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OPPORTUNITIES TO INCREASE THE PRODUCTIVITY OF SPENT FUEL SHIPPING CASKS IN THE UNITED STATES

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One of the authors (Winsor) had extensive experience with the handling and transportation of spent fuel from San Onofre to the General Electric Company's Morris Operation where he was Manager of Safety and Analytical Service from 1969 to 1975. This experience is the origin of many statements in this report that are not otherwise referenced.

FOREWORD

This report describes a task performed in the Energy Material Transport, Now Through 2000, System Characteristics and Potential Problems (Transportation Problems) Project. This project was sponsored by the Department of Energy, Environmental Control Technology Division. The DOE Project Monitor was R. F. Garrison; Project Manager at PNL was J. G. DeSteese. A continuation of the cask turnaround study is currently supported by the Transportation Technology Center at Sandia National Laboratories, the DOE's lead laboratory for Transportation Technology. Funds for the completion and publication of this report were provided by the TTC. The TTC Project monitor for this task is A. A. Trujillo.

The overall objectives of the Transportation Problems Project were: 1) to provide advanced warning of potential problems that may inhibit the safe and environmentally acceptable development of fossil and nuclear energy material transportation systems between now and the year 2000; and 2) to recommend research, development and other action to mitigate the potentially adverse impacts of these problems. The results of effort in other tasks of this project are reported as indicated below:

1. An Overview of Transportation in the Nuclear Fuel Cycle (BNWL-2066).
2. Project Task 2 Final Report - Coal Transportation (PNL-2420).
3. Project Task 3 Final Report - Petroleum Transportation (PNL-2421).
4. Project Task 4 Final Report - Natural Gas Transportation (PNL-2422).
5. Assessment of Synfuel Transportation to Year 2000 (PNL-2768).
6. Selected Legal and Regulatory Concerns Affecting Domestic Energy Transportation Systems (PNL-2989).

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1.0 SUMMARY

This report identifies opportunities to increase the productivity of spent fuel shipping casks. Improved cask productivity is one approach available to address the current concern that spent fuel transportation may become inadequate during the next decade. This concern has been expressed by representatives of industry and government and is based on the expectation of a future cask and vehicle shortage.

The trend of current conditions indicates that future transportation requirements for spent fuel will be different from those anticipated when the current generation of casks and vehicles was designed. Increased storage capacity at most reactors will increase the average post irradiation age of the spent fuel to be transported. A scenario is presented which shows the 18 casks currently available should be sufficient until approximately 1983. Beyond this time, it appears that an adequate transportation system can be maintained by acquiring, as needed, casks of current designs and new casks currently under development. Spent fuel transportation requirements in the post-1990 period can be met by a new generation of casks specifically designed to transport long-cooled fuel.

The emphasis of this study is on the increased productivity that results from reducing in-plant turnaround time for casks and vehicles. The sensitivity of productivity to turnaround time was determined for rail and truck casks in a 1986 spent fuel transportation scenario. In terms of the number of casks needed, productivity may be increased by 19% if rail cask turnaround time is reduced to 4 days from the current range of 6.5 to 8.5 days. Productivity defined as payloads per cask year could be increased 62% if the turnaround time for legal weight truck casks were reduced from 12 hours to 4 hours. On a similar basis, overweight truck casks show a 28% increase in productivity. While the magnitude of these improvements may be less in practice, the sensitivity study established that reduced turnaround time can result in worthwhile improvements in system performance. Other important advantages are potential reductions in the labor and radiation doses associated with loading and unloading spent fuel.

Significant reductions in turnaround times can be achieved by innovations and modifications in cask design and handling, facility operation and system

development. Many of the following recommendations applicable to new casks are also recommended as modifications to existing casks that may be used to transport long-cooled fuel.

1.1 CASK DESIGN AND HANDLING

A new generation of casks, specifically designed for long-cooled fuel should be developed. The reduction in shielding requirements and thermal loads associated with long-cooled fuel should permit new casks with double the payload of existing designs. The use of an overpack as a contamination barrier is strongly recommended. By eliminating the currently-required stringent and time-consuming decontamination of the cask exterior, an overpack would significantly reduce turnaround time. Cask handling labor and radiation doses would be reduced correspondingly.

Long-cooled fuel should be shipped dry in casks containing air at approximately atmospheric pressure. Improved cask closure methods are needed. Wedge-type seals and designs that minimize head-bolt torquing requirements should be developed. Other recommendations include the use of smooth casks to reduce surface contamination and the elimination of liquid neutron absorbers and auxiliary cooling systems. Electropolishing techniques for certain decontamination tasks should be developed. Where practical, existing casks should be retrofitted and new casks, built to current designs, should incorporate the above recommendations.

1.2 FACILITY OPERATIONS

The lack of rail sidings and inadequate space and cask handling equipment at some reactors suggest that planning of fuel transportation procedures needs more attention during the facility design and site selection phases of a project. Standardized cask handling requirements should be developed to aid facility design. This would include space and clearance requirements as well as specifications for auxiliary equipment such as the lifting capacities and transit speeds of cranes. During the site selection phase greater attention should be paid to arranging for adequate rail service, delivery of cars with the required orientation and handling the turnaround of more than one cask at a time.

Cask turnaround times and handling costs could be significantly reduced by developing a uniform test for surface contamination which gives rapid results. Currently, the non-uniformity between instruments and techniques used by shippers and receivers cloud the meaning of test results. Priority should be given to development of a standardized surface contamination test procedure and specified instruments which permit rapid, consistent interpretation.

1.3 SYSTEM DEVELOPMENT

Two areas are worthy of further consideration to improve the productivity of the spent fuel transportation system. The use of unit (dedicated) trains is one possibility for improving system productivity. This study adds the following perspective on the unit train option.

Average train speeds of about 6 mph are common throughout most of the country, the exception being the 14 ± 2-mph average speed of the western railroads. This variation of average rail speed with geographic location has the implication that unit trains are more likely to be desirable in the eastern states. The relatively higher speed of western railroads suggests that spent fuel casks carried on a unit train would be only marginally more productive than casks moved in regular freight service. The advantages of unit trains include shorter transit times, the possible use of traveling crews that are expert in the handling and protection of spent fuel, and the opportunity to carry spare parts for casks and handling equipment. Disadvantages include greater overall turnaround times if more than one cask is transported and increased costs unless the train carries several casks at a time.

The attempts of the railroad industry to require special train service for the shipment of spent fuel has been successfully challenged in court. However, the optional use of dedicated trains should be considered on a cost/benefit basis in the planning and design of future nuclear fuel transportation systems.

The development of waterway transportation has potential advantages in providing an alternative to road and rail transport. While this is a slower mode of transportation, the use of waterway links in the transport of spent fuel may contribute positively to the overall effectiveness of the system. Since some reactors have direct access to river systems, intermodal rail/water and road/water casks could provide a crucial alternative if state or local authorities restrict overland transport.

2.0 INTRODUCTION

Irradiated (spent) nuclear fuel is accumulating in storage basins at each operating nuclear reactor in the United States. Most of these reactors were built when it was assumed that residual fissile materials would be recycled on a relatively rapid schedule. Many reactor storage basins were built, therefore, with relatively low storage capacity. Recycling spent fuel is not currently permitted as a policy of the Federal government. As a result of this, electrical utilities are building new reactors with greatly increased storage capacity and enlarging the storage capacity of their older plants. If current trends continue, most reactors in the 1980s will have over 15 years of spent fuel storage capacity.

The existing casks and associated vehicles were designed to transport irradiated fuel that is cooled 90 to 120 days, consistent with the previously held expectation of rapid recycling of fissile material. The trend of current conditions indicates that future transportation requirements for spent fuel will be different from those anticipated when the current generation of casks and vehicles was designed. These differences include the volume to be moved, the thermal age of spent fuel, and the possibility of extensive shuttling of material between temporary storage sites.

Concerns have been expressed by representatives of both industry and government (References 1 and 2), that the transportation system for spent nuclear fuel may become inadequate during the 1980s. A possible shortage of spent fuel casks and vehicles is a major concern. Whether or not a shortage of spent fuel casks will occur depends, in part, on: 1) how much spent fuel will be shipped; 2) what can be done to improve the carrying capacity and productivity of spent fuel casks and systems that are currently available; and 3) how future casks, vehicles and logistics can be developed to improve the system capacity.

Considerable uncertainty exists about the volume of spent fuel that will be shipped, particularly during the next decade. If an Away from Reactor Repository (AFR) is put into operation in 1983, the volume of spent fuel that would be transported could be high enough to require an increase in the number of casks from the current 19 casks[a] to 60 to 90 casks by 1990.[3] On the other hand, if an AFR is not built, only modest additions to the cask inventory would be required since spent fuel shipments would probably be limited to shipments between reactor basins.

It appears that in the U.S. over 90% of the spent fuel shipments throughout the remainder of this century will consist of fuel that has been cooled at least two years with much of it cooled beyond five years. Consequently, there is considerable incentive to build a fleet of casks specifically designed for this long-cooled fuel because its lower thermal and radiation output would permit an increase in cask capacity and reduce handling costs. However, spent fuel transportation requirements must be met during the 5- to 9-year period currently required to develop, license and start operations with a new cask design. While the current cask inventory is presently under-utilized, a future need to operate a spent fuel transportation system at maximum efficiency is to be expected. Therefore, established practices in spent fuel handling and transportation may need updating to anticipate operations under new conditions.

The purpose of this study is to identify new opportunities in the design and handling of shipping casks, that improve the productivity of spent fuel transportation. Particular emphasis is placed on approaches for reducing the turnaround time, cask handling labor, and radiation doses associated with spent fuel loading and unloading. The recommendations resulting from this study cover potential improvements in the handling and operation of present and future cask generations.

(a) Six rail casks and 13 highway casks (see Table 4.1).

3.0 NUMBER OF CASKS REQUIRED BASED ON FUTURE CONDITIONS

Spent nuclear fuel is the principal by-product material that accumulates as a result of operating a nuclear power station. Spent fuel must be handled underwater for cooling and shielding purposes and stored in subcritical arrays. When the fuel is removed from a reactor site, it must be packaged in specially designed, licensed and approved shipping casks.

The future adequacy of spent fuel transportation will depend on the amount of fuel to be moved and the effectiveness of equipment utilization. It appears now that most spent fuel shipments will contain fuel cooled for five years or even longer. Reactor owners are seeking and gaining Nuclear Regulatory Commission (NRC) approval to increase the storage capacity of existing water basins. Various utility spokesmen have publicly stated their intentions to store their own spent fuel indefinitely. Therefore, the present inventory of six rail and 13 truck casks may be adequate well into the 1980s. This would not have been the case if extra storage had not been built and the shipment of 120-day cooled fuel were required. However, there may come a time when optimum utilization of the present inventory of casks will be necessary while a new generation of casks and vehicles is being designed, built, and licensed.

The lead time for procuring a currently licensed cask is one to two years. Up to nine years is required to develop and deploy a new cask design. Thus, accurate projections of shipping requirements for spent fuel are needed to aid the planning of future systems. Unfortunately, accurate predictions cannot be made at this time because of the uncertainty which exists about when and where spent fuel will be shipped. The following projections relating to spent fuel accumulation rates and reactor storage capacities provide a reasonable basis for estimating the number of casks required in the period 1982 to 1990.

3.1 SPENT FUEL ACCUMULATION

Table 3.1 shows recent estimations of cumulative U.S. reactor spent fuel discharges and a planning basis for domestic AFR requirements. These requirements are anticipated by the Department of Energy assuming maximum pool expansion at operating reactors and no interpool transshipments. The shipment of spent fuel entering the U.S. from abroad is expected to add to domestic transportation requirements.

TABLE 3.1. Projected Storage Requirements for Spent Fuel[a]

	(MTU)		
Year	U.S. Reactor Discharges	Domestic AFR Requirements	Foreign Requirements
1981	9,102	186	50
1983	13,103	377	220
1988	30,425	1,985	885
1993	53,894	7,013	1,000

(a) Source: Spent Fuel Storage Requirements - The Need for Away-From-Reactor Storage; An Update of DOE/ET-0075, DOE/NE-0002, January 1980.

These estimates do not allow for the improvements that may be obtained such as increasing burnup of the fuel from 33,000 to 50,000 MWd/tonne. The currently experienced slippage in plant construction schedules may result in the values given by Table 3.1 being conservatively high. While delays in construction schedules make estimates beyond five years highly uncertain the above estimates appear to be a reasonable basis for the projection of cask acquisition needs, because the lead time for acquiring licensed casks is short compared to plant construction time.

3.2 SPENT FUEL STORAGE AT REACTORS

The principal uncertainty about future transportation needs is the lack of policy on when and where the fuel will be shipped. There is no pressing technical, safety or economic need to ship spent fuel in the absence of reprocessing. As a result about fifty of the currently licensed reactors are expanding their storage capacity. Figure 3.1 shows the status of spent fuel storage for boiling water reactors (BWR) in the U.S. and Figure 3.2 is a similar display for pressurized water reactors (PWR).[4] New reactors are being built with over 20 years of spent fuel storage capacity. If current trends continue, an average of 15 or more years of spent fuel storage will be available at most reactors. Except for interbasin transfers, this could delay the need for shipping significant amounts of spent fuel until 1993 or later, depending upon fuel management and storage techniques. Less than 200 MTU of spent fuel was moved during each of the past three years, less than a third of the carrying capacity of the existing cask inventory.[3] This surplus of casks could conceivably continue for a decade or more.

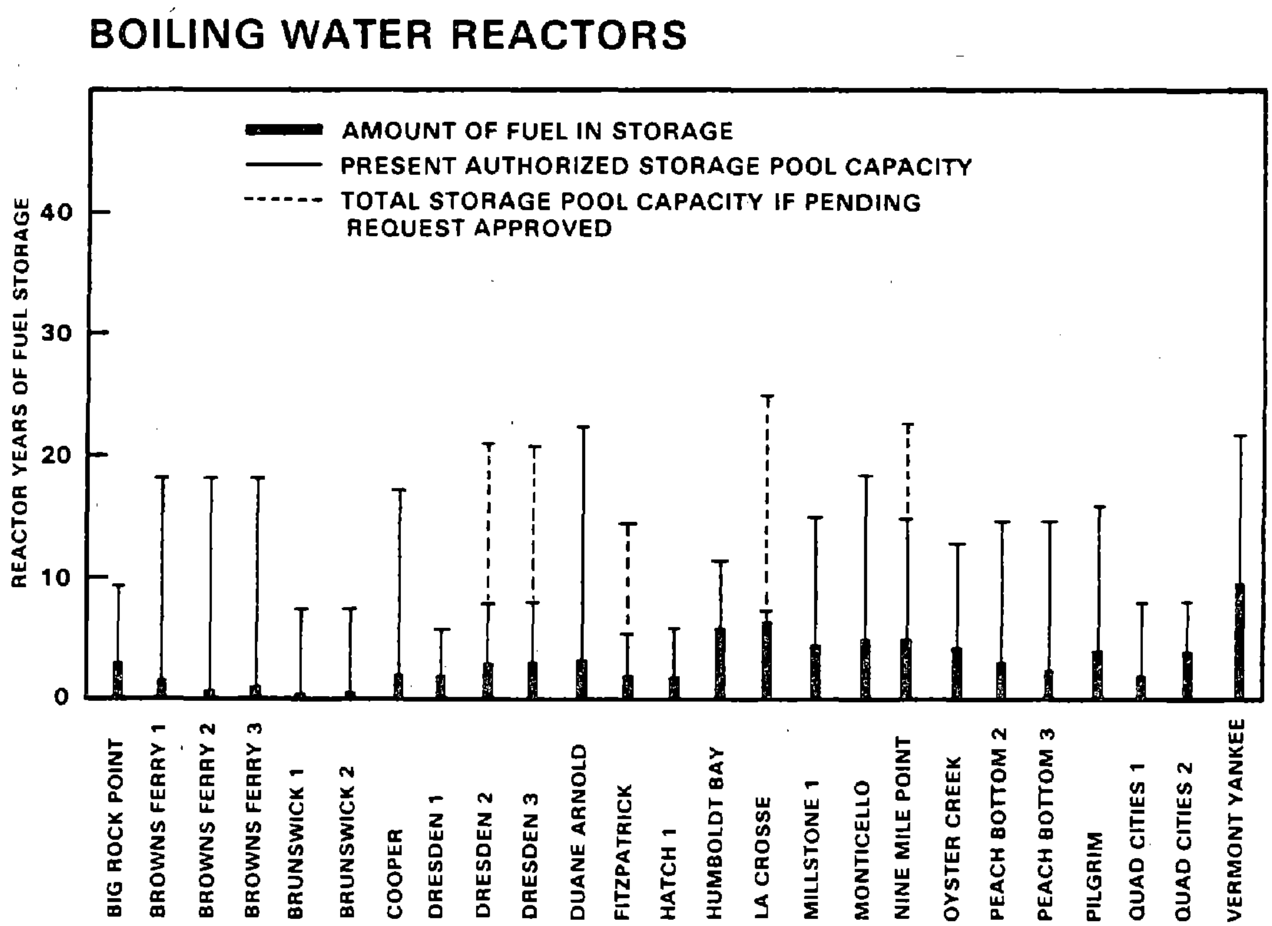

FIGURE 3.1. Status of Spent Fuel Storage Capacity for BWRs (Reference 4)

