NDS-23

LMFBR FUEL SHIPPING STUDY

July 15, 1970

AEC Contract (04-3)-782

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LMFBR FUEL SHIPPING STUDY

Report No. _____

15 July 1970

I. INTRODUCTION

A. OBJECTIVE

The objective of the LMFBR Fuel Shipping Study has been to review pertinent literature, fuel reprocessing technical factors and applicable AEC and DOT regulations from the standpoint of obtaining, compiling and evaluating data in support of the design of an LMFBR Spent Fuel Shipping Cask System. This study is preliminary to the general cask design effort which is directed towards the economic objectives of the LMFBR Program Plan. Specifically the cask design effort "is to provide the engineering effort required to insure a licensed cask availability suitable for and on a schedule compatible with the first shipment of FFTF fuel for reprocessing on 1 January 1975." The cask must also be compatible with fuel shipments from early LMFBR Demonstration Plants.

B. INFORMATION SOURCES

1. LMFBR 1000 Mwe Follow-On Studies

a. Atomics International

AI-AEC-12765, 12791, 12792 & 12793

b. Babcock and Wilcox

BAW-1316, 1326, 1328 & 1331

c. Combustion Engineering

CEND-322, 337 & 346

d. General Electric

GEAP-5618, 5678, 5710, 5769

e. Westinghouse

WARD-2000-20, 22, 31, 33, 84, 90, 93, 96, 97

f. Fast Flux Test Facility

Bechtel Corp. B-3-06001

2. LMFBR Fuel Cycle Studies

a. LMFBR Program Plan WASH 1108

b. ORNL Progress Reports

ORNL-TM-2552, 2585, 2624, 2650, 2671, 2710,
2748, 2764, 2795, 2819, 2871, 2918, 2949, 2996

c. Private Communication - Savannah River Plant

d. Private Communication - Atlantic Richfield

Hanford Company

e. "Processing of FFTF Fuels in Purex"

ARH-1374

3. Federal Regulations

a. 10 CFR 71

b. 49 CFR 173

c. AEC 0529

4. Fuel Shipping Cask Literature

a. Cask Designers Guide

ORNL-NSIC-68

b. Proceedings of the Second International Symposium
on Packaging and Transportation of Radioactive
Materials - CONF 681001

C. METHOD OF APPROACH

The LMFBFR Spent Fuel Shipping Cask System is to accommodate any of the contending LMFBFR fuel assemblies, including those of FFTF. Thus the data with respect to fuel assembly weight, dimensions, interface and grapple configurations, fuel and blanket material distribution, expected fission product and transuranium neutron source distributions and strengths and the heat transfer parameters of pin size, spacing and conduction paths were compiled. In addition the spent fuel preparation for shipment proposed for each plant was reviewed to determine the interfaces and associated equipment requirements which might be imposed on the shipping cask system.

Shipping regulations relative to shielding, criticality limitations, heat removal and temperature limitations and radioactive source containment under conditions imposed by specified accident situations were extracted from the Code of Federal Regulations to serve as guidelines for design and evaluation.

Information on the state-of-the-art of shipping cask design, fabrication, and utilization has been and is continuing to be accumulated to serve the long range objectives of this task. Data pertinent to this study report is given for reference.

A summary of the problem areas in the design of the LMFBFR Spent Fuel Shipping Cask System and some preliminary analyses results are given as an introduction to a "Reference Model" cask concept. The "Reference Model," which will serve as a basis for evaluation and design criteria development, is described along with suggested reactor plant and fuel reprocessing plant facility and equipment requirements.

II. LMFBR REACTOR REFUELING SYSTEMS

A. LMFBR FUEL ASSEMBLIES

Figure 1 illustrates the various LMFBR fuel assembly configurations with the fuel, blanket and fission gas plena or vent regions identified. Table 1 presents further pertinent data on dimensions weight, fissile and fertile material masses, burnup expectations, refueling cycle numbers and parameters useful for thermal analysis. It should be emphasized that these data are taken from reports published in 1970. Continuing work by the respective study groups can be expected to change the data. As given, though, it is representative of the variations in fuel assembly design which must be considered in the design of the LMFBR shipping cask.

B. SPENT FUEL PREPARATION FOR SHIPMENT

The five LMFBR Follow-On Studies have been reviewed with respect to the "Spent Fuel Preparation for Shipment" and have been found to be common with respect to decay storage provisions, canning of fuel assemblies for shipment and transfer to the cask in a special loading location separated from the cask railroad car. Differences in the five concepts included reactor hot cells (Westinghouse and General Electric) vs shielded fuel handling machines, pot vs loop heat transfer arrangements and various equipment and/or hot cells to accomplish the canning of the fuel assemblies. Figure 2 illustrates the equipment symbols used in the subsequent fuel preparation schematics for the five concepts.

The scheme by Atomics International is shown in Figure 3. Spent fuel is removed from the reactor in a sodium filled transfer container using a

TABLE 1

Reactor Designer	Dwg. No. & Ref.	Fuel Assembly			Pin Geometry		
		Max. Length in.	Max. Diameter in.	Weight lb	Number Assembly	Diameter in.	Spacing in.
Atomics International	N09624006	180	6.544	750	217 Hex	.300	.3592
Babcock and Wilcox	A31073E	111	7.448	--	331 Hex	.280	.337
Combustion Engineering	Figure 1-2	144	7.224	~ 750	163 Round	.400	.451
General Electric	174F140	111	6.525	--	331 Hex	.250	.300
Westinghouse	ED _{SK} 334577J	123+	7.486	--	~ 168 Square	.302	.3745
FFTF		144	5.444	430	217 Hex	.230	.286

TABLE 1 (Continued)

