LEGIBILITY NOTICE

A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ORNL/CSD/TH-150

TTC-0317

Distribution Category UC-20

71

A SUMMARY REPORT ON OPTIMIZED DESIGNS FOR SHIPPING CASKS CONTAINING 2-, 3-, 5-, 7-, OR 10-YEAR-OLD PWR SPENT FUEL

ORNL/CSD/TH--150

J. A. Bucholz

DE83 010219

Date Published - April 1983

NOTICE This document contains information of a preliminary nature.
It is subject to revision or correction and therefore does not represent a
final report.

COMPUTER SCIENCES
at
Oak Ridge National Laboratory
Post Office Box X
Oak Ridge, Tennessee 37830

Union Carbide Corporation, Nuclear Division
operating the
Oak Ridge Gaseous Diffusion Plant Paducah Gaseous Diffusion Plant
Oak Ridge Y-12 Plant Oak Ridge National Laboratory
under Contract No. W-7405-eng-26
for the
Department of Energy

NOTICE PORTIONS OF THIS REPORT ARE ILLEGIBLE.

It has been reproduced from the best
available copy to permit the broadest
possible availability.

THIS DOCUMENT IS UNCLASSIFIED

29

TABLE OF CONTENTS

	<u>Page</u>
LIST OF TABLES	v
LIST OF FIGURES.	v
ACKNOWLEDGMENTS.	vii
ABSTRACT	ix
I. INTRODUCTION	1
II. BASIC DESIGN PHILOSOPHY.	3
III. SHIELDING.	9
IV. HEAT TRANSFER.	13
A. Steady-State Thermal Analysis.	13
B. Accident/Post-Accident Transient Thermal Analysis.	16
V. CRITICALITY.	19
VI. RESULTS AND CONCLUSIONS.	21
REFERENCES	27

LIST OF TABLES

	<u>Page</u>
1. Thicknesses of Specific Structural Components in Each Type of Spent Fuel Cask.	5
2. Optimized Shielding Requirements for Various Types of Casks, as a Function of the Age of the Spent Fuel and the Number of Assemblies in the Cask.	10
3. SCOPE Results for a Number of Cases of Potential Interest. . .	22
4a. Optimal Pb, Fe, and U-Metal Cask Designs vs Decay Time of Spent Fuel (Weight $\leq 198,000$ lbs)	25
4b. Optimal Pb, Fe, and U-Metal Cask Designs vs Decay Time of Spent Fuel (Weight $\leq 207,000$ lbs).	25

LIST OF FIGURES

	<u>Page</u>
1. Overview of a Typical Spent Fuel Shipping Cask with External Cooling Fins	4
2. Inherently Subcritical, Removable Aluminum Insert Designed to Hold 10 PWR Fuel Assemblies	6
3. Optimal Packing Arrangements for Casks Containing 10-21 Square Fuel Assemblies	8
4. Details Regarding the Use and Placement of the Hollow, Borated Stainless-Steel Tubes Within the Wall-Forming Structure of the Insert Used to Separate Fuel Assemblies and Ensure Subcriticality	20

ACKNOWLEDGMENTS

This report was sponsored by Sandia National Laboratories' Transportation Technology Center for the United States Department of Energy under Contract Number DE-AC04-76-DP00789.

The author would like to acknowledge Mr. L. B. Shappert of the Chemical Technology Division (ORNL) for his role in defining the objectives of this study, and Billie Ferguson of Computer Sciences for her skill and patience in preparing the final manuscript.

ABSTRACT

The purpose of this study was to develop new conceptual designs for large Pb, Fe, and U-shielded spent fuel casks which have been optimized for the shipment of 2-, 3-, 5-, 7-, or 10-year-old PWR spent fuel assemblies. Design specifications for about 100 cases of potential interest are presented along with a brief 20-page synopsis of the associated analyses.

Optimized shielding requirements are presented for each type of cask as a function of the age of the spent fuel and the number of assemblies in the cask. With respect to criticality, a new type of inherently subcritical fuel assembly separator is described which uses hollow, borated stainless-steel tubes in the wall-forming structure between the assemblies. Steady-state and transient heat transfer analyses for casks under nominal and accident conditions were performed using the SCOPE code for Shipping Cask Optimization and Parametric Evaluation.

Based on criticality, shielding, and heat transfer considerations, it appears that optimized cask designs could be developed to carry 15-18 five-year-old PWR fuel assemblies or as many as 18-21 ten-year-old PWR fuel assemblies.

I. INTRODUCTION

Today, much of the spent fuel stored at various reactor sites is already 5-10 years old. Because less neutron and gamma shielding is required, shipping casks designed for such fuel could be expanded to carry significantly larger payloads than those currently in use, without adding appreciably to the overall weight. The purpose of this study was to identify realistic designs for large rail casks which have been optimized for the shipment of 2-, 3-, 5-, 7-, and 10-year-old PWR fuel assemblies.

To generate and evaluate the various designs, extensive use was made of the SCOPE program which was developed by Computer Sciences at Oak Ridge National Laboratory (ORNL) as an inexpensive scoping code for Shipping Cask Optimization and Parametric Evaluation.^{1,2} Using tabulated shielding thicknesses specified by the user, and a fixed set of optimal packing arrangements, the code will "design" a cask to carry a single fuel assembly, and then increment the number of assemblies until one of the design limits, such as the overall weight, is exceeded. For each design, the code will calculate the steady-state temperature distribution throughout the cask and perform a complete 1-D space/time transient thermal analysis following a postulated half-hour fire.

Using the SCOPE program, a wide range of conceptual designs were evaluated at minimal cost. About 100 cases of potential interest are presented in Section VI.

II. BASIC DESIGN PHILOSOPHY

The object of this study was to optimize a series of large rail casks designed to carry spent PWR fuel assemblies. Typically, such casks can be expected to weigh ~100 tons, although there is some latitude in the maximum allowable weight, as noted in Section VI. Lead (Pb), Iron (Fe), and depleted uranium-metal (U) were considered as primary shielding materials. In each case, a borated-water neutron shield was also used (cf. Fig. 1 and/or Section III). Assuming that the total radiation dose rate 10 feet from the cask centerline was not to exceed 10 mrem/hr, the relative amount of neutron and gamma shielding used in each case was optimized for the shipment of 2-, 3-, 5-, 7-, and 10-year-old PWR spent fuel.

The key physical features of those casks considered in this study are illustrated in Fig. 1. Depending on the amount of decay heat that must be dissipated, the cask may or may not have fins (casks with forced circulation cooling systems were not considered in this study). In each case, the cask has an inner shell, a gamma shield, an outer shell, a neutron shield, and an outside liner. The inner and outer shells and the outside liner were all assumed to be stainless-steel. The thicknesses of these components varied, however, depending on the type of cask (cf. Table 1). The length of the cavity inside the cask (171.6 in.) was chosen so as to accommodate a 13.8-ft PWR fuel assembly while leaving an additional 6-in. space for an internal axial shock absorber.

