to have been out of the reactor for one year.

[b] 20 assemblies for Cask-Unloading Cell Events, 24 assemblies for Spent Fuel Storage Pool events (see Sec. 2.0 of Appendix J).

[c] 20 assemblies for Cask-Unloading Cell Events, 1000 assemblies for Spent Fuel Storage Pool Events (see Sec. 2.0 of Appendix J).

[d] Same as Mode 1 (no late fatalities due to groundwater dispersion).

Short-term evacuation of the local population is not assumed in the above estimate because it was determined that immediate evacuation has an insignificant effect on the consequences of the events treated here. However, the cost of evacuating all of the population within 5 miles of the plant site, and downwind within 25 miles, would total $\$7.8 \times 10^6$ (1974 dollars) if it were undertaken for any of the events studied.

In addition to the above estimates, a calculation was made to determine occupational exposures for each of the reference events. The resulting estimated whole-body doses are less than 1 rem per person and are well below the acute occupational exposure limits currently set.

5.2.2 Storage in At-Reactor (AR) Facilities

5.2.2.1 Aged Spent Fuel Storage Locations

Each of the three basic alternatives for increasing interim spent fuel storage capacity (Chapter 3.0) involves utilization of at-reactor storage pools. Both conventional and compact storage techniques are presently employed at existing nuclear power plants, and present design and construction practices are expected to continue for storage pools at all reactors under construction or in planning. These practices are discussed in detail in Section 3.1 and Appendix B of this statement.

Technical design requirements analogous to those discussed above for AFR facilities are applicable to the storage of spent fuel assemblies at reactor stations. The configuration of the fuel storage pools is essentially the same for all nuclear power plants. There are, however, variations in their respective physical locations at PWRs and BWRs. The PWR system uses a ground-level fuel storage pool that is exterior to the reactor building in the fuel (or auxiliary) building. BWR systems are designed with the fuel storage pool on the reactor operating floor. In most cases the operating floor is elevated in the reactor building above ground level about 90 to 95 feet, while the bottom of the pool is 50 to 55 feet above ground level. This feature necessitates some additional requirements (regarding seismic loading) over those for pools located at ground level. More recent BWR designs provide for ground-level storage pools.

Reactor pools are constructed of reinforced concrete with sufficient thickness to meet radiation shielding and structural requirements. Each pool is lined with stainless steel plates (3/16" to 1/4" thick) welded together to ensure a leaktight system. An estimate of the comparative physical sizes of existing reactor storage pools for a range of reactor sizes and for the two basic types can be inferred from the figures for pool storage capacity given in Table B.1 in Appendix B. These capacities (without compaction) range from 162 assemblies for a 500-MWe PWR to 1160 assemblies for a 1100-MWe BWR.

With regard to the potential environmental effects associated with the successful sabotage of spent fuel stored in AR locations, the same basic considerations as were discussed for AFR locations apply, viz., sabotage events may be radiologically similar to certain spent fuel accident conditions and the effects therefore will be similar. The increased storage of spent fuel at reactors results in the retention of older fuel (greater than one year after discharge) that otherwise would have gone to reprocessing or disposal. Volatile and nonvolatile radionuclides with short half-lives will have decayed, and therefore the radiological and heat load impacts of this older fuel are factors of 10 lower than that of the less-cooled fuel. Just as the environmental and health impacts of spent fuel storage at reactors are dominated by new spent fuel (see Sec. 4.2.2.1), so would be the radiological consequences of successful sabotage at such storage locations. Whether the older fuel is present or has been removed to a location offsite has little impact on the overall hazard to the public posed by potential sabotage. This incremental impact is expected to be on the same order of magnitude as the potential environmental effects analyzed above for AFR storage pools.

5.2.2.2 Protection Measures

Spent fuel at reactor sites is subject to the same physical protection as other vital equipment at the reactor. Requirements for physical security at nuclear power reactors are contained in Section 73.55 of 10 CFR Part 73. The principal features include:

- A physical security organization including armed guards trained and qualified in accordance with specific NRC requirements.
- Physical barriers such that vital equipment is protected by two security barriers.
- Access restrictions to control the movement of personnel, vehicles, and materials.
- Entrance search of personnel, packages, and vehicles for firearms and explosives.
- Intrusion-detection aids, including alarms which must annunciate in continuously manned central and secondary alarm stations.

- A dedicated onsite response force of at least five armed guards.
- Offsite radio communications and liaison with local police.
- A requirement for testing and maintenance of all security-related equipment.
- Contingency plans for dealing with safeguards emergencies.

The safeguards programs at all power reactors currently licensed to operate are implemented to meet the design-basis threat contained in Section 73.55(a) of 10 CFR Part 73. The primary security consideration at such sites is the establishment of an adequate level of protection against acts of sabotage that could lead to the release of the radioactive inventory present in the reactor core or in recently discharged fuel.

5.2.3 Spent Fuel Shipments

Storage options involving (1) increased AFR storage at ISFSIs or (2) storage of spent fuel from one or more reactors at other newer reactors with unused available storage capacity (transshipment between reactors) require additional transportation steps. (Increasing AR compact storage capacity does not in itself involve any additional transportation of spent fuel.) The security-related impacts of increased transportation of aged spent fuel are examined below.

5.2.3.1 Shipment Description

Massive, durable containers (casks) weighing 25 to 100 tons are used for the transport of spent fuel assemblies (by road, rail, or sea). All casks must meet Department of Transportation (DOT) requirements set forth in 49 CFR Part 173 and Nuclear Regulatory Commission (NRC) requirements for fissile material packages and large quantity packages set forth in 10 CFR Part 71.

A typical cask is cylindrical and about 20 feet long. The arrangement of the basic components constituting the cask can be viewed as a series of hollow coaxial cylinders, each of progressively larger diameter. A steel innermost cylinder contains the spent fuel. A coolant such as helium, air, or water is in contact with the spent fuel to aid in heat dissipation. The innermost cylinder is surrounded by a cylinder of dense metal, such as lead, several inches thick. The dense metal cylinder, in turn, is encased in a second steel cylinder. A jacket several inches thick containing hydrogenous material, such as water, surrounds the second steel cylinder. The jacket is encased in an outer steel cylinder. The end members, one of which is removable, are made of steel several inches thick. The end members are often equipped with sacrificial impact limiters to absorb forces involved in impact accidents.

5.2.3.2 Response of Shipments to Sabotage

Although it appears that no sabotage threat to spent fuel shipments exists (Sec. 5.2), the response of the cask and its spent fuel contents to sabotage has been studied for a wide range of sabotage scenarios. The NRC believes that publication of specific details pertaining to the sabotage of certain nuclear activities would be contrary to the public interest. Accordingly, much of the information concerning the techniques for sabotage of spent fuel casks is classified as security information and is withheld from public disclosure.

For the purpose of this unclassified discussion, sabotage scenarios are grouped into three categories: (i) sabotage through mechanical means or deliberate "accident-like" means,

(ii) sabotage through the use of projectiles, and (iii) sabotage through the use of explosives. Successful sabotage would involve breaching the cask in a way that would discharge a portion of the radioactive contents into the environment.

Deliberate acts directed at mechanical breaching of the cask most probably would not be successful owing to cask design and the great difficulties associated with mechanical disassembly:

- Drop tests conducted by Sandia Laboratories using spent fuel shipping casks showed that there would be no releases at impact velocities up to 250 mph onto hard soil (equivalent to a free fall drop of 2000 ft).[6]
- The consequences of dropping a cask into deep water have been considered.[7] It is expected that no radioactive material would be released if a cask were dropped into water of the depths encountered along the route.
- Removing the cask cover would be both difficult and dangerous. The cover is heavy and in practice is removed with the aid of a crane. The removal operation is performed with the entire cask submerged underwater to provide shielding from radiation. In absence of shielding, the radiation emanating from the open end of the cask would be lethal to anyone in the immediate vicinity.
- It is very unlikely that breaching of the cask cavity would be attempted using power tools, burning bars or similar types of equipment. If sections of both the gamma and neutron shielding were removed, the radiation field at working distances would probably be lethal.

Deliberate use of firearms directed at breaching of the cask to release significant radiation probably would not be successful due to cask design. Most small firearms would cause no functional damage to the cask. High-power rifle and machine gun projectiles might penetrate the outer jacket and release a portion or all of the neutron shield water. The external radiation levels under this condition would still be within the regulatory limits for post-accident conditions.

The use of a light antitank weapon against a cask has been considered. The most effective of the light antitank weapons is a rocket-propelled projectile that employs a shaped warhead capable of penetrating several inches of armor. The precise effect of an attack on a cask with an antitank weapon is not known. It is known, however, that the quantity of explosives used in an antitank warhead is less than that which could be used in an explosive attack. Accordingly, it can be safely stated that the worst-case consequences arising from the use of an antitank weapon would be less than those resulting from an explosive attack using a heavy, shaped charge. The consequences of successful explosive attack are discussed in Section 5.2.3.3.