PRESSURIZED WATER REACTORS

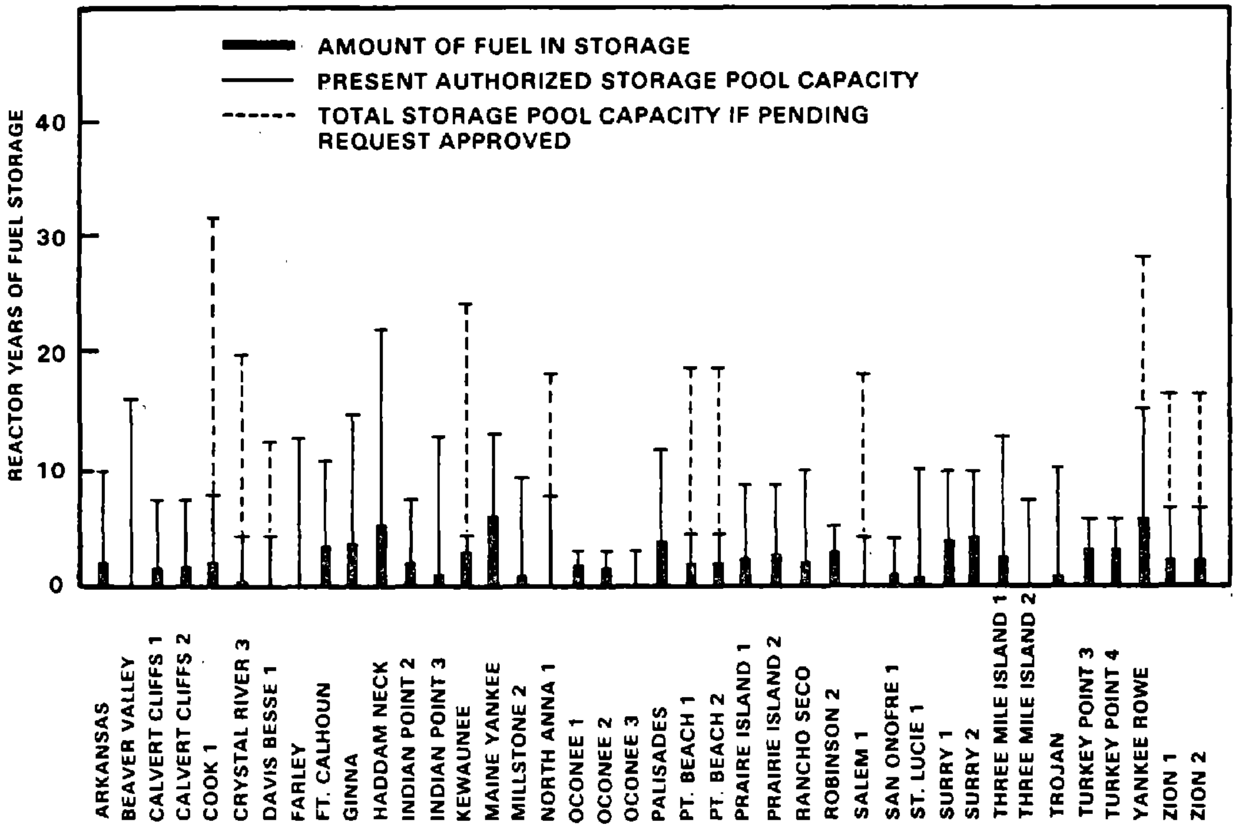

FIGURE 3.2. Status of Spent Fuel Storage Capacity for PWRs (Reference 4)

3.3 NUMBER OF CASKS REQUIRED

Eventually, significant amounts of spent fuel will have to be moved. The cumulative totals given in Table 3.1 are indicative of the size of this task. Because first-in, first-out fuel handling is the most probable scheme to be used, it is unlikely that a significant volume of fuel cooled less than five years will be transported.[a] An estimation of the amount of spent fuel that might be shipped if an Away from Reactor Repository (AFR) becomes operational in 1983, was made by Allied-General Nuclear Services (AGNS).[3] Using a simplified linearization of various utility projections, AGNS anticipated that 750 MTU would

(a) Excluding interbasin transfers when reactors temporarily exceed their basin capacity prior to reracking or the relatively uncommon need to ship damaged fuel assemblies.

be shipped in 1983, increasing at the rate of 300 MTU/year until 1990. The resulting number of casks required is shown in Table 3.2.

TABLE 3.2. Estimates of Spent Fuel Cask Requirements (U.S.)[a]

Year	MTU Shipped/Year	Number of Cask Systems LWT[b]	OWT[c]	Rail	Total
1982 and Before	500 or Less	5	2	4	11
1983	750	7	2	6	15
1984	1,050	9	3	9	21
1985	1,350	12	4	11	27
1986	1,650	15	5	13	33
1987	1,950	17	6	16	39
1988	2,250	20	7	18	45
1989	2,550	22	8	21	51
1990	2,850	25	8	23	56

Source: Reference 3.
(a) Based on a 5,000 MTU AFR opening in 1983.
(b) Legal weight truck.
(c) Overweight truck.

If no new casks were built in the meantime, the 19 casks currently available appear to be adequate until 1983 or 1984 in the AGNS scenario. The growth in cask fleet size estimated by AGNS greatly exceeds the spent fuel transportation requirements currently anticipated by the DOE (Table 3.1). Beyond 1984 it appears that an adequate spent fuel transportation system can be achieved by acquiring, as needed, casks of current designs and new casks currently under development. Between now and 1990, there is enough time to develop a new generation of casks specifically designed for the transport of long-cooled fuel. Regardless of the size of the cask fleet, the capacity of the transportation system will improve if the productivity of casks and vehicles can be increased. This study focuses on opportunities for improving cask productivity by reducing turnaround time at the reactor and storage facility.

3.4 NUMBER OF CASKS AND PRODUCTIVITY VERSUS TURNAROUND TIME

A system description and analysis is included in Appendix A to provide a basis for determining the relative value of reducing cask turnaround time to improve system performance. Two examples of the results of this analysis are shown in Figures 3.3 and 3.4.

Figure 3.3 shows the number of rail casks required in 1986 versus total cask turnaround time. In this scenario, only two types of casks, the IF-300 and the NLI-10/24[a] were considered to handle all the spent fuel requiring shipment to an AFR. This particular scenario was based on the

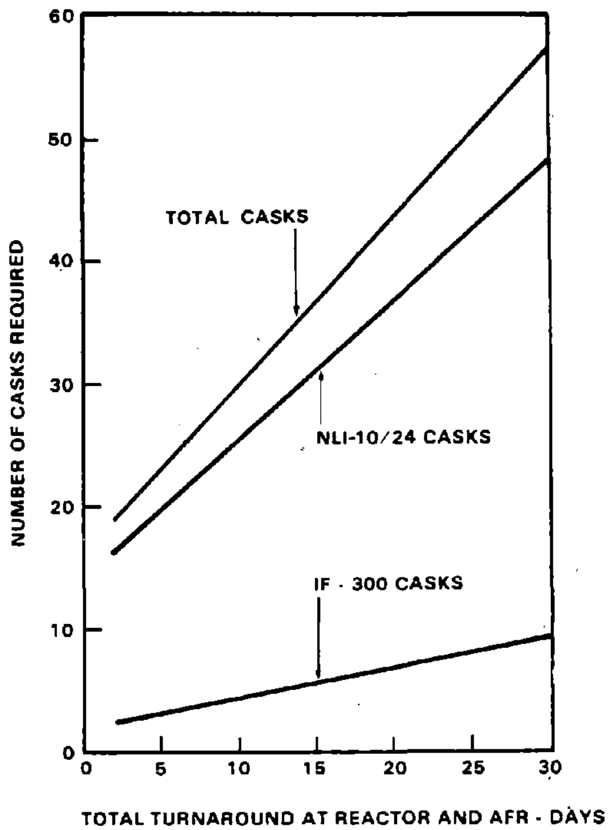

FIGURE 3.3. Rail Cask Requirements (1986)

(a) Descriptions of these casks are contained in Section 4 and Appendix B.

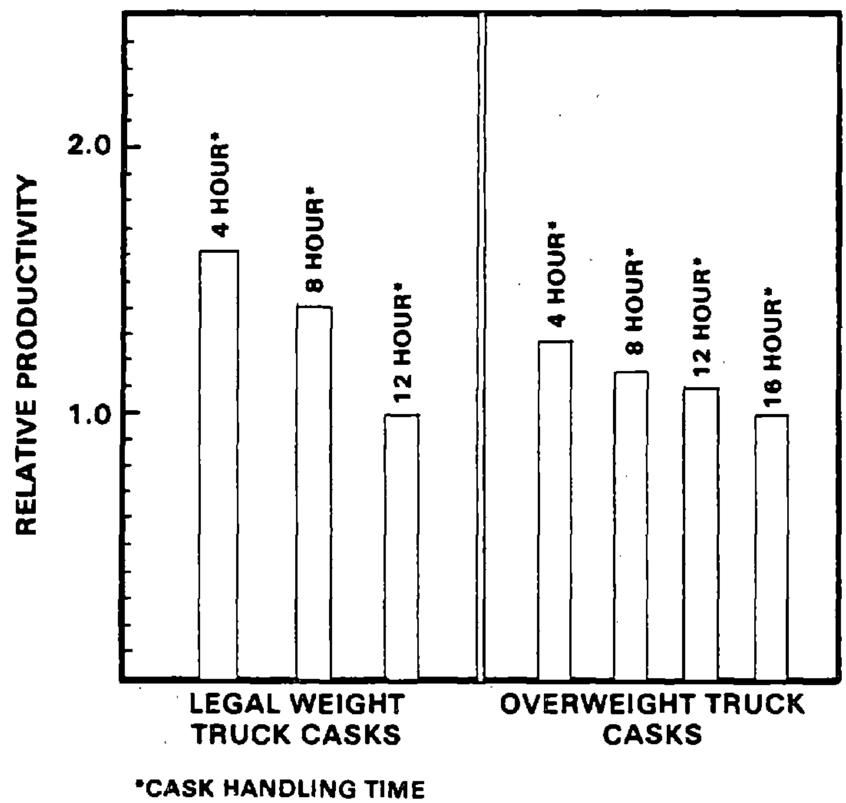

FIGURE 3.4. The Effect of Cask Handling Time on Cask Productivity

hypothesis that the NLI-10/24 casks would be used at plants with railroad access and the IF-300s would operate intermodally (road/rail) at plants without rail connections.

The absolute numbers of casks indicated in Figure 3.3 are artifacts of this scenario and, as such, are less significant than the sensitivity they exhibit as a function of turnaround time. Based on current estimates total turnaround times[(a)] of about 6.5 days for the NLI-10/24 and 8.5 days for the IF-300, 21 NLI-10/24 and 4 IF-300 casks would be required in this scenario. If total turnaround for both casks could be reduced to 4 days, the total number of casks needed would be 21. This represents a 19% reduction.

Figure 3.4 shows an example of the relative effects of turnaround time on truck cask productivity (payloads/cask year). Turnaround times[(b)] of 12 hours

(a) Total turnaround includes inplant time at reactor and AFR.
(b) Time at reactor or at fuel storage facility.

and 16 hours are currently achievable with legal weight and overweight truck casks, respectively. If turnaround could be reduced to 4 hours in both cases, the potential improvement in legal weight cask productivity would be 62%. For overweight casks this improvement would be 28%.[a] These improvements may be difficult to achieve, but the trend of these comparisons shows that system performance improves significantly if cask turnaround times can be reduced. These indications are the incentives for the assessments and recommendations contained in the balance of this report.

(a) This relatively smaller gain results from limitations discussed in Appendix A.

4.0 CHARACTERISTICS OF EXISTING CASKS, TURNAROUND TIMES AND HANDLING PROCEDURES

The present status of the U.S. cask inventory and turnaround times are summarized in this section. This information serves as a background for following sections dealing with in-plant cask handling and its effects on cask productivity and fuel transportation costs.

4.1 CHARACTERISTICS OF THE EXISTING CASK FLEET

Shipping casks are generally massive, having a low payload to total weight ratio, and are expensive, having daily use charges of approximately $800/day for legal weight truck casks and up to $4,500/day for rail casks. Reference 3 gives a comprehensive description of current casks from which the information in Tables 4.1, 4.2, and 4.3 was obtained. Spent fuel casks can be divided into three types as shown in Table 4.1. These are casks designed for legal weight trucks (NFS-4/NAC-1 and NLI-1/2), those designed for overweight truck transportation (TN-8 and TN-9) and rail casks (IF-300, TN-12 and NLI-10/24). Table 4.2 lists the characteristics of these principal cask designs. Table 4.3 lists the design variations found in existing casks.

TABLE 4.1. Current USA Spent Fuel Cask Inventory

Model	Type	Number
NAC-1/NSF-4	Legal Weight Truck	7[a]
NLI-1/2	Legal Weight Truck	5
TN-9	Overweight Truck	1[b]
IF-300	Rail	4
NLI-10/24	Rail	2[c]
Total		19

(a) Three casks currently in service. The remaining casks are subject to license suspension pending the resolution of possible problems in their shield structure.
(b) Two TN-8 casks currently in Europe have an NRC certificate of compliance for use in U.S., if needed. With ongoing and planned fabrication, 4 TN-8's and 3 TN-9's will be available by the end of 1981.
(c) These casks are currently without fuel baskets and require additional work before they can be made operational.

TABLE 4.2. Characteristics of LWR Spent Fuel Casks[a]

Cask Name	Nuclear Assurance Corp. Atlanta, GA NAC-1/NFS-4[b]	General Electric Co. San Jose, CA IF-300	Transnuclear, Inc. White Plains, NY TN-8/9	Transnuclear, Inc. White Plains, NY TN-12	NL Industries, Inc. Nuclear Division Wilmington, DE NLI-1/2	NL Industries, Inc. Nuclear Division Wilmington, DE NLI-10/24
Transport Mode	LWT[c]	OWT/Rail[d]	OWT	Rail	LWT	Rail
Capital Cost 1978 $ millions	0.75	3.5 to 4.0	~1.5	5.5	1.25	4.5
Daily Use Chg. $ thousands	0.8	3.5	1.5 to 2.0	4.4	0.8	3.6
PWR/BWR Assemblies/ Cask	1/2	7/18	3/7	12/32	1/2	10/24
Loaded Cask Weight Tonnes	22.5	63.5	34.5	97 to 105	21	91
Gross Vehicle Weight Tonnes	32	120	48	136 to 147	32	160
Cavity Dimensions (dia. x length) in.	13.5 x 178	37.5 x 180	$(9^2 \times 168)$ $(5.5^2 \times 178)$	48 x 180	13.375 x 178	45 x 179
Overall Dimensions (dia. x length) in.	50 x 214	64 x 208	68 x 192 (68 x 202)	98 x 265	40 x 193	103.5 x 224
Gamma Shield Material	Lead	Uranium	Lead	Steel	Lead/Uranium	Lead
Neutron Shield	Borated Water	Water	Organic	Organic	Water	Water
Cavity Coolant	Water[e]	Water[e]	Air	Air	Helium[e]	Helium
Cask Exterior Surface	Smooth	Corrugated	Copper Fins	Copper Fins	Smooth	Stainless Steel Fins
US NRC License	Yes	Yes	Yes	Pending	Yes	Yes
Number of Units (operational/under construction)	4/2	4/0	(0/1)	0/0	5/0	1/2
Approximate Number of Trips/Reactor Year, BWR/PWR	80/65	9/9.3	23/22	5/5.5	80/65	6.7/6.5

(a) From Reference 3.
(b) NAC-1 and the NFS-4 cask designs are essentially identical.
(c) LWT--Legal Weight Truck.
(d) OWT--Overweight Truck.
(e) These casks may be shipped dry (air) under low heat load conditions.

Rail casks have the advantage of carrying a greater payload than truck casks. This reduces the number of shipments (5 to 9 shipments per reactor year depending upon the cask design), labor and radiation doses involved in transporting spent fuel by rail. Legal weight truck casks compensate for their reduced payload (65 to 80 shipments required per reactor year) by providing faster and more responsive service. Overweight truck casks offer better payloads than legal weight truck casks (about 22 shipments per reactor year) but suffer from overweight restrictions (no weekend or nighttime travel) and the requirements for special route permits which can be difficult to obtain.

TABLE 4.3. Typical Cask Design Variations[a,b]

Design Feature	Variations
Shielding (gamma)	Steel; steel-lead; steel-depleted uranium; steel-lead-depleted uranium
Shielding (neutron)	Water; borated water; solid hydrogenous material
Cavity Coolant	Water; air; evacuated air; helium
Heat Rejection	Finned, corrugated surface; smooth outer surface; auxiliary cooling (water-air)
Closure Heads	Single; double
Lifting Trunnions	Two in upper region; four in upper region; upper and lower region trunnions
Fuel Capability	Both PWR and BWR fuel; dedicated solely to PWR; dedicated solely to BWR
Basket Internal Designs	Extruded aluminum; fabricated steel structure; poison sleeves and rods; leaker fuel cans
Drain Systems	Bottom drain; side draining; top drain (air displacement of water)
Lifting Yokes	Single yokes; redundant (double yokes)
Impact Limiters	Integral with the cask; removable - remain on vehicle; removable - removed from vehicle; doughnut shaped top-hat shaped; etc.
Surface Contamination Protection	None; contamination barriers (plastic and metal).
Varying Fuel Length	Different closure head designs, basket length modifications; dedicated casks for long fuel accomplished by axial lengthening of the cask body

(a) From Reference 3.
(b) Other variations include cavity lengths; gasket types (steel polymeric O-rings, etc.); valve connections; use of safety valve, rupture disc, zero release; personal barrier (clamshell opening; horizontal opening; and barrier directly removed from the car).

