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AEC Research and
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UC-81, Reactors - Power
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**spent fuel transfer, storage
and shipment for PL-3**

Contract No. AT[30-1]-2900
with U. S. Atomic Energy Commission
New York Operations Office

ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPARTMENT

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SPENT FUEL TRANSFER, STORAGE
AND SHIPMENT FOR PL-3

By:
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Issued: March 7, 1962

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ABSTRACT

In refueling development studies performed on PL-3 Phase I design, several methods of fuel transfer, storage, and shipment were investigated. An evaluation of the relative merits of the systems and designs under study, as applied to either the BWR or PWR concepts, is made and optimum designs are selected. An analysis of spent fuel shipping cask shielding requirements is presented, along with recommendations for future study in this area.

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1.0 SUMMARY

The study and evaluation of several different refueling, storage, and shipping methods has yielded the following results:

1. The optimum transfer system for the BWR concept is one in which fuel is removed, carried in, and deposited by a flask. Location of selected elements for transfer is achieved by an index plate in the shield cover assembly placed over the reactor vessel flange. Element grappling tools are incorporated in the flask design.
2. The optimum transfer system for the PWR concept is one which utilizes a fuel chute or chutes through the vapor container wall. Fuel is manually transferred by hand tools from the reactor to the storage receptacle. Adequate personnel protection is provided by the shield water, and vapor containment is maintained by a seal plug in the chute.
3. The optimum storage arrangement is one which utilizes the shipping cask as a spent fuel receptacle, thereby saving the weight of shielding that would be necessary for a spent fuel tank storage facility. Further refinement will be required to arrive at the best natural convection cooling system for these casks.
4. The optimum shipping cask arrangement for the reference core is four units if the 20,000 lb shipping weight limit is not to be exceeded, and two casks if the gross shipping weight is 27,500 lb.
5. To provide an optimum weight spent fuel shipping cask, a series of analytical shielding calculations were performed. The graphical results may be used to determine the shield requirements, optimum cask size and decay time before shipment.

2.0 INTRODUCTION

Studies were undertaken under Phase I of the PL-3 contract, which consisted of the following areas in development of a reactor refueling system for PL-3:

1. Development of a fuel transfer system
2. Storage of spent fuel elements
3. Shipping of spent fuel elements
4. Tooling requirements for refueling

Each of the above topics was necessarily considered individually. The study of a fuel transfer, storage, and shipment was based on two different reactor types and four different fuel cores. The positioning of the control rod drives above or below the reactor core affected the fuel transfer time.

A basic design requirement kept the maximum shipping weight of any unit below a maximum of 20,000 lb and within a package size of 8 x 8 x 30 ft. A literature survey and study of existing techniques preceded the development study on any of the systems.

3.0 FUEL TRANSFER SYSTEM

The development of the spent fuel transfer system was to some extent predicated on the reactor type. For boiling water reactors (BWR) it is undesirable to penetrate the reactor vessel wall with fuel chutes or tubes to transfer spent elements. Therefore, transfer by flask to an adjacent or slightly removed storage area is the appropriate system. Any of the fuel transfer concepts investigated could be applied to a pressurized water reactor (PWR), so selection of a system for use with this type reactor was based on cost, ease of maintenance, and reliability. The following three methods were investigated.

3.1 FUEL TRANSFER BY FLASK

A typical flask design for transfer of spent fuel elements is shown in Dwg. AEL-731 (Fig. 1)*. This design is based on the BWR plate type element and cruciform rod as proposed on one of the BWR concepts. At the bottom of the flask there is an adapter ring that locates the flask on the index plate. Just above the adapter is a sliding shield gate that is operated by handwheel from the top of the flask. The screw actuated slide gate is more desirable than the rotating plug type gate, for PL-3 application, for it can be made smaller and will weigh less.