Sabotage through the use of high explosives could likely produce cask penetration. However, the effort required would be extensive. Various sabotage scenarios involving the use of high explosives were considered in a recent NRC-supported study.[8] The study has been issued in draft form and is currently under review by the NRC staff. The study concludes that the only realistic way to attack a spent fuel shipment in order to cause dispersal is with high explosives. The amounts of explosives considered range upward into several hundred pounds and even tons. The explosives configurations discussed include airblast, breaching charges, shaped charges, and platter charges. The details of the response of a cask and its contents to explosive sabotage are not well understood at this time and are under study as explained in the next section. There is, however, general agreement among the study authors and the NRC staff reviewers concerning the following points:

- To breach a cask would require the skillful use of explosives as well as knowledge of cask design parameters.
- Large charges, in the range of many tens to many hundreds of pounds of explosives, would be needed.
- In the more credible scenarios, the saboteur would need to gain and retain control of the transport vehicle in order to place the charge.
- The charges would have to be placed with considerable skill to achieve a release of the radioactive contents, particularly if smaller charges are used.

5.2.3.3 Radiological Consequences of Successful Sabotage

Although it is unlikely that a sabotage threat exists, and although it would require extensive effort to sabotage the cask so as to cause dispersal of radioactive materials, the consequences of such a scenario have been calculated. The calculation begins with the assumption that sabotage is attempted and is successful. The consequences then depend upon a number of factors, including the population density, the fraction of fission products released, the fraction of release that is in respirable form, and the meteorological conditions. Of the radioactive material released, it is the aerosolized, respirable material capable of being deposited in the lung that would likely dominate the health consequences. The data available to aid in estimating the release fraction and the respirable fraction are sparse. Accordingly, there are large uncertainties in the estimates of these quantities. Because of these uncertainties, it is a common practice to assign conservative values (i.e., values that lead to a high level of consequences) to the quantity of material that is postulated to be released in aerosolized and respirable form. The consequences of release from a truck cask containing one spent fuel element have been calculated for a release of 1% of the solids, 1% of the volatiles, and 100% of the gases (all released material assumed to be 100% respirable) for various population densities. The quantities of material postulated to be released and the assumption that all released material would be 100% respirable are believed to be conservative. The results of the calculation are as follows:

Population Density (persons per square mile)	Early Fatalities	Latent Cancer Fatalities
250	0	9
2,000	0	72
10,000	1	362

The fatality figures above are derived from the results of a computer-aided calculation[9,10] in which the following data were used:

- Population density: 2,000 people per square mile
- Number of fuel assemblies: 3
- Release fraction: As specified in the preceding paragraph.
- Time for exposure to contaminated ground: 24 hours

The computer-aided calculation predicted 0.4 early fatality and 217 latent cancer fatalities. The figures shown above were derived from these values by assuming that fatalities would be directly proportional to population density and to the number of fuel assemblies subjected to sabotage.

As was noted in the previous section, the NRC staff has in progress a program designed to provide confirmatory data on the response of spent fuel and spent fuel casks to explosive attack. These data would be used in future consequence calculations to replace values that are now assigned on a conservative basis. This program, however, is not expected to yield useful results before 1980.

5.2.3.4 Protection of Licensed Spent Fuel Shipments

The Commission has issued interim regulations (in 10 CFR Part 73) to strengthen the protection of licensed spent fuel shipments, pending the outcome of the confirmatory research program. The protection requirements include:

- NRC to be notified in advance of spent fuel shipments;
- Route planning (to be approved by the NRC) to avoid where practicable heavily populated areas and the use of additional protection measures, such as armed escorts, in instances where heavily populated areas cannot be avoided;
- Liaison with police forces along the routes;
- Equipping of transports with radio-telephones, CB radios, and immobilization features;
- Use of at least two escorts or drivers specifically trained in physical protection and radiological emergencies;
- Nonstop shipments where possible and special precautions if stops are necessary; and
- The development of response procedures for coping with safeguards emergencies.

These measures are designed to provide additional assurance that response forces can be summoned in a timely manner if needed and to lower further the level of risk.

5.3 SUMMARY OF FINDINGS

Based upon the foregoing analysis, the increased storage of aged spent fuel in AR or AFR storage pools has little relative safeguards significance. This conclusion is a result of the staff's consideration of the following factors:

- The absence of any information confirming an identifiable threat.
- The intrinsic features of plant designs that provide protection against potential releases.
- The protection requirements of the regulations which provide deterrence and a capability for summoning response forces in a timely manner.
- The potential consequences of certain sabotage events involving aged spent fuel.

Regarding shipments of aged spent fuel, after consideration of:

- The difficulty of breaching a spent fuel cask and fragmenting the spent fuel,
- The magnitude of the estimated consequences of successful sabotage,

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- The applicable protection measures, and
- The absence of an identifiable threat to such activities,

the staff has concluded that the shipments do not constitute a serious risk.

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6.0 ECONOMIC ANALYSIS OF ALTERNATIVES

The costs associated with implementation of Alternatives 1-4 (defined in Chapter 3.0) are identified and estimated herein. Alternatives 1-3 involve the development of necessary AFR spent fuel storage without or with interim transshipment between AR storage pools. Alternative 4 assumes termination of spent fuel production (beyond the capacity of AR storage) with the consequent replacement of nuclear power plants by coal fired generation. Cost estimates are generally stated in 1979 dollars.

6.1 STORAGE TECHNOLOGIES

6.1.1 Compact Storage

The costs of examples detailed in Appendix D, "Increasing Fuel Storage Capacity," are estimated in this section. These examples include two operating plants, one PWR and one BWR, and two plants under construction, one PWR and one BWR. The four examples are summarized in Table 6.1. An estimate of the time necessary to implement this alternative is given in Figure 6.1. The current early pool modifications appear to be taking longer than indicated in Figure 6.1, but the times shown are believed to represent an average over a period of several years.

Modifications made to operating plants can be more expensive once fuel is stored in the spent fuel pool. If fuel is stored in the pool, all fuel rack installation work must be performed under water and all equipment removed from the pool must be assumed to be contaminated. This contamination and the necessary decontamination procedures substantially increase the cost of removing old racks and installing new ones in the pool. Whenever possible, it is advantageous to make all modifications to the fuel pool without any spent fuel stored in it.

Where applicable, costs for the following have been included in the cost estimates for each example:

- Fuel rack design and analysis
- Fuel rack fabrication
- Fuel rack installation
- Fuel pool structural analysis and modification
- Fuel pool cooling and filter-demineralizer analysis and modification
- Building ventilation system analysis and modification
- Fuel handling system modifications
- Replacement of equipment storage locations displaced by fuel racks
- Removal, decontamination, and disposal of old spent fuel racks
- Increased in-service inspection or maintenance costs for new racks.

Table 6.1. Summary of Examples Used for Cost Estimates[a]

Case	Plant Type	Plant Size	Storage Spaces		Modification Cost, 1979 Dollars[b]		
			Original	After Modification	Per Additional Space	Cost per Additional MTU Stored[c]	Total Costs
A	PWR operating	Two 1040-MWe units	340	868	3,600	8,000	1,900,000
B	BWR operating	545 MWe	740	2,237	3,700	18,000	5,500,000
C	PWR operating[d]	852 MWe	272	833	3,900	8,700	2,200,000
D	BWR under construction	1103 MWe	1,020	2,658	700	3,400	1,100,000

[a] See Appendix D for more complete descriptions of the plants and modifications.

[b] When necessary, costs were escalated by 7.5% per year to 1979 dollars.

[c] Based on the conversion factors for equating fuel elements to MTU in new fuel as employed in this statement.
BWR: (No. of fuel assemblies) x (0.20) = MTU
PWR: (No. of fuel assemblies) x (0.45) = MTU.

[d] Compaction occurred before any spent fuel was placed in the pool.