Reactor Designer	(U + Pu) Kgm /		Power Mwt /		Burnup Mwd/Kgm	Refueling Cycle	
	Lower Blanket	Core	Upper Blanket	Inner Blanket		Outer Blanket	# Assys./Cycle Time Core Blanket
Atomics International	26.6/.14/3.1	69.7/8.0/67.4 2 Cycles	21.3/.3/3.6	127/1.3/14 5 Cycles	102/.51/10 7 Cycles	137/Year	23.5/Year
Babcock and Wilcox	33.1/.59/19	82.3/7.7/100 3 Cycles	33.1/.59/19	116/.64/5.9 3 Cycles	116/.29/4.5 5 Cycles	96/Year	34/Year
Combustion Engineering	58/.60/8.6	78/9.4/100 3 Cycles	58/.60/8.6	116/2.3/49 9 Cycles	--	73/344 Days	7/344 Days
General Electric	29.7/.72/15	53.2/8.4/100 2 Cycles	29.7/.72/15	132/1.2/8.6 3 Cycles	132/.6/5.8 4 Cycles	133-/Year	18+/Year
Westinghouse	19/.67/18	49.8/9.8/100 2 Cycles	19/.67/18	135/-/-	135/-/-	122/400 Days	65/400 Days 130/800 Days
FFTF	--	37.5/4.9/45 3 Cycles	--	--	--	25/136 Days	--

shielded fuel handling machine to transfer the fuel to decay storage. After a suitable decay time the fuel handling machine transfers the fuel in its transfer container to a Fuel Hot Cell Canning Station where a cover is welded to the container. The weld sealed container is then returned to decay storage, to await loading into the cask.

The shipping cask is received at the reactor plant and transferred to a dolly. The cask on the dolly is then transported through an air lock into the containment building where it is erected and placed in a loading pit. The weld sealed containers are then removed from decay storage and loaded into the shipping cask using the shielded fuel handling machine. Here AI suggests that sodium will be removed from the cask and the exterior of the fuel containers. Then the cask is closed and, using the transfer dolly, delivered through the air lock to be installed on the railroad car.

The Babcock and Wilcox scheme is illustrated in Figure 4. Here spent fuel is transferred, under sodium, from the reactor to decay storage within the pot type reactor vessel. The fuel is held for a suitable decay period in the decay storage.

B&W indicates that the shipping cask is to be for a single fuel assembly. The cask, with an internal container is removed from the carrier (railroad car illustrated) and transferred on a dolly into a tunnel to an interface station under the hot cell in the containment building. The fuel container is removed from the cask, into the hot cell, and prepared to receive the spent fuel.

The spent fuel is transferred from decay storage, using a gas cooled shielded fuel handling machine, to the fuel hot cell and canning station. The fuel is placed in the container and a lid is weld sealed in place. The spent fuel in the container is then transferred to the cask and the cask is closed and transferred to the carrier.

Combustion Engineering identifies the general scheme illustrated in Figure 5. Fuel is transferred in sodium filled pots from the reactor to decay storage. From the decay storage bare fuel is transferred to a three assembly container supported in a transfer cask below the reactor building floor. The container is a finned pot partially filled with a Pb-Bi mixture. The transfer cask has a canning head arrangement to allow welding a cap on the container.

The transfer cask is moved out from the interface loading station on a dolly to the fuel building. The three assembly container is transferred to the shipping cask in the fuel building and then to the carrier (railroad car) for shipment offsite.

The General Electric scheme for spent fuel preparation is illustrated in Figure 6. The General Electric concept involves a pot type reactor vessel and a hot cell over the reactor for refueling but with a separate vessel for decay storage.

Inspection of the General Electric facility drawings indicates that the shipping cask is delivered into the reactor building, through an air lock, while still attached to the railroad car. The cask is then erected and placed on a transfer dolly in a transfer tunnel which leads to an interface

port under the reactor hot cell. A fuel canning station has been assumed to be within the reactor hot cell. Fuel would thus be removed from decay storage, canned and then transferred to the shipping cask. After loading the cask is returned through the tunnel to be installed on the railroad car.

The Westinghouse spent fuel preparation for shipment is illustrated in Figure 7. The reactor concept utilizes a loop type vessel with a hot cell over the reactor and decay storage for remote fuel handling operations. The decay storage tank is interconnected to the reactor vessel for fuel transfer under sodium. Two vertical fuel handling machines in the hot cell and a lateral fuel handling machine in the decay storage tank provide for new and spent fuel exchanges in the reactor. After an appropriate decay time a transfer pot is brought from the fuel hot cell to the decay storage tank in a transfer cask and dolly rig. The fuel is transferred into the pot under sodium and then to the transfer cask using one of the vertical fuel handling machines in the reactor hot cell.

The dolly and transfer cask are moved into the fuel hot cell where a can changing machine is positioned. The fuel is transferred from the transfer cask to the can changing machine where the fuel is removed from the transfer pot to a clean shipping can. The clean can is then moved to a cap and weld station, then a leak check station and then back to the transfer cask on the dolly. The shipping can is then removed from the transfer cask into a separate decontamination cell from whence it is transferred to the shipping cask. After the shipping cask is fully loaded it is sealed, closed and removed from the loading pit for installation on the railroad car.

III. FEDERAL REGULATIONS

A. RADIATION

Radioactive materials, liquid, solid and gaseous must be packaged in suitable containers so that during normal transport conditions the radiation dose rate does not exceed any of the limits specified in the following subparagraphs.

1. 200 millirem per hour at any point on the external surface of the package.

2. 10 millirem per hour at three feet from any accessible external surface of the package.

Packages for which the radiation dose rate exceeds the limits specified above but does not exceed any of the limits specified below may be transported in a vehicle (except aircraft) assigned for the sole use of that consignor, and unloaded by the consignee from the transport vehicle in which originally loaded.