The choice of transport mode for spent fuel is made largely on the basis of economics and convenience. Some reactors do not have rail sidings and have to use truck transport. Although intermodal shipments are possible from these sites (the IF-300 is designed to be intermodal), rail shipments are not expected to be made unless a rail siding is relatively close to the site. In general, rail shipments have economic advantages because of larger per unit cask capacity. Overweight truck casks are also economically attractive if the operating restrictions, mentioned above, do not create logistic problems for the particular route under consideration. Intermodal handling systems should have the economic advantages of rail shipments, but may be handicapped by the complexity of the railhead transfer procedures. The design features that provide the IF-300 with an intermodal capability also complicate cask handling procedures.

As shown in T-ble 4.1, the current cask inventory is 19 with more in fabrication. New cask programs have been announced by Transnuclear, Inc., Nuclear Assurance Company and Edlow International Inc.[3] Transnuclear has announced the intention to fabricate six TN-8/9 cask systems for service by 1981-1982. Several of these cask development efforts are addressing the prospect of transporting long-cooled fuel. Industry is, therefore, already anticipating future needs despite the current under-utilization of existing casks.

4.2 CASK TURNAROUND TIMES[a]

Experience gained from the operation of NAC-1/NFS-4 legal weight truck casks and IF-300 rail casks provides the basis for what may be considered as typical turnaround times for present generation casks.

4.2.1 NAC-1/NFS-4 Truck Cask

This cask was put into service in 1973; since then approximately 200 shipments have been successfully completed. The first series of shipments with

(a) Turnaround is defined in this report as entry and exit from one plant. It is also customary in the industry to consider turnaround as a complete cycle of fuel delivery involving cask loading, transit unloading and return to base.

the cask were made from the Rochester Gas and Electric Company's (RG&E) Ginna Nuclear Power Station.[5] The first shipment took approximately 12 hours for a complete turnaround. As the work crew gained experience and minor improvements were made in handling and facility procedures, this time rapidly decreased to about four hours. Their typical work shift would turn one cask around in the morning and the second in the afternoon. Similar turnarounds at the receiving plant, combined with the rather short transport distance (approximately 110 miles) enabled this cycle to be repeated on a daily basis. The record established by RG&E's crew, and likely a world's record, was two complete cask turnarounds in less than 4½ hours.

A more typical turnaround time for truck casks, including the NFS-4, is 12 hours with "out by the next day" a common working plan. The handling procedure for unloading the NFS-4 cask is listed in Table 4.4.

TABLE 4.4. Typical Steps for Unloading the NFS-4 Truck Cask

Step	Procedure
1	Receive cask and obtain surface smears as may be required.
2	Release forward and aft tie-downs.
3	Unbolt lid impact limiter and roll forward on carriage.
4	Attach cask yoke and remove cask from trailer.
5	Open vent valve, attach lid lifting spider, remove lid bolts (6), and lid.[a]
6	Lower cask into pool and load fuel.
7	Place lid on cask, move cask to decontamination area.
8	Torque lid bolts and pressure test double O-ring seal.
9	Decontaminate exposed cask surfaces while draining prescribed amount of coolant from cavity to provide expansion void.
10	Pressure test cask cavity and valves.
11	Check cask surfaces for contamination. Obtain release survey.
12	Load cask onto trailer and secure.

(a) When unloading a cask the lid is not removed until the cask is submerged in the pool.

4.2.2 IF-300 Rail Car Cask

Handling procedures have been modified at the detail level several times. The outline presented in Table 4.5 is specific for the IF-300 system but is also a generalized procedure that could apply to most existing rail casks.[6] This procedure does not apply to the use of intermodal equipment. Intermodal equipment, shown in Appendix B, has been designed and similar equipment has been tested. However, since this system has not yet been used for transferring fuel, cycle time information is not available for this option of the IF-300.

The General Electric Spent Fuel Services Operation at Morris, IL, has turned each of its four IF-300 casks around enough times to demonstrate that 32 hours is an achievable average turnaround time. However, 40 to 48 hours is, perhaps, a more reasonable range that allows for contingencies.

4.2.3 Turnaround Comparisons with Other Casks

The Allied General Nuclear Services (AGNS) has conducted operational assessments of four spent fuel shipping casks.[3,7-10] The results of these AGNS studies are presented in Table 4.6. The values shown for the IF-300 cask were computed from information given in Reference 6; the values for the remaining three casks were taken from Reference 3. It is important to note that contamination barriers were assumed to be used with all casks. The AGNS studies express doubt that the NLI-10/24 rail cask will be a feasible design unless a contamination barrier is developed and used with it. Without a contamination barrier the time required to clean the finned surfaces on the NLI-10/24 could be prohibitive.

The AGNS times and man-hour estimates based on use of the AGNS facility at Barnwell are useful for planning purposes. However, shorter turnaround times are possible and have been demonstrated, such as the 4-hour turnarounds with the NFS-4 truck cask mentioned above. Also, the General Electric Company at Morris, IL, and Commonwealth Edison have demonstrated 14-hour turnarounds with the IF-300 rail cask.

TABLE 4.5. Typical Steps for Unloading the IF-300 Rail Car Cask

A - Prepare

1. Receive and inspect cask at the reactor
   - Inspect for shipping damage
   - Take radiological smears and surveys
2. Remove cask from transport vehicle
   - Unlock and open enclosures
   - Move cooling air ducts to extended position
   - Remove valve box covers and attach lifting yoke to cask
   - Lift cask and transport to wash-down area
3. Prepare cask for loading fuel assemblies
   - Fill cask with water and remove closure nuts
   - Wash cask exterior surfaces
   - Place cask in fuel handling pool
   - Remove closure and take it to gasket inspection

B - Load--Unload

4. Load fuel into cask
   - Handle bundles one at a time
   - Verify identification of each bundle

C - Dispatch

5. Removal of cask from fuel pool
   - Put spray ring in place
   - Lower closure through spray ring onto cask
   - Engage lifting yoke and lift cask from pool
   - Install some head bolt nuts when cask is up to surface
   - Spray cask with high pressure water as removed from pool
   - Set cask down on decontamination pad
6. Prepare cask for shipment
   - Install closure nuts and torque in sequence
   - Pressure test the cask
   - Flush pool water from cask and adjust water level
   - Monitor temperature and pressure of cask hourly
   - Sample cask water one hour after flushing and before removal to car
   - Analyze samples and extrapolate activity to 100 hour concentrations
   - Decontaminate cask exterior to shipping release guidelines
7. Shipment of cask
   - Move cask to rail car
   - Remove trunnions, install tiedowns and valve box covers
   - Reposition and activate cooling system
   - Close and lock enclosures
   - Complete required check lists, surveys, bill of lading
   - Dispatch rail car to storage facility
8. Receive and inspect cask at storage facility
   - Identify shipment from bill of lading and material transfer information
   - Unlock and open enclosures, record cooling system information
   - Perform radiological and smear surveys
9. Remove cask from transport vehicle
   - Slide cask enclosures back
   - Record cask temperature readings
   - Shutdown cooling system and extend air ducts
   - Remove valve box covers and cask tiedown pins
   - Install lifting trunnions and attach lifting yoke to cask
   - Lift cask and transport to wash-down area
10. Preparations for unloading fuel
    - Connect flush water piping
    - Sample first water discharged from lower fitting
    - Flush primary coolant to low activity waste collection
    - Wash to cask exterior surfaces
    - Loosen closure nuts in sequence
    - Place cask in fuel storage pool
    - Remove closure and take to gasket inspection
11. Unload fuel from cask and store in racks
    - Handle bundles one at a time
    - Verify identification of each bundle
    - Install handles on PWR bundles
12. Removal of cask from unloading pool
    - Lower closure onto cask
    - Put split spray ring into place
    - Engage lifting yoke and lift cask
    - Spray cask with high pressure water as removed from pool
    - Set cask down on decontamination pad
13. Prepare cask for shipment
    - Lift closure from the cask
    - Drain water from the cask to the pool, monitor while draining
    - Flush cask until release limits are reached
    - Drain cask and remove drain line
    - Replace closure on cask, inspect each bolt, torque to specifications
    - Decontaminate the cask exterior to shipping release guidelines
14. Shipment of cask to the reactor
    - Move cask to rail car
    - Remove trunnions, install tiedowns and valve box covers
    - Reposition cooling ducts
    - Close and lock enclosures
    - Complete required check lists, surveys, bill of lading
    - Dispatch rail car to reactor.

TABLE 4.6. Spent Fuel Cask Turnaround Cycle Comparison (cask unloading)

Operation	Legal Weight Truck Cask Time (min)	Legal Weight Truck Cask Number Operators	Legal Weight Truck Cask Man-hours	Overweight Truck Cask Time (min)	Overweight Truck Cask Number Operators	Overweight Truck Cask Man-hours	NLI-10/24 Rail Cask Time (min)	NLI-10/24 Rail Cask Number Operators	NLI-10/24 Rail Cask Man-hours	IF-300 Rail Cask Time (min)	IF-300 Rail Cask Number Operators	IF-300 Rail Cask Man-hours
Outside Receiving												
Cask receipt, inspection, survey, wash-down, move to unloading bay	125	3	6.25	120	3	6.0	160	3	8.0	191	3	9.55
Unloading Bay Operation												
Removal of impactor, move to Test and Decontamination (T&D) pit	40	4	2.67	70	3	3.50	120	4	8.0	88	3	4.40
Preparation for Unloading												
Cask sampling, outer-head removal, valve cover removed, cooldown (fill and flush) inner-head bolt removed, contamination barrier attached	125	3	6.25	210	4	14.0	200	4	13.33	319	3	15.95
Fuel Assembly Unloading												
Move to Cask Unloading Pool (CUP), head removed, unload assemblies, return cask to T&D pit	135	3	6.75	205	3	13.67	380	3	19.00	248	3	12.40
Cask Preparation for Return												
Replace inner-head, flush and drain contamination barrier, replace outer-head, pressure tests. Valve covers, survey	210	4	14.0	215	4	14.33	545	4	36.33	1,094	4	72.93
Return to Outside Area												
Move to carrier, tie down, replace impactors	50	3	2.50	70	4	4.67	175	4	11.67	141	4	9.40
Outside Preparation for Cask Return												
Move to parking area, final survey, prepare papers, signoffs	80	3	4.0	55	3	2.75	85	3	4.25	72	3	3.60
Total Time (hours)	12:75		42.4	15:75		58.9	27:75		100.6	35:50		128.2
Summary												
Time in Fuel Receiving and Storage Station (FRSS), Hours		9.25			12.45			18.2			30.8	
Time Outside FRSS, Hours		3.5			3.0			4.1			4.7	
Man-hours/MTU		94.2			43.6			22.3			38.0	

NOTES:
1. Manpower required for cask handling includes one Health Physicist.
2. Use of contamination barrier is assumed for all casks.

With the surplus of casks there is no current motivation for a cask owner or lessee to minimize turnaround time. All that is required is a sufficiently short turnaround time so that the cask owner can meet his business volume and the lessee can complete the fuel movement before the lease runs out. Though daily use charges appear to be high, the present cask surplus leads to a somewhat relaxed attitude about scheduling. What is probably happening is an attempt to minimize labor costs and scheduling dislocations at the reactors since the cask cost, for all practical purposes, is constant. Thus present turnaround times may be greater than those which would be allowed if casks were in short supply.

5.0 FACTORS ADVERSELY AFFECTING CASK PRODUCTIVITY

The factors which adversely affect cask productivity and the manpower and cost of transporting spent fuel are described in this section. Two principal categories of problem areas are identified. The first category is associated with cask handling; the second includes other factors such as regulatory and maintenance requirements, and coordination problems.

5.1 CASK HANDLING PROBLEM AREAS

Existing casks and cask handling procedures have amply demonstrated that spent nuclear fuel can be transported safely and economically. However, as experience has been gained, problem areas have been identified. These include surface contamination, excessive time required to seal casks, the potential need to treat road dirt as low level waste, and the need to pay increased attention to having spare parts available. In addition, the future prospect that long-cooled fuel rather than short-cooled fuel will be shipped, has important implications for cask and vehicle design and for cask handling systems.

5.1.1 Surface Contamination

Surface contamination is the single most important problem in cask handling. Except for the TN-8/9 overweight truck casks, which have contamination barriers, the entire outside surface of a spent fuel cask is contaminated when spent fuel is loaded or unloaded underwater. Even in the case of the TN-8/9 casks, a significant part of the surface is contaminated, although the finned surfaces are not.

The source of this contamination is the reactor crud activation products which coat the spent fuel bundles. The crud not only contaminates the cask directly but also contaminates the pool water while the fuel is being transported through the pool and racked. Treatment given to the pool water removes enough of this contamination to keep it from being highly radioactive; however, the pool water can still contaminate the cask surface well beyond NRC standards. For example, the residue from a 0.01-cm thick film of the pool water characterized in Table 5.1 would, if allowed to evaporate in place, exceed NRC standards for permissible radioactivity.

TABLE 5.1. Activity of Typical Pool Water[a]

Isotope	Concentration μCi/ml	MPC_W μCi/ml[b]	Relative Hazard[c]
^{134}Cs	133×10^{-5}	9×10^{-5}	15
^{137}Cs	280×10^{-5}	20×10^{-5}	14
^{60}Co	4×10^{-5}	50×10^{-5}	0.08
^{63}Ni[d]	630×10^{-5}	30×10^{-5}	21
^{3}H	3×10^{-5}	$3{,}000 \times 10^{-5}$	0.001
Total	$1{,}050 \times 10^{-5}$		50

(a) From Reference 11.
(b) Maximum permissible level permitted in water by Reference 12
(c) A relative hazard value of 1.0 means that a radiation worker could use this water for all of his needs without exceeding the limits of Reference 12.
(d) Determined by subtraction of known activities from the gross beta activity.

Reactor crud activation products are highly radioactive. They coat the fuel bundles and often leave a visible wake as a fuel bundle is moved from one place in the pool to another. Not only do they add to the surface contamination dose, but they add to the doses received by workers during maintenance operations such as gasket changeouts because they are deposited on the inside surfaces of the cask.

The Atomic Energy Commission (AEC) published a requirement in 1974 (Reference 12) that required reporting whenever a radioactive shipment was received with a surface contamination exceeding 220 alpha disintegrations per minute or 22,000 beta disintegrations per minute. This regulation has significantly increased turnaround times, not because it tightened the limit of surface contamination, but because it, in effect, created a receiving limit. Surface contamination often increases with time because contaminants lodged in cracks or pores are often transported to the cask surface. The degree of this build-up with time is unpredictable as it depends upon the quality of the surface, the existence of nooks and crannies, the type of cleaning technique used, the chemistry of the pool water, the meteorological conditions (rain, fog, or dew), and the protection given the cask (e.g., the use of tarps). Thus, a cask could be cleaned to 220 dpm beta, which is only one percent of the allowed level, and still exceed the 22,000 dpm limit when it arrives at its destination.

The action taken by the receiver of a contaminated cask clearly affects turnaround. In one case, a cask was immobilized for weeks while the shipper and receiver tried to determine who should clean the cask. Undoubtedly there is the fear that if a dirty cask is accepted, it might be one that cannot be cleaned without great expense. However, the cask cannot be moved until all NRC requirements are met; that is, the surface contamination will have to be removed. As a result, some cask receivers measure surface contamination but proceed to process the cask before the results are back from the counting room based on the expectation that it will be necessary to decontaminate the casks.

Decontamination of the IF-300 cask takes about 8 to 12 hours after the cask has been removed from the pool. As stated before, AGNS does not believe it is feasible to decontaminate the NLI-10/24 cask unless a decontamination barrier is developed for the cask. Four-hour truck cask turnaround is no longer possible because of the time taken to measure surface contamination upon receipt.

Another factor which has increased turnaround is that instruments which are more sensitive to weak beta emissions are, with increasing frequency, being used to measure surface contamination smear samples. These instruments are windowless counters and at most reactors are located away from the cask handling facility because they require a low radiation background. Formerly, hand-held counters were used, they were less sensitive to weak beta emissions but were much more convenient to use. With the above mentioned concern about receiving levels, turnaround times increase up to 4 hr if cask processing is held up providing the receipt of the contamination survey performed after receipt of the cask. Because spent fuel radiation measurements have a low priority at reactors compared with those measurements affecting reactor operation, this 4-hr interval is not likely to be reduced. Turnaround is increased another 4 hr while this process is repeated prior to dispatching the cask.