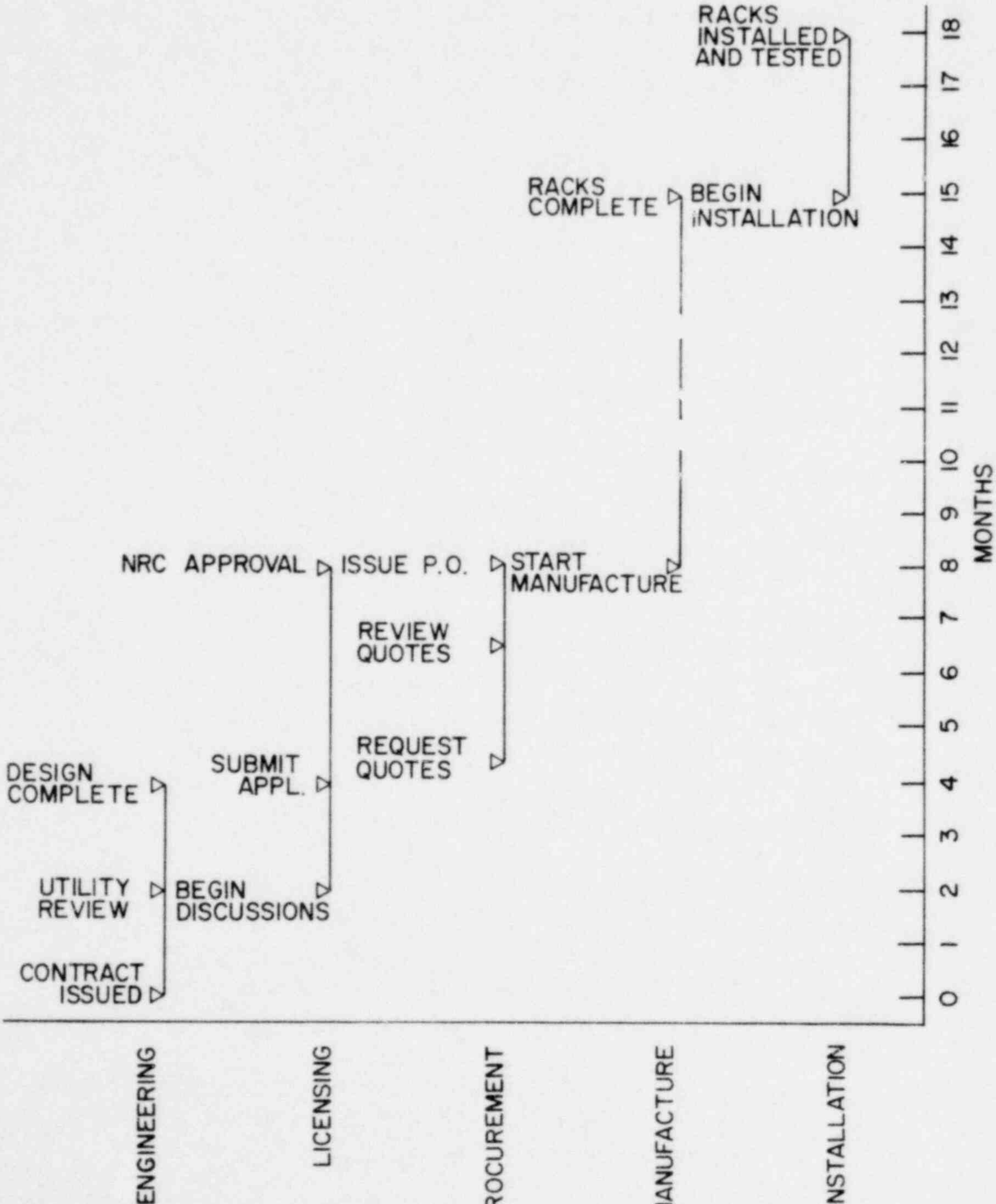

Figure 6.1 Typical Schedule for Existing Pool Modification.

6.1.1.1 Case A--Operating PWR

The plant described in Case A is an operating PWR which has spent fuel stored in its fuel pool. The new rack installed in this plant provides storage space for 868 fuel assemblies.

Due to the basic similarities in design of the old and new racks for Case A, there was no need for modification of the fuel handling systems, and there has been no increase in in-service inspection or maintenance costs. The racks occupy only positions previously used for fuel racks and spare positions intended for fuel racks. No equipment storage racks were displaced by the new racks.

The modifications to this plant resulted in a 155% increase in storage capacity (868 spaces total) at a cost of about \$1.9 million (escalated to 1979 dollars).

6.1.1.2 Case B--Operating BWR

This plant is an operating BWR with spent fuel stored in the fuel pool. The NRC has approved an increase in spent fuel storage capacity for this reactor to 2237 BWR assemblies. The increase in storage capacity is being accomplished through the use of storage racks containing Boral, a neutron-absorbing material. Each storage rack is capable of storing 169 assemblies in a 13 x 13 array. There are presently four of these racks installed. A total of 13 racks are planned. In addition to the storage space provided by these racks, there is room for the storage of 40 more assemblies, resulting in the total of 2237 spaces. When completed, the modifications to this storage pool will result in a 202% increase in storage capacity at an estimated cost of \$5.5 million (escalated to 1979 dollars).

6.1.1.3 Case C--Operating PWR

Storage space at this reactor was compacted soon after operation began but before any spent fuel had been discharged. Thus no decontamination procedures were needed before modification of the storage pool. The new racks are constructed of stainless steel and provide storage for 833 assemblies. This modification resulted in a 206% increase over the storage capacity as originally designed. The total cost was about \$2.2 million (escalated to 1979 dollars).

6.1.1.4 Case D--BWR Under Construction

Case D is a BWR plant that is currently under construction. For this plant it is possible to have the new spent fuel racks installed before the plant commences operation. Since this is being done during construction there is some flexibility in arrangement of the fuel racks and modification to the fuel pool structure.

Spent fuel storage is being increased to 2658 spaces using high-density storage racks containing boron carbide plates. This compaction will allow a 160% increase in storage capacity from that originally planned. The estimated cost is \$1.1 million (1979 dollars).

6.1.1.5 Storage at Existing Reprocessing Plants

Spent fuel storage capacity at fuel reprocessing plants can be increased by similar means to those available for spent fuel pools at existing power plants.

The capital and operating costs that are attributable to spent fuel storage are not readily separable from the costs of other plant functions. However, it is reasonable to assume that the costs will be comparable to those of independent storage facilities. The cost for storage in an independent facility is described in Section 6.1.3.

6.1.2 Expansion of Spent Fuel Storage Pool Volume

Conditions under which expansion of the volume of a spent fuel storage pool, principally at reprocessing plants, might be a reasonable alternative are discussed in Section 3.1.3. In summary, the most important condition is the provision in the original pools for future pool areas to be operationally connected to the original pool complex.

These new storage pool areas can be considered as new installations with some of the support services provided. Therefore, the capital and operating costs of these pools can be expected to be approximately the same as those indicated for the independent facilities discussed in Section 6.1.3.

6.1.3 Storage at Independent Facilities

The cost of storage of spent fuel at independent storage facilities is dependent on plant investment and annual operating costs, which were estimated from conceptual design studies. These costs are dependent on pool storage capacity, specific design features, and staffing requirements to operate and maintain the facility. In addition, the annual cost of storage is dependent on assumed business parameters, which include the form of financing, amortization period, average pool utilization factor, duration of storage between input and output, handling costs, and profit goals.

Several published estimates[1-3] contain projections of such costs. Estimates of investment required range from \$20-\$30 million for 1,000 MTU capacity and from \$30-40 million for 2,000 MTU capacity. Approximately 60 to 90 operating personnel probably would be required. Annual operating costs for a 1,000-MTU facility will be about \$1.3 million. Implementation time is estimated in Figure 6.2.

An alternative concept has been developed by Stone & Webster Engineering Corporation (SWECO)--that of a 500-1500 MTU capacity facility to be located at an existing power reactor site but functionally independently of the reactor complex. Transportation of spent fuel would be minimized by this approach, as would be site qualification difficulties. Some reduction of operating cost might also be expected since the work force could be integrated into that required for reactor operation. A recent rough estimate of construction cost is \$24.4 million (1979 dollars) for a 1400 MTU facility,[4] about \$17,000 per MTU.

A subsequent study has been performed by the Tennessee Valley Authority (TVA) regarding relative costs of a centralized ISFSI at a separate site versus smaller, at-reactor-site ISFSI. Comparative costs based on the mid-point of construction and discounted to 1979 dollars were \$73 million for a 2400 MTHM centralized ISFSI versus a total of \$111 million for three separate ISFSI (700 MTHM each). Inclusion of operation and maintenance and transportation costs in discounted to 1979 dollars (through year 2000) resulted in total costs of \$111 million for the centralized ISFSI versus \$138 million for the three corresponding at-reactor-site ISFSI. The above TVA