Inside the cask, the fuel assemblies are separated by means of an aluminum insert, as illustrated in Fig. 2. Each of the square holes

Note:

- 1) The removable aluminum insert containing the spent fuel is more fully illustrated in Fig. 2.
- 2) The thicknesses of the components were assumed to be the same in the axial and radial directions.
- 3) Actual dimensions of the various components depend on the type of cask, as shown in Table 1.
- 4) Sketch not drawn to scale; many casks had 45-50 fins; center-to-center spacing was 4 inches.
- 5) When calculating the net weight, the fins were assumed to extend outward from the outer shell.

Fig. 1: Overview of a Typical Spent Fuel Shipping Cask with External Cooling Fins

Table 1: Thicknesses of Specific Structural Components in Each Type of Spent Fuel Cask

TYPE OF CASK	THICKNESS IN INCHES		
	INNER SHELL	OUTER SHELL	OUTSIDE LINER
LEAD	1.5	2.0	.75
U-METAL	.75	2.0	.75
IRON	.375	.375	.75

ORNL-DWG 82-12215

**Fig. 2: Inherently Subcritical, Removable Aluminum Insert
Designed to Hold 10 PWR Fuel Assemblies**

shown in Fig. 2 measures 8.7 in. x 8.7 in. and can accommodate most typical PWR fuel assemblies with 0.125-in. clearance on all four sides. Other insert designs capable of holding 10-21 fuel assemblies were also considered (cf. Fig. 3). Indeed, the configurations shown in Fig. 3 are considered "optimal" insofar as they minimize the diameter of the circular cavity required to enclose any given number of square assemblies ($10 \leq N \leq 21$). Given the spatial configurations shown in Fig. 3, the size of the square holes (8.7 in. x 8.7 in.), and the thickness of the aluminum webbing between the fuel assemblies (2.25 in.), the outside diameter of the insert and/or the inside diameter of the cask can be calculated.

In addition to physically separating the fuel assemblies, the insert must provide a low-resistance path by which the decay heat may be carried away from the innermost assemblies and, secondly, it must provide an inherently passive means of ensuring subcriticality under the most reactive conditions conceivable. These requirements are discussed further in Sections IV and V. To prevent possible leakage of radioactive contaminants in the event of an accident, it was assumed that the spent fuel would be shipped dry, with only air as the primary coolant.

N=10 Dia = $(\sqrt{18})$ PITCH

N=15 Dia = $(\sqrt{26})$ PITCH

N=12 Dia = $(\sqrt{20})$ PITCH

N=18 Dia = $(\sqrt{32})$ PITCH

N=13 Dia = $(\sqrt{22.6})$ PITCH

N=21 Dia = $(\sqrt{34})$ PITCH

∞

Fig. 3: Optimal Packing Arrangements for Casks Containing 10-21 Square Fuel Assemblies

III. SHIELDING

On a volumetric basis, the neutron shield in each case was assumed to consist of 28.5% water (1.0 g/cc), 66.0% ethylene glycol (1.11 g/cc; $\text{HOCH}_2\text{CH}_2\text{OH}$) and 5.5% potassium tetraborate (1.74 g/cc; $\text{K}_2\text{B}_4\text{O}_7 \cdot 8\text{H}_2\text{O}$) made with natural boron. By weight, this common mixture of water and antifreeze contains ~1% boron.

Considerable effort was spent in determining the relative amount of neutron and gamma shielding that should be used in each case so as to minimize the overall weight of the loaded cask.² Given the age of the spent fuel and the type of cask (Pb, Fe, or U), the thickness of the gamma shield can be held constant while a zone-width search calculation is performed to determine the corresponding amount of neutron shielding that would yield a total dose rate of 10 mrem/hr at a point 10 feet from the cask's centerline. This procedure was repeated many times for gamma shields of different thicknesses in order to identify the optimal n/ γ split for each type of cask as a function of the spent fuel's decay time.

Once the optimal n/ γ splits were established, extensive tables of neutron and gamma shielding requirements were compiled for each material as a function of the age of the fuel and the number of assemblies in the cask. These results are summarized in Table 2. Used in conjunction with the other structural components described in Table 1, these optimized shield dimensions will ensure a dose rate of 10 mrem/hr at a

Table 2: Optimized Shielding Requirements for Various Types of Casks, as a Function of the Age of the Spent Fuel and the Number of Assemblies in the Cask

2 YEAR OLD PWR FUEL			
TYPE OF CASK	NO OF ASSYS	THICKNESS (IN INCHES)	
		γ SHIELD	N SHIELD
PB	1	4.47	3.71
PB	8	5.18	4.06
PB	15	5.44	4.24
FE	1	10.11	3.81
FE	8	11.18	3.86
FE	15	11.56	3.90
U	1	2.72	3.10
U	8	3.13	3.49
U	15	3.27	3.67

7-YEAR-OLD PWR FUEL			
TYPE OF CASK	NO OF ASSYS	THICKNESS (IN INCHES)	
		γ SHIELD	N SHIELD
PB	1	3.27	3.54
PB	8	3.91	3.82
PB	21	4.27	4.03
FE	1	8.35	3.49
FE	8	9.31	3.55
FE	21	9.84	3.62
U	1	2.05	2.67
U	8	2.40	3.14
U	21	2.61	3.49

3 YEAR OLD PWR FUEL			
TYPE OF CASK	NO OF ASSYS	THICKNESS (IN INCHES)	
		γ SHIELD	N SHIELD
PB	1	4.06	3.73
PB	8	4.74	4.05
PB	18	5.05	4.24
FE	1	9.52	3.68
FE	8	10.54	3.74
FE	18	10.99	3.82
U	1	2.49	2.86
U	8	2.88	3.30
U	18	3.05	3.58

10 YEAR-OLD PWR FUEL			
TYPE OF CASK	NO OF ASSYS	THICKNESS (IN INCHES)	
		γ SHIELD	N SHIELD
PB	1	2.98	3.68
PB	8	3.61	3.93
PB	21	3.97	4.13
FE	1	7.90	3.61
FE	8	8.85	3.66
FE	21	9.39	3.71
U	1	1.89	2.61
U	8	2.25	3.06
U	21	2.45	3.42

5 YEAR OLD PWR FUEL			
TYPE OF CASK	NO OF ASSYS	THICKNESS (IN INCHES)	
		γ SHIELD	N SHIELD
PB	1	3.55	3.60
PB	8	4.19	3.95
PB	18	4.48	4.07
FE	1	8.79	3.44
FE	8	9.76	3.51
FE	18	10.19	3.57
U	1	2.21	2.54
U	8	2.58	3.09
U	18	2.74	3.35

Note: When used in conjunction with the various structural components shown in Table 1, the amount of neutron and gamma shielding given here is sufficient to reduce the total dose rate down to 10 mrem/hr at a point 10 feet from the centerline of the cask.

point 10 feet from the centerline. As in the optimization study, these estimates are based on a series of one-dimensional S_8P_3 discrete ordinates calculations using the XSDRNPM code³ and the DLC-23/CASK coupled cross-section library⁴ having 22 neutron groups and 18 gamma groups.

IV. HEAT TRANSFER

As noted previously, the SCOPE code will calculate the steady-state temperature distribution throughout the cask and perform a complete 1-D space/time transient thermal analysis following its exposure to a postulated half-hour fire as prescribed in 10CFR71, Appendix B.⁵ A summary description of the heat transfer analysis performed by the code is provided below. Additional details may be found in refs. 1 and 2.