Another aspect of this problem is that it is not possible to predict exactly when a cask will be decontaminated with current decontamination procedures. After the results of the first contamination smear samples come back, it may be necessary to continue the decontamination effort. This uncertainty about whether decontamination is complete or not can add 12 to 24 hr to the turnaround time of a rail cask. This is because most railroads require at least 12 hours notice prior to picking up a cask car.

Decontamination can give rise to a significant percentage increase in radiation dose to workers since it involves hand scrubbing and, therefore, close proximity to loaded casks. The AGNS estimates of radiation dose are for cask unloading procedures in which decontamination takes place with the cask empty. Radiation doses will be significantly higher for reactor operations where loaded casks must be decontaminated. Another disadvantage of current decontamination procedures is that significant quantities of low-level solid waste are produced.

Contamination barriers can be a partial solution to the problem. The TN-8/9 cask system uses a contamination barrier and has performed well in Europe.[10] However, a significant portion of the cask surface must still be decontaminated and contamination barriers themselves become contaminated, posing handling and storage problems (particularly if the number of designs is allowed to increase). A significant amount of close proximity cask handling is also required to attach and detach the barriers.

Turnaround times and cask handling personnel requirements can be significantly reduced by adapting a standardized method for reading surface smears in the vicinity of the cask. This would solve the problem of the 4-hr wait at reactor counting rooms and would probably eliminate the need to have a full time health physicist available during cask handling as recommended by AGNS in Reference 3.

5.1.2 Cask Sealing

The "zero release" philosophy has imposed demanding requirements on cask designers and builders of casks for short-cooled fuel. Gaskets to prevent leakage have progressed through several designs from double O-rings to flexible metal gaskets that require 32 head bolts torqued to 700 ft-lb. Empty casks are required to be torqued to the same specifications as loaded casks (Reference 3).

The sequence of unbolting the cask head is a significant fraction of the unloading time. Turnaround time is extended by difficulties caused by the galling of stainless steel nuts and bolts when torqued to the specified range. Special lubricants that are compatible with basin water specifications are required to prevent galling of the bolt threads. Changing galled head bolts on a contaminated cask means extra radiation exposure for the handling crew and lost time as the cask must be repaired before it is shipped again.

Containing the helium atmosphere in the primary (fuel containing) cavity of the NLI-10/24 to a "zero release" leak rate is a task currently being investigated by AGNS at Barnwell, SC. An AGNS report indicates that it requires 2,500 to 3,000 ft-lb of torque for the inner head bolts (Reference 8).

Because long-cooled fuel can be shipped dry (or as in the case of the NLI-10/24 cask, helium does not have to be used to assist in heat transfer), the need for current cask leak tightness does not seem justified for long-cooled fuel. The definition of what constitutes a dry shipping condition is also subject to debate. There is probably no need for the cask cavity to be absolutely dry. All that may be required is that the amount of water in the cask does not pose a threat to the cask integrity during an accident such as creating high internal pressure during a fire.

In addition, considerable room for improvement exists for making head seals that are easier to assemble. The AGNS recommendations for greater dimensional tolerances so that the heads can be more easily placed upon the casks can be applied here.(3)

5.1.3 Road Dirt

All road dirt must be removed from the cask before it is placed in a fuel storage pool to maintain pool cleanliness. Up to one half ton of dirt may be removed from a truck during the winter, an amount that may cause the truck to exceed weight limitations. This dirt, if contaminated, must be disposed of as low-level waste.

5.1.4 Auxiliary Cooling Systems

Auxiliary cooling systems are provided on some of the existing cask designs to keep short-cooled fuel at a low enough temperature so that it can be placed in the basin directly upon arrival. Since these systems are not required with long-cooled fuel, their future use would unnecessarily complicate cask handling.

5.1.5 Spare Parts Availability

Casks have been immobilized at a reactor for weeks because of the absence of spare parts such as gaskets and lifting yokes to replace failed or unusable components. The practice of placing spare parts on IF-300 rail cask cars is a wise one. Redundant lifting yokes with their matched cables can be hard to replace and have cost weeks of lost time. Planning must provide for preshipping of spare lifting yokes when truck cask shipments are expected.

5.2 OTHER FACTORS AFFECTING TURNAROUND

Factors other than cask handling which reduce cask productivity and the manpower and cost of transporting spent fuel include elements of typical design facility and increased limitations, regulatory requirements, maintenance requirements and coordination problems. These are discussed below.

5.2.1 Reactor Facility Limitations

As mentioned previously, a number of the reactors in operation or under construction do not have direct rail access. Some of these reactors have cranes that do not have the lifting capacity necessary for handling the larger casks. Cranes at reactors are used in general service and are not designed specifically to expedite spent fuel and cask handling. Cranes are typically limited to 3 ft/min travel speeds. Sixty- to seventy-ft lifts are very time consuming at this slow rate, as are horizontal traverses of over 100 ft.

Access to fuel handling pools in some facilities required unbolting wall and roof sections, removing these sections, moving the cask into the building, and then reinstalling the sections using the same crane before underwater handling operations take place. Lack of onsite rail sidings or even nearby turning Ys means rail cars have to be delivered singly and according to a designated orientation.

5.2.2 Interpretation of Regulations

Differing interpretations of what constitutes compliance with decontamination regulations have resulted in variations in procedures from site to site. In addition, time is lost when it is necessary to suspend turnaround operations while awaiting the results of a cask contamination smear survey to come back from the counting room.

5.2.3 Maintenance Requirements

Pressure control valves must be tested each calendar quarter. Valves are bench-tested and exchanged once each quarter on the cask during normal handling operations to minimize lost time.

Transport vehicles are maintained while the cask is off. Trace amounts of radioactive contamination complicate maintenance activities and in practice restrict such operations to specially provide facilities.

Rail cars must be inspected and maintained at least annually. Once a car is "contaminated", regular railroad maintenance facilities cannot be used. One consequence of this was the requirement that the General Electric Company build a special crane equipped facility at Morris, IL to take care of maintenance needs for the IF-300 rail cars.

5.2.4 Coordination Problems

Arrival times of a cask at the facility seldom coincide with handling crew availability. If a train arrives during the night, and the fuel handling crew does not start work until morning, 8 to 16 hours can be lost.

Reactor facilities seldom have multiple crews that are trained and experienced in handling heavy casks. For example, Carolina Power and Light cask handling crews work two 10-hr shifts each day of a turnaround leaving four hours of dead time each day. However, in most cases the fuel handling crew works one shift per day, week days only.

Railroads require 12- and preferably 24-hr notification in advance of picking up a car. Uncertainties surrounding the release of casks for shipment have delayed the issuing of this notification until the cask is pronounced clean. As indicated above, this procedure can add at least 12 hr to the turnaround time.

Casks have sometimes been left standing without attention when they have arrived at a reactor facility during an unplanned plant outage. The fuel handling staff generally have other assigned tasks during such outages that take precedence over spent fuel handling.

The following section contains recommendations that address the problems discussed above.

6.0 RECOMMENDATIONS

Significant reductions in turnaround times, cask handling labor and radiation doses associated with spent fuel handling can be achieved by taking advantage of the properties of long-cooled spent fuel. A new generation of rail and truck casks specifically designed for long-cooled spent fuel should be built. Not only will these casks have improved handling characteristics but they promise to have as much as twice the payload of existing casks. Since existing casks will be required to meet the transportation needs during the five to nine years required to deploy the new generation of casks, the productivity of the existing cask fleet should be improved by modifying cask handling procedures and, in some cases, by modifying the cask system. In addition, a standardized surface contamination test should be developed. Finally, greater attention should be paid to cask handling requirements during power plant siting and design.

Studies performed by AGNS(3) have resulted in a number of recommendations relating to cask vehicle and facility designs and cask handling procedures which are generally compatible with the following recommendations.

6.1 CASK DESIGN AND HANDLING

Most of the following recommendations apply to new casks, as well as one or more existing cask designs if long-cooled fuel is shipped.

6.1.1 Overpacks and Contamination Barriers

The need to decontaminate the surface of the cask during the loading or unloading of spent fuel has been identified in Section 5.0 as the problem which has been primarily responsible for the increase in turnaround time during recent years. In addition, the possible necessity of disposing of road dirt in low-level burial grounds exists since its contamination from contact with the cask surface is possible. Current decontamination procedures also produce significant quantities of low-level solid waste.

Contamination barriers can be a partial solution to the problem. The TN-8/9 cask system makes use of one and has performed well in Europe. However, a significant portion of the cask surface must still be decontaminated. Since, the contamination barriers themselves become contaminated, they pose handling and storage problems (particularly if the number of cask designs is allowed to increase) and significant close proximity cask handling is required to put them on and take them off. Contamination barriers appear to be a solution for casks designed for short-cooled fuel which have extended heat transfer surfaces, but they may not the best answer for long-cooled fuel.

The solution proposed here is the use of overpacks wherever possible. Overpacks should be feasible from a thermal standpoint for long-cooled fuel. Weight limitations may pose problems with current truck casks, but not with truck casks specifically designed for long-cooled fuel. The overpack does not need to be particularly strong. All that is required is reasonable protection from the elements. This philosophy should be kept in mind, particularly when designing overpacks for trucks.

Surface contamination is an insignificant portion of the direct dose; it only poses a problem in that it may be removed from the cask and contaminate something in an unrestricted zone. An overpack that contains the surface contamination that falls off the cask could meet all regulatory requirements. Consequently, surface contamination of the cask could be allowed to reach to considerably higher levels than are currently permitted. Decontamination could be achieved by remote washing with high pressure water sprays applied to the cask as it is removed from the fuel basin. The exterior surfaces of the overpack would not, under ordinary conditions, require decontamination.

The use of overpacks will reduce turnaround times in two ways: 1) by reducing decontamination times, and 2) by allowing an accurate prediction of when a cask will be ready to ship. The latter is especially important with rail casks, because it will eliminate the 12- to 24-hr wait that is now required because of the time lag between notification of the railroad and the time the rail cask car is picked up. For example, the 32-hr estimate for the existing IF-300 rail cask added to a minimum of 12-hr waiting for pickup gives a total turnaround time of 44 hr; with an overpack the return trip could be scheduled in advance thus eliminating the 12-hr wait. Additional time savings accrue because less time will be required to check the cask for contamination upon receipt (spot checking of the overpack with immediate processing of the cask while taking the radiation readings will suffice) and the need to remove road dirt will be eliminated, all of which shorten turnaround time.

Consideration should be given to using solid neutron absorbing materials, such as borated fiberglass-reinforced phenolic foam, for advanced rail overpacks. The neutron absorbing overpack could eliminate the need to use antifreeze solutions and their required surge tanks as neutron shielding.

Another important advantage of overpacks is that they keep road dirt away from the cask. Thus, the need to clean the cask is eliminated as is the need for low-level waste disposal of road dirt.[a]

6.1.2 Surface Area Minimization

Casks used for long-cooled fuel should have smooth exterior surfaces to minimize contamination. For example, the fins on the NLI-10/24 could be removed to make a long-cooled fuel version of that cask. Similarly, the finned surface of the IF-300 could be enclosed by a smooth, permanently attached, leak proof metal cover.

6.1.3 Increased Capacity

There is every likelihood that significant improvements in both truck cask and rail cask payloads can be obtained. The lower radiation and thermal loads of long-cooled fuel may permit an increase in fuel cask capacity without major redesign. For example, preconceptual studies with the PACRAT code indicates that, even with the same cavity size and even after removal of the fins, the capacity of the NLI-10/24 cask could be increased from 10 PWR or 24 BWR fuel assemblies to 12 PWR of 34 BWR fuel assemblies. Larger payloads appear possible with redesign; the PACRAT code indicates that a cask similar in size and weight to the NLI/10-24 but with a cavity diameter of 55 in. instead of

(a) Tarps are recommended for casks without overpacks to eliminate the need for disposing of radioactive dirt.

45 in. could be built to carry about twice the number of fuel assemblies (again, no cooling fins are required). A cask/overpack combination optimized specifically for aged fuel might have an even larger capacity. Similarly, studies conducted by Exxon indicate that legal weight truck casks with twice the payload of existing legal weight casks appear feasible for fuel cooled five years.(13)

A study should be made to determine the optimum fuel age for which to design a new generation of casks in order to prevent early obsolescense of the cask design. Inputs from industry, regulatory bodies and transportation entities should be sought.

6.1.4 Dry Shipment

Long-cooled fuel should be shipped "dry", in an air atmosphere at roughly atmospheric pressure. There is no need for complete dryness of cask interiors or for absolute leak tightness. All that need be guaranteed is spill prevention and the absence of sufficient moisture to give overpressure problems during a fire accident. The requirements for valve box covers for current generation casks are based on preventing damage to valves through which contaminated water might be released from the cask interior during an accident. If long-cooled fuel is shipped dry, the philosophy of using valve covers should be reevaluated.

6.1.5 Cask Closure Gaskets and Heads

Considerable room for improvement exists for making head seals which are easier to assemble. The AGNS recommendations(3) about loosening up dimensional tolerances so that the heads can be more easily placed upon the casks apply here. The promising concept of reducing head bolt torquing requirements by hydraulically preloading the cask head is under investigation at the General Electric Company Morris Operation.

The use of wedge type seals, such as those used with autoclaves, should also be investigated. If feasible, these would permit rapid cask closure with little or no close proximity handling.

Since long-cooled fuel can be shipped dry (or in the case of the NLI-10/24 cask, helium does not have to be used to assist in heat transfer), the seal system may be amenable to simplification on casks specifically designed for long-cooled fuel. Thus, the closure requirements should reflect what is actually required for dry shipped long-term fuel. A study to determine what these requirements are should receive high priority as they may lead to simpler cask closure methods.

6.1.6 Basket Preloading

A significant amount of time is required to load the fuel into or remove fuel from large capacity casks as it takes about 10 min per BWR fuel assembly and 20 min per PWR fuel assembly. Loading of the casks then would consist of removing an empty basket from the cask and loading a full basket. Appropriate criticality checks can be made when the fuel is loaded into the basket. Basket preloading permits the reactor crew to move and load fuel prior to the arrival of the cask, thus, reducing peak crew size and speeding up turnaround.

Basket preloading also offers advantages at the receiving site. Conceivably, the spent fuel would be stored in the basket until it is disposed of or reprocessed. In any event, separating the basket unloading procedure from the cask unloading procedure offers increased operating flexibility. Basket preloading will require licensing review and amendment.

6.1.7 Neutron Shielding

If possible, liquid neutron absorbers should not be used as the complexities of surge tanks complicates turnaround procedures. Water-extended polyester offers promise as an alternative to the use of water-antifreeze solutions.

6.1.8 Auxiliary Cooling System

The redundant cooling systems used with the IF-300 and the NLI-10/24 are used only to keep the fuel cool enough to unload immediatedly; they are an operational convenience, not a licensing requirement. These cooling systems not only add considerably to handling time and system complexity, but the blower warning alarms on the IF-300 system have the effect of making the IF-300 cask a special handling item as far as the railroads are concerned. These cooling systems need not be used on casks other than those used for short-cooled fuel.

6.1.9 Electropolishing

Current generation shipping casks often have surfaces which are pitted and marred providing places where contamination cannot be easily removed. In addition, reactor crud activation products are ground into the surfaces which are under compressive load when in the basin (such as the trunnions and the bottom of the cask). The use of electropolishing as a method for providing a smooth cask surface and as a method for removing, if necessary, contamination from the surface of the casks (when no overpack is used) should be investigated. The amount of material that is contaminated during submergence in the pool should be minimized by the use of removable impact limiters.

6.2 FACILITY OPERATIONS

The lack of rail sidings at a number of operating reactors suggests that greater attention needs to be paid to the needs of spent fuel handling during site selection. The same is true during facility design because inadequate space and cask handling facilities are found at some reactors. It is clear that the lack of any standardization of maximum cask weight, dimensions, or handling requirements has made the facility designer's task difficult in the past. A standardized cask handling requirement to which all future casks will be built should be developed to aid power plant fuel handling facility design. This standardized cask handling requirement would include space and clearance requirements, as well as specifications for auxiliary equipment such as the lifting capacities and transit speeds of cranes. During plant site selection, greater attention should be paid to whether or not the site has adequate rail service, including the ability to deliver cask cars with proper orientation and possibly to handle trains of several cask cars.

The cask design and procedural improvements discussed above would permit the transportation of spent fuel economically and safely within current regulations. However, cask turnaround times and handling costs could be significantly reduced with no reduction in safety by developing a uniform test for surface contamination which gives rapid results. Currently the nonuniformity between instruments and techniques used by the shipper and receivers cloud the meaning of test results. The increasingly common utility practice of sending samples to their counting room rather than using meters in the vicinity of the cask typically adds eight hours to turnaround times. Thus, the highest priority should be given to developing a standardized surface contamination test procedure with specified instrumentation which permits rapid and consistent interpretation by all involved.

6.3 SYSTEM OPERATION

A major opportunity for system improvement may involve the innovative use of unit trains to ship spent fuel. The advantages of unit trains include shorter transit times, the possibility of using traveling cask-handling crews that are expert in the handling of spent fuel and the opportunity to carry a small but potentially crucial inventory of spare parts for casks and handling equipment. The disadvantages of unit trains include a greater overall turnaround time (unless only one cask is used) and increased costs arising from the dedicated use of locomotives, and associated equipment.