1. 1000 millirem per hour at three feet from the external surface of the package (closed transport vehicle only);

2. 200 millirem per hour at any point on the external surface of the car or vehicle (closed transport vehicle only);

3. 10 millirem per hour at six feet from the external surface of the car or vehicle; and

4. 2 millirem per hour or equivalent in any normally occupied position in the car or vehicle except this does not apply to private motor carriers.

The LMFBR Spent Fuel Shipping Cask transported on its special design railroad car puts it in the class requiring "10 mrem/hr at six feet from the external surface of the car or vehicle."

Under the hypothetical accident conditions (Section III,F,2) for a single package:

The reduction of shielding would not be sufficient to increase the external radiation dose rate to more than 1000 mrem/hr at three feet from the external surface of the package.

It is assumed that the term "reduction of shielding" applies to "any displacement of the radioactive source material."

B. RADIOACTIVE MATERIAL

The LMFBR Spent Fuel Shipping Cask is a Fissile Class I package requiring "no nuclear criticality controls during transportation." It can be shown that a close pack infinite array of casks will be subcritical.

71.35(a)(4) Radioactive contamination of the liquid or gaseous primary coolant will not exceed 10^{-7} ci/ml of activity of Group I radionuclides, 5×10^{-6} ci/ml of Group II, 3×10^{-4} ci/ml of Groups III and IV.

Since this imposes an expensive processing requirement on the reactor plant it is planned to take advantage of special design verification and control procedures as allowed by:

71.34(c) Normal conditions of transport and hypothetical accident conditions different from those specified in 71.35 and 71.36 may be approved by the Commission if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

It should be noted that compliance with 71.34(c) eliminates the requirement that "leakers" or vented LMFBR fuel be processed or packaged in a special manner different from normal spent fuel.

C. CRITICALITY (Ref. 71.33)

Every shipment of fissile material is to remain subcritical at all times during normal transport, including loading and unloading, and under hypothetical accident conditions leading to the most reactive credible configuration.

D. MECHANICAL (Ref. 71.31)

1. Lifting Devices (Ref. 71.31(c))

Lifting devices are defined as items that are attached permanently to a shipping cask and serve to transmit the entire load to lifting equipment such as a crane.

a. If the system of lifting devices is a structural part of the package, the system shall be capable of supporting three times the weight of the loaded package without generating stress in any material of the packaging in excess of its yield strength.

b. If the system of lifting devices is a structural part of the lid only, the system shall be capable of supporting three times the weight of the lid and any attachments without generating stress in any material of the lid in excess of its yield strength.

c. If there is a structural part of the package that could be employed to lift the package but does not comply with 1., above, this part shall be securely covered or locked during transport to prevent its use for that purpose.

d. If a lifting device is a structural part of the package, it shall be designed in such a manner that failure of the device under excessive load will not impair the containment or shielding properties of the package.

2. Tie Down Devices (71.31(d))

The performance requirements for tie-down devices are:

a. If there is a system of tie-down devices which is a structural part of the cask, it shall be capable of withstanding, without generating stress in any material of the cask in excess of its yield strength, a static force applied at the center of gravity of the package having a vertical component of two times the weight of the cask, with its contents, a horizontal component along the direction in which the vehicle travels of ten times the weight of the cask with its contents, and a horizontal component in the transverse direction of five times the weight of the cask with its contents.

b. Also if there is a structural part of the cask which could be employed to tie the package down and which does not comply with the above paragraph, that part shall be securely covered or locked during transport in such a manner as to prevent its use for that purpose.

c. Each tie-down device which is a structural part of the package shall be so designed that failure of the device under excessive load would not impair the ability of the device to meet other requirements of the regulations.

E. THERMAL

No regulations specifying the temperature limitations for the actual cask surface or fuel are given. It is required, though, that the "accessible cask surface temperature not exceed 180°F under normal operating conditions."

F. CASK DESIGN CONDITIONS

1. Normal Conditions of Transport (71 Appendix A)

- a. Heat - Direct sunlight at an ambient temperature of 130°F in still air.
- b. Cold - An ambient temperature of -40°F in still air and shade.
- c. Pressure - Atmospheric pressure of 0.5 times standard atmospheric pressure.
- d. Vibration - Vibration normally incident to transport.
- e. Water Spray - A water spray sufficiently heavy to keep the entire exposed surface of the package except the bottom continuously wet during a period of 30 minutes.
- f. Free Drop - Between 1-1/2 and 2-1/2 hours after the conclusion of the water spray test, a free drop through a distance of one foot (for packages over 30,000 lb) onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.
- g. Corner Drop - (not applicable)

h. Penetration - Impact of the hemispherical end of a vertical steel cylinder 1-2/4 inches in diameter and weighing 13 pounds, dropped from a height of 40 inches onto the exposed surface of the package which is expected to be most vulnerable to puncture.

i. Compression - (not applicable)

2. Hypothetical Accident Conditions (71 Appendix B)

a. Free Drop - A free drop through a distance of 30 feet onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected.

b. Puncture - A free drop through a distance of 40 inches striking in a position for which maximum damage is expected, the top end of a vertical cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The bar shall be 6 inches in diameter, with the top horizontal and its edge rounded to a radius of not more than 1/4 inch, and of such a length as to cause maximum damage to the package, but not less than 8 inches long. The long axis of the bar shall be normal to the package surface.

c. Thermal - Exposure to a thermal test in which the heat input to the package is not less than that which would result from exposure of the whole package to a radiation environment of 1475°F for 30 min with an emissivity coefficient of 0.9, assuming the surfaces of the package have an absorption coefficient of 0.8. The package shall not be cooled artificially until 3 hr after the test period unless it can be shown that the temperature on the inside of the package has begun to fall in less than 3 hr.

d. Water Immersion (packages containing fissile material only) -

Immersion in water to the extent that all portions of the package to be tested are under at least 3 ft of water for a period of not less than 8 hr.