IV.A Steady-State Thermal Analysis

Knowing the decay heat load that must be dissipated to the environment, the temperature on the surface of the cask can be calculated in an iterative fashion using an expression of the form:

$$Q = A \left\{ \sigma \epsilon (T_{\text{surf}}^4 - T_{\text{amb}}^4) + C (T_{\text{surf}} - T_{\text{amb}})^{4/3} \right\}$$

where σ is the Stefan-Boltzmann constant, ϵ is the surface emissivity of the cask, C is a constant having a value of 0.18, and A is the outside surface area (excluding the ends of the cask).^{*} Note that the first term in this expression accounts for radiation heat transfer while the second term accounts for natural convection from a horizontal cylinder in air.⁶ Since existing regulations require that the cask be capable of sustained operation with an ambient temperature of 130°F (590°R), that

^{*}In this scoping design study, it was assumed that the cask would normally be sheltered from the direct rays of the sun by means of an opaque covering over a large, light-weight frame structure surrounding the entire cask. Notes regarding the effect of direct solar heating under steady-state, accident, and post-accident conditions may be found in ref. 2.

value is used in the above equation as the code numerically iterates to determine T_{surf} . If the surface temperature is found to be less than 250°F, a finless cask design is assumed. In those cases where fins are required to reduce the outside surface temperature to 250°F, a separate numerical search is conducted to determine the particular fin dimensions which could satisfy this criteria while minimizing the overall weight of the loaded cask.² In all the cases considered in this study, the circumferential fins shown in Fig. 1 were assumed to be stainless-steel and spaced on a 4-in. pitch

The temperature distribution inside the cask itself may be calculated assuming simple heat conduction through the various components. The neutron shield, however, must be treated in a slightly different manner. Because the borated water is trapped inside a long horizontal cylindrical annulus, large kidney-shaped convective loops often develop and are responsible for transporting much of the decay heat in this region. Based on a number of experiments, Liu, Mueller, and Landis⁷ have developed an expression for the effective thermal conductivity of the fluid (k_e) which depends on the inside and outside radius of the region, the average temperature of the fluid, the ΔT across the region, and the flow regime as characterized by the Grashof and Prandtl numbers. Knowing the decay heat load, the temperature drop across the neutron shield may be calculated in an iterative fashion using their expression for the effective thermal conductivity. (See refs. 2, 7, and 11 for additional details.)

Across the thin (0.125-in.) air gap between the cavity insert and the inner shell of the cask, radiation and conduction serve as the primary modes of heat transfer. Knowing the decay heat load and the temperature on the inside surface of the inner shell, the ΔT across this gap is then calculated in an iterative fashion.

In addition to physically separating the fuel assemblies, the use of an aluminum insert, as shown in Fig. 2, provides a low-resistance thermal conduction path by which the decay heat may be carried outward, away from the innermost assemblies. Instead of being surrounded by other hot fuel assemblies (all of which may be emitting substantial amounts of decay heat), the innermost assemblies are, in fact, surrounded by a relatively cool aluminum surface. The SCOPE code solves the 2-D heat conduction problem throughout the entire insert to determine the heat flow through each segment of the webbing and the temperature at each node.

The last parameter of interest is the surface temperature of the hottest fuel pin in the innermost fuel assembly. Knowing the temperature of the surrounding insert and the amount of decay heat emanating from the particular assembly, we can calculate this temperature in an iterative fashion using the Wooten-Epstein equation.⁸ This semitheoretical, semiempirical equation accounts for both radiation and convection from a single fuel assembly in a horizontal enclosure.

IV.B. Accident/Post-Accident Transient Thermal Analysis

To determine the transient thermal effects of the hypothetical half-hour fire defined in 10CFR71, the SCOPE code solves the actual time-dependent, finite-differenced, one-dimensional heat transfer equations for the entire cask. (To account for the relatively large heat capacity of the aluminum insert without adding undue complexity to the problem, the insert has been modeled as a solid annular region just inside the inner shell. It should also be noted that the small gap between the inner shell and the insert has been maintained, as has the overall cross-sectional area of the insert.) At each time step, the resulting spatial equations are solved using matrix factorization. The steady-state temperature distribution used as the initial condition at the start of the transient assumes that the neutron shield has long-since been rendered void as a result of the 30-ft drop test.* The postulated fire, having a flame temperature of 1475°F, is then assumed to last for 30 minutes. Because the thermal transient peaks in some components long after the external fire has been extinguished, this analysis follows the transient for 12 full hours. Numerical results for the transient thermal analysis package used in the SCOPE code have been benchmarked against HEATING-5 results^{2,9} with good agreement. Using a similar 1-D model, the two sets of results were

*This scenario differs from that used in most Safety Analysis Reports for Packages (SARP's) in that they assume the temperature distribution throughout the cask at the start of the hypothetical fire is the same as the steady-state distribution under normal operating conditions.^{10,11} The SCOPE code is capable of analyzing temperature transients on either basis.

generally within $\pm 1^\circ\text{F}$ at all spatial points during the entire transient. To conservatively estimate the maximum temperature at points inside the cask cavity (i.e., in the insert and the fuel), the maximum temperature rise in the insert, as given by the simplified 1-D model, is added to the maximum steady-state value given by the detailed 2-D analysis. Likewise, the maximum fuel pin clad temperature is also recalculated at this elevated temperature.

:
0

V. CRITICALITY

Most spent fuel shipping casks are loaded under water. Inadvertent loading of the cask with fresh fuel (or fuel with very little accumulated burnup) is then typically taken as the most reactive condition considered in the licensing application. Should casks be designed to carry large numbers of fuel assemblies, as might be the case for long-cooled spent fuel, the problem of ensuring subcriticality becomes more difficult.² The approach used here relies on the use and placement of hollow, borated stainless-steel tubes within the walls of the aluminum insert between the fuel assemblies, as shown in Fig. 4.* Given an infinite array of infinitely long PWR fuel assemblies @ 3.4 wt % ²³⁵U, this flooded configuration was found to be safely subcritical with $k_{eff} = 0.916 \pm 0.003$. Even at 3.9 wt % ²³⁵U, this configuration was safely subcritical with $k_{eff} = 0.941 \pm 0.003$. These criticality calculations were performed using the KENO-IV Monte Carlo code¹² as implemented in the CSAS2 analytic sequence of the SCALE system for Standardized Computer Analyses for Licensing Evaluation.¹³ In each case, the SCALE 27-group ENDF-IV cross-section library was used, with the homogenized cell-averaged cross-section data being weighted as noted in ref. 13. Use of this inherently subcritical insert design in all of the casks studied, preempted the need for a separate analysis of each cask, and lent an important degree of credibility to the designs that finally evolved.