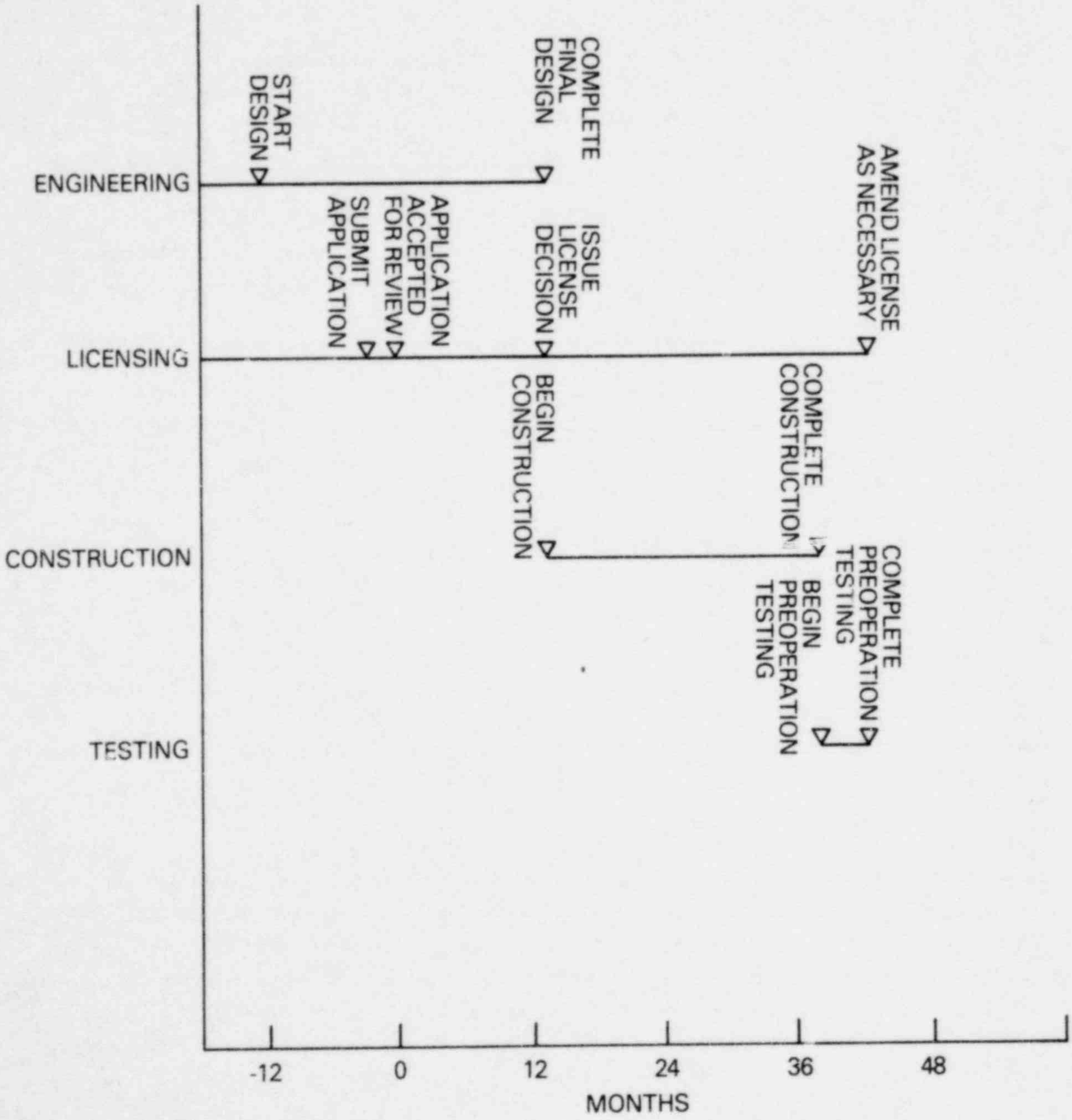

Figure 6.2 Typical Schedule For Wet Or Dry Independent Storage Facility

costs were indicated to be for comparative analysis only and were not intended to represent actual costs.[5]

Another alternative is the storage of spent fuel by the federal government. According to a proposed national policy, the Department of Energy (DOE) would accept spent fuel from commercial reactors for interim storage and later "ultimate disposition" on the basis of a one-time fee. DOE estimates of the capital cost of the needed AFR storage range from about \$22,000 per MTU for expansion of storage at existing (unused) reprocessing plants to about \$60,000 per MTU for a completely new facility (1978 dollars).[6] Each estimate applied to an AFR wet-storage facility of about 5000 MT total storage capacity, which would function as a "centralized" facility, receiving spent fuel from a number of distant power reactors. Using DOE's values for providing such storage total increment in cost of power reactor operation due to the need for AFR spent fuel storage and ultimate disposition can be derived and reflects separately, capital, operation, financing and decommissioning costs for interim AFR storage and also these costs for ultimate disposition in geologic repositories. The DOE preliminary estimates are \$117,000 per MTU for ultimate disposition (in future facilities, not expected to be available until the late 1990s) and \$232,000 per MTU for interim AFR storage followed by ultimate disposition.[6,7] They correspond to about \$3.5 million per year of operation of a 1000-MWe power reactor for disposition alone, and a similar amount for AFR storage (1979 dollars), or about one mill/kWh of electrical output for AFR storage and eventual disposition.

6.1.4 Dry Storage Facilities

6.1.4.1 Canadian Dry Storage

Several methods of dry storage for fuel from Canadian (CANDU) reactors have been evaluated.[8] Although fuel used in Canadian reactors is different than fuel used in the light water reactors in the United States, the same type of dry storage systems should be applicable to both types of fuel. Although the dry storage concept appears feasible for U.S. spent fuel, it has attracted little consideration in this country. The Canadian study suggests that overall costs would be comparable to the water basin approach usually favored in the United States.

6.1.4.2 Dry Caisson Storage

Preliminary cost estimates for the dry caisson storage concept are not publicly available at this time. However, cost savings, relative to construction of additional storage pool capacity, may be attainable.

6.1.4.3 Implementation Time

The time needed to build independent spent fuel storage facilities, wet or dry, can be divided into four partially overlapping steps: design, licensing, construction, and testing. Design initiation can precede the time required for licensing review and issuance but will overlap it. The actual time for a licensing review will be of the order of two years. Construction and preoperational testing will also overlap and require in the order of two to three years. The total implementation time may range from 4 to 6 years.

One standardized design has been submitted to NRC for a pool type independent spent fuel storage facility which would be located on the site of a parent facility, such as a nuclear power plant.

Although capable of independent operation, this facility would use the parent facility for waste treatment and for the supply of electricity and water. Such a facility could have an implementation time of the order of 4 to 5 years.

6.2 COST OF REPLACEMENT POWER

Under Alternative 4 as defined in Section 3.0, some power reactors would be forced to terminate operation because of inability to discharge spent fuel from the core. Such shutdowns would begin in 1980 and increase in number during following years (see Table 3.2). Two types of costs would ensue from the removal from service of a specific nuclear generating plant. As an immediate consequence, power equivalent to that formerly provided by the subject plant would have to be generated by other existing generating plants to ensure availability and reliability, typically at substantially increased fuel costs. In the longer term, equivalent new generating capacity would have to be provided at substantial capital cost. An exception to the preceding condition might occur if there were to be no further increase in consumption of electrical energy, at least for those regions where present generation reserves are relatively ample. However, the possibility of no increase in consumption of electrical energy is unlikely.

Early 1979 steam-electric plant fossil fuel costs in mills/kWh were about 12 for coal and 23 for oil.* The staff estimates nuclear fuel cost under recent contracts at about 9.3 mills/kWh.** Since a 1000-MWe power plant (at the typical capacity factor of ~ 0.6) generates 5.26×10^9 kWh per year, the estimated 2.7 mills/kWH cost difference between coal and nuclear fuel would imply an annual fuel cost increase of about $14 million if 1000 MWe of nuclear capacity were forced to shut down under Alternative 4, and equivalent electrical energy could be supplied by existing coal-fired plants. The annual cost increment would be about $72 million if oil-fired steam-electric plants provided the makeup electrical energy, and $115 million if it were necessary to use oil-fired combustion turbines. These incremental costs may be compared with the interim AFR storage cost increment of about $3.5 million for one year's operation of a 1000-MWe nuclear plant, based on the DOE "one-time charge" estimate.

In the longer term (under Alternative 4), construction of replacement coal-fired plants would almost certainly be necessary. Based on an extensive projection of future nuclear and coal-fired generating plant costs, Table 6.2 gives estimated replacement costs.

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*Based on extrapolation of "Cost of Fossil Fuels Delivered to Steam Electric Utility Plants," as reported in Reference 9.

**Based on nuclear fuel cycle cost projections from Reference 10, Table 11 (No Recycle Case) with "spent fuel disposal" component adjusted to DOE "onetime charge" estimate.

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Table 6.2. Estimated Annual Baseload Generating Plant Costs[a] (in millions of 1979 dollars, for 1000-MWe plant with 1990 first year of operation)

Cost Component	Nuclear	Coal
Fixed cost[b]	121.3	97.9
Operation & maint.	9.3	19.2
Fuel	45.4	81.5
Total	176	199

[a] Based on Table 1 of J. O. Roberts et al., "Coal and Nuclear: A Comparison of the Cost of Generating Baseload Electricity by Region," U.S. Nuclear Regulatory Commission, NUREG-0480, December 1978, averaged over ten regional estimates and de-escalated (at 5% annually) to 1979 dollars.

[b] Interest, depreciation, insurance, and taxes on capital investment.