The fuel element or absorber will be housed in the cylindrical cavity above the shield gate during transfer. The grappling tools, for engagement of fuel elements or absorbers, are raised or lowered by the handwheel on the top of the flask connected to the horizontal shaft. Accidental dropping of the unit being handled is prevented by a ratchet wheel and pawl on the horizontal shaft. During lifting, the spring loaded pawl will cam out of engagement, but will hold if the handle is released. During lowering operations, the pawl release on the handle is depressed, holding the pawl out of engagement with the ratchet. Removal of the hand intentionally or accidentally will immediately engage the pawl with the ratchet wheel and prevent dropping of the element. The space limitations may necessitate use of a grappling tool built in two or three sections, and the sections would be removed or added during the transfer operation. The tool configurations will be contingent on the final design of the fuel element and absorber.

Transfer by spent fuel flask would probably utilize a system similar to that depicted in Fig. 2. Following is a complete procedure for this transfer as it would apply to a BWR concept such as that shown in Dwg. AEL-740 (Fig. 3). Drawing AEL-740 is used for reference on steps 1-10, and Fig. 2 is used for steps 11-29.

* All figures are in Appendix B.

1. Pump water into reactor vessel until completely full.
2. Drain water from upper shield tanks and remove.
3. Remove shielding from around control rod drive units.
4. Remove control rod drive units and place in stored position.
5. Unbolt and remove vapor container dome.
6. Remove control rod drive thimbles and delatch control rods.
7. Remove control rod extensions and racks.
8. Crack open nuts on reactor vessel.
9. Drain reactor vessel to flange level and remove cover nuts.
10. Remove and store vessel cover with housing and steam dryer attached.
11. Place shield cover over reactor vessel flange in proper position.
12. Rotate section guide to desired location.
13. Rotate element guide to position over desired element.
14. Position transfer flask on element guide, with proper tool in flask.
15. Open viewing port and check that shield gate is open on flask.
16. Crank grapppling tool down until contact is made with element.
17. Engage element with tool.
18. Close viewing port and raise element into flask, monitor radiation.
19. Close shield gate at bottom of flask, monitor radiation.
20. Lift flask by crane and position over shipping cask in shield tank; monitor radiation.
21. Check locating adapter on shipping cask to assure proper position.
22. Lower transfer flask until it engages locating adapter.
23. With extension tool, open bottom shield gate in flask.
24. With extension tool, lower element from flask into shipping cask.

25. Disengage element from grappling tool and withdraw tool.
26. Raise transfer flask slowly, monitoring radiation.
27. Check transferred element for proper positioning.
28. Move locating adapter on cask to next selected position.
29. Repeat process, steps 12-28 until all of fuel is transferred.

It will be necessary to supply sufficiently thick lead shielding around the top of the reactor (shield cover) to reduce radiation to a safe level for operating personnel. This shielding would be based on the hottest element in the core. The transfer flask will probably require an air or liquid cooling system, to assure adequate cooling in event of equipment failure causing the loaded flask to be held out of the water. Heat release from a hot element after one day cooldown could run as high as 13,380 Btu/hr. For calculating purposes, the hottest element is figured to be 150% of average.

The transfer flask could also be used with a spent fuel pit, where elements would be stored in racks instead of casks. In this application, it would be advantageous to use a second indexing shield cover over the pit to preclude any chance of the transfer flask dropping onto a loaded spent fuel storage rack.

In using a transfer flask with a pressurized water reactor, the cover shield could be used and placed on the top of the vapor container flange. A simpler and less expensive approach would be to use an indexing adapter plate on the reactor vessel flange and to lower the flask to this level for operation, utilizing the reactor shield water for radiation protection.

3.2 FUEL TRANSFER BY SPENT FUEL CHUTE

A typical reactor configuration using a spent fuel chute is depicted in Dwg. AEL-762 (Fig. 4), and a chute assembly is shown in Fig. 5. To maintain vapor container integrity, a seal plug, capable of withstanding maximum anticipated pressure in event of accident, must be inserted in the chute. This plug is seated against a tapered shoulder in the fuel chute and then the rubber seal is tightened against the tube wall, forming a leak-tight closure. At the lower or discharge end of the chute is a hopper fabricated of the same size pipe as that used in the chute. This hopper can be latched in alignment with the chute or in the vertical position. Operation of the hopper is performed with the same tool that is used for control rod element and absorber removal. Using Dwg. AEL-762 (Fig. 4) and Fig. 5 for reference, the following procedure is used in refueling after shutdown of the reactor:

1. Remove vapor container cover bolts.
2. Remove and store vapor container cover.

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3. Remove cable net (if used) and store.
4. Fill, unbolt, and remove dry cap (if used).
5. Remove and store reactor vessel cover nuts.
6. Lift cover from reactor vessel and store.
7. Remove and store core cover.
8. Remove and store control rod caps
9. Loosen, remove, and store plug from fuel chute.
10. Check fuel chute hopper for alignment with chute.
11. Using appropriate tool, engage fuel element or absorber.
12. Lift element from core, place in chute and lower into hopper.
13. Disengage and remove tool.
14. Unlatch hopper and rotate to vertical (unloading) position.
15. Engage element, lift from hopper and place in storage receptacle.
16. Unlatch and rotate hopper to align with fuel chute.
17. Repeat steps 10 through 16 until core is transferred.

In the event that the spent elements are to be stored in shipping casks for cooling, there may be a fuel chute for each shipping cask required. To protect personnel from radiation during transfer to a shipping cask, a U-shaped auxiliary shield would be placed on the top of the cask being loaded. This shield would be moved from cask to cask as transfer progresses. The chute plugs would be removed from all the chutes at the start of refueling operations and replaced at the completion of transfer. The number of chutes required would be contingent on the number of casks needed to ship an entire core. Transfer to shipping casks would utilize the cask shielding and eliminate the heavy shielding required on a spent fuel storage tank.

3.3 FUEL TRANSFER BY CARRIAGE

This system of fuel transfer involves placing the spent fuel element on a guided carriage and mechanically traversing the carriage through 2-pipe tunnel to a fuel storage area. The complexity of the mechanism, higher cost, and

difficulty of maintenance; exclude this system for any reactor arrangement except one in which the fuel pit is somewhat removed from the reactor shielding. Even if the storage tank is in a removed position, transfer by flask would undoubtedly prove to be as fast, more reliable, and easier to maintain.

4.0 STORAGE OF SPENT FUEL ELEMENTS

There are numerous methods of storing fuel elements during decay after removal from a reactor. The following approaches to storage of spent PL-3 cores were investigated:

1. Storage in shielded spent fuel tank
2. Storage in shipping cask in peripheral tank
3. Storage in shipping cask in tank on skid

Each of these systems has advantages and disadvantages as will be shown in the following description.

4.1 STORAGE IN SHIELDED SPENT FUEL TANK

This storage method can be utilized whether the fuel is transferred by flask or chute. The spent fuel tank would be cylindrical in shape and heavily shielded. On the side of the tank adjacent to the vapor container, shielding may be largely eliminated, as shown in Dwg. AEL-732 (Fig. 6). Inside the tank there are two storage racks, each capable of holding an entire spent core. These racks would allow free flow of coolant water through and around the elements by natural convection. The rack material would be 1% boron type steel to reduce neutron activity to a minimum. The base of the rack would be elevated sufficiently from the tank floor so that convectional cooling will not be impaired. Around the tank there would be adequate lead shielding to keep radiation to acceptable site levels. The water level in the tank will provide required shielding for the operating crew.

4.2 STORAGE IN SHIPPING CASK IN PERIPHERAL TANK

In this system, the fuel is loaded directly into the shipping cask from a transfer flask (see Fig. 2) or placed in the cask after removal from the spent fuel chute. The shipping cask in this application provides the shielding required. After loading of the cask, the cover would be supported on a pedestal mount above the shipping cask. This arrangement would eliminate direct gamma streaming and would reduce scattering of gamma rays. When first loaded, the spent fuel elements have a high heat dissipation. Investigation of cooling by natural convection is being undertaken and indications are that proper sizing of flow areas at the top and bottom of the cask should permit cooling by this method. In the event that cooling by natural convection proves impractical, an arrangement for forced circulation has been devised, utilizing the siphon drain at the bottom of the cask (Fig. 7).