*The U. S. Department of Energy, Oak Ridge Office of Patent Counsel, has recently filed a patent application on this design concept.¹⁴

ORNL-DWG 82-12217

Fig. 4: Details Regarding the Use and Placement of Hollow, Borated Stainless-Steel Tubes Within the Wall-Forming Structure of the Insert Used to Separate Fuel Assemblies and Ensure Subcriticality

VI. RESULTS AND CONCLUSIONS

The purpose of this study was to develop new conceptual designs for lead, iron, and uranium-shielded spent fuel casks which have been optimized for the shipment of 2-, 3-, 5-, 7-, or 10-year-old PWR spent fuel assemblies. Using the SCOPE program in conjunction with the optimized shielding data given in Table 2, a wide range of conceptual cask designs were evaluated at minimal cost. SCOPE output for those cases of potential interest is presented in Table 3. Each line of output gives the age of the spent fuel (in years); the number of assemblies in the cask; the materials used for the insert, gamma shield, and neutron shield; the thickness of the gamma shield and the neutron shield; the overall weight of the loaded cask; and some characteristic dimensions [including the inside diameter of the cask, the outside diameter of the cask (including fins, if required), the overall exterior length of the cask, and the length and thickness of the fins (if required)]. It also gives the steady-state temperature on the outside surface of the cask, on the innermost surface of the gamma shield, at the hottest point inside the insert, and on the surface of the hottest fuel pin. Finally, it presents the maximum transient temperature calculated in the gamma shield, in the insert, and on the surface of the hottest fuel pin during or after the postulated 30-minute fire.

Since many design limits are not absolutely rigid, this rather extensive table shows a number of cases on either side of the nominal 100-ton weight limit (200,000 lbs). The utility of this "extra" information becomes apparent when one notes that the inside diameter of

Table 3: SCOPE Results for a Number of Cases of Potential Interest

FUEL AGE	NO. ASSY	MATERIALS			THICKNESS IN INCHES		CASK WEIGHT (KILBS)	DIMENSIONS IN INCHES					STEADY STATE TEMPERATURES IN DEG. F				MAX FIRE-TEST TEMPERATURES IN DEG. F		
		INSRT	CAN.	HEUT	CAN.	HEUT		TO	OO	LENGTH	FIN	FIN	FUEL	INSRT	CANNA	CASK	FUEL	INSRT	CANNA
		SHLD	SHLD	SHLD	SHLD	SHLD					WT.	THK.	PIN	MATL	SHLD	SURF.	PIN	MATL	SHLD
10.0	15	AL	PB	H2O	3.84	4.03	171.3	55.8	80.0	195.4	0.0	0.0	351	269	187	180	480	402	391
10.0	16	AL	PB	H2O	3.86	4.03	195.1*	61.9	86.2	195.9	0.0	0.0	357	275	186	179	479	401	388
10.0	18	AL	PB	H2O	3.90	4.02	196.6*	61.9	86.3	195.9	0.0	0.0	369	288	192	184	499	422	401
10.0	19	AL	PB	H2O	3.92	4.06	205.0*	63.8	88.3	196.1	0.0	0.0	371	290	194	186	502	425	404
10.0	21	AL	PB	H2O	3.97	4.13	206.9*	63.8	88.5	196.3	0.0	0.0	341	301	199	190	520	445	415
10.0	22	AL	PB	H2O	3.98	4.15	218.7*	66.6	91.4	196.4	0.0	0.0	385	305	200	191	520	445	416
10.0	13	AL	FE	H2O	9.13	3.68	173.9	52.0	80.7	200.2	0.0	0.0	339	256	179	173	546	367	347
10.0	14	AL	FE	H2O	9.16	3.68	189.1	55.8	84.5	200.3	0.0	0.0	341	258	180	174	446	367	348
10.0	15	AL	FE	H2O	9.19	3.68	189.8	55.8	84.5	200.3	0.0	0.0	347	265	183	177	457	378	355
10.0	16	AL	FE	H2O	9.22	3.68	215.1*	61.9	90.7	202.4	0.0	0.0	353	272	183	176	458	380	353
10.0	18	AL	FE	H2O	9.27	3.68	216.7*	61.9	90.8	200.5	0.0	0.0	365	284	189	181	476	399	366
10.0	18	AL	U	H2O	2.41	3.33	179.4	61.9	80.4	190.1	0.0	0.0	372	291	196	189	508	431	423
10.0	19	AL	U	H2O	2.42	3.34	187.3	63.8	82.4	190.2	0.0	0.0	374	293	198	190	511	435	426
10.0	21	AL	U	H2O	2.45	3.42	189.0	63.8	82.6	190.3	0.0	0.0	385	304	204	195	530	455	438