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9. "Monthly Energy Review," U.S. Dept. of Energy, Energy Information Administration, April 1979. Available in public technical libraries.

10. J. O. Roberts, S. M. Davis, and D. A. Nash, "Coal and Nuclear: A Comparison of the Cost of Generating Baseload Electricity by Region," U.S. Nuclear Regulatory Commission, NUREG-0480, December 1978. Available from National Technical Information Service (NTIS), Springfield, Virginia, 22161.

7.0 EVALUATION

7.1 UNAVOIDABLE ADVERSE ENVIRONMENTAL EFFECTS

This document has identified four possible courses of action for dealing with the shortfall of spent fuel storage capacity through the year 2000. One, the termination case (Alternative 4), does not solve the problem but rather permits LWR-generated electricity to be replaced by coal-produced electricity. The others include the reference case (Alternative 1) and two variations of it (Alternatives 2 and 3) which involve transshipment of spent fuel from one reactor site to storage at another reactor site. These alternatives solve the problem by providing for additional spent fuel storage through compact storage at reactor storage pools and away-from-reactor (AFR) storage capacity. Each of these courses of action results in some unavoidable adverse environmental impact, although qualitatively and quantitatively the impacts are quite different.

7.1.1 Abiotic Effects

7.1.1.1 Land

The effect of taking no positive action to forestall the shortage of spent fuel storage capacity will lead to de facto derating of present nuclear reactor facilities and reduced electrical output. This process of itself neither increases nor decreases land use. For replacement of nuclear capacity, coal is the most likely choice, and for each new coal plant new space must be provided near the transmission network, possibly at the site of the nuclear station being replaced. Table 4.1 shows the approximate land areas required for nuclear and coal fired plants. As many as 112 1,000-MWe coal fired plants may be needed through year 2000, requiring new land for the plant, transport facilities for fuel and storage area for fuel and waste. One such plant may require about 300 acres, which may be added to the area already disturbed by the nuclear site. New transmission corridors might be avoided by proper siting of replacement plants. Finally, mining of the 220 to 250 million tons of coal required annually will cause significant land disturbance, though not usually in the power plant region.

Creation of independent spent fuel storage facilities, expansion of onsite holding pools, and dry storage involve some new use of land. The first two involve construction and dedication of small amounts of land for an indefinite time period. Dry storage might require larger amounts of space, depending on the means of implementation. Areas used for these two purposes would probably be chosen, in part, for lack of other usefulness.

7.1.1.2 Water

In the termination case, reduced generation would cause a decrease in the use of cooling and process water at nuclear power stations. Some water is required for residual heat removal in cold shutdown, but makeup water requirements and thermal discharges would be a small fraction of those requirements during power operation. Replacement of some or all of this power is to be expected. Organized replacement of the electrical capacity using coal fired plants would produce water demands similar to those currently encountered as thermal discharge requirements are less for coal plants of a given megawatt rating, but other uses of water in waste treatment and fuel preparation may balance relative consumption. Land disturbance may result in some loss of water quality due to runoff.

Other alternatives do not entail significant new incremental impacts on water use over those for normal power operations.

7.1.1.3 Air

Any strategy which involves construction will result in release of air pollutants such as dust and vehicle emissions.

Mining, transport and burning of coal produce airborne particulates and contaminants, and release of these contaminants would increase if fossil fuels were used more extensively to replace nuclear plants. Health effects from these effluents are shown in Chapter 4.0.

7.1.1.4 Noise

Any construction activity associated with implementation of an alternative will probably add to noise levels in local regions. This aspect is difficult to assess without the more specific details which become available when implementation is actually in planning stages. However, traffic to and from coal stations would add considerably to noise levels; at least one large trainload of fuel would be required daily at the coal fired plant.

7.1.1.5 Esthetics

The alternatives considered generally do not change the present state of esthetic quality, or lack of quality, in regions affected by power plants and spent fuel storage shortage. Independent storage facilities and dry storage will result in new surface structures which may occasion displeasure to viewers, but this depends to a great extent on choice of location. New fossil fired stations serving demand vacated by shut down nuclear plants would provide major additional visual intrusions; these would include tall stacks, coal storage piles and coal handling equipment and structures as well as heavy rail and truck traffic.

7.1.2 Biotic Effects

Compact storage at reactors should have little incremental impact on biota, while activities requiring new structures and concomitant construction activity inevitably disturb flora and fauna at a site. Large impacts to aquatic habitats, either through construction or use of water, are not expected from either course of action.

Coal extraction to supply coal fired plant replacements for nuclear plants would surely disturb large habitats.

Total excess mortality associated with the operation of a 1,000-MWe nuclear power plant for one year is estimated to be about 0.59 to 1.7. This includes the following components of the fuel cycle: resource recovery, processing, power generation, fuel storage, transportation, reprocessing and waste management (see Sec. 4.2.1). Similarly, the operation of a coal-fired plant of the same capacity is estimated to cause an excess mortality of about 15 to 120 due to resource recovery, processing, power generation, fuel storage, transportation and waste management (see Sec. 4.2.5).

7.1.3 Radiological Effects

Upper bounds for annual incremental population and occupational exposures associated with spent fuel storage are presented in Table 4.3 of this statement. As discussed in Section 4.2.1, there are no major differences in the doses associated with any of the storage techniques considered. U.S. population dose associated with spent fuel storage modes would be for the critical organ, skin, 350 person-rem/yr in year 2000. This is less than 0.002% of the annual U.S. population dose from natural background sources of about 26 x 10^6 person-rem per year.

Radioactive particulates may be expected to be emitted to the atmosphere from coal-fired plants. In some cases, the total quantity of radioactive substances released in the stack effluent of a coal-fired boiler may exceed that normally released by a nuclear reactor (see Sec. 4.1.2.2).

7.2 RELATIONSHIP BETWEEN LOCAL SHORT-TERM USES OF MAN'S ENVIRONMENT AND LONG-TERM PRODUCTIVITY

7.2.1 Scope

The National Environmental Policy Act (NEPA) requires specific consideration of the extent to which the exercise of proposed alternatives involves trade-offs between short-term environmental gains at the expense of long-term losses of productivity, or vice versa, and of the extent to which they foreclose future options. "Short-term" is typically taken to mean approximately the period of construction and operation. For the purposes of this document, it will be defined as one to two decades.

Resources which might be otherwise committed to long-term productivity are immobilized as long as spent fuel storage continues. It should be recalled that most thermal power generation methods provide large long-term economic benefits, while they also entail some inescapable drain on long-term productivity. The staff concludes that the negative aspects of continued nuclear power generation are outweighed by positive long-term effects.

7.2.2 Enhancement of Short-Term Productivity

The alternatives which allow for continued generation of electricity on demand by nuclear power plants clearly enhance short-term productivity. Conversely, diminution of electrical supply and resulting economic insecurity in a region are destructive to short-term productivity. Use of either coal or nuclear electric generating units assures a stable supply of electricity.

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The long-term environment will be strongly influenced by generation of electrical power, which creates considerable waste heat and byproducts, and depletes non-renewable resources. Alternatives which allow nuclear power generation continue, though probably do not increase, the level of long-term environmental degradation currently accepted by society for short-term enhancement of productivity. Replacement of nuclear power with coal-fired units will be more inimical to the long-term environmental quality.[1]

7.2.3 Uses Adverse to Long-Term Productivity

It has been concluded in most cases that short-term environmental effects of nuclear power plants are acceptable given their contribution to the immediate and long-term productivity of a region. Maintenance of a technical framework in which productivity is assured in the future is important, and nuclear power plants represent an option critical to national productivity over the long-term. The same might be said for fossil-fueled generating capability which, according to alternatives outlined, would probably replace shut down nuclear facilities given limiting shortages of storage space. In a sense, the only real options are to continue generating electricity from plant sites by one means or the other.

7.2.4 Effect of Alternatives on Future Options

Both courses of action result in the use of resources. The level of commitment implied through the year 2000 should not result in loss of future options except to the extent that resources are used.

7.3 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

7.3.1 Introduction

Irreversible commitments generally concern changes set in motion by the proposed action which at some later time could not be altered so as to restore the present environmental conditions. Irretrievable commitments are generally the use or consumption of resources that are neither renewable nor recoverable for subsequent use.

Commitments inherent in environmental impacts are identified in this section, whereas the main discussions of the impacts are in Chapter 4.0 and commitments that involve local, long-term effects on productivity are discussed in Section 7.2.

7.3.2 Commitments Considered

The types of resources of concern in this case can be identified as material resources, including materials of construction, renewable resource materials consumed in operation, and non-renewable resources consumed, and nonmaterial resources, including a range of beneficial uses of the environment.