4.3 STORAGE IN SHIPPING CASK IN TANK ON SKID,

This storage method would be used if it is desirable to use the cask shielding in place of a shielded tank, and sufficient storage space is not available in the shield or transfer tank. The elements would be loaded directly from the reactor into the shipping cask, utilizing either a spent fuel chute or transfer flask. As soon as the cask loading is completed, the cover is lowered onto the cask and the assembly is lifted from the tank and placed in a small tank on the skid. From the time that the cask is closed, until it is placed in the skid tank, cooling is dependent on natural convection. As soon as the cask is in the skid tank, a forced convection cooling system is hooked up and started (Fig. 8). The cover nuts are then applied and tightened and the cask secured with skid hold downs. During transportation of the skid to a storage room, the circulating pump is powered by battery. When the skid is placed in the storage room, the pump is placed on rectified plant power. After the heat generation has decreased due to time in storage, the pump may be bypassed and the cask cooled by closed loop natural convection. This system has the inherent hazard of element overheat if the removal of the closed cask from the transfer or shield tank is delayed by mechanical failure. The delay of securing the cover to the cask while it is still in the transfer tank could cause element overheat provided the closed cask cannot be cooled sufficiently by natural convection and conduction. The hazard potential of this system makes it undesirable for use with the PL-3 plant.

5.0 SHIPPING OF SPENT FUEL ELEMENTS

The design of a shipping cask for spent fuel elements is contingent on the following factors:

1. Number of elements to be shipped in cask.
2. Required shielding for selected number of elements.
3. Weight and physical size of elements.
4. Maximum weight permissible for assembled, loaded cask.

5.1 CASK SIZE

In arriving at an optimum cask size, all the above items must be integrated into a cask arrangement that is feasible. The sizing of the casks is pictorially demonstrated in Fig. 9, based on BWR rod type elements which weigh approximately 200 lb each. The six element casks, requiring four casks per core, is above the allowable gross weight of 20,000 lb for the bare cask alone. To attempt to ship the same core in five casks, the irregular configuration shown would be required and the weight of the bare cask would be only slightly reduced, remaining too high. To ship the core in six casks, the 4 element casks would be within the weight limit. Three of the six casks would require a channel in the cask wall to allow a second cruciform rod in the cask (9 cruciforms per core). This channel would be surrounded by a depleted uranium insert to reduce radiation to an even intensity around the cask. It is possible, since absorber life exceeds that of the fuel elements, that the channel could be eliminated and partial shipments of cruciforms made with each spent core shipment. This same principle might be applied to square absorbers used in control rod assemblies, thereby reducing the number of compartments required per shipping casks. This might also reduce the size and weight of each cask.

The optimum shipping cask arrangement for three different cores is shown in Fig. 10. The shielding on which the designs were based was derived from the ROC code developed by Alco Products, Inc. Data regarding these casks and the casks for the PWR 5 x 5, Type 3 element core are presented in Table 1 (Appendix A). The shielding development is covered in Section 7.0 of this report.

5.2 CASK DESIGN

All cask design is predicated on the requirements of the I. C. C., A. E. C. and I. C. P. P. regulations, as well as the logistic limitations for the PL-3 site. It is anticipated that loaded spent fuel shipping casks will be flown from Byrd.

Station to McMurdo Sound, carried by boat from McMurdo Sound to the United States and then transported by truck and rail from the port of entry to the processing plant. Shielding design will be based on maximum dose rates for any carrier used.

A typical shipping cask design is shown in Dwg. AEL-735 (Fig. 11). This design is for fifteen PWR, 7 x 7, Type 2 fuel elements in a 3 x 5 arrangement. This cask would hold 1/4 core for the PWR, 7 x 7, Type 2 arrangement or 1/2 core for the PWR, 5 x 5, Type 3 arrangement, since overall dimensions of the elements are almost identical. Shielding would be slightly thicker for the half core cask than for the quarter core cask.

5.3 CASK SHIPMENT

When the cask is shipped, it will be dry and heat dissipation will be through the walls of the cask. The heat removal requirements for fractional parts of a core after various periods of decay following shutdown are presented in Table 2 (Appendix A). It is readily seen that shipment of fuel 90 days to a year after shutdown of the reactor will involve much less heat removal than during the period right after shutdown. This decline in decay heat generation allows shipment without auxiliary cooling systems. A conceptual design of a skid for shipment of casks is shown in Fig. 12. The skid will be sized to accept the base mounting dimensions of the cask and to allow angular orientation without tripping over. Four adjustable tie downs will secure the upper portion of the shipping cask to the skid.