Mean transit speeds vary greatly from site to site; therefore, so does the economics of unit trains. Philosophy of cask handling also varies as the plant operators may opt either for "one big push" or a "handle them as they come in" approach. Thus, in the absence of regulatory actions to the contrary, the value of unit trains will be site-dependent. It is not clear whether the recommendations made within this report will make unit trains more or less competitive. On the other hand, the recommendations, if followed, will also make spent fuel even more of a material that can be routinely transported in regular freight trains as well as making use charges on spent fuel casks lower for a given amount of fuel.

The analysis in Appendix A provides some perspective on the unit train option. Figures 6.1 and 6.2 show average train speed versus one way transit-time and distance, respectively, for the 1986 spent fuel transportation scenario indicated in Table A.1. Average train speeds of about 6 mph are common throughout most of the country, the exception being the 14 ± 2-mph average speed of the western railroads. The better performance of the western

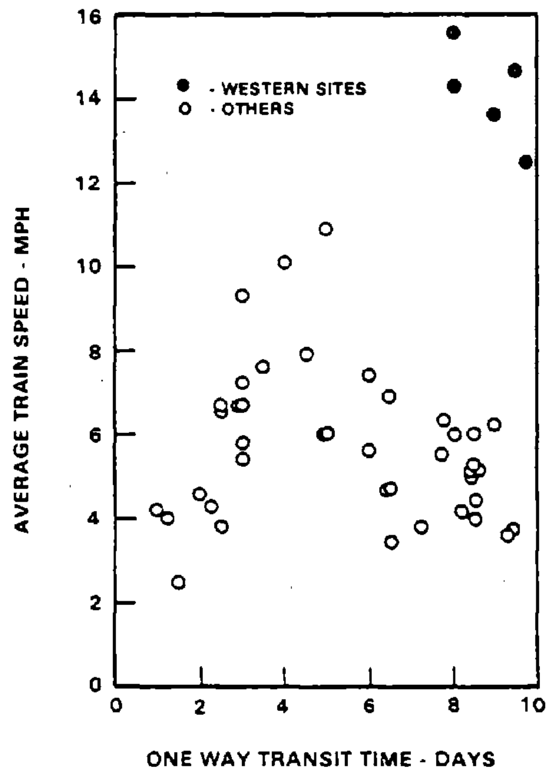

FIGURE 6.1. Average Train Speed as a Function of One Way Transit Time

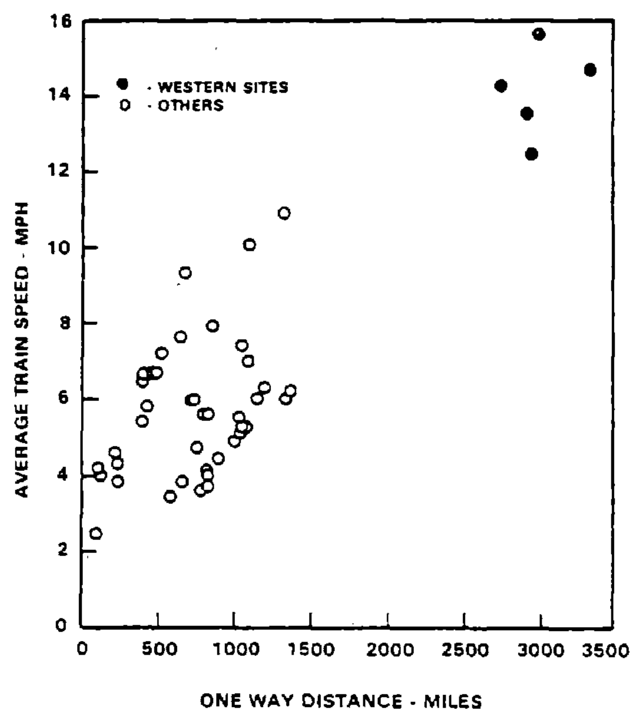

FIGURE 6.2. Train Speed versus Haulage Distance

railroads is apparently due to longer single-line hauls requiring fewer interline transfers. This variation of rail speeds with geographic locations has several significant implications. Unit trains are much more likely to be desirable in the eastern states because of the low transit speeds found there for regular freight. The relatively higher speed of western railroads suggests that unit train cars would be only marginally more productive than cars in regular freight.

The use of special train service for shipping radioactive materials is the subject of litigation in the courts and has created adversary positions between the railroads and the utility industry and DOE.[14] This study recognizes some attributes of dedicated train use that may warrant further consideration in the planning and design of future nuclear transfer systems. The concept of using a unit train to take up to several years' worth of reactor's spent fuel in one operation has merit and should be investigated. It should be possible to carry a complete set of spares on such a train. A crew of licensed cask handlers who assist in the operation could considerably reduce costs and operational uncertainties. The advantage of lessened impact on the public from fewer shipments is an important consideration.

The use of an intermodal system including waterway transportation is also worthy of consideration. Waterway transportation is generally slower than overland modes. However, some reactors have direct access to the nation's river system. An intermodal rail/water or road/water transport system could open up crucial alternative routing in the event that states, or local authorities, continue to restrict the overland transport of spent fuel. While productivity in terms of casks per year would probably decrease on a route with waterway linkage, the overall effectiveness and capacity of the system could be improved by intermodal transportation.

7.0 SYSTEM BENEFITS FROM IMPLEMENTING RECOMMENDATIONS

It is expected that a broad range of system benefits will result from implementing the recommendations made in Section 6. These recommendations offer the potential of reducing spent fuel transportation costs and the radiation exposure of cask handling personnel. A generally more viable future system is projected in which a potentially smaller cask fleet, than that based on current capacity, would service the nation's reactors.

This section contains the results of a scoping analysis to determine the potential value of applying these recommendations. While it is acknowledged that a more detailed evaluation would be required before implementation decisions can be made, the analysis below shows encouraging trends that should motivate further study and development. The following comparisons show the reductions in turnaround time that are estimated to result if the recommendations of this report are applied to 1) existing casks, 2) modified casks based on existing designs and 3) new generation cask concepts.

7.1 RAIL CASK TURNAROUND

Table 7.1 displays estimated turnaround times for the existing cask and four modifications based on the IF-300, showing the progressive incorporation of features recommended in Section 6. The turnaround times are estimated by taking account of the time that might be saved as a result of using each new feature and subtracting these times from a 32 hour baseline value.

Turnaround time for short-cooled fuel could be reduced from 32 hours to approximately 24 hours by using a contamination barrier (Case II in Table 7.1). When long cooled fuel is transported, further reductions are possible. With dry shipment, and the use of tarps and a contamination barrier (Case III) turnaround time could be reduced to 23 hours. An overpack with the removal of external cooling equipment, and use of basket preloading may permit (Case IV) a further reduction in turnaround time to about 16 hours. A new cask for long cooled fuel, based on the IF-300 design (Case V) could conceivably be turned around in 12 hours, if the incentive to do so develops.

TABLE 7.1. Estimated Turnaround Times for Rail Casks

		Turnaround Time, Hrs.
I.	Existing Procedures (IF-300 Cask)	32
II.	Existing Cask (IF-300) with Six-Month Cooled Fuel • Existing procedure except contamination barrier used (requires that cask surface be decontaminated to 10CFR71 limits)	24
III.	Existing Cask (IF-300) with Long Cooled Fuel Same as I except: • Contamination barrier • Shipped dry, i.e., water drained from primary cavity (therefore no water sampling) • Cask tarped to keep surface clean and free from road dirt • External cooling not operating	22
IV.	Modified IF-300 with Long Cooled Fuel • Personnel barrier modified to form an overpack (decontamination of cask limited to high pressure water sprays followed by drying) • Cask shipped dry, therefore no water sampling • Basket preloading used • External cooling equipment removed	16
V.	New Cask Design Long Cooled Fuel Based on Cask IV with: • Overpack • Decontamination of cask surface limited to high pressure water sprays followed by drying • Basket preloading • Improved cask closure • Standardize contamination testing procedure used	12

7.2 TRUCK CASK TURNAROUND

In a similar manner, turnaround times for the NAC-1/NFS-4 cask were estimated for a series of progressive improvements recommended in Section 6. These improvements are shown as Cases II through V in Table 7.2 and result in the progressive reduction of turnaround time from 13 to 6 hours.

7.3 RAIL AND TRUCK CASK TURNAROUND AND PRODUCTIVITY SUMMARY

A summary comparison of turnaround times and productivity changes for both rail and truck casks is shown in Table 7.3. Productivity was estimated on the basis of payloads per cask year using the methods described in Appendix A. The relative productivity increase is shown as a percentage of the baseline values (Case I).

The existing IF-300 rail cask and the NAC-1/NFS-4 truck cask show increased productivity for each modification level considered. The values for the NLI-10/24 cask were obtained by assuming turnaround times similar to those of the IF-300. The estimates for the NLI-10/24 are somewhat more speculative because no operational experience has been generated with this cask. The methodology of this analysis does not show the NLI-10/24 to benefit from Case II or Case III modifications. All cask modifications designed specifically for long-cooled fuel and next generation derivative designs show worthwhile productivity improvements. The range of increased productivity is from 10% to 220% depending upon cask type and modification.

As indicated previously, other values can be expected to result if the recommendations made here are carried out. Cask costs can probably be reduced or at least be held constant with inflation because of lower shielding requirements and simpler overall designs that are associated with long-cooled fuel. These in turn lead to significant reductions in cask handling labor and in the exposure of cask handlers to radiation. From the perspective gained by this analysis, it appears there is much incentive to evaluate the recommendations of this report in detail as a further step towards implementing those which prove to be practical.

TABLE 7.2. Estimated Turnaround Times for Legal Weight Truck Casks

		Turnaround Time-hours
I.	Existing Procedures	13
II.	Existing Cask - Short-Cooled Fuel (NAC-1 or NFS-4) Same as Case I except: • Contamination barrier	11-12
III.	Existing Casks - Long-Cooled Fuel (NAC-1 or NFS-4) Same as Case I except: • Contamination barrier • Shipped dry (therefore no water sampling) • Cask tarped to keep surface clean and free from road dirt	10
IV.	Modified Existing Casks - Long-Cooled Fuel Same as Case I except: • Personnel barrier modified to act as overpack (therefore cask decontamination limited to high pressure water sprays followed by drying) • Shipped dry (therefore no water sampling)	8
V.	New Cask Design - Long-Cooled Fuel Same as Case IV except: • Overpack • Decontamination of cask surface limited to high pressure water sprays followed by drying • Improved cask closures • Standardized contamination testing procedure followed	4-6

TABLE 7.3. Summary Comparison of Turnaround Times and Cask Productivity

	Legal Weight Truck Cask (NACI/NSF-4)		Rail Cask (IF-300)		Rail Cask (NLI-10/24)	
	Turnaround Time-hours	Productivity Increase - %	Turnaround Time-hours	Productivity Increase - %	Turnaround Time-hours	Productivity Increase - %
Existing Casks with Current Procedures	13	0	32	0	24	0
Existing Cask - Short Cooled Fuel	11-12	10	24	18	24	0
Existing Cask - Long Cooled Fuel	10	35	22	18	22	0
Modified Existing Cask - Long Cooled Fuel	8	50	16	31	16	8-30[a]
New Cask - Long Cooled	4-6	60-220[b]	12	46-192[b]	12	17-134[b]

(a) Assuming a 20% increase in cask payload.
(b) Assuming a doubling in a cask payload.

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APPENDIX A

SPENT FUEL TRANSPORTATION SYSTEM DESCRIPTION AND PERFORMANCE

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SPENT FUEL TRANSPORTATION SYSTEM DESCRIPTION AND PERFORMANCE

The purpose of this analysis is to give some perspective on the relative increase in cask productivity, (payloads/cask year) or conversely, the reduction in cask inventory that results if cask turnaround times are reduced from their present values. Since we are primarily interested in the effects that improvements in cask turnaround time will have on the required cask inventory and only secondarily interested in the absolute magnitude of the transportation system required, it is not necessary to conduct a systems study that encompasses a long time span, or for that matter, gives highly accurate predictions of the number and locations of shipments involved. Thus, the transportation system used in Reference A.1 which considered fuel shipments likely to be made in 1986, is adequate for comparison purposes.

The transportation system scenario (Table A.1) consists of 50 reactor sites having a total of 90 reactors with spent fuel shipped to AFRs located at Oak Ridge, TN, and at Barnwell, SC. Additional data on the railroad system feeding the fifty reactor sites and the two AFRs are given in Table A.2.

An equivalent truck transportation grid was generated from the information presented in Table A.1 Highway distances were obtained from Rand McNally Road Atlas (Reference A.2). Annual truck cask shipments from each site were generated from the number of annual rail cask shipments given in Table A.1 by using the cask capacities for rail and truck casks given in Table A.3. The results are given in Table A.4.

A combination of truck and rail casks will be used in practice. However, for the purpose of this analysis, it suffices to consider only the two extremes; rail casks only and truck casks only.

TABLE A.1. Plants Shipping Spent Fuel in 1986

O/D No.	Plant	Shipments	Origin	Originating Rail Service	Destination
1	Arkansas 1,2	11	Russellville, AR	Missouri Pacific	Oak Ridge, TN
2	Bailly	4	Gary, IN	Chicago South Shore & South Bend	Oak Ridge, TN
3	Beaver Valley 1,2	9	Shippingport, PA	New Cumberland & Pittsburg	Barnwell, SC
4	Braidwood 1,2	11	Braidwood, IL	Illinois Central Gulf	Oak Ridge, TN
5	Brunswick 1,2	11	Southport, NC	Seaboard Coast Line	Barnwell, SC
6	Commanche Peak 1,2	11	Somerville County, TX	Atchison, Topeka & Santa Fe	Oak Ridge, TN
7	Cook 1,2	11	Benton Harbon, MI	Chesapeake & Ohio	Barnwell, SC
8	Cooper	6	Brownville, NB	Burlington Northern	Oak Ridge, TN
9	Crystal River	6	Red Level, Tampa, FL	Seaboard Coast Line	Barnwell, SC
10	Davis Besse 1,2	11	Oak Harbon, OH	Norfolk & Western	Barnwell, SC
11	Duane Arnold 1	4	Cedar Rapids, IA	Chicago, Rock Island & Pacific	Barnwell, SC
12	Enrico Fermi 2	7	Monroe, MI	Conrail	Oak Ridge, TN
13	Farley 1,2	14	Dothan, AL	Seaboard Coast Line	Barnwell, SC
14	Fort Calhoun 1,2	8	Blair, NB	Chicago & Northwestern	Barnwell, SC
15	Fitzpatrick 1	6	Oswego, NY	Conrail	Barnwell, SC
16	Forked River 1	7	Toms River NJ	Conrail	Oak Ridge, TN
17	Ginna 1	4	Rochester, NY	Penn Central	Barnwell, SC
18	Hatch 1,2	12	Baxley, GA	Southern	Oak Ridge, TN
19	Hope Creek 1,2	15	Bordentown, NJ	Conrail	Oak Ridge, TN
20	LaSalle 1,2	14	Seneca, IL	Atchison, Topeka & Santa Fe	Oak Ridge, TN
21	Limerick 1,2	15	Pottstown, PA	Conrail	Oak Ridge, TN
22	Maine Yankee	6	Portland, ME	Main Centrail	Barnwell, SC
23	McGuire 1,2	11	Charlotte, NC	Seaboard Coast Line	Barnwell, SC
24	Midland 1,2	11	Midland, MI	Chesapeake & Ohio	Oak Ridge, TN
25	Millstone 1,2,3	16	Hartford, CT	Penn Central	Barnwell, SC
26	Monticello	5	Monticello, MN	Burlington Northern	Oak Ridge, TN
27	North Anna 1,2,3,4	20	Mineral, VA	Chesapeake & Ohio	Barnwell, SC
28	Oconee 1,2,3	23	Seneca, SC	5 mile (truck) to Southern	Barnwell, SC
29	Oyster Creek 1	6	Toms River, NJ	Conrail	Barnwell, SC
30	Palisades	8	South Haven, MI	Chesapeake & Ohio	Barnwell, SC
31	Peach Bottom 2,3	18	Peach Bottom, PA	Maryland & Pennsylvania	Barnwell, SC
32	Prairie Island 1,2	6	Redwing, MN	Chicago, Milwaukee, St. Paul & Pacific	Oak Ridge, TN
33	Quad Cities 1,2	11	Cordova, IL	Chicago, Milwaukee, St. Paul & Pacific	Oak Ridge, TN
34	Rancho Seco	5	Sacramento, CA	Southern Pacific	Oak Ridge, TN
35	Robinson 2	5	Hartsville, SC	Seaboard Coast Line	Barnwell, SC
36	San Onofre, 1,2,3	16	San Clemente, CA	Atchison, Topeka & Santa Fe	Barnwell, SC
37	Sequoyah 1,2	11	Chattanooga, TN	Southern	Barnwell, SC
38	Susquehanna 1,2	14	Shickshinny, PA	Conrail	Oak Ridge, TN
39	Three Mile Island, 1,2	11	Middletown, PA	Conrail	Barnwell, SC
40	Trojan	6	Ranier, OR	Burlington Northern	Oak Ridge, TN
41	Virgil Summer	6	Jenkinsville, SC	Southern	Barnwell, SC
42	Vermont Yankee	4	Vernon, VT	Central Vermont	Barnwell, SC
43	Waterford	6	Norco, LA	Texas and Pacific	Oak Ridge, TN
44	Watts Bar 1,2	11	Spring City, TN	Southern	Oak Ridge, TN
45	WPPSS 1,2,3,4,5	32	Richland, WA	Chicago, Milwaukee, St. Paul & Pacific	Barnwell, SC
46	Zion 1,2	11	Zion, Chicago, IL	Chicago & Northwestern	Barnwell, SC
47	Turkey Point 3,4[(a)]	13	Florida City, Miami, FL	9 mile (truck) to Florida East Coast	Barnwell, SC
48	St. Lucie 1,2[(a)]	14	Fort Pierce, FL	9 mile (truck) to Florida East Coast	Barnwell, SC
49	Browns Ferry 1,2,3[(a)]	30	Athens, AL	9 mile (truck) to Soutnern.	Barnwell, SC
50	Humboldt Bay	3	Eureka, CA	Northwestern Pacific	Barnwell, SC

(a) Requires truck and rail shipment using IF-300 casks. All others use NLI-10/24 Casks.