Resources considered which may be irreversibly or irretrievably committed are:

- Biological resources destroyed in the vicinity,

- Construction materials that cannot be recovered and recycled with present technology,
- Materials that are rendered radioactive but cannot be decontaminated,
- Materials consumed or reduced to unrecoverable forms of waste,
- The atmosphere and water bodies used for disposal of heat and certain waste effluents, to the extent that other beneficial uses are curtailed, and
- Land areas rendered unfit for other uses. Those of importance to this project are discussed in the following sections.

7.3.3 Biotic Resources

Construction involved with implementing alternatives will result in marked effects on onsite biota and disturbance of some of the biota adjacent to a site. Some lands occupied by present or future structures utilized in connection with interim spent fuel storage will be permanently altered. While complete restoration of this land might be possible, it is believed that the considerable difficulties that would be encountered make this possibility unlikely. Therefore, the above uses can be essentially considered as irreversible or irretrievable commitments. This is especially true for alternatives requiring that spent nuclear fuel, or a derivative, be stored for many years.

In most areas under consideration, with the nominal land requirements of most alternatives in mind, it is thought that the reproductive potential of most species is sufficiently high that losses as a result of the implementation and operation of alternatives will not have a long-term effect on population stability and structure of local ecosystems. The alternatives requiring massive new uses of coal or other fossil fuels are a possible exception: major construction, fuel and waste storage, fuel transport, and possibly new transmission corridors may introduce large new commitments of resources which are irreversible.

7.3.4 Material Resources

7.3.4.1 Materials of Construction

Alternatives requiring new construction would result in use of materials almost entirely of the depletable category. Concrete and steel constitute the bulk of these materials, but numerous other mineral resources are often incorporated. It is not certain whether these materials will be recycled when their use terminates. Replacement of existing nuclear capacity would obligate a quantity of depletable materials that are basic in nature (e.g., concrete and steel) and which are already committed to use for power plants.

There will be a long period of time before terminal disposition of construction materials must be decided. At that time, quantities of materials in the categories of precious metals, strategic and critical materials, or resources having small natural reserves must be considered individually, and plans to recover and recycle as much of these valuable depletable resources as is practicable will depend on need.

7.3.4.2 Replaceable Components and Consumable Materials

Continued generation of power, either by nuclear means or by means of fossil fuels, entails irretrievable consumption of energy resources. Other reactor components consumed are fuel cladding, reactor control elements, replaceable core components, process chemicals and minor quantities of materials used in maintenance and operation. Fossil-fueled plants require analogous replacements since degradation occurs from high temperatures and other corrosive conditions. Most spent fuel storage alternatives do not differ greatly as to replaceable components.

7.3.5 Land Resources

Most of the land required for nuclear power plants is or will be committed for the period under consideration in this document. If fossil plants replace nuclear plants, reduced generation by nuclear plants would result in increased requirements for land. Alternatives such as independent storage facilities or dry storage would have their own land requirements equivalent to or less than that dedicated for a typical power station. The options presented require little additional land use. In general, land commitment is potentially reversible except for that occupied by the reactor building, an area which undergoes considerable stress during operation and may require isolation for many years after shutdown. Other land, in any sort of power station, is probably retrievable. The amount of commitment is a function of the level of decommissioning chosen. At the onset of any construction, use of dedicated land areas for recreational or other public uses will cease for the life of a facility.

7.4 BENEFIT-COST ANALYSIS OF ALTERNATIVE COURSES OF ACTION

7.4.1 Purpose and Nature of the Analysis

The benefit-cost analysis is intended to provide an orderly and objective basis for decisions by the Commission as to the need for further consideration of the matters treated in this Statement and the possible need for new regulatory actions related to the storage of spent nuclear fuel.

7.4.1.1 Revisions

This section has been substantially revised from that which appeared in the draft statement (DGEIS) in order to recognize the substantial changes in circumstances which have occurred since the DGEIS was prepared. The major changed circumstances are the following:

1. A Federal spent fuel storage and disposal policy has been proposed and the Department of Energy (DOE) has published related cost estimates.

2. The Commission has found it compatible with its responsibility for the public health and safety to amend a number of power reactor operating licenses to permit

storage pool modifications which have substantially increased the storage capacities. Such modifications have been proposed (or completed after Commission approval) for most of the power reactors now operating or under construction.

3. The relevant economic costs have escalated markedly from the reference year 1976 used in the DGEIS to the updated 1979 estimates appearing below and in Chapter 6.

The elements of the treatment here have been substantially revised in response to the changed circumstances but the point of view embodied in the analysis is unchanged. The major revisions are the following:

- The economic cost of spent fuel storage and ultimate disposition associated with continued power reactor operation is now estimated entirely on the basis of published DOE estimates. This is a "worst case" estimate, for reasons discussed in the text.

- The Reference Case and the Termination Case (Alternative 4) are compared. The Reference Case assumes compact storage at reactor pools with no transshipment and with maintenance of full core reserve (FCR) as did the "reference" case of the DGEIS, but Alternative 4, the Termination Case, differs from the "termination" case of the DGEIS in that AR storage capacity is assumed to have been increased by modification. This change affects the timing, rather than the nature of the cost.

- The discussion of the possibility that replacement of "terminated" power reactors would not be required has been updated and modified.

7.4.1.2 Scope

There are no benefits to be considered in the analysis of spent fuel storage other than the already realized one of electrical energy production from the nuclear power plants considered. The alternative courses of action, which would permit continuation of nuclear generated electricity or would replace it with coal fired power, would have associated environmental costs which are compared here.

The power reactors for which storage of spent fuel might demand special consideration during the next decade were licensed under post-NEPA regulations which require a benefit-cost analysis for each. Each such analysis balanced the expected electrical energy production of the proposed plant against all of the expected economic and environmental costs associated with both the construction and operation of the plant. Since the benefit-cost analysis for each plant either has or will have withstood the successive tests inherent in the Commission's procedures, it would be unproductive to reconsider the same benefits and costs collectively for these plants.

7.4.1.3 Courses of Action

The potential problem addressed by this environmental statement is simply described. The operation of nuclear power plants to provide their desired product--electrical energy--produces spent fuel. Interim storage for spent fuel has been provided for each nuclear plant but the original design storage capacity has been typically adequate for only a few years' operation, since it was originally expected that spent fuel assemblies would be shipped to a reprocessing plant within six months to a year after removal from the reactor. The decision to defer reprocessing indefinitely resulted in an unanticipated accumulation of spent fuel in reactor storage pools. This threatened to fill each pool to capacity at plants either existing or under construction if no action were taken. At that point, further refueling would be impossible and nuclear power generation would necessarily cease. The problem has been mitigated during the last few years by modification of the storage pools at some power reactors, and it is likely that nearly all storage pools will be modified.

A set of four alternative courses of action has been defined in Section 3.0, each of which assumes the estimated maximum reasonable increase in AR storage by pool modification. The limiting alternatives are Alternative 1, in which no transfer of spent fuel from one AR site to another occurs but sufficient AFR storage capacity is assumed available so that all power reactors are able to continue operation, and Alternative 4, the Termination Case, in which no AFR capacity and no transshipment are assumed. Under the Termination Case, operation of a few power reactors is terminated in the early 1980s by inability to discharge spent fuel, the number of terminated reactors increasing with time as more and more AR facilities are filled (see Table 3.2). Under Alternatives 2 and 3, transfer of spent fuel among AR facilities is permitted, either within each utility system (Alternative 2) or generally (Alternative 3). Such transshipment tends to defer the need for AFR facilities.

"Ultimate disposition" for spent fuel is assumed to become available in the year 2000, at the end of the period considered in this statement. Earlier availability could reduce the need for AFR storage, of course, since spent fuel could be shipped directly to a disposition site without interim AFR storage.

For benefit-cost analysis, it suffices to consider the Reference Case of Alternative 1 and Alternative 4 since these pose the maximum costs for continued operation of nuclear plants or early termination of operation, respectively. The incremental costs (economic and environmental) associated with Reference Case are those associated with the additional spent fuel produced. They include the costs due to shipping of spent fuel, first to an AFR storage facility and second to ultimate disposition, as well as the costs incurred by construction and operation of the AFR storage and of the ultimate disposition facility. The incremental costs associated with Alternative 4 are those due to the construction and operation of replacement generation capacity for the nuclear capacity assumed to be rendered inoperable under this alternative.

The analysis herein assumes that replacement of lost nuclear generating capacity (under Alternative 4) by equivalent baseload generating plants (coal-fired steam) would be necessary. That assumption would be in error if a chronic surplus of such capacity were to develop in the future, a contingency which the staff believes to be very improbable. Historically, U.S. consumption of electrical energy has increased rather steadily for more than 60 years, although absence of growth or small declines in annual use have occurred in years of sharp economic recession (1930-33, 1937, 1974) and at the end of World War II.