6.0 TOOLING REQUIREMENTS FOR REFUELING

The tooling required to perform refueling of the PL-3 reactor will be contingent on final design of the reactor vessel, vapor container, core cover, transfer method, storage method, fuel element and absorber size, and end configurations. A listing of the anticipated tooling is presented in Table 3 (Appendix A). Limited clearance above the operating floor level may necessitate design of some tools with either telescoping or sectional handles. Telescoping tools of Alco design have been successfully used for several years at the SM-1 reactor site. If a specific tool is required at more than one location, it will be made in duplicate to accelerate operations. All tools subject to wetting will be designed of corrosion resistant material. The time required to make a complete fuel transfer will vary considerably with the method of refueling. Estimated times for refueling operations on the BWR and PWR concepts are shown in Tables 4 and 5 respectively. These figures are based on a four man refueling crew, using tools as listed in Table 3.

7.0 SPENT FUEL SHIPPING CASK SHIELDING STUDY

7.1 REQUIREMENTS

As previously discussed in this report, spent fuel elements will be shipped to a reprocessing station in the U. S. in lead shielded casks by air, sea, and land routes. The logistics of Byrd Station dictate severe weight limitations on the shipping casks. To optimize for a minimum total weight of fuel casks the shielding requirements and the effects of decay time and number of elements per cask must be determined.

In addition to the requirement that the total weight be minimum, Appendix B - Technical Provisions to Contract AT(30-1)-2900 PL-3, and revisions, provides the following guidelines for shipping casks:

1. Casks shall conform to Idaho Chemical Processing Plant shipping cask requirements.
2. The number of casks shall be adequate to load two complete cores at one time.
3. Casks and fuel shall be protected to prevent damage by an ambient temperature of -100°F .
4. Maximum weight of 20,000 lb going in, and 27,000 lb flying out, for a single cask.

The casks are also designed in accordance with the AEC proposed rule 10 CFR Part 72, "Protection Against Radiation in the Shipment of Irradiated Fuel Elements."

The task consisted of performing calculations on an IBM-650 computer to determine the side shielding requirements for four PL-3 core concepts. Modifications to the machine results were made to evaluate the requirements for partial cores. The shield requirements for the ends of the selected core cask were determined on the basis of a hand calculation model.

7.2 DESCRIPTION OF CORES

7.2.1 PWR 7 x 7, Type 2

This core is composed of fuel elements and absorbers similar to those currently employed in the SM-1, Core II at Ft. Belvoir, Va. The core employs flat plate fuel elements composed of a highly enriched UO_2 stainless steel matrix

clad with low cobalt stainless steel. The fuel plates are 30 mils thick, including the 5 mil cladding on each side of the fuel matrix. Control is accomplished by seven box-type absorbers with fuel element followers. The absorbers are composed of Eu_2O_3 in stainless steel, clad with stainless steel.

7.2.2 PWR 5 x 5, Type 3

This core is composed of fuel elements and absorbers similar to those employed in the 7 x 7, Type 2 core. The Type 3 fuel plates are 40 mils thick, including 5 mils of cladding on each side of the fuel matrix. The fuel matrix of the Type 3 element is slightly wider than that of the Type 2 element and employs a slightly reduced weight percent of UO_2 .

7.2.3 BWR High Enrichment Plate Type Core

The dimensions of these fuel assemblies and plates are nearly the same as the 5 x 5, Type 3 core described above, except that the fueled portion of the fuel is 28 in. long instead of 21.75 in. long. Because of the need for larger flow channels in a BWR, the number of fuel plates per assembly was reduced from 18 to 8.

Additional information on the above cores may be found in AP Note-408,⁽¹⁾ the PL-3 Concept Selection Report.