TABLE A.2. Summary of Estimated Train Miles and Regular Train Transit Times[a]

Territory	O/D No.	Origin	Destination	Originating Railroad	Estimated Train Miles[b]	Estimated Regular Train Transit Time, Days[b]
North Pacific Coast	40	Rainier, OR	OR	BN	2,920	9-3/4
	45	Richland, WA	B	MILW	2,940	9
Pacific South Coast	50	Eureka, CA	B	NWP	3,340	9-1/2
	34	Sacramento, CA	OR	SP	2,990	8
	36	San Clemente, CA	B	ATSF	2,740	8
Southwestern	1	Russellville, AR	OR	MP	850	4-1/2
	6	Somerville, County, TX	OR	ATSF	1,310	5
Western Trunk Line	26	Monticello, MN	OR	BN	1,180	7-3/4
	32	Redwing, MN	OR	MILW	1,080	6-1/2
	14	Blair, NB	B	CNW	1,340	9
	8	Brownville, NB	OR	BN	1,020	7-3/4
	11	Cedar Rapids, IA	B	RI	1,150	8
Illinois Freight Association	4	Braidwood, IL	OR	ICG	720	5
	20	Seneca, IL	OR	ATSF	725	5
	46	Zion, IL	B	CNW	1,060	6
	33	Cordova, IL	OR	MILW	810	6
Southern	37	Chattanooga, TN	B	SOU	390	2-1/2
	44	Spring City, TN	OR	SOU	100	1
	23	Charlotte, NC	B	SCL	230	2-1/4
	5	Southport,NC	B	SCL	230	2-1/2
	35	Hartsville, SC	B	SCL	120	1-1/4
	41	Jenkinsville, SC	B	SOU	90	1-1/2
	28	Seneca, SC	B	SOU	220	2
	18	Baxley, GA	OR	SOU	420	3
	9	Red Level Junction, FL	B	SCL	390	3
	48	Fort Pierce, FL	B	FEC	480	3
	47	Florida City, FL	B	FEC	640	3-1/2
	13	Dothan, AL	B	SCL	400	2-1/2
	49	Athens, AL	B	SOU	520	3
	27	Mineral, VA	B	CO	480	3
General	15	Oswego, NY	B	PC	1,070	8-1/2
	17	Rochester, NY	B	PC	1,040	8-1/2
	21	Pottstown, PA	OR	RDG	660	7-1/4
	38	Schickshinny, PA	OR	EL	810	8-1/4
	3	Shippingport, PA	B	?	890	8-1/2
	39	Middletown, PA	B	PC	740	6-1/2
	31	Peach Bottom, PA	B	MPA	730	6-1/2
	16	Toms River, NJ	OR	CNJ	820	9-1/4
	29	Toms River, NJ	B	CNJ	810	8-1/2
	19	Bordentown, NJ	OR	PC	790	9-1/4
	30	South Haven, MI	B	CO	1,060	n.d.
	24	Midland, MI	OR	CO	640	n.d.
	7	Benton Harbor, MI	B	CO	1,030	n.d.
	12	Monroe, MI	OR	PC	530	6-1/2
	10	Oak Harbor, OH	B	NW	1,090	4-1/2
	2	Bailey Town, (Gary) IN	OR	CSS	560	n.d.
New England	22	Portland, ME	B	MEC	1,230	8-1/2
	42	Vernon, VT	B	CV	1,060	8-1/2
	25	Hartford, CT	B	PC	1,000	8-1/2

(a) From Reference A.1.
(b) Regular train transit times listed for general and New England territories are preliminary estimates. All data were obtained from direct contact with railroad companies.

TABLE A.3. Spent Fuel Cask Capacities

Cask	Transportation Type	No. of PWR Assemblies	No. of BWR Assemblies
IF-30C	Intermodal	7	18
NLI-10/24	Rail	10	24
NLI-1/2	Truck (legal weight)	1	2
NAC-1	Truck (legal weight)	1	2
NFS-4	Truck (legal weight)	1	2
TN-8	Truck (overweight)	3	N/A
TN-9	Truck (overweight)	N/A	7

TABLE A.4. Truck Miles and Shipments (1986)[a]

O/D No.	Plant	Reactor Type	Highway Miles	Annual Cask Shipments Legal Weight	Overweight
1	Arkansas 1,2	PWR	560	110	37
2	Bailly	BWR	570	48	14
3	Beaver Valley 1,2	PWR	660	90	30
4	Braidwood 1,2	PWR	610	110	37
5	Brunswick 1,2	BWR	220	132	38
6	Comanche Peak 1,2	PWR	910	110	37
7	Cook 1,2	PWR	920	110	37
8	Cooper	BWR	1,060	72	21
9	Crystal River	PWR	360	60	20
10	Davis Besse 1,2	PWR	820	90	30
11	Duane Arnold 1	BWR	1,070	48	14
12	Enrico Fermi 2	BWR	500	84	24
13	Farley 1,2	PWR	340	140	47
14	Fort Calhoun 1,2	PWR	1,240	80	27
15	Fitzpatrick 1	BWR	930	72	21
16	Forked River 1	PWR	690	70	23
17	Ginna 1	PWR	940	40	14
18	Hatch 1,2	BWR	420	144	41
19	Hope Creek 1,2	BWR	690	180	52
20	LaSalle 1,2	BWR	630	168	48
21	Limerick 1,2	BWR	650	180	52
22	Maine Yankee	PWR	1,190	60	20
23	McGuire 1,2	PWR	190	110	37
24	Midland 1,2	PWR	640	110	37
25	Millstone 1,2,3	1 BWR/2 PWR	930	182	57
26	Monticello	BWR	1,060	60	17
27	North Anna 1,2,3,4	PWR	460	200	67
28	Oconee 1,2,3	PWR	180	161	54
29	Oyster Creek 1	BWR	760	72	21
30	Palisades	PWR	880	80	21
31	Peach Bottom 2,3	BWR	820	216	62
32	Prairie Island 1,2	PWR	1,010	60	20
33	Quad Cities 1,2	BWR	680	132	38
34	Rancho Seco	PWR	2,520	50	17
35	Robinson 2	PWR	150	50	17
36	San Onofre 1,2,3	PWR	2,410	160	53
37	Sequoyah 1,2	PWR	340	110	37
38	Susquehanna 1,2	BWR	830	168	48
39	Three Mile Island 1,2	PWR	650	110	37
40	Trojan	PWR	2,590	60	20
41	Virgil Summer	PWR	110	60	20
42	Vermont Yankee	BWR	990	48	14
43	Waterford	PWR	660	60	20
44	Watts Bar 1,2	PWR	80	110	37
45	WPPSS 1,2,3,4,5	4 PWR/1 BWR	2,960	357	115
46	Zion 1,2	PWR	890	110	37
47	Turkey Point 3,4	PWR	610	91	30
48	Saint Lucie 1,2	PWR	450	98	33
49	Browns Ferry 1,2,3	BWR	460	270	77
50	Humboldt Bay	BWR	2,980	36	10

(a) From Reference A.2.

A.1 SPENT FUEL TRANSPORTATION USING RAIL CASKS ONLY

Before discussing the number of rail casks which are required, some of the properties of the rail transportation system warrant discussion.

Figures A.1 and A.2 display average transit speed as a function of one-way transit time and of one-way distance. It is interesting to note that it can take as many days (8) to go 810 miles (site 38) as to go coast to coast (2,740 miles--site 36). Average train speeds of about 6 mph are common throughout most of the country, the exception being the 14 ± 2 mph average speed of the western railroads. The better performance of the western railroads is apparently due to longer single-line hauls requiring fewer interline transfers.

The number of casks required to move the fuel over the transportation system shown in Table A.1 is displayed in Figure A.3 as a function of total portal-to-portal turnaround time. NLI-10/24 casks are considered to be used

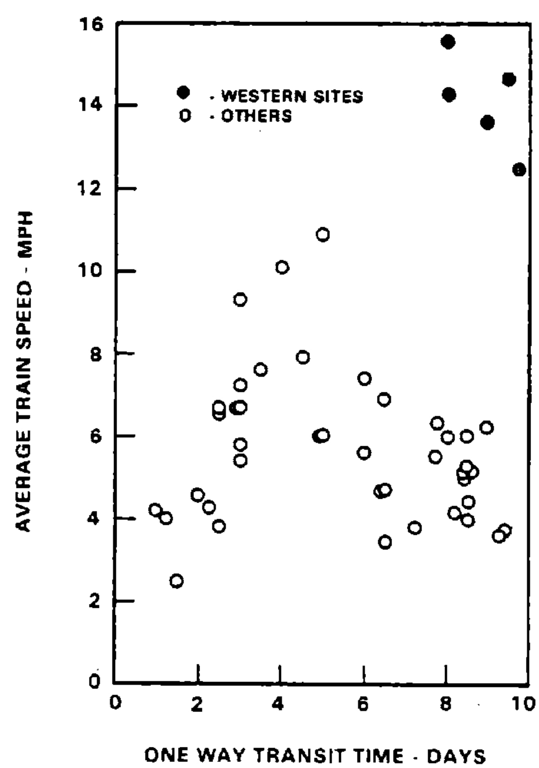

FIGURE A.1. Average Train Speed as a Function of One Way Transit Time

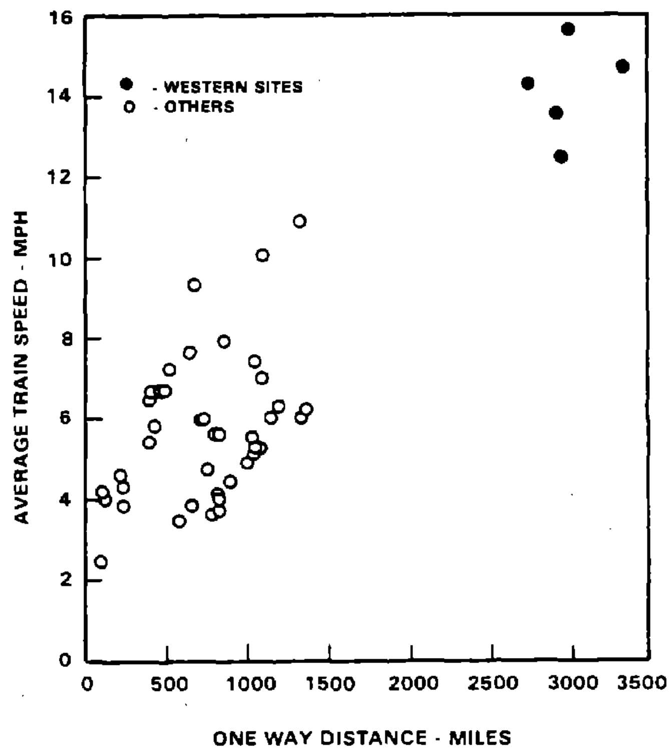

FIGURE A.2. Train Speed versus Haulage Distance

for those sites with rail service; IF-300 casks (which have intermodal capability) are used for the four sites without rail service (these sites are located five to nine miles from the nearest rail spur).

The results presented in Figure A.3 assume that the casks are in useful service 100% of the time (cask utilization factor of unity). In practice the cask utilized factor will be less than unity. The current surplus of casks has led to low values of cask utilization factor. For normal conditions, it is reasonable to assume that perhaps 45 days per year would be required for cask maintenance or otherwise lost due to scheduling problems. The cask availability factor would then be (365-45)/365 or 0.88. The number of casks required would then increase by 1/0.88 or 14%.

The values of cask turnaround time presented in Table A.5 can be used to estimate the number of rail casks of current design which would be required. The NLI-10/24 takes 22 hours to turn around. The AFR is assumed to work round

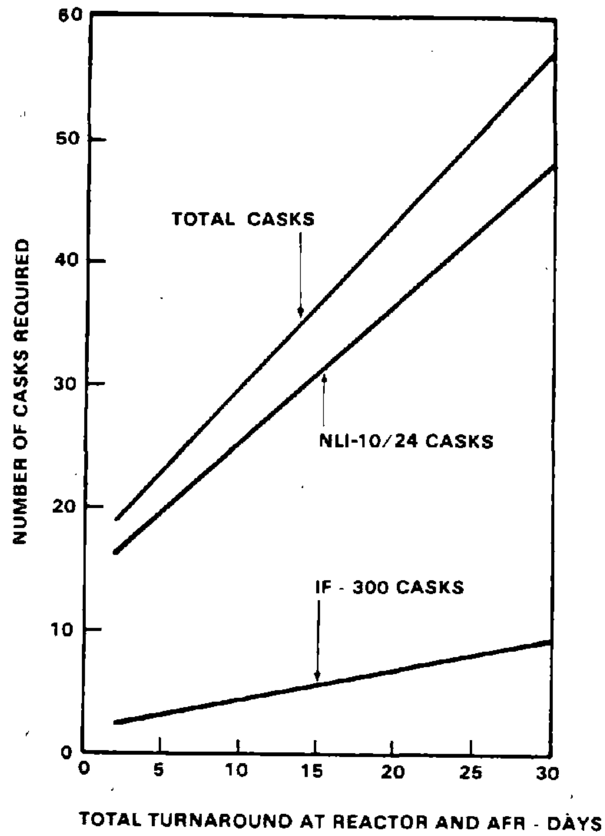

FIGURE A.3. Rail Cask Requirements

TABLE A.5. Effects of Cask Handling Time on Rail Cask Requirements

Action	Number of Casks Required[a] IF-300[b]	NLI-10/24	Total	Relative Productivity
None; current cask handling practices.	5	24	29	1.0
One day turnaround except no weekend cask handling at reactor; elimination of 12-hr delay for rail pickup.	3	19	22	1.32

(a) Cask utilization factor of 0.88 assumed.
(b) IF-300 casks service the four sites without rail service.

the clock. Assuming that work begins immediately upon receipt of the cask and that a 12-hour pick-up notification to the railroad is required, the portal-to-portal turnaround time at the AFR is 34 hours or approximately 1.5 days. The fuel handling crews of most reactors work only one shift per day, five days a week. Taking the effects of this into account for seven days of the week and again using a 12-hour pick-up notification indicates an average portal-to-portal turnaround time of 5 days. Adding the 1.5 days of turnaround at the AFR to the 5-day turnaround time at the reactor gives a total turnaround time of 6.5 days. Twenty-four NLI-10/24 casks are required if a cask utilization factor of 0.88 is assumed. Similar reasoning using a 35.5-hr turnaround for the IF-300 cask shows average portal-to-portal turnaround times of 2 days at the AFR and 6.5 days total turnaround time, 5 IF-300 casks are required to service those sites without rail service.

If 29 rail casks can service 90 reactors, a cask capital cost of $4,000,000 represents about $1,300,000 per reactor. This is a significant but certainly not large cost compared to the cost of the power plant.

A measure of the effects that improved turnaround time would have on the number of casks that would be required can be obtained by computing the number of NLI-10/24 and IF-300 casks that would be required if they had the turnaround characteristics of the advanced cask design proposed in Section 7. A rail version of the advanced cask design should be capable of being turned around in one day or less. In addition, an improved ability to predict when a cask will be ready for shipment will make it possible to notify the railroad before the cask is completely turned around, thereby eliminating the 12 hours spent waiting for the pickup. If the AFR works 7 days a week, the portal-to-portal turnaround time is one day. The reactor fuel handling crew is assumed to work only on weekdays; thus the average portal-to-portal turnaround time at the reactor is 1.5 days, giving 2.5 days in total. Applying a cask utilization factor of 0.88 to the results in Figure A.3 shows a need for 19 NLI-10/24 and 3 IF-300 casks (Table A.6). This is a reduction of 24% in the number of casks required or, conversely, the improved turnaround has increased the cask productivity by 32% for the entire fleet (Table A.5) or 67% for the IF-300 and 26% for the NLI-10/24 (Figure A.4). Thus, significant improvements in cask productivity can be made by reducing turnaround time.