The following table of radioactive material release limits is given for reference.

No radioactive material, except gases and contaminated coolant, may be released from the cask; the total radioactivity content of the coolant must not exceed either 0.1% of the total radioactivity of the cask contents or the following designated limits:

<u>Transport Group</u>	<u>Curies</u>
I	0.01
II	0.05
III & IV	10.
Inert gases	1000.

IV. PROBLEM AREAS

A. RADIATION

Radiation source data, for use in this cask design study, is taken from the ORNL ORIGEN computer program which has been used to analyze the fission products and source strengths for the Atomic International LMFBR 1000 Mwe reactor and fuel assembly. These source strengths are conservative being for a burnup of only 67 Mwd/Kgm. Doubling this burnup, as for 1460 days exposure rather than 730 days, and normalizing to a reactor power of 10 Mwt per fuel assembly gives an upper limit for the most intense of the fuel assemblies under consideration, namely that of Combustion Engineering. This latter spectrum and source strength is presented in Figure 8. It will be used for shielding evaluation with modifications according to power, as $P/10$, and axial distribution, as $\cos 120 \frac{Z}{L}$. Typical cask shield thicknesses for this spectrum range from 20 in. for Westinghouse fuel assemblies with 10 days decay to 17 in. for FFTF fuel assemblies with 90 days decay.

Shielding design for gamma radiation is a minor problem well in hand with analytical techniques readily available. The minor problem existent is associated with the potential source redistribution which could result from the accident situation. Whereas it would be desirable to taper the shielding away from the fuel region it is necessary to determine the possible source distribution before this can be done. Thus the problem is one for mechanical and thermochemical analysis to determine the source distribution. The shield design would follow from this data.

Recycled plutonium has an increasing neutron source strength as the transuranium elements build up. This neutron source strength becomes quite

high for fuel recycled through thermal reactors. LMFBR fuel, in contrast, approaches an equilibrium due to burnup and buildup. The source strength given in Table 2 is reported by Oak Ridge to be a maximum for recycled LMFBR fuel and is thus suggested as a source for neutron shielding analysis.

TABLE 2

Neutrons/sec - Kgm Pu x 10^{-6}

	<u>10</u>	<u>30</u>	<u>60</u>	<u>100</u>	<u>210</u>	<u>360</u>
(α, n)	1.85	1.73	1.58	1.40	1.05	.76
Fission	4.31	4.08	3.76	3.39	2.64	2.04
Total	6.16	5.81	5.34	4.79	3.69	2.80

The total neutron source for a maximum size cask may be in the order of 10^9 neutrons/sec times the multiplication factor for the assembly. It would be desirable to minimize this latter factor even though the criticality problem is well under control. A boron loading within the cask cavity would be appropriate to minimize the neutron shielding.

B. CRITICALITY

Criticality must be prevented for both normal loading and potential redistribution of fuel in an accident situation. Oak Ridge reports that the k value for a 37 assembly cask capacity will range from .924 to .683 for AI fuel assemblies depending on the fuel burnup and the particular assemblies (inner or outer core loadings) chosen. These factors may be further reduced by judicious placement of fuel and blanket assemblies in the cask for each

shipment. The use of lithium, rather than sodium, for the primary coolant, could reduce k by about $2/3$ rds thus greatly reducing the neutron multiplication factor.

C. THERMAL

The LMFBR cask thermal problem is quite difficult to solve because of the heterogeneous heat sources and combined two dimensional conduction and natural convection character of the heat transfer media. Oak Ridge National Laboratory is conducting an experimental program to determine the effectiveness of natural convection in reducing the peak temperatures which would result from the conduction effect alone. The two dimensional conduction problem will be done with the CINDA computer program and suitable approximations to keep the problem within practical limits on storage and operating time.

It appears, on the basis of simplified analyses, that normal transport operations can be handled without excessive temperatures in the fuel after very short decay time, such as 10 days. Peak temperatures can be maintained below 1000°F and average sodium temperatures may be in the order of $500\text{-}600^{\circ}\text{F}$. In the event of an accident involving loss of secondary coolant and a portion of the ancillary fin cooling area followed by a fire the peak temperatures may exceed 1400°F . The heat input from a fire at 1475°F for 30 min. is small compared with the internal heat source. Also the heat capacity of the cask is large enough to limit the temperature rise during the 30 min. to a small extent. The major temperature rise occurs after the fire due to the loss of the secondary coolant. The equilibrium temperature, computed for this condition, may result in very high peak temperatures, $> 1700^{\circ}\text{F}$, but is this

excessive? Assuming that the cask is sacrificed and the fuel is unavailable for a long time (years) and as long as the radioactive material is contained and the exterior radiation environment is maintained within regulation limits then the peak temperature need not be the criterion for fuel capacity or decay power limits.

An alternate criterion for the accident situation limits is suggested to be the actual containment objective. Sodium, when heated from 500°F to 1500°F expands 13.5%. In order to insure that this primary coolant will not rupture the cask and release the radioactive material a mechanism for providing an expansion volume within the cask cavity is required. This source of potential damage plus the accident impact source of potential damage to the cask are considered to be more important than limiting the peak fuel temperature.

D. MECHANICAL

A practical limit on the size of the LMFBR Spent Fuel Shipping Cask is imposed by unrestricted railway transport. The width limit for the cask-car combination is 10'8" (128"). Using data from the Oak Ridge parameter survey the following dimensions result in a limited cask cavity diameter.