10.0	22	AL	U	H2O	2.46	3.43	200.2*	66.6	85.4	190.4	0.0	0.0	388	308	204	196	530	455	439
10.0	23	AL	U	H2O	2.47	3.44	211.3*	69.2	88.0	190.4	0.0	0.0	387	307	205	196	527	452	440
10.0	24	AL	U	H2O	2.48	3.45	212.0*	69.2	88.1	190.5	0.0	0.0	392	312	208	199	535	461	445
10.0	25	AL	U	H2O	2.49	3.46	216.1*	70.1	89.0	190.5	0.0	0.0	405	326	210	200	550	477	449
10.0	26	AL	U	H2O	2.49	3.47	216.7*	70.1	89.0	190.5	0.0	0.0	410	331	212	203	559	486	454
7.0	14	AL	PB	H2O	4.12	3.94	176.7	55.8	80.4	196.2	0.0	0.0	381	287	193	185	512	422	403
7.0	15	AL	PB	H2O	4.15	3.95	177.4	55.8	80.5	196.3	0.0	0.0	388	294	196	188	524	435	411
7.0	16	AL	PB	H2O	4.16	3.97	201.8*	61.9	86.7	196.4	0.0	0.0	396	302	196	187	524	436	408
7.0	18	AL	PB	H2O	4.20	4.01	203.3*	61.9	86.8	196.5	0.0	0.0	409	316	202	193	545	459	422
7.0	19	AL	PB	H2O	4.22	4.01	211.9*	63.8	88.8	196.6	0.0	0.0	411	319	204	195	549	462	425
7.0	21	AL	PB	H2O	4.27	4.03	213.7*	63.8	88.9	196.7	0.0	0.0	423	332	210	200	569	483	438
7.0	22	AL	PB	H2O	4.29	4.06	225.8*	66.6	91.8	196.8	0.0	0.0	427	336	211	201	570	485	439
7.0	12	AL	FE	H2O	9.56	3.59	168.3	48.9	78.3	200.9	0.0	0.0	366	270	186	178	479	388	361
7.0	13	AL	FE	H2O	9.59	3.59	180.8	52.0	81.4	201.0	0.0	0.0	374	279	188	180	486	396	365
7.0	14	AL	FE	H2O	9.62	3.59	196.4*	55.8	85.2	201.0	0.0	0.0	377	282	189	181	488	398	367
7.0	15	AL	FE	H2O	9.65	3.59	197.2*	55.8	85.3	201.1	0.0	0.0	384	290	192	184	499	410	375
7.0	16	AL	FE	H2O	9.68	3.59	223.1*	61.9	91.4	201.1	0.0	0.0	391	298	192	184	502	414	373
7.0	15	AL	U	H2O	2.53	3.37	160.3	55.8	74.6	190.4	0.0	0.0	392	298	202	193	534	446	435
7.0	16	AL	U	H2O	2.54	3.38	183.4	61.9	80.8	190.4	0.0	0.0	399	306	201	192	533	446	431
7.0	18	AL	U	H2O	2.56	3.40	184.7	61.9	80.8	190.5	0.0	0.0	412	320	207	198	555	469	445
7.0	19	AL	U	H2O	2.58	3.43	192.8*	63.8	82.8	190.6	0.0	0.0	414	322	209	200	558	473	448
7.0	21	AL	U	H2O	2.61	3.49	194.5*	63.8	83.0	190.8	0.0	0.0	427	336	214	204	579	495	462
7.0	22	AL	U	H2O	2.61	3.50	204.0*	66.6	85.8	190.8	0.0	0.0	431	340	217	206	580	495	462
7.0	23	AL	U	H2O	2.62	3.51	217.3*	69.2	88.5	190.9	0.0	0.0	430	338	218	207	577	493	464
5.0	13	AL	PB	H2O	4.39	4.07	167.8	52.0	77.4	197.0	0.0	0.0	439	325	207	197	583	476	434
5.0	14	AL	PB	H2O	4.41	4.07	182.9	55.8	81.3	197.1	0.0	0.0	443	329	208	198	583	477	436
5.0	15	AL	PB	H2O	4.43	4.08	183.7	55.8	81.3	197.1	0.0	0.0	452	338	213	202	597	491	445
5.0	16	AL	PB	H2O	4.45	4.07	208.7*	61.9	87.5	197.1	0.0	0.0	462	349	212	201	600	496	442
5.0	18	AL	PB	H2O	4.49	4.07	210.1*	61.9	87.5	197.2	0.0	0.0	478	366	220	208	624	521	458
5.0	19	AL	PB	H2O	4.51	4.12	219.0*	63.8	89.6	197.4	0.0	0.0	480	369	223	210	628	525	462
5.0	12	AL	FE	H2O	10.02	3.57	175.1	48.9	79.1	201.8	0.0	0.0	474	308	200	190	546	437	392
5.0	13	AL	FE	H2O	10.05	3.57	187.9	52.0	82.3	201.8	0.0	0.0	474	319	202	192	555	448	397
5.0	14	AL	FE	H2O	10.08	3.56	203.9*	55.8	86.1	201.9	0.0	0.0	438	323	204	194	558	451	399
5.0	15	AL	FE	H2O	10.11	3.56	204.7*	55.8	86.2	201.9	0.0	0.0	447	333	208	197	571	464	408
5.0	16	AL	FE	H2O	10.14	3.56	231.3*	61.9	92.3	202.0	0.0	0.0	457	344	208	197	577	472	406
5.0	15	AL	U	H2O	2.71	3.33	165.5	55.8	74.9	190.7	0.0	0.0	456	343	220	209	608	503	449
5.0	16	AL	U	H2O	2.72	3.33	189.2	61.9	81.0	190.7	0.0	0.0	466	354	218	208	611	507	465
5.0	18	AL	U	H2O	2.74	3.35	190.6*	61.9	81.1	190.8	0.0	0.0	482	371	227	215	635	533	482
5.0	19	AL	U	H2O	2.76	3.38	198.9*	63.8	83.1	190.9	0.0	0.0	484	374	229	217	639	537	486
5.0	21	AL	U	H2O	2.79	3.45	200.6*	63.8	83.3	191.1	0.0	0.0	499	390	237	224	662	562	501
5.0	22	AL	U	H2O	2.79	3.44	212.3*	66.6	86.0	191.1	0.0	0.0	534	395	238	225	663	564	502
5.0	23	AL	U	H2O	2.80	3.44	223.8*	69.2	88.7	191.1	0.0	0.0	502	393	240	226	660	561	504