TABLE A.6. Legal Weight Truck Casks--Portal-to-Portal Turnaround Time

	Portal-to-Portal Turnaround Time (hours)		
Cask Handling Time (hours)	AFR	Reactor (minimum)	Reactor (maximum)
4	4	4	68
8	8	8	72
12	12	28	92

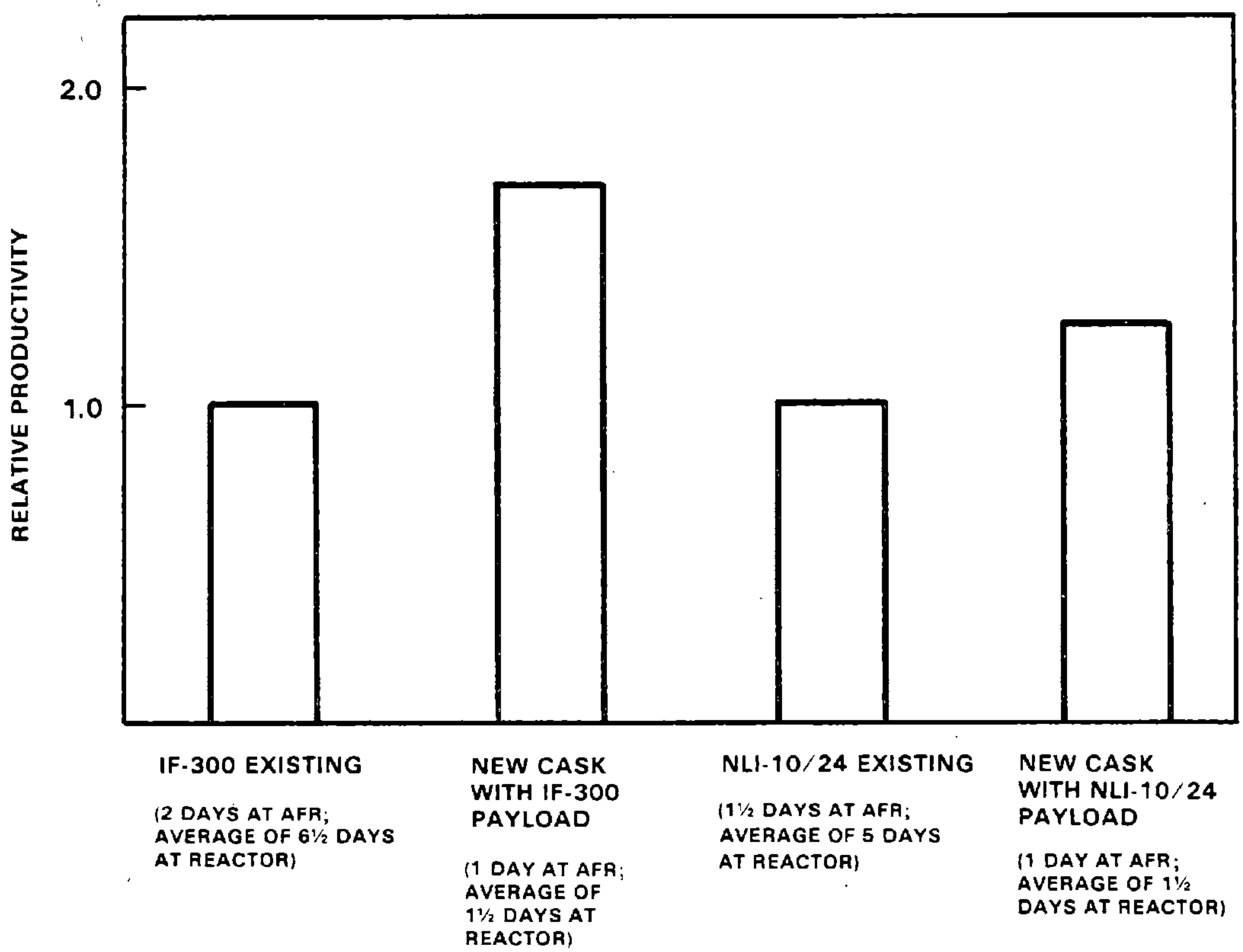

FIGURE A.4. The Effect of Cask Handling Time on Rail Cask Productivity

A.2 SPENT FUEL TRANSPORTATION USING TRUCK CASKS ONLY

Truck casks fall into two categories: legal weight and overweight. Overweight truck casks offer significant advantages because of their higher payloads; however, special permits are required and travel is generally restricted to weekdays and to daylight hours. An AGNS study[(A.3)] concludes that it will probably be difficult to obtain permission for overweight trucks in Connecticut, Pennsylvania, Maryland, Delaware, Iowa, Illinois, Indiana, Arkansas, Missouri, Tennessee and Mississippi. Even a cursory view of a map of the Unites States shows that if this assessment is correct, overweight shipments will be severely limited. The prohibition against nighttime and weekend travel applies to all overweight shipments, not only nuclear.

The average truck speed for legal weight trucks was assumed to be 38 mph. Thus, the transit time in hours was obtained by dividing the distance by 38. The over-the-road average speed for overweight loads is also 38 mph, but transit time is considerably longer because travel is allowed only during daylight hours, restricting travel to about 380 or 400 miles per day. For simplicity, a 10-hour day, 40-mph speed was used in the computations.

The fuel handling crew at the reactor was assumed to work one shift a day during weekdays only. The AFR was assumed to operate 24 hours per day, seven days a week. Both the reactor and AFR were assumed to begin processing the casks immediately upon arrival and the truck left as soon as the cask was ready (or conversely, any lost time of this nature is included in the cask handling time). These assumptions are identical to those used in the rail cask study.

Cask handling times of 4, 8 and 12 hours were studies for legal weight trucks. Since it is assumed that the AFR begins processing a cask immediately upon receipt, the equivalent portal-to-portal turnaround times are 4, 8 and 12 hours, respectively. The situation at the reactor is more complicated. If a cask arrives at the end of working hours on Friday, the processing of the cask will not begin until Monday morning. Thus, even with a 4-hour cask handling time, the portal-to-portal turnaround time would be 68 hr since the cask would not leave until noon Monday.

Maximum portal-to-portal turnaround for an 8-hr cask handling time is 72 hours. For the 12-hr cask handling time, a cask which arrived at the reactor at quitting time Friday would not leave until noon Tuesday giving a 92-hr maximum portal-to-portal turnaround time. Minimum and maximum portal-to-portal turnaround times are shown in Table A.5. This reasoning was used with a 38-mph average speed and the haulage distances given in Table A.4 to compute the cask cycles per week for each of the fifty sites. From this information and from the number of truck shipments required given in Table A.4, the legal weight truck cask requirements given in Table A.7 were computed.

TABLE A.7. Legal Weight Truck Cask Relative Productivity[a]

Cask Handling Time (hr)	Number of Casks	Relative Productivity[b]
4	48	1.60
8	55	1.40
12	77	1.00

(a) Unity cask utilization factor.
(b) Taken to be unity for 12-hour turnaround.

A similar approach was used for overweight truck casks except that cask handling times of up to 16 hr were considered. For daylight-only, weekdays-only travel, daylight was assumed to last 10 hr during which an average speed of 40 mph was achieved. The daylight shift of 8 hr was assumed to be centered during daylight hours (i.e., a truck at noon would have had 5 hr of useful travel time left that day and a cask would receive 4 hr of cask handling at a reactor). However, if a cask was ready to ship with only 1 or 2 hr of daylight remaining, the truck would not leave either a reactor or the AFR until the next morning. Using these ground rules, the portal-to-portal turnaround times shown in Table A.8 were obtained as a function of cask handling time.

TABLE A.8. Overweight Truck Casks--Portal-to-Portal Turnaround Times

Cask Handling Time	Portal-to-Portal Turnaround Time (hr) AFR Minimum	AFR Maximum	Reactor Minimum	Reactor Maximum
4	4	67	4	68
8	14	71	23	87
12	14	71	28	92
16	16	95	47	111

A 40-mph average speed was used to compute the cask cycles per week for each of the fifty sites. From this information and from the number of annual overweight truck shipments given in Table A.4, the overweight truck cask requirements given in Table A.9 were computed.

TABLE A.9. Overweight Truck Cask Relative Productivity (Referenced to TN-8/9 Requirements)[a]

Cask Handling Time	Number of Casks	Relative Productivity[b]
4	41	1.24
8	44	1.16
12	47	1.09
16	51	1.00

(a) Unity cask utilization factor.
(b) Taken to be unity for 16 hours turnaround.

Although overweight truck casks have larger payloads than legal weight truck casks, the travel restrictions imposed on them reduce their advantages considerably. At current cask turnaround times of 12 hr for legal weight casks and 16 hr for overweight casks, only 33% fewer overweight casks are required. However, overweight casks do require fewer trips and less cask handling labor per fuel assembly. Even with today's casks and cask handling procedures, the number of casks required is not large. For example, if a cask availability factor of 0.88 is assumed, only 88 legal weight or 58 overweight truck casks would be required. That is less than one cask per reactor.

A legal weight truck cask costs about $750,000 which comes out to be $733,000 per reactor; overweight truck casks cost about $1,500,000, which comes out to be $967,000 per reactor.

Cask handling time has a significant effect on cask productivity as shown in Figure A.5. Reducing the cask handling time of legal weight truck casks from the current 12 hr to 4 hr would increase the productivity of legal weight truck casks by 60%. A 4-hr reduction would give a 40% increase in productivity. The percentage increase in cask productivity, while significant, is not as large with the overweight truck casks. Reducing the cask handling time from 16 hr to 4 hr would increase overweight cask productivity by 24%.

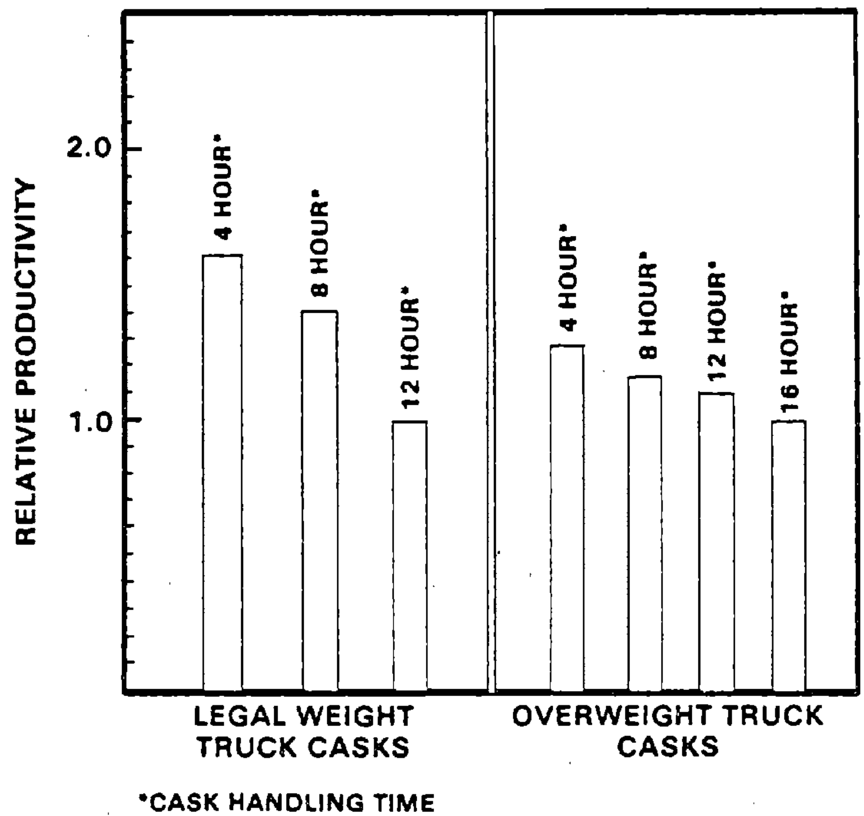

FIGURE A.5. The Effect of Cask Handling Time on Cask Productivity

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A.1. W. V. Loscutoff et al., A Safety and Economic Study of Special Trains for Shipment of Spent Fuel. BNWL-2263, Pacific Northwest Laboratory, Richland, WA, May 1977.

A.2. Rand McNally Road Atlas. 1973.

APPENDIX B

DETAILED DESCRIPTIONS OF THREE AVAILABLE RAIL AND TRUCK CASKS

APPENDIX B

DETAILED DESCRIPTIONS OF THREE AVAILABLE RAIL AND TRUCK CASKS

B.1 NLI-10/24[(B.1)]

The NLI-10/24 of National Lead Industries is a helium-filled rail cask capable of holding 10 PWR or 24 BWR fuel elements (Figure B.1). The approximate loaded cask weight is 88 metric ton (MT) (193,000 lb). The cask and cooling systems are transported on a special 18-m (59-ft) long, six-axle railroad flat car. Total weight of the system is about 152 MT (335,000 lb). The cask was licensed in 1976.

The cask has an overall length of 5.19 m (204.5 in.) and a diameter of 2.24 m (88 in.). The cask cavity has a length of 4.56 m (179.5 in.) and a diameter of 1.14 m (45 in.). Two interchangeable aluminum baskets provide a capability for transporting either PWR or BWR fuel assemblies.

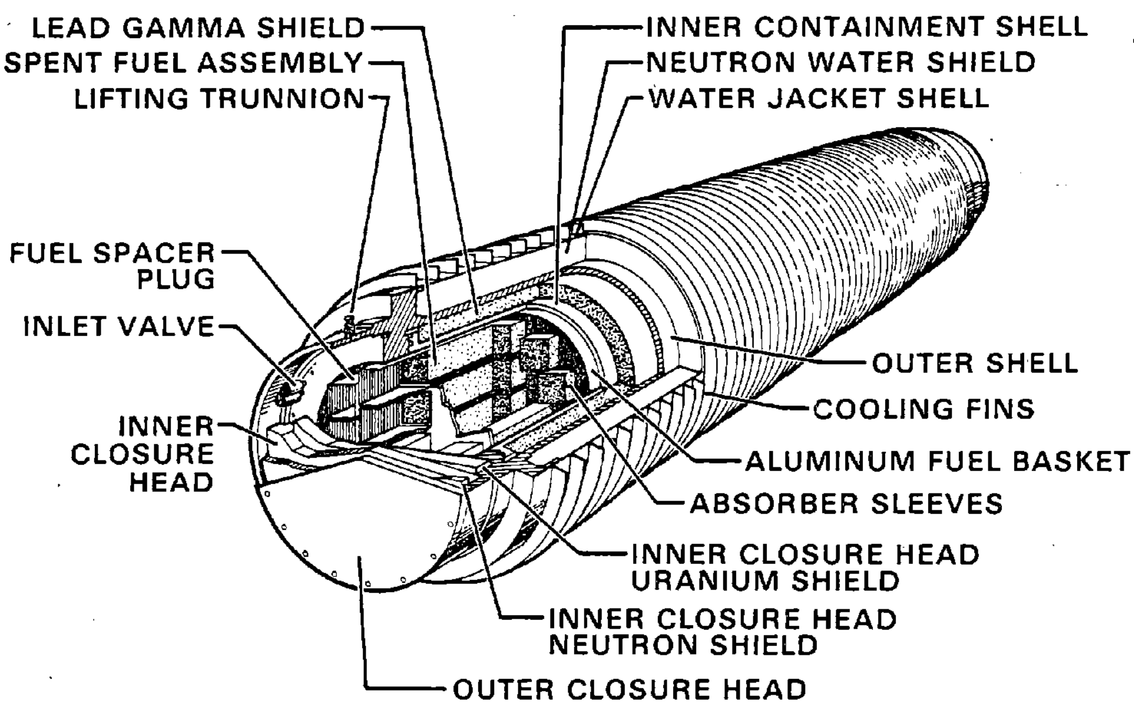

FIGURE B.1. NLI-10/24 Rail Cask Assembly

The cask body consists of an inner stainless steel shell 2-cm (3/4-in.) thick and an outer stainless steel shell 5-cm (2-in.) thick joined by stainless steel forgings at each end to make a continuous weldment. The annulus between the inner and outer shells contains a lead gamma shield 15-cm (6-in.) thick. Depleted uranium shielding is used on the ends of the cask and at strategic locations in the wall of the cask. Neutron shielding is provided by 23-cm (9-in.) of water contained in a finned stainless steel jacket surrounding the outer shell. Criticality control is provided by the stainless steel clad Ag-In-Cd liners of the aluminum fuel baskets. Balsa impact limiters at each end of the cask, in addition to the circumferential cooling fins, give impact protection.

B.2 GE IF-300[B.2]

The General Electric IF-300 spent fuel shipping cask is designed to ship 18 BWR (7 x 7 or 8 x 8) elements or 7 PWR (14 x 14 or 15 x 15) fuel elements irradiated to design exposures, and is shown in Figures B.2 and B.3.

The various loads are individually accommodated through the use of removable fuel baskets and two different length closure heads.

The cask weight when loaded is between 136,000 and 140,000 pounds depending on the particular type of fuel being shipped. The skid and cooling system weigh approximately 45,000 pounds.

The cask is mounted on the skid in a horizontal position during transport. Transportation is primarily by rail, although the skid is designed to accept wheel assemblies for short-haul, special permit trucking.