Rail car edge barrier	4" each side
Auxiliary cooling fins	6" each side
Water jacket-neutron shield	2" each side
Steel shielding	<u>19" each side</u>
	31
	<u>x 2</u>
	62" total

The remainder, 128"-62" = 66", is available for the cask cavity.

Figure 9 shows several possible arrangements of fuel assembly support cells as appropriate to a lazy susan fuel magazine within the cask cavity. The 6 & 12 & 18 array could be utilized if the minimum spacing of cells were 9.68". This is just a bit snug and it does correspond to a high temperature case with three rings of fuel cells. The smaller arrangement of 10 & 16 fits in a 62.5" diameter cavity with a 10" spacing between cells. Also it allows a central region of 22", about 12% of the cavity volume which might be used for a sodium expansion void.

The major mechanical design problem is in the closure and sealing of the cavity to preclude radioactive material loss in case of an accident. Double seals and isolation of the sealing device from shock loads are considered to be the approach to this problem. Further, in order to limit the shock loads to the sealing device, it is desirable to include exterior energy absorbing structures on the cask. The combination of double seals, seal isolation and energy absorbers should be sufficient to insure containment of the radioactive material.

V. REFERENCE MODEL LMFBR SPENT FUEL SHIPPING CASK SYSTEM

A. GENERAL DESCRIPTION

The Reference Model LMFBR Spent Fuel Shipping Cask System, Drawing 1137755, is a steel shielded package with a capacity for 26 LMFBR fuel assemblies and shielding sufficient to provide for 10 day decay fission products of maximum burnup fuel. Cooling is provided by natural convection liquid sodium within the cask cavity plus conduction to the water jacket. The water serves both as the secondary coolant and as neutron shielding. Radial fins on the exterior surface of the cask provide for natural convection air cooling in case of an accident involving the loss of the secondary coolant.

Energy absorbers, in the form of toroidal bundles of tubes, are attached to each end of the cask to limit the shock loading to the cask seal-containment in case of accident. The fins serve as energy absorbers for lateral impact loadings.

The shipping cask is transported on a railroad car, Drawing 1137756, with support and tie down provisions as required. The railroad car is designed for the transport of the cask and its support equipment only. The support equipment includes a natural convection air heat exchanger for the secondary coolant and auxiliary tools and equipment for operational use.

The cask may be erected on the railroad car and then transferred to the facility loading - unloading interface. Alternatively the cask can be removed from the railroad car and, with facility provided equipment, transferred to the interface. An erecting and lifting sling will be provided with the cask but the facility would supply the crane or other means to power the operation.

Auxiliary equipment to allow removal and installation of shield plugs, seal plugs and fuel-container retention plugs are necessary to the loading and unloading operation. Means to replace seal rings are also required. These tools could be provided with the shipping cask. The means for working with these tools under alpha-gamma containment controls would be provided by the shipping or receiving facility.

It should be noted that the reference design presented herein is to serve as a basis for evaluation and development of a concept for a licensable LMFBR shipping cask. The finer details of auxiliary tools and equipment will be developed after the major points of concern have been resolved. These major points are:

- o The cask capacity
- o Maximum decay power
- o Total decay power
- o Sealing mechanisms
- o Energy absorber means
- o Sodium expansion volume

Figure 10 is presented as a composite of the LMFBR Spent Fuel Preparation for Shipment applicable to the reference model cask. Note that the "Hot Cell and Canning Station" is indicated as a facility provision. It might also be represented as an equipment item which provides for the removal and replacement of the cask plugs. Such a piece of equipment could be operated within the containment building in conjunction with the fuel handling machine.

An alternate to the composite "preparation", if there is a hot cell over the reactor, is well represented by the General Electric concept shown in Figure 6.

In any case it is recommended that a "tunnel" or isolation access to the loading interface be provided so that decontamination can be accomplished prior to exposing the cask to the external, uncontrolled environment.

B. SPENT FUEL CONTAINERS

Containers for LMFBR spent fuel are proposed to serve as carriers only rather than as sealed canisters for secondary containment. Normal handling operations from the reactor to decay storage are readily accomplished, without excessive temperatures in sodium filled pots. If necessary, for very high heat generation rates, NaK dip tubes from an auxiliary natural convection heat exchanger (ref. G.E. LMFBR concept), helium cooled fuel handling machine (ref. A.I. LMFBR concept) or finned containers (ref. FFTF) might be used. For the reference model cask it is assumed that Spent Fuel Containers as illustrated in Drawing 1137757, Sheets 1 and 2, will be used. Sheet 2 shows how the container might be modified for other fuel configurations by omitting the nose piece and applying adapters to the container.

The lateral support leaf springs within the containers serve to limit the normal shipping shock and vibration loads. They also minimize the accident shock loading, thus reducing the probability of a major shift in the radiation source.

Drawing 1137757 illustrates, in addition to the container, the interface with the fuel magazine by means of a fuel-container retention plug. The retention plug is locked into the fuel magazine by rotation of the drive nut which actuates the linkage to secure the wedges under the fuel magazine cell lip. A heavy spring load is applied to the fuel assembly to hold it without motion under 2g shipping loads. A lighter spring bears against the container to hold it in place if no fuel assembly is being carried. The

retention plug is designed for a maximum filling of the region between the fuel and the cask head with steel, thus reducing the cask head shield thickness requirement.

The reduced diameter of the container nose piece for the A.I. and C.E. fuel designs is to allow a reduction in the total volume of sodium in the cavity. This reduces the sodium expansion void requirement.

C. FUEL MAGAZINE

The fuel magazine, Drawing 1137758, is essentially a solid block of mild steel with two rings of cells to retain 10 and 16 fuel containers and a central void for the Volume Displacement Bellows. The relatively large solid fraction is to reduce the sodium volume in the cavity. The fuel magazine is supported in the cask cavity on the two end bearing rings. The lower bearing is secured to the cask and the magazine where it serves as a combination thrust-radial bearing. The upper bearing is secured to the magazine only, thus being free to move axially for any differential expansion or fitup.