Note:

- 1) Pb casks have a 1.5-inch inner shell, a 2.0-inch outer shell, and a 0.75-inch outside liner.
- 2) Fe casks have a 0.375-inch inner shell, a 0.375-inch outer shell, and a 0.75-inch outside liner.
- 3) U-metal casks have a 0.75-inch inner shell, a 2.0-inch outer shell, and a 0.75-inch outside liner.
- 4) An asterisk (*) is used to flag any parameter that is close to or over the nominal design limit.

Table 3 (cont.)

FUEL AGE	NO. ASSY	MATERIALS			THICKNESS IN INCHES		CASK WEIGHT (LBS)	DIMENSIONS IN INCHES					STEADY STATE TEMPERATURES IN DEG. F				MAX FIRE-TEST TEMPERATURES IN DEG. F		
		INSRT	CAN. SHLD	FEUT SHLD	CAN. SHLD	FEUT SHLD		ID	OD	LENGTH	FIN HT.	FIN THK.	FUEL FIN	INSRT MATH	GAMMA SHLD	CASK SURF.	FUEL FIN	INSRT MATH	GAMMA SHLD
3.0	12	AL	PB	H2O	4.92	4.19	166.5	48.9	75.7	198.3	0.0	0.0	597	428	249	231	761	607	517
3.0	13	AL	PB	H2O	4.94	4.20	179.2	52.0	78.8	198.4	0.0	0.0	614	447	252	234	775	624	522
3.0	14	AL	PB	H2O	4.97	4.20	195.0*	55.8	82.6	198.4	0.0	0.0	619	454	255	237	778	628	525
3.0	15	AL	PB	H2O	4.99	4.21	195.8*	55.8	82.7	198.5	0.0	0.0	632	468	262	242	795	647	538
3.0	16	AL	PB	H2O	5.01	4.22	222.1*	61.9	88.9	198.6	0.0	0.0	651	489	261	242	808	663	534
3.0	10	AL	FE	H2O	10.68	3.77	175.1	46.4	78.3	203.5	0.0	0.0	571	400	228	214	704	545	453
3.0	11	AL	FE	H2O	10.75	3.78	186.5	48.9	81.0	203.7	0.0	0.0	575	403	233	218	710	552	462
3.0	12	AL	FE	H2O	10.82	3.79	187.9	48.9	81.2	203.8	0.0	0.0	589	420	241	224	728	573	477
3.0	13	AL	FE	H2O	10.85	3.79	201.3*	52.0	84.3	203.9	0.0	0.0	606	438	244	227	745	592	483
3.0	14	AL	FE	H2O	10.88	3.79	218.2*	55.8	88.1	203.9	0.0	0.0	612	445	247	229	750	598	486
3.0	14	AL	U	H2O	3.01	3.54	174.9	55.8	75.9	191.7	0.0	0.0	625	460	264	247	791	643	551
3.0	15	AL	U	H2O	3.02	3.57	179.7	55.8	80.0	191.8	2.0	0.25	614	448	238	219	808	660	586
3.0	16	AL	U	H2O	3.03	3.58	204.8*	61.9	86.1	191.8	2.0	0.25	632	469	236	219	818	673	581
3.0	18	AL	U	H2O	3.06	3.58	206.2*	61.9	86.2	191.9	2.0	0.25	654	493	247	226	848	706	602
3.0	19	AL	U	H2O	3.07	3.59	215.0*	63.8	88.2	191.9	2.0	0.25	656	495	250	229	852	711	607
3.0	21	AL	U	H2O	3.11	3.61	217.0*	63.8	88.3	192.0	2.0	0.25	675	517	259	236	879	741	625
2.0	9	AL	PB	H2O	5.23	4.10	161.7	46.4	73.6	198.7	0.0	0.0	737	510	271	249	898	693	557
2.0	10	AL	PB	H2O	5.28	4.13	167.5	46.4	77.7	198.9	2.0	0.25	736	508	247	223	925	722	598
2.0	11	AL	PB	H2O	5.32	4.19	178.7	48.9	80.5	199.1	2.0	0.25	739	511	253	227	930	728	608
2.0	12	AL	PB	H2O	5.37	4.25	180.0	48.9	80.7	199.3	2.0	0.25	757	532	261	234	953	756	626*
2.0	13	AL	PB	H2O	5.39	4.25	193.3*	52.0	83.8	199.4	2.0	0.25	780	560	265	237	974	782	632*
2.0	14	AL	PB	H2O	5.41	4.24	210.0*	55.8	87.6	199.4	2.0	0.25	788	570	268	240	979	788	635*
2.0	15	AL	PB	H2O	5.44	4.24	210.7*	55.8	87.7	199.4	2.0	0.25	803	588	276	245	999	812	651*
2.0	16	AL	PB	H2O	5.46	4.24	238.3*	61.9	93.8	199.5	2.0	0.25	833	624	275	245	1073	861	646*
2.0	8	AL	FE	H2O	11.18	3.86	169.9	43.3	76.4	204.7	0.0	0.0	704	470	253	234	840	626	502
2.0	9	AL	FE	H2O	11.26	3.87	183.8	46.4	79.7	204.9	0.0	0.0	728	499	260	240	867	658	514
2.0	10	AL	FE	H2O	11.33	3.89	185.3	46.4	79.9	205.0	0.0	0.0	749	523	271	248	892	688	534
2.0	11	AL	FE	H2O	11.40	3.91	202.1*	48.9	80.6	205.2	2.0	0.25	731	502	244	219	893	688	559
2.0	12	AL	FE	H2O	11.46	3.92	203.5*	48.9	80.7	205.4	2.0	0.25	748	523	252	225	915	714	576
2.0	13	AL	FE	H2O	11.50	3.92	217.6*	52.0	89.9	205.4	2.0	0.25	772	550	256	229	939	743	583
2.0	13	AL	U	H2O	3.25	3.66	171.5	52.0	76.8	192.4	2.0	0.25	784	565	275	247	988	798	659
2.0	14	AL	U	H2O	3.26	3.67	187.2	55.8	80.7	192.5	2.0	0.25	792	574	277	250	992	803	662
2.0	15	AL	U	H2O	3.27	3.67	188.8	55.8	82.7	192.5	3.0	0.25	802	587	277	248	1014	828	685
2.0	16	AL	U	H2O	3.29	3.67	214.9*	61.9	88.8	192.5	3.0	0.25	831	622	276	247	1036	856	679
2.0	17	AL	U	H2O	3.30	3.67	216.6*	61.9	90.9	192.5	4.0	0.25	842	635	279	248	1056	879	700
2.0	18	AL	U	H2O	3.31	3.67	220.2*	61.9	92.9	192.6	5.0	0.25	852	646	280	248	1076	901	718
2.0	9	AL	PB	H2O	5.23	4.10	168.5	46.4	74.6	199.7	0.0	0.0	737	509	270	248	895	689	545
2.0	10	AL	PB	H2O	5.28	4.13	174.4	46.4	78.7	199.9	2.0	0.25	736	508	247	222	922	718	582
2.0	11	AL	PB	H2O	5.32	4.19	186.0	48.9	81.5	200.1	2.0	0.25	738	511	252	225	926	723	582
2.0	12	AL	PB	H2O	5.37	4.25	187.3	48.9	81.7	200.3	2.0	0.25	756	532	261	232	943	751	609
2.0	13	AL	PB	H2O	5.39	4.25	201.0*	52.0	84.8	200.4	2.0	0.25	780	560	265	235	971	778	616
2.0	14	AL	PB	H2O	5.41	4.24	218.1*	55.8	88.6	200.4	2.0	0.25	788	570	268	238	976	785	619*
2.0	15	AL	PB	H2O	5.44	4.24	218.9*	55.8	88.7	200.4	2.0	0.25	803	588	276	243	995	808	634*

a) For added thermal protection, a 2.5-inch outer shell was used in lieu of the 2.0-inch outer shell.

Note:

- 1) Pb casks have a 1.5-inch inner shell, a 2.0-inch outer shell, and a 0.75-inch outside liner.
- 2) Fe casks have a 0.375-inch inner shell, a 0.375-inch outer shell, and a 0.75-inch outside liner.
- 3) U-metal casks have a 0.75-inch inner shell, a 2.0-inch outer shell, and a 0.75-inch outside liner.
- 4) External cooling fins, when required, were assumed to be stainless-steel unless noted otherwise.
- 5) An asterisk (*) is used to flag any parameter that is close to or over the nominal design limit.

a cask (and hence its overall weight) is a nonuniform function of the number of assemblies in the cask (cf. Fig. 3). Thus, for example, while there may be very little difference in the overall weight of the casks designed to carry 16, 17, or 18 assemblies, a cask designed to carry 14 or 15 assemblies would weigh considerably less, while one designed to carry 19, 20, or 21 assemblies would weigh somewhat more. Because of the "magic numbers" associated with the various packing arrangements, the rigid enforcement of one weight limit as opposed to another may have very little impact on the estimated capacity of some casks while at the same time having a severe impact on the estimated capacity of others. With the aid of Table 3, each cask can be evaluated on a case-by-case basis.

Ultimately, however, one must eventually answer the basic question: "How many 2-, 3-, 5-, 7-, or 10-year-old PWR fuel assemblies could actually be shipped in a Pb, Fe, or U-shielded cask?" Using the information in Table 3 and assuming 198,000 lbs as the maximum allowable weight for the loaded cask, Table 4a shows the estimated capacity of each type of cask as a function of cooling time. Assuming that a slightly heavier cask could be tolerated, the estimated capacity of 10 of these 15 designs could be adjusted upward - some by as many as three assemblies. Table 4b, for example, shows the estimated capacity for each type of cask as a function of cooling time assuming a slightly higher weight limit of 207,000 lbs. In either case, it appears that optimized cask designs could be developed which could carry as many as 15-18 five-year-old PWR fuel assemblies or as many as 18-21 ten-year-old PWR fuel assemblies.