The rate of growth of electrical energy use seems to have declined in recent years. The five-year increase in annual kWh used in the United States was 18.7% from 1973 to 1978, against 41.4% from 1968 to 1973.[2,3] It is probable that the long-term rate of growth will continue to decline slowly in the future because of increasing real cost of electrical energy, reduced economic and population growth, and increased emphasis on conservation of all forms of energy. However, a significant national surplus of generating capacity for a considerable period could arise only if electrical energy consumption declined substantially or unexpectedly failed to increase for many years. (In the latter case, already-committed plants under construction might be completed during the first five "no-growth" years, resulting in some surplus capacity.) The staff has been unable to identify any reason to expect either train of circumstances.

Moreover, of the order of one GWe of very old generating capacity may be expected to be retired from service each year,[2] and about 40% of fossil-fueled generation in 1978 depended on oil (22.2%) and natural gas (18.6%).[3] It appears likely that both national policy and economic considerations would tend to force any "surplus" of nuclear- and/or coal-fueled capacity to be employed for reduction of oil and natural gas consumption by utilities.

7.4.1.4 General Approach to the Benefit-Cost Analysis of Alternatives

The analysis to be presented in Section 7.4.2 is essentially the comparison of the estimated environmental and economic costs for each of the course of action alternatives, guided by the following principles.

- Environmental and economic costs are generally compared separately. That is, no attempt is made to monetize environmental costs in order to facilitate balancing them against economic costs.* This choice is made because of the inevitably subjective and controversial character of attempted monetization of environmental costs.

- Course-of-action alternatives are compared on the basis of a single "typical" means to implementation for each in Section 7.4.2. The validity of the choice of "typical" implementation is then tested by a comparison of implementation alternatives in Section 7.4.3.

- Environmental costs are generally estimated on the basis that actual construction and operation of the physical facilities implied by implementation of each alternative (e.g., replacement of coal-fired plants under continuation of present practice) would be carried out in such a manner as to minimize environmental costs. This assumption is supported by the existence of substantial state and Federal regulatory efforts addressed to control and reduction of environmental impacts and by the vigorous "watch-dog" activities of a number of environmentally-concerned public organizations.

7.4.2 Cost Comparison of Alternatives

The objective in this section is to compare the incremental economic costs of the Reference Case and Alternative 4 in an even-handed way. A reasonable approach is to consider a nuclear plant at the stage where AR spent fuel storage has all been used. Under Alternative 4, operation of the plant would be terminated. All of the costs associated with prior operation of the plant, construction cost, cost of future decommissioning, cost of ultimate disposition of existing spent fuel, etc., would have been incurred already. The incremental cost of operation for one more year, say, under Reference Case would be the cost of the nuclear fuel consumed (including cost of ultimate disposition), the "normal" operating and maintenance cost (less the corresponding cost for a shutdown plant), and the cost of AFR storage for the additional spent fuel produced. The benefit resulting would be the generation of a substantial amount of electrical energy, 5.3 billion kWh for a 1000-MWe plant at 0.6 capacity factor.

Under Alternative 4, the Termination Case, generation of the same amount of electrical energy would require a replacement plant, assumed to be coal fired in order to have a definite basis for estimates. Since the replacement plant would not otherwise be needed (during the year considered), the incremental cost of its operation would include a pro-rata fraction of construction cost (i.e., interest, depreciation, and taxes due to the construction investment). That is, the incremental cost under Alternative 4 would be the "total cost of generation" for one year of such a plant. The resulting benefit would be the same as under the Reference Case.

The estimated incremental economic costs associated with the two alternatives are summarized in Table 7.1. The costs for Alternative 4 are about three times greater than for Reference Case, primarily because of the large incremental fixed cost (pro-rata construction cost) required for the replacement plant. Because the replacement plant construction cost dominates the comparison, no reasonable change in other cost-component estimates could change the sense, nor much weaken the force, of the comparison. At the same time, it is noteworthy that the estimated incremental fuel cost alone under Alternative 4 is much larger than the estimated cost for AFR storage under the Reference Case.

Table 7.1. Incremental Costs (millions of 1979 dollars) for One-Year Operation of a 1000-MWe Generating Plant[a]

Reference Case		Termination Case	
Nuclear fuel[b]	47	Fixed cost[e]	98
Operation & maint.[c]	19	Fuel	81
AFR storage[d]	3	Operation & maint.	19
Total	69	Total	198

[a] Based on Table 6.2 except as noted.

[b] Nuclear fuel cost estimate increased by N$2 million to reflect DOE spent fuel disposal estimate.

[c] Increased to match coal-fired operation and maintenance estimate in response to utility comments on draft statement.

[d] DOE "one-time charge" estimate.

[e] Interest, depreciation, and taxes on construction cost.

Alternatives 2 and 3 (with FRC as in the Reference Case) would permit many GW-years of continued nuclear plant operation with transshipment cost (which is only a fraction of AFR cost) substituted for AFR cost, although some AFR cost would eventually occur. These alternatives therefore would be slightly less costly than Reference Case. It follows that Alternatives 1, 2, and 3 (with FCR) are each greatly preferable to Alternative 4 with respect to economic cost.

7.4.3 Conclusions

7.4.3.1 Environmental Costs

According to Chapter 4 and Section 7.1, the principal unavoidable adverse environmental impacts associated with the Reference Case and Alternative 4, the Termination Case, are land use for both construction and mining, a complex of (generally modest) impacts associated with construction of new facilities, and the overall impact on public health due to occupational accidents and both public and occupational exposure to pollutants (including radiation). As evaluated in Chapter 4, these environmental costs are summarized in Table 7.2 on a unit basis, i.e. for one year's operation of a 1000-MWe power plant.

Table 7.2. Estimated Environmental Costs for One-Year Operation of 1000-MWe Generating Plant

	Magnitude	
Type of Impact	Reference Case (nuclear with AFR)	Alternative 4 (coal-fired)
Disturbed land (acres):		
New construction	< 0.1	~30
Mining	~ 60	~90
General construction impacts[a]	~0.5	~30
Mortality	~1	~40

[a] In arbitrary units, assumed to be proportional to construction cost.

Based on Table 7.2, the environmental costs associated with the Reference Case are substantially less than those associated with Alternative 4, mainly because the Reference Case involves comparatively little construction and because of the relatively high mortality rate for the coal/electricity cycle.

7.4.3.2 Economic Costs

As shown in Table 7.1 and discussed in Section 7.4.2, the economic costs expected for the Reference Case are much smaller than estimated for the Termination Case. The unit difference in cost is estimated as about $130 million (1979 dollars) per year of operation of a 1000-MWe generating plant, about 2.5 cents/kWh.

7.4.3.3 Overall Cost Comparison

Both environmental and economic cost comparisons clearly favor the Reference Case over the Termination Case. Alternatives 2 and 3 (with FCR) are estimated to have somewhat lower economic costs than the Reference Case and comparable environmental cost, so that each also appears superior to the Termination Case.

References

1. U.S. Nuclear Regulatory Commission, "Final Environmental Statement Related to Construction of Tyrone Energy Park," USNRC Report NUREG-0226, Docket No. STN 50-484, April 1977. Available from National Technical Information Service (NTIS), Springfield, Virginia, 22161.

2. Edison Electric Institute, "Statistical Yearbook of the Electric Utility Industry, 1977," published October 1978. Available in public technical libraries.

3. "Monthly Energy Review," U.S. Dept. of Energy, Energy Information Administration, April 1979. Available in public technical libraries.

8.0 FINDINGS

1. The lack of sufficient spent fuel storage capacity at nuclear power plants has been alleviated by ongoing and planned modifications of at-reactor spent fuel storage pools. Modifications of at-reactor spent fuel storage pools by redesigning fuel racks and making more efficient use of available pool floor space can increase spent fuel storage capacity, on the average, by a factor of 3.0.

   As of January 1979, NRC had received applications for modifications of spent fuel storage plans at 65 power reactors. Forty applications have been approved to date.

2. Licensing reviews of these applications have shown that the modifications are technically and economically feasible and justified. Licensing of these actions is adequately covered by existing regulations and established regulatory practices. This statement supports the finding that increasing the capacities of individual spent fuel storage pools is environmentally acceptable.

   Because there are many variations in storage pool designs and limitations caused by spent fuel already in some pools, the licensing reviews must be done on a case-by-case basis. Modifications in the Technical Specifications applicable to the reactor plant involved, covering safety considerations both during the construction phase of the proposed modifications and subsequent operations, are made where necessary.

3. Table 3.1 contains upper bound requirements for AFR storage with compact storage of spent fuel at reactor pools. The reference case selected for this study is the upper bound storage capacity considering compact storage of fuel in reactor pools that has negligible environmental impact and no transshipment to offsite reactor pools. The AFR storage requirements assume that the FCR option will be selected by plant owners for operational reasons. The timing and magnitude of the AFR spent fuel storage requirements* are as follows:

Year	MTHM
1980	40
1985	1,900
1990	6,300
1995	14,000
2000	27,000

   Assuming that the national objective of an operational geologic repository for high-level nuclear wastes and possible disposal of spent fuel is attained by or before year 2000, the amount of spent fuel requiring away-from-reactor storage is not great. No more than six storage pool installations of 5000-MTHM size would be required by the year 2000. However, the effect of the announcement by the U.S. Department of Energy (DOE) of a proposed Spent

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*These include the effect of the recent reactor basin storage capacity expansion applications for the Oconee 1 & 2 basin, for the Big Rock Point basin, and for the Hatch 1 & 2 basins.