An annular gap is illustrated at the inside of the fuel magazine. This is a convenient location for an annular heat pipe which might serve to limit the peak temperature possible in the accident situation. This feature will be investigated to determine its utility and practicality.

Two drive gears are indicated, one on the upper bearing assembly and the other on the end plug of the volume displacement bellows void. It is proposed to rotate the fuel magazine with a drive inserted into the cask through the loading ports. This avoids an additional penetration and potential leakage path.

D. SHIELDING

The LMFBF Spent Fuel Shipping Cask Drawing 1137755 shows the basic shielding material. The radial shielding opposite the fuel is a total of 19 in. including the outer portion of the fuel magazine. An additional 2 in. of water, serving as the secondary coolant, is indicated for neutron shielding. The cask shielding is tapered beyond the fuel region to reduce the cask total weight. The particular shielding thicknesses indicated will be evaluated on the basis of any potential redistribution of fuel in an accident situation. The end shielding will be similarly evaluated. Note that the head end shielding includes both the cask head and the retention plug material.

Because of the large void of the volume displacement bellows, assembly end plugs have been included to supplement the cask head and base shielding.

E. COOLING

Internal heat transfer is accomplished by the two mechanisms, natural convection of the liquid sodium and conduction to the secondary water cooling circuit. The fuel magazine material has been selected as mild steel with stainless steel cladding. The mild steel has a thermal conductivity of about $30 \text{ btu/ft}^2\text{hr } ^\circ\text{F}$, three times that of stainless steel.

The reduced volume of sodium is a disadvantage but is compensated by the reduced volume required for the expansion bellows. The adequacy of this concept will be determined in the forthcoming thermal analysis study. An alternate fuel magazine material, copper, could relieve the peak temperature problem considerably. Copper is expensive and also a strategic material. It

should be avoided if possible. The possibility of increasing axial conduction, by using heat pipes, has been investigated briefly and will be reported when complete.

F. SODIUM EXPANSION

The expansion of sodium when heated from 500°F to 1500°F is 13.5%. In order to accommodate this an assembly of 172 Volume Displacement Bellows, as illustrated in Drawing 1137759 is proposed. The diaphragms, of .020" thickness are corrugated to relieve the stress of the large displacement required. In addition the bellows are preformed to the compressed configuration shown in the larger scale illustration corresponding to a 70% internal volume reduction. A further compression to 80% results in a strain of .005 in./in. and a decompression to the nominal configuration results in a strain of .004. These strains are within the static limits of Rene' 41 and Inconel 718 thus verifying the feasibility of the concept.

The individual bellows would be made up as illustrated in the 70% compressed form. Then 172 of them would be assembled on the base plug and a top retainer plate with assembly rods as shown. After this assembly each one would be purged of air and pressurized to 16.5 psia with argon to force them into conformity with each other. The pressurizing lines would then be weld sealed closed ready for emergency service in the cask.

In service the shipping cask would be filled brim full with sodium to preclude a void over any fuel pin when the cask is on its side. The excess pressure in the bellows, about 32 psia at 500°F, prevents them from being compressed by the head of sodium thus preserving their volume for emergency service. The total volume of 172 bellows is 57,750 in.³. A 70% compression

provides a sodium volume expansion of 40,000 in.³. If the original sodium volume is restricted to 300,000 in.³, this corresponds to the 13.5% expansion. The reference model cask cavity minus the fuel magazine and normal bellows volume is less than 300,000 in.³. The argon gas pressure in the bellows, and therefore also within the cask cavity, builds up to about 200 psia with a 1500°F average sodium temperature. This is well within the state of the art for metal seals as planned for the head closures.

G. SEAL CLOSURES

The reference model cask has only two penetrations which must be sealed after each loading and unloading operation. The remainder of the cask assembly is either structurally welded as is the base shield cover or seal welded as is the head shield cover and the access penetrations to the lower fuel magazine bearing.

Sheet 2 of Drawing 1137755 illustrates the concept for sealing the loading ports. The inner plug, referred to as the seal plug, is mounted on a shock attenuating structure so as to insure that the seal-plug will not be distorted in any possible accident situation. The outer shield plug is provided with the same type of metal seal to provide a secondary containment for the cask contents.

Mechanical analysis of this seal arrangement remains to be done. It may be determined that the shock attenuation path to the seal plug is insufficient in which case the cask head thickness may have to be increased. Also it may be desirable to provide the same type of mount for the shield plug. In conjunction with a suitably designed energy absorbing crash frame the concept appears adequate for the required containment of the cask contents.

H. ENERGY ABSORBERS

A crash frame, energy absorber, is considered to be mandatory for the accident situation of a 30 ft drop onto an unyielding surface. In addition to this hypothetical accident, potential shock loadings from derailment in transit should be considered. This is particularly important in insuring that the crash frame structure is not lost before it has served its function.

The energy absorbers, suggested for the reference model cask, include the crushable tube filled torus at each end and the auxiliary cooling fins around the cask cylinder. There has been no attempt to design these structures to limit any external shock loads but the concept is known to be valid from previous experience. The fins may have to be larger or a cage type structure may be built around them as a supplemental crash frame. In such a case it may be necessary to cut down on the size of the cask so as to fit it within the railway car limits for unrestricted service. It may be found appropriate to design the vehicle-cask system, as Westinghouse did for the 75 ton Yankee spent fuel shipping cask, to provide for absorption of a large part of the impact energy in the deformation of the railroad car structure.