Table 4a: Optimal Pb, Fe, and U-Metal Cask Designs
vs Decay Time of Spent Fuel (Weight $\leq 198,000$ lbs)

FUEL AGE	GAMMA SHIELD	NO. OF ASSYS	LOADED WT (1000-LBS)	CASKID (IN)	GSHLD (IN)	NSHLD (IN)	L-FIN (IN)	T-FIN (IN)
10	PB	18	196.6	61.9	3.90	4.02	--	--
7	PB	15	177.4	55.8	4.15	3.95	--	--
5	PB	15	183.7	55.8	4.43	4.03	--	--
3	PB	15	195.8	55.8	4.99	4.21	--	--
2	PB ^a	12	187.3	48.9	5.37	4.25	2.00	0.25
10	FE	15	189.8	55.8	9.19	3.68	--	--
7	FE	15	197.2	55.8	9.65	3.59	--	--
5	FE	13	187.9	52.0	10.05	3.57	--	--
3	FE	12	187.9	48.9	10.82	3.79	--	--
2	FE	10	185.3	46.4	11.33	3.99	--	--
10	U	21	189.0	63.8	2.45	3.42	--	--
7	U	21	194.5	63.8	2.61	3.49	--	--
5	U	18	190.6	61.9	2.74	3.35	--	--
3	U	15	179.7	55.8	3.02	3.57	2.00	0.25
2	U	15	188.8	55.8	3.27	3.67	3.00	0.25

Table 4b: Optimal Pb, Fe, and U-Metal Cask Designs
vs Decay Time of Spent Fuel (Weight $\leq 207,000$ lbs)

FUEL AGE	GAMMA SHIELD	NO. OF ASSYS	LOADED WT (1000-LBS)	CASKID (IN)	GSHLD (IN)	NSHLD (IN)	L-FIN (IN)	T-FIN (IN)
10	PB	21	206.9	63.8	3.97	4.13	--	--
7	PB	18	203.3	61.9	4.20	4.01	--	--
5	PB	15	183.7	55.8	4.43	4.08	--	--
3	PB	15	195.8	55.8	4.99	4.21	--	--
2	PB ^a	13	201.0	52.0	5.39	4.25	2.00	0.25
10	FE	15	189.8	55.8	9.19	3.68	--	--
7	FE	15	197.2	55.8	9.65	3.59	--	--
5	FE	15	204.7	55.8	10.11	3.56	--	--
3	FE	13	201.3	52.0	10.85	3.79	--	--
2	FE	12	203.5	48.9	11.46	3.92	2.00	0.25
10	U	22	210.2	66.6	2.46	3.42	--	--
7	U	22	206.0	66.6	2.61	3.49	--	--
5	U	21	200.6	63.8	2.79	3.45	--	--
3	U	18	206.2	61.9	3.06	3.58	2.00	0.25
2	U	15	188.8	55.8	3.27	3.67	3.00	0.25

45/26

a) For added thermal protection, a 2.5-inch outer shell was used in lieu of a 2.0-inch outer shell.

REFERENCES

1. J. A. Bucholz, SCOPE: The Shipping Cask Optimization and Parametric Evaluation Code, ORNL/CSD/TM-148 (to be published).
2. J. A. Bucholz, Scoping Design Analyses for Optimized Shipping Casks Containing 1-, 2-, 3-, 5-, 7-, or 10-Year-Old PWR Spent Fuel, ORNL/CSD/TM-149 [TTC-0316] (January 1983).
3. L. M. Petrie and N. M. Greene, "XSDRNPM: An AMPX Module for Multi-group One-Dimensional Discrete-Ordinates Transport Calculations," as described in Section 8 of AMPX: A Modular Code System for Generating Coupled Multigroup Neutron-Gamma Libraries From ENDF/B, ORNL/TM-3706 (March 1976).
4. G. W. Morrison, E. A. Straker, and R. H. Odegarden, CASK: 40-Group Neutron and Gamma-Ray Cross-Section Data, DLC-23/CASK (March 1974); available from the Radiation Shielding Information Center at ORNL.
5. Packaging of Radioactive Material for Transport, 10 CFR 71, Code of Federal Regulations (Rev. through August 1, 1980); available from the U.S. Nuclear Regulatory Commission, Washington, DC.
6. J. P. Holman, Heat Transfer, pub. by McGraw-Hill Book Co. (1963); See Table 7-4 for a good description of the McAdams correlation.
7. C. Y. Liu, W. K. Mueller, and F. Iandis, "Natural Convection in Long Horizontal Cylindrical Annuli," presented at the 1961 ASME Conf. on International Developments in Heat Transfer, Boulder, CO. (August 28 - September 1, 1961); see pp. 961, in Part V of the Conf. Proceedings.
8. R. O. Wootton and H. M. Epstein, "Heat Transfer From a Parallel Rod Fuel Assembly in a Shipping Container," as summarized in Appendix J of Scoping Design Analyses for Optimized Shipping Casks Containing 1-, 2-, 3-, 5-, 7-, or 10-Year-Old PWR Spent Fuel, ORNL/CSD/TM-149 [TTC-0316] (January 1983).
9. W. D. Turner, D. C. Elrod, and I. I. Siman-Tov, HEATING5 - An IBM-360 Heat Conduction Program, ORNL/CSD/TM-15 (March 1977).
10. National Lead Industries, "NLI-10/24 Spent Fuel Shipping Cask Safety Analysis Report," NRC Docket No. 71-9023 (1975); available from National Lead Industries, Nuclear Division, Barnwell, SC.
11. General Electric Corp., IF-300 Shipping Cask: Consolidated Safety Analysis Report, NEDO-10084-2 (October 1979); available from General Electric Corp., Nuclear Fuel and Services Division, San Jose, CA.

12. L. M. Petrie and N. F. Cross, KENO-IV: An Improved Monte Carlo Criticality Program, ORNL-4938 (November 1975).
13. J. A. Bucholz, "SCALE System Criticality Safety Analysis Module CSAS2," as described in Section C2 of SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, ORNL/NUREG/CSD-2, Volume 1, Revision 1 (October 1981).
14. U. S. Patent Application Serial Number 257,030(79), CNID-4043, "Separator Assembly for Use in Spent Nuclear Fuel Shipping Casks," Filed by U. S. Department of Energy (April 1981).

INTERNAL DISTRIBUTION

1. D. E. Bartine	34. R. T. Prima, III
2. M. A. Bjerke	35. J.-P. A. Renier
3. J. O. Blomeke	36. T. H. Row
4. W. D. Box	37. J. C. Ryman
5-9. J. A. Bucholz	38. C. D. Scott
10. W. D. Burch	39-43. L. B. Shappert
11. B. P. Carter/CS Library	44. M. G. Stewart
12. A. G. Croff	45. J. S. Tang
13-14. H. L. Dodds	46. J. T. Thomas
15. D. E. Ferguson	47. W. D. Turner
16. W. E. Ford	48. V. C. A. Vaughen
17. R. W. Glass	49. J. F. Walker, Jr.
18. N. M. Greene	50. C. C. Webster
19. O. W. Hermann	51. C. R. Weisbin
20. J. R. Hightower, Jr.	52-56. R. M. Westfall
21. T. J. Hoffman	57. S. K. Whatley
22. W. P. Huxtable	58. J. R. White
23. D. T. Ingersoll	59. G. E. Whitesides
24. D. S. Joy	60. R. G. Wymer
25. J. R. Knight	61-64. Engineering Physics
Information Center
26. R. F. Leuze	65. Central Research Library
27. J. L. Lucius	66. Y-12 Document Reference
Section
28. A. P. Malinauskas	67-68. Laboratory Records
29. K. J. Notz, Jr.	69. Laboratory Records - RC
30. J. V. Pace, III	70. ORNL Patent Section
31. C. V. Parks	
32. L. M. Petrie	
33. W. W. Pitt, Jr.	