7.2.4 BWR Low Enrichment Rod Type Core

Each of the 24 fuel assemblies in this core consist of 59, 20-mil wall, stainless steel tubes containing low enriched UO_2 pellets. The rods are 0.42 in. in diameter. The fuel height is 38.3 in. Additional information on this core may be obtained from 100-19030-CEND-135,⁽²⁾ the PL-2 Final Design Report.

Table 6 (Appendix) gives core data used in the shielding calculations.

7.3 CALCULATIONAL METHODS

7.3.1 Side Shielding

The shielding requirements for the sides of the shipping cask 10 days after reactor shutdown were calculated by using an IBM-650 computer and the ROC shielding codes. A detailed discussion of the ROC shielding program may be found in APAE Memo-142.⁽³⁾

The ROC code was first used to determine the source strength of the irradiated fuel. The average fast and thermal neutron fluxes, the volume fraction of the various core materials, and the material properties for the neutron irradiation, are input to this code. Material properties may be found in APAE Memo-145.⁽⁴⁾ The output consists of the volume source strength in photons

per cc per second and the core cross-section in cm^{-1} . An infinite operating time is assumed. Table 7 (Appendix) shows the source output for the four cores.

The shielding calculations done by the ROC code are patterned after a cylindrical source model as discussed in the Reactor Shielding Design Manual⁽⁵⁾ using build-up factors and self-attenuation distances from curve fits in APAE Memo-52. ⁽⁶⁾

Since the shipping cask will not be shipped within 10 days after reactor shutdown and since the core will not have an infinite operating history, adjustments were made to the ROC output.

In order to determine the dose rates due to the activation of stainless steel, input to the ROC code was adjusted so that a source strength with and without stainless steel activation was obtained. The ROC shielding calculation was done with both source strengths. The two resulting doses from the above ROC calculations were then adjusted for 2 yr of reactor operation and for various decay times from 2 hr to 10 yr. Decay information for fission products was obtained from reference (7) taken for the controlling energy group from the ROC codes (1-3 Mev). Stainless steel decay and activation information came from reference (8).

Since it seemed quite likely that an entire core could not be shipped in one cask due to weight limitations, the lead thickness required for partial cores was investigated.

The equation the code uses for the full core side dose rate is as follows:^{(3), (5)}

$$D = \frac{S_v R_o^2}{2(a+z)C_e} F(b_1, \theta)$$

D = dose rate (r/hr)

S_v = volumetric source strength (photons/ cm^2 sec)

R_o = core radius (cm)

μ_s = macroscopic cross-section of core (cm^{-1})

z = self-absorption distance (cm)

b = μt (macroscopic cross-section of shield x shield thickness)

θ = half the angle between the dose point and the top and bottom of the core

C_e = flux to dose conversion

$$F(b, \theta) = \int_0^{\theta} e^{(-b \sec \theta')} d\theta' \quad (\text{curves are given in Rockwell})^{(5)}$$

$$b_1 = b + \mu_s z$$

The partial core dose rates were calculated as follows:

$$D_{\text{partial core}} = D_{\text{full core}} \times \frac{(Ro)_p^2 F(\theta, b_1) p (a + z_f)}{(Ro)_f^2 F(\theta, b_1) f (a + z_p)}$$

7.3.2 End Shielding

The cylindrical geometry model used by the ROC code cannot be used to determine the end shield requirements.

Since the source diameter is small relative to the distance to the dose point, a model using a series of 6 point sources was used to determine the dose from the ends of the shipping cask. The sources were located on the vertical center line of the fuel. Their location and weight fraction were determined by a Gaussian method of quadratures. ⁽⁹⁾

The equation for the dose rate from one point source of one energy with one lead thickness is:

$$D = \frac{V \text{ Ce } S_v}{4 \pi R^2} B A F \exp(-\mu_s t_s - \mu_L t_L)$$

V = volume of core (cm³)

Ce = flux to dose conversion factor

S_v = volume source strength (mev/cm³-sec)

B = dose build-up factor B = f(μ_st_s + μ_Lt_L)

A = Gaussian weighting factor

F = flux factor

μ_s = macroscopic cross section of core (cm⁻¹)

μ_L = macroscopic cross section of shield (cm⁻¹)

t_s = thickness of core (cm)

t_L = thickness of lead (cm)

R = distance from dose point to point source (cm)

625 024

Since 24 solutions (4 energies x 6 point sources) to the D equation were required to obtain the total dose for each leak thickness, a Fortran IBM-650 computer program was written for its solution.