I. INTERFACE CONFIGURATION

It is proposed that the shipping cask will make contact with the loading (and unloading) port by means of an interface adapter to a facility loading port ceiling valve as illustrated in Figure 11.

The cask will be placed on the transfer dolly, at the tunnel entry station, such that the two ports are in line with the dolly rails.

The two shield plugs are removed and replaced with Interface Adapters. Then the cask is transferred to the interface station. The adapter section is raised to seal against the ceiling valve and the inflatable seals are operated to make the containment closure for cask loading. The seal plug and retention plugs are removed from the cask through the ceiling valve and the one ring of cells in the fuel magazine is loaded. After loading the plugs are replaced, the adapter section lowered and the dolly is moved to align the other cask port-adapter with the ceiling valve. The process is repeated to load the other ring of the fuel magazine.

After the cask is loaded the dolly is returned to the tunnel entry station. The adapters are removed and the shield plugs replaced. Decontamination and inspection is done next, prior to returning the cask to the railroad car.

The trunnions shown in Drawing 1137755 will be displaced 90° to allow this same procedure to be done with the cask on the railroad car. It is expected that the fuel reprocessing plant will be arranged to interface with the cask on the railroad car. By appropriate design this might also be done at the reactor plant, thus eliminating the requirement to remove the ~ 200 ton cask from the railroad car and the need for a transfer dolly.

VI. EVALUATION AND SELECTION

The Reference Model LMFBR Spent Fuel Shipping Cask will be used as a base for evaluation and selection of design criteria during the next increment of work on this task. In addition to the analytical effort for shielding, heat transfer and mechanical design, suggestions received from other agencies and reactor plant designers will be considered in making modifications to the reference model. Cask configuration and design features of immediate concern are indicated below.

A. THERMAL

1. What is the upper limit to decay power vs fuel assembly capacity which can be accommodated by the cask?
2. Are heat pipes practical and necessary for reducing peak accident temperatures?
3. Is there an upper limit to fuel pin temperature in an accident situation?
4. What is the limiting fuel pin temperature for normal shipping conditions?

The major effort on thermal analysis will be devoted to answering question number 1. This will be done in a series of computer models built up to an eventual transient analysis of temperatures following the hypothetical accident specified in 10 CFR 71. From these thermal analyses will also come the data for evaluation of the Volume Displacement Bellows and thermal stress within the cask structure and seal joints. Heat pipe utility will also be determined.

B. MECHANICAL

1. What is a satisfactory shock attenuation structure between the cask head and seal plug?
2. Can the auxiliary cooling fins be adequately sized to serve as energy absorbers?
3. What is a suitable crash frame-energy absorber system for the cask or railroad car-tie down-cask combination?
4. Is thermal stress a limiting factor in the cask design?
5. What interface features are desired and required for the loading (reactor plant) and unloading (reprocessing plant) facilities?
6. Is the Volume Displacement Bellows concept satisfactory?
7. What is the maximum credible shift of fuel in an accident situation?

Mechanical analyses will be performed on the reference design and required modifications thereof to answer the above questions or establish design guidelines for continuing design study.

C. RADIATION

1. What is the shield design configuration required to satisfy the regulations for the maximum credible fuel shift in an accident?
2. What is the potential maximum level of primary coolant contamination?

Normal and accident situation models of the cask will be prepared for the QAD computer program to answer question 1. Answers to question 2 will be sought from the literature and industrial groups presently active on related work in the LMFBR program.

D. CRITICALITY

1. What is the maximum credible accident fuel distribution within the cask?
2. What is the normal fuel distribution neutron source strength, including multiplication, in the cask?

Criticality analyses will be done, or obtained from other agencies, to support the evaluation and selection effort on the cask. Neutron shielding requirements will be determined along with criticality analysis data.

E. FUNCTIONAL ANALYSIS

A step by step functional analysis of fuel processing for shipment, cask loading, car installation, transport, unloading, etc. will be prepared. Variations, as suggested or required by different plant designers will be added to the reference model. Equipment and facility requirements will be identified so as to complete the "system" identification of the LMFBR Spent Fuel Shipping Cask System.

A preliminary Design Criteria document will be prepared and submitted with the System Evaluation Report in October 1970. Review of this work will be done by those concerned and an approved Design Criteria document is scheduled to be completed by January 1971. Conceptual design of the first LMFBR cask, for use with FFTF and the early LMFBR demonstration plants will then be initiated.

FIGURE 1
LMFBR FUEL ASSEMBLIES
REFERENCES: 1000 Mwe
FOLLOW ON STUDIES

DECAY
STORAGE

REACTOR

REACTOR &
DECAY STORAGE

SHIPPING
CASK

R.R. CAR

TRANSFER
CASK

TRANSFER
DOLLY

TRANSFER CASK
& CANNING HEAD

FIGURE 2

SPENT FUEL PREPARATION
FOR SHIPMENT
EQUIPMENT SYMBOLS

FIGURE 3

SPENT FUEL PREPARATION
FOR SHIPMENT
ATOMICS INTERNATIONAL
1000 Mwe LMFB

FIGURE 4

SPENT FUEL PREPARATION
FOR SHIPMENT
BABCOCK & WILCOX
1000 Mwe LMFB

FIGURE 5

SPENT FUEL PREPARATION
FOR SHIPMENT
COMBUSTION ENGINEERING, INC.
1000 Mwe LMFBR

FIGURE 6

SPENT FUEL PREPARATION
FOR SHIPMENT
GENERAL ELECTRIC
1000 MWe LMFB

FIGURE 7

SPENT FUEL PREPARATION
FOR SHIPMENT
WESTINGHOUSE ELECTRIC CORP.
1000Mwe LMFB

FIGURE 8
 (AI) LMFBR 1000
 1460 DAYS @ 10 MW
 GAMMA SOURCE VS. DECAY TIME

6 & 12 & 18

7 & 13

8 & 14

3 & 9 & 15

10 & 16

FIGURE 9

MULTIPLE FUEL ASSEMBLY
ARRAYS FOR SHIPMENT

FIGURE 10

SPENT FUEL PREPARATION
FOR SHIPMENT
COMPOSIT REFERENCE
1000 MWe LMFB

FIGURE 11

INTERFACE-ADAPTER SEAL

227 IN.

203 IN.

12 IN.

ERECTION & LIFTING
TRUNNIONWATER JACKET NEUTRON
SHIELD & COOLANT -
TWO PASS FLOWAUXILIARY COOLING
FINSRAILROAD CAR SUPPORT
TRUNNIONWATER ENTRY-EXIT
MANIFOLDS