EXTERNAL DISTRIBUTION

71. F. M. Alcorn, Lynchburg Research Center, Babcock & Wilcox Company, P. O. Box 1260, Lynchburg, VA 24505
72. G. C. Allen, Sandia Laboratories, Transportation Systems Technology Division 4552, P. O. Box 5800, Albuquerque, NM 87185
73. W. B. Andrews, Battelle Pacific Northwest Laboratories, Energy Systems Department, Battelle Boulevard, Richland, WA 99352
74. S. R. Bierman, Battelle Pacific Northwest Laboratories, P. O. Box 999, Richland, WA 99352

75. L. G. Blalock, Transportation Branch Manager, Department of Energy, ORO, P. O. Box , Oak Ridge, TN 37830
76. R. W. Bostian, Systems Results and Fuel Management, Duke Power Company, P. O. Box 33189, Charlotte, NC 28242
77. W. D. Bromley, Nuclear Fuel Operations, Bechtel National, Inc., P. O. Box 3965, San Francisco, CA 94119
78. D. R. Brown, Nuclear Research and Development, Department of Energy, ORO, P. O. Box E, Oak Ridge, TN 37830
79. R. M. Burgoyne, General Atomic Company, Radioactive Materials Shipping, P. O. Box 81608, San Diego, CA 92138
80. L. Burris, Jr., Chemical Engineering Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439
81. K. A. Carlson, Transportation Program Manager, Department of Energy, ALO, Albuquerque, NM 87115
- 82-84. J. W. Cashwell, Sandia Laboratories, Transportation Systems Technology Department 4552, P. O. Box 5800, Albuquerque, NM 87185
85. R. B. Chitwood, Transportation Branch, NFW, Department of Energy, Mail Station B-107, Germantown, MD 20545
86. G. R. Choppin, Department of Chemistry, Florida State University, Tallahassee, FL 32306
87. E. D. Clayton, Battelle Pacific Northwest Laboratories, P. O. Box 999, Richland, WA 99352
88. W. H. Corcoran, Department of Chemical Engineering, California Institute of Technology, Pasadena, CA 91125
89. D. M. Dawson, General Electric Company, M/C 861, 175 Curtner Avenue, San Jose, CA 95125
90. S. W. Drew, Merck, Sharp & Dohme Research Laboratories, P. O. Box 2000, Rahway, NJ 07065
91. W. J. Eich, Electric Power Research Institute, P. O. Box 10412, Palo Alto, CA 94033
92. H. M. Epstein, Battelle Columbus Laboratories, 505 King Avenue, Columbus, OH 43201
93. F. P. Falci, Office of Nuclear Waste Management, Department of Energy, Mail Station B-107, Germantown, MD 20545

- 94. R. F. Garrison, Office of Defense Programs (DP-122), Department of Energy, Germantown, MD 20545
- 95. A. M. Jacobs, Nuclear Engineering Department, University of Florida, Gainesville, FL 32601
- 96. R. M. Jefferson, Sandia Laboratories, Nuclear Materials Transportation Technology Department 4550, P. O. Box 5800, Albuquerque, NM 87185
- 97. Norman Ketzlach, Fuel Processing & Fabrication Branch, U. S. Nuclear Regulatory Commission, Washington, DC 20555
- 98. M. H. Lipner, Westinghouse Electric Corporation, P. O. Box 10864, Pittsburgh, PA 15236
- 99. M. C. Kirkland, Spent Fuel Project Office, Savannah River Operations Office, Department of Energy, Aiken, SC 29801
- 100. L. W. Kruse, Sandia Laboratories, Project Engineering Division, P. O. Box 5800, Albuquerque, NM 87185
- 101-102. D. E. Large, Department of Energy/ORO, P. O. Box E, Oak Ridge, TN 37830
- 103. M. J. Lawrence, Office of Nuclear Waste Management, Fuel Storage and Transfer Division, DOE, Mail Station B-107, Germantown, MD 20545
- 104. R. Y. Lowrey, Director, Waste Management and Transportation Development Div., Department of Energy/ALO, Albuquerque, NM 87115
- 105. R. E. Luna, Sandia Laboratories, Transportation Analysis and Information Division 4551, P. O. Box 5800, Albuquerque, NM 87185
- 106. L. Macklin, Transnuclear, Inc., One North Broadway, White Plains, NY 10601
- 107. D. H. Malin, Nuclear Assurance Corporation, 24 Executive Park West, Atlanta, GA 30329
- 108. D. McGoff, Office of Defense Programs (DP-123), Department of Energy, Germantown, MD 20545
- 109. W. G. Morrison, Allied Chemical Corporation, 550 Second Street, Idaho Falls, ID 83401
- 110-111. R. H. Odegarden, U. S. Nuclear Regulatory Commission, Mail Stop 396-SS, Washington, DC 20555

- 112. P. F. Pasqua, Nuclear Engineering Department, University of Tennessee, Knoxville, TN 37916
- 113. G. W. Perry, Nuclear Fuels Division, Tennessee Valley Authority, Kryptal Bldg., Chattanooga, TN 37401
- 114-115. R. W. Peterson, Battelle Columbus Laboratories, Office of Nuclear Waste Isolation, 505 King Avenue, Columbus, OH 43201
- 116. R. R. Pope, Sandia Laboratories, Transportation Systems Technology Department 4552, P. O. Box 5800, Albuquerque, NM 87185
- 117. W. A. Pryor, Department of Energy/ORO, P. O. Box E, Oak Ridge, TN 37830
- 118-119. J. Ridihalgh, Ridihalgh, Eggers and Associates, 2119 Summit Street, Columbus, OH 43701
- 120. J. N. Rogers, Div. 8324, Sandia Laboratories, Livermore, CA 94550
- 121. K. A. Schneider, Transnuclear, Inc., 2308 Yale Avenue, Camp Hill, PA 17011
- 122. Charles Shih, Kaiser Engineers, 300 Lakeside Drive, P. O. Box 23210, Oakland, CA 94623
- 123. C. G. Shirley, Sandia Laboratories, Transportation Systems Technology Department 4552, P. O. Box 5800, Albuquerque, NM 87185
- 124. J. D. Simchuck, Vice-President, Nuclear Packaging, Inc., 1833 S. Fawcett, Tacoma, WA 98402
- 125. D. R. Smith, MS-560, Los Alamos Scientific Laboratory, Post Office Box 1663, Los Alamos, NM 87545
- 126. A. M. Squires, Department of Chemical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061
- 127. J. M. Viebrock, Operations and Engineering, Nuclear Assurance Corporation, 24 Executive Park West, Atlanta, GA 30329
- 128. M. E. Wadsworth, College of Mines & Mineral Industries, University of Utah, Salt Lake City, UT 84112
- 129. J. T. West, III, Los Alamos Scientific Laboratory, P. O. Box 1663, Los Alamos, NM 87545

- 130. F. E. Woltz, Goodyear Atomic Corporation, P. O. Box 628,
Piketon, OH 45661
- 131. Chief, Mathematics and Geoscience Branch, Department of Energy,
Washington, DC 20545
- 132. Office of Assistant Manager for Energy Research and Development,
Department of Energy/ORO, Oak Ridge, TN 37830
- 133-140. Transportation Technology Center Library, Sandia Laboratories,
P. O. Box 5800, Albuquerque, NM 87185
- 141. Transportation Technology Center, File Reference No. 82/T113
- 142. Transportation Technology Center, Master File
- 143-455. Given distribution as shown in TID-4500 under Category UC-70.