Fuel Policy on October 18, 1977, has been to discourage private construction of AFR storage capacity since the announcement of such policy. It takes several years to license and construct new AFR capacity--about five years if new construction on a separate site is involved. The time needed to provide the required AFR storage capacity has become short. Consequently, unless some use is made of existing licensed AFR storage capacity in combination with intrautility transshipment, it is possible that individual reactor shutdowns due to shortfalls in spent fuel storage capacity at reactor storage pools will occur.

4. The storage of LWR spent fuels in water pools has an insigificant impact on the environment, whether at AR or at AFR sites. Primarily this is because the physical form of the material, sintered ceramic oxide fuel pellets hermetically sealed in Zircaloy cladding tubes. Zircaloy is a zirconium-tin alloy which was developed for nuclear power applications because of its high resistance to water corrosion in addition to its favorable nuclear properties. Even in cases when defective tubes expose the fuel material to the water environment, there is little attack on the ceramic fuel.

   The technology of water pool storage is well developed; radioactivity levels are routinely maintained at about 5×10^{-4} µCi/ml. Maintenance of this purity requires treatment (filtration and ion exchange) of the pool water. Radioactive waste that is generated is readily confined and represents little potential hazard to the health and safety of the public.

   There may be small quantities of ^{85}Kr released to the environment from defective fuel elements. However, for the fuel involved (fuel at least one year after discharge), experience has shown this to be not detectable beyond the immediate environs of a storage pool.

   There will be no significant discharge of radioactive liquid effluents from a spent fuel storage operation as wastes will be in solid form.

   This statement supports the finding that the storage of spent fuel in away-from-reactor facilities is economically and environmentally acceptable.

5. There is an increasing need for away-from-reactor spent fuel storage starting in the early to mid-1980's. This is primarily due to the older nuclear power plants where there is a limited capability for the expansion of their spent fuel storage capacity. Based on the experience to date with underwater storage, the construction and operation of "storage only" facilities is assessed to be both technically feasible and environmentally acceptable.

   The use of alternative dry passive storage techniques for aged fuel, now being investigated by the Department of Energy, appears to be equally feasible and environmentally acceptable.

6. Two existing "storage only" facilities are now licensed. One, the NFS West Valley plant under 10 CFR Part 50, and the GE Morris plant, under 10 CFR Part 70. However, neither of these regulations addresses the specific requirements of a spent fuel "storage only" type of facility. There is a recognized need for a more definitive regulatory basis for the licensing of future facilities of this type. Action is now underway to meet this need. The proposed 10 CFR Part 72, "Storage of Spent Fuel in an Independent Spent Fuel Storage

Installation," has been issued for comment. Supporting regulatory guides are also in preparation.

7. Curtailment of the generation of spent fuel by ceasing the operation of existing nuclear power plants when their spent fuel pools become filled is found to be undesirable, and the prohibition of construction of new nuclear plants is not necessary. As shown in this statement, viable measures can be instituted to alleviate the spent fuel storage capacity shortfall. Such measures are economically and environmentally preferable to replacing nuclear generated power with coal fired power plants. The societal costs would also be significant as the excess mortality rates and environmental impacts of coal fired power generation are much higher than those for nuclear power.

8. No modification of 10 CFR 51.20(e) (the summary of environmental considerations for the uranium fuel cycle) appears necessary for spent fuel storage considerations.

9.0 DISCUSSION OF COMMENTS RECEIVED ON THE DRAFT ENVIRONMENTAL STATEMENT

Pursuant to 10 CFR Part 51, the "Draft Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel" was transmitted, with a request for comments, to:

Advisory Council on Historic Preservation
Arms Control and Disarmament Agency
Department of Agriculture
Department of the Army, Corps of Engineers
Department of Commerce
Department of Health, Education and Welfare
Department of Housing and Urban Development
Department of the Interior
Department of State
Department of Transportation
Department of Energy
Environmental Protection Agency

In addition, the NRC requested comments on the draft environmental statement from interested persons by a notice published in the FEDERAL REGISTER on March 24, 1978, (43 FR 12402). In response to the requests referred to above, comments were received from the following (letters in parentheses are codes keyed to comments and responses):*

State of Indiana, State Board of Health
Eugene N. Cramer (A)
State of New Jersey, Department of Community Affairs
Texas Energy Advisory Council (B)
Mississippi State Clearinghouse for Federal Programs
Lt. Col. Emil G. Garrett (RET) (C)
State of Utah, State Planning Coordinator
State of Louisiana, Department of Urban and Community Affairs
State of Iowa, Office for Planning and Programming
State of North Carolina, Utilities Commission (D)
State of West Virginia, Office of Economic and Community Development (E)
North Dakota State Planning Division
South Dakota State Planning Bureau (Commissioner)
South Dakota State Planning Bureau (Executive Director)

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*In some cases where no specific responses to a letter of comment were deemed necessary by the staff, no code letter has been assigned.

South Dakota Fourth Planning and Development District (G)
State of Kansas, Department of Administration (F)
U.S. Department of Commerce (H)
U.S. Department of the Interior (I)
Wisconsin Electric Power Company (K)
State of North Carolina, Department of Administration
State of Texas, Budget and Planning Office (N)
Portland General Electric Company (L)
Detroit Edison (J)
General Electric Company (M)
State of Colorado, Department of Local Affairs
Gulf States Utilities Company (O)
State of New Mexico, Department of Finance and Administration (P)
Babcock & Wilcox (Q)
GPU Service Corporation (R)
State of Oregon, Intergovernmental Relations Division (S)
State of Ohio, Environmental Protection Agency (T)
U.S. Department of Health, Education and Welfare (U)
Commonwealth of Virginia, Council on Environment (V)
Environmental Coalition on Nuclear Power (Y)
State of Nevada, Office of Planning Coordination (W)
State of California, The Resources Agency of California (X)
State of Illinois, Bureau of the Budget (Z)
State of Missouri, Office of Administration
State of Texas, Budget and Planning Office [Railroad Commission comments] (AA)
Environmental Coalition on Nuclear Power [additional comments] (Y)
State of Alaska, Sta[illegible]learinghouse
Southwest Research and Information Center (AB)
Virginia Electric & Power Company (AC)
University of Kentucky (AV)
Commonwealth of Puerto Rico, Department of Natural Resources
Arizona State Clearinghouse (AD)
Commonwealth of Massachusetts, Energy Facilities Siting Council (AE)
Allied-General Nuclear Services (AG)
Tennessee Valley Authority (AF)
Kaman Sciences Corporation (AH)
Atomic Industrial Forum, Inc. (AI)
Georgia Power (AJ)
Natural Resources Defense Council, Inc. (AK)
Yankee Atomic Electric Company [UWMG] (AL)
U.S. Department of Energy (AM)
Power Authority of the State of New York (AN)
Yankee Atomic Electric Company (AO)
Commonwealth Edison (AP)
State of Illinois, Attorney General (AQ)
State of Wyoming (AW)
State of New York, Department of Environmental Conservation (AR)

State of Oregon, Department of Energy and Energy Facility Siting Council (AZ)
State of California, The Resources Agency of California (AT)
State of California, Office of Planning and Research (AS)
W. Bonmia (AX)
State of Illinois, Attorney General [corrected comments] (AQ)
U.S. Environmental Protection Agency (AU)
Duke Power Company (AY)
State of Alabama, Alabama Development Office
Boston Edison Company (AAA)
Institut fur Metallurgie (AAB)
State of Pennsylvania, Pennsylvania State Clearinghouse
Natural Resources Defense Council, Inc. (supplements to comments)

The letters of comment are reproduced in their entirety in Chapter 1 of Volume 3. The staff's consideration of the comments received and its disposition of the issues involved are reflected in part by revised text in the pertinent sections of this final environmental statement and in part by the responses presented in Chapter 2 of Volume 3.

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The Generic Environmental Impact Statement on spent fuel storage was prepared by the Nuclear Regulatory Commission staff in response to a directive from the Commissioners published in the Federal Register, September 16, 1975 (40 FR 42801). The Commission directed the staff to analyze alternatives for the handling and storage of spent light water power reactor fuel with particular emphasis on developing long range policy. Accordingly, the scope of this statement examines alternative methods of spent fuel storage as well as the possible restriction or termination of the generation of spent fuel through nuclear power plant shutdown.

Volume 1 includes the Executive Summary and the Text.

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