This dual-mode shipping configuration permits the use of the IF-300 cask at those reactor sites which have no direct rail access. The short-haul capability is used to move the cask to the nearest convenient railhead, where it will be transferred to its primary mode of transportation using roll-on/roll-off techniques.

The cask is supported on the skid by a saddle at the head end and a cradle at the bottom end. The cradle forms the pivot about which the cask is rotated

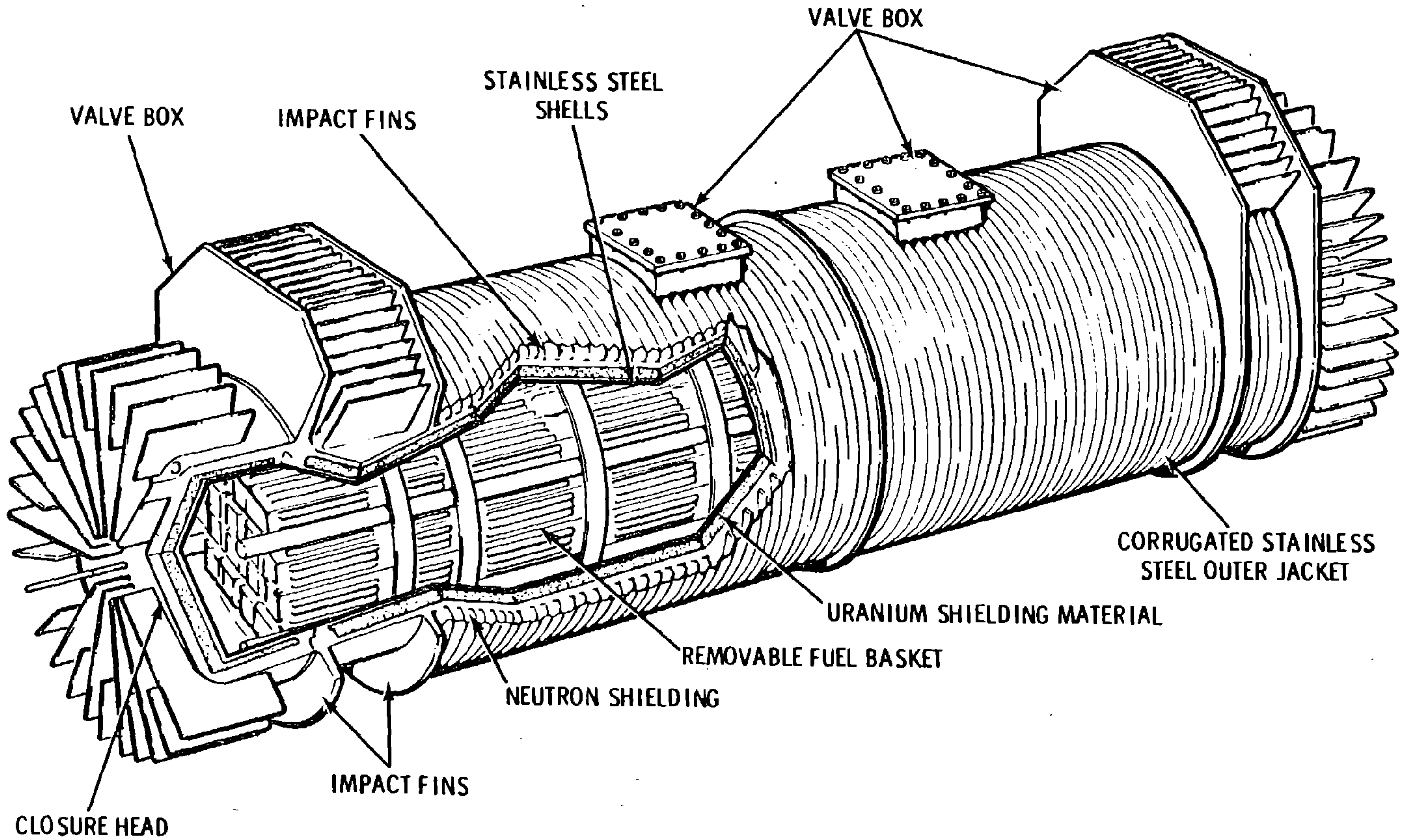

FIGURE B.2. IF-300 Cask

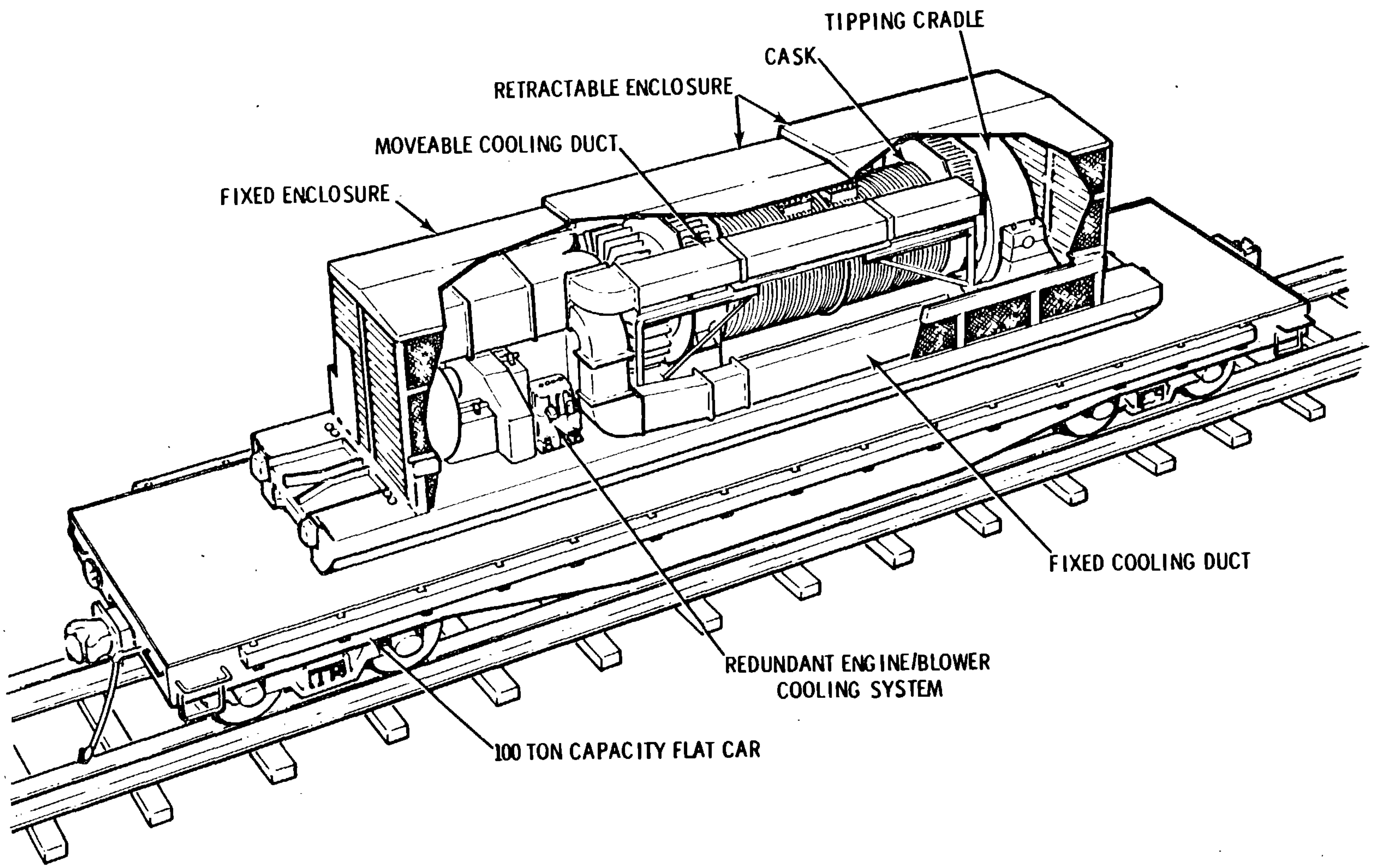

FIGURE B.3. IF-300 Irradiated Fuel Shipping Cask (Shown in Normal Rail Transport Configuration) for vertical removal from the skid. There is one pickup position on the cask body just below the closure flange. The support saddle engages the cask at this section. The lifting trunnions are removed during transport.

The cask is lifted by a special yoke. This yoke accepts the normal reactor building crane hook in its upper end and engages the cask lifting trunnions with two hooks on its lower end. The yoke is designed to be used with either length head. The cask head is removed using two steel cables which are part of the lifting yoke. The same yoke is used for both cask rotation and cask lifting.

All external and internal surfaces of the cask are stainless steel. The inner and outer shells are Type 317 stainless steel, and the flanges and fins are ANSI-300 stainless steel Type 304. The fuel baskets also are made of stainless steel. Both gamma and fast neutron shielding are provided in the IF-300 cask. Shielding is provided by the presence of water in the cask cavity, depleted uranium metal within the cask shell, and an exterior water-filled enclosure. The exterior shielding water enclosure is fabricated from thin-walled stainless steel, and is corrugated to maximize the heat transfer area. The corrugations also significantly increase the strength of the outer jacket and its resistance to damage. This cylindrical containment is attached to the cask body and masks the active fuel zone.

The closure head is sealed with a metallic gasket. The maximum normal operating pressure for the cask cavity is 200 psig. However, the design working pressure is 400 psig at a material temperature of 815°F. Overpressure for the valve is 350 psig. The valve is set for a maximum steam or gas blowdown of 5% and a liquid blowdown of 10%. The cask cavity is equipped with two nuclear service valves, one in each of two valve boxes for filling, draining, venting and sampling. These valves have quick disconnect fittings for ease in servicing. Both valve handles are secured during transit to prevent tampering. A pressure gage with quick disconnect fittings is provided with the cask tool kit. The shielding water containment is protected from overpressure by a 200 psig relief valve. It is also serviced by fill and drain valves located in two valve boxes. Four tanks have been fitted to each cask to contain the shielding water when it heats and expands.

A thermocouple well is attached to the outside of the inner shell at a point expected to experience the highest temperature. The thermocouple well emerges from the cask bottom and accepts a replaceable thermocouple.

The fuel assemblies are contained within a removable, slotted, stainless steel basket: one designed to accommodate BWR assemblies and one for the PWR assemblies. Criticality control is achieved by using B_4C-filled, stainless steel tubes welded to the basket. Fuel elements are restrained axially by spacers mounted on the inside of the closure head. The basket is centered within the cask cavity by disc spacers. Nine such spacers are mounted along the fuel basket length. Fuel elements are inserted and removed from the basket using standard grapples. The basket is removed only when the cask is to be used for the shipment of another fuel type.

The outer surface of the cask body is finned for impact protection. These fins are stainless steel and are circumferential to the cask diameter. The cask ends and valve boxes are also finned for impact protection. All fins are welded to the cask surface. The external water jacket is constructed of thin-walled material and does not contribute to the impact protection of the cask.

B.3 NFS-4[B.3]

A fabrication contract for two NFS-4 casks was awarded to Stearns-Roger, Inc., Denver, CO, in February 1972 and ran in parallel with the AEC licensing activity. These casks were the first of their type to require a detailed quality assurance program, in-process inspection by AEC Directorate of Regulatory Operations, and an extensive acceptance test program. This test program involved hydraulic checks, verification of thermal performance (both normal operation and simulated accident conditions), shielding acceptability, temperature and pressure tests of valves and O-ring seals. All phases were completed without major problem with the first cask delivered in January 1973 and the second the following month (i.e., 11 and 12 months after the contract award date). The casks were checked out and a dry run made at NFS's West Valley, NY, reprocessing facility. They were then shipped to Rochester Gas and Electric's Ginna reactor plant for their first operational usage.

The NFS-4 cask is illustrated in Figure B.4. It has a cavity 178 inches in length by 13-1/2 inches in diameter. Interchangeable fuel baskets provide a capacity of 1 PWR or 2 BWR fuel assemblies from the second generation reactors or up to 4 assemblies from some of the earlier first generation reactors. The primary cask cavity consists of a nominal 5/16-in. stainless steel pressure shell surrounded by a 6-5/8-in. thick lead gamma shield and a 1-1/4-in. thick compartmentized neutron shield tank containing a borated water antifreeze solution surrounds the cask. An expansion chamber for the shield tank is built into this section to accommodate temperature changes of the solution.

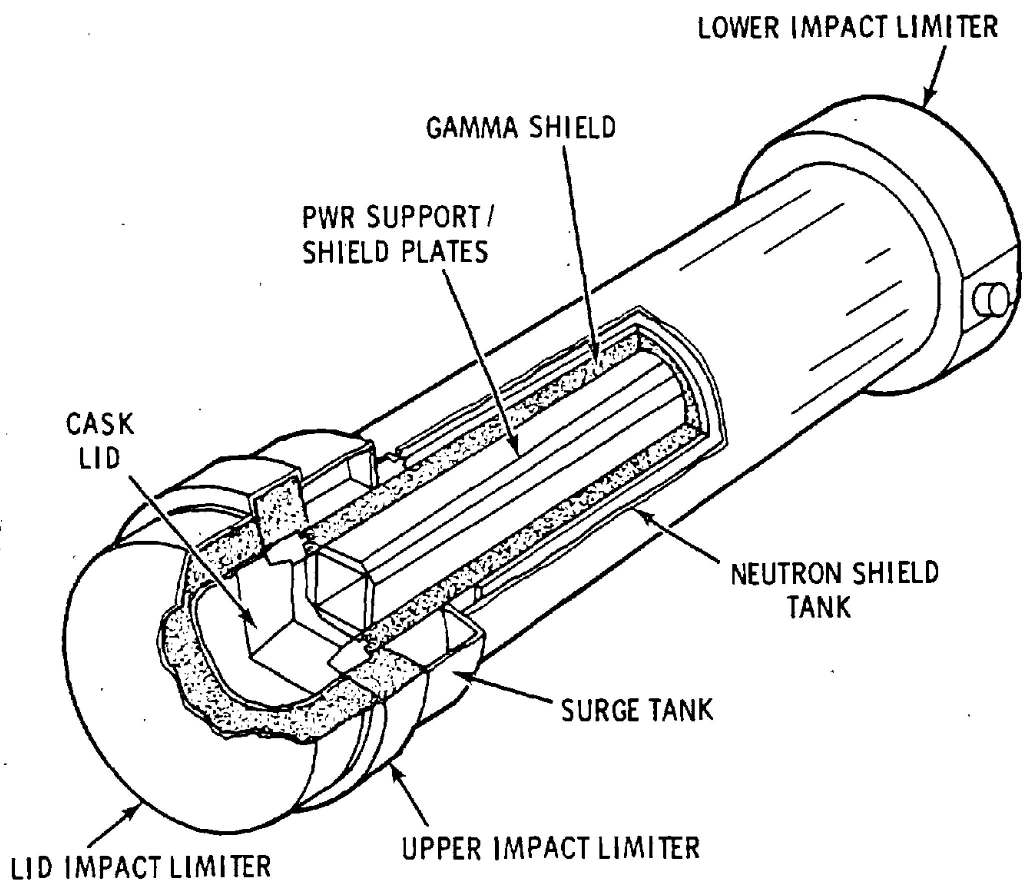

FIGURE B.4. Schematic of NFS-4 Spent Fuel Shipping Cask

The cask lid which seals and shields the cask cavity is solid stainless steel and is attached to the cask by 6 high strength bolts. Two Teflon® O-rings, arranged so that each may be pressure tested, provide the head seal.

Balsa wood impact limiters, encased in stainless steel, are permanently located on the sides and bottom of the cask to provide necessary crash protection. The lower impact limiter also serves as an expanded base when the cask is set vertical. A removable impact limiter of similar design is used to protect the cask head. This limiter is normally removed and stored on the transport trailer during the normal unloading operation. Necessary connections to the primary cavity (i.e., vent and drain valves, pressure test connections, and relief valves) are buried within the impact limiter and special structure to maintain integrity under all accident conditions.

Two sets of trunnions are used for normal cask handling and transport tie-down purposes. The upper set, attached to the upper impact limiter, is used for lifting the cask in conjunction with a special "swing arm" type yoke. This yoke is normally permanently locked to the lift trunnions throughout the complete handling cycle at the reactor or reprocessing site. The lower trunnions are offset to provide a gravity pivot from the vertical loading position into the horizontal transport mode.

The most unique feature of the NFS-4 cask is its ability to handle defective fuel assemblies without the use of special check fixtures. This greatly reduces associated manpower requirements at the reactor site as well as the expense of the special hardware. A weight penalty is paid for this "zero release" concept; however, the operational ease and added safety margin more than offset this disadvantage. The primary cavity is designed to withstand temperature and pressure conditions of 532°F and 984 psig under fire accident condition. Maximum transport conditions for design basis fuel (i.e., 130°F direct sunlight, still air, maximum fuel burnup, minimum fuel cooling period) are 345°F and 150 psig.

The over-the-road weight of the cask/vehicle combination must remain below 73,280 lb in order to travel in the U.S. without restrictions. Because of the desire to simplify both cask licensing and manufacture, lead shielding was used as the main gamma shield instead of a lighter weight uranium or uranium/lead combination. This imposed a weight restriction on the transport vehicle which made it necessary to use a special trailer.

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