EXIT

ENTRY

FUEL MAGAZINE
BEARINGDRIVE
GEARS

FUEL MAGAZINE

UPPER
BLANKET
LIMITFUEL REGION
LIMITLOWER
BLANKET
LIMIT

STA. 12.9

STA. 109.9

STA. 76.1

STA. 52.1

STA. 0.0

VOLUME DISPLACEMENT BELLOWS ASSEMBLY
(REF. DWG. NO. 1137759)

178 IN.

FUEL CONTAINER

RETENTION
PLUGFUEL MAGAZINE
BEARING13
SEE SHEET #2SHIELD
PLUGSEAL
PLUG

CASK SHIELDING (STEEL)

ENERGY ABSORBER TORUS
WITH INTERNAL TUBING

I.D. 66 IN.

O.D. 104 IN.

O.D. 116 IN.

0 1 2 4 6 8 10 12 14 16

SCALE - INCHES

CONTRACT NO.		AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA	
DRAWN J. D. SUDDETH	DATE 7/2/70	TITLE LMFBR SPENT FUEL SHIPPING CASK, REFERENCE	
CHECK		SIZE CODE IDENT NO. DWG NO. F 05824 1137755	
DESIGN		SCALE 3/16" = 1" RELEASE DATE SHEET 1 OF 2	
DESIGN ACTIVITY			
CUSTOMER

ENERGY ABSORBER TORUS
MOUNTING PLATE

VIEW B SEE SHEET #1
0 1 2 3 4 5 6
SCALE - INCHES

A-A
SEE SHEET #1

CONTRACT NO.		AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA	
DRAWN J.D. SUDDETH	DATE 7/8/70	TITLE LMFBR SPENT FUEL SHIPPING CASK, REFERENCE	
CHECK			
DESIGN			
DESIGN ACTIVITY		SIZE 05824	CODE IDENT NO. DWG NO. 1137755
CUSTOMER		SCALE NOTED	RELEASE DATE
		SHEET 2 OF 2

0 1 2 3 4 5 6 7 8
SCALE IN FEET

CONTRACT NO.		AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA	
DRAWN J.D. SUDDETH	DATE 7-14-70	TITLE RAILROAD CAR INSTALLATION LMFBR SPENT FUEL SHIPPING CASK, REFERENCE	
CHECK		SIZE	CODE IDENT NO. DWG NO. 05824 1137756
DESIGN		SCALE NOTED	RELEASE DATE
DESIGN ACTIVITY		SHEET 1 OF 1	
CUSTOMER

0 1 2 3 4 5 6
SCALE - INCHES

FUEL-CONTAINER RETENTION PLUG ASSEMBLY

VIEW A

0 1 2 3 4
SCALE - INCHES

13-13
MODIFIED TO SHOW
FULL DIA.

CONTRACT NO.		AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA	
DRAWN J.D. SUDDETH	DATE 7/2/70	TITLE LMFBR FUEL ASSEMBLY TRANSFER-SHIPING CONTAINER REFERENCE	
CHECK		SIZE F	CODE IDENT NO 05824
DESIGN		DWG NO.	1137157
DESIGN ACTIVITY		SCALE 1/8" = 1"	RELEASE DATE
CUSTOMER		SHEET 1 OF 2

CONTRACT NO.		AERJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA	
DRAWN J.D. SUDDETH	DATE 7-2-70	TITLE LMFBR FUEL ASSEMBLY TRANSFER SHIPPING CONTAINER REFERENCE	
CHECK			
DESIGN			
DESIGN ACTIVITY		SIZE F	CODE IDENT NO. 05824
CUSTOMER		DWG NO. 1137757	
SCALE N=11.0		RELEASE DATE	SHEET 2 OF 2

VOLUME DISPLACEMENT
BELLOWS ASSEMBLY
(REF. DWG. 1137759)

0 1 2 3 4 5 6 7 8
SCALE - INCHES

CONTRACT NO.		AEROJET GENERAL CORPORATION SACRAMENTO, CALIFORNIA	
DRAWN J. D. SUDETH	DATE 7/2/70	TITLE FUEL MAGAZINE - LMFBR SPENT FUEL SHIPPING CASK REFERENCE	
CHECK		SIZE F 05824 1137758	
DESIGN		CODE IDENT NO. DWG NO.	
DESIGN ACTIVITY		RELEASE DATE	
CUSTOMER		SHEET 1 OF 1

0 1/2 1 2
SCALE - INCHES

0 1 2 3 4
SCALE - INCHES

CONTRACT NO.		AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA	
DRAWN J. D. SUDDETH	DATE 6/26/70	TITLE VOLUME DISPLACEMENT BELLOWS & ASSEMBLY	
CHECK			
DESIGN			
DESIGN ACTIVITY		SIZE CODE IDENT NO. DWG NO. F 05824 1137750	
CUSTOMER		SCALE NOTED	RELEASE DATE SHEET 1 OF 1