Volume source strengths for fission products at 2500 hr after shutdown were obtained from reference (7). These source strengths were calculated in four energy groups. The stainless steel activation source strengths were obtained from the ROC Code cases previously described.

The total sources used were as follows:

<u>Group</u>	<u>Energy Mev</u>	<u>Se Mev/cm³ sec</u>
1	0.7	1.37×10^{11}
2	1.25	3.90×10^9 (including S. S.)
3	1.60	1.02×10^9
4	2.20	7.5×10^8

The build-up factors for lead were obtained from the Reactor Shield Design Manual. (5) However, the μ_t used was taken equal to the μ_t for the lead shielding plus the μ_t for the core.

The flux factors are used to take into account the variation in source distribution over the length of a fuel element. The test report "Gamma Scanning Spent SM-1 Fuel Elements" (10) plots this variation. An average fuel element source distribution curve was derived from these plots. Deviations from the average flux of this source curve were used to derive the flux factors.

Cross sections for the core materials were taken from ANL-5800 (11). Lead cross sections were obtained from Rockwell. (5)

7.4 RESULTS

Results have been plotted in Figs. 13 - 16 for each core showing the lead equivalent shield required to reduce the dose at 1 meter for the full core to 10 mr/hr for various shutdown times. These curves may be used to determine an optimum shipping time. For example, by delaying shipment from 10 days to 30 days almost 1 in. of lead may be saved; by waiting from 30 days to 90 days about 2 in. of lead may be saved; waiting from 90 days to one year, however, will save less than 1/2 inch.

Figure 17 shows the lead thickness reduction for partial core shipment. An examination of the curves shows that even a large reduction in the number of fuel elements shipped in a cask results in only a small lead thickness reduction. This is partially due to the self shielding value of the fuel. Fuel elements

in the inner rows of the cask are shielded by the elements in the outer row.

Figure 18 is the dose attenuation curve of the side shield at 10 days for each full core. Also shown in Fig. 18 is the attenuation curve after 2500 hr shutdown for the ends of 15 of the reference core elements operated for 2 yr.

The dose rate from the end breaks down as follows:

<u>Energy Group</u>	<u>Source Energy</u>	
1	0.7 Mev	0.4%
2	1.25 Mev	10% (including S. S.)
3	1.4 Mev	20%
4	2.2 Mev	70%

The dose rate from the sides of the cask, as calculated by the ROC Code, is from two source energy groups - 0 to 1 Mev is calculated at 0.75 Mev and 1 to 3 Mev is calculated as 2 Mev. The low energy group yields answers that are several orders of magnitude lower than the higher (2 Mev) group. The total dose, thus, essentially all comes from sources in the 2 Mev group. By adjusting the input to ROC Code it is possible to separate this dose into two groups, one from the fission products and one from stainless steel.

For an SM-1 core operated 2 yr and shutdown 2500 hr the dose breakdown is:

Fission product dose	55%
S. S. dose (Co-60)	45%

It is believed that the stainless steel (Co-60) dose from the ROC Codes is a high contributor because stainless steel is considered to be a 2 Mev source (by the ROC code) when in reality it is nearer a 1.25 average Mev source.

It may be observed from Fig. 18 that the shielding required for the top and bottom of the shipping cask is almost 2 in. less than that required for the sides at the same decay time. Previous reports (12),(13) discussing shielding requirements for the top and bottom of the shield casks indicate thicknesses greater than or equal to the sides.

The discrepancy is due to the use of two different models for calculating shielding requirements for the end and sides. The ROC code calculation for the side shielding is extremely conservative for the following reasons:

1. The code effectively uses a single energy group for calculation.
2. The average energy is assumed to be 2 Mev, well above the true effective average energy.

3. The analytical model used with ROC code is based upon conservative assumptions.

The minimum weight shield which would meet the shipping requirements could be evaluated by judicious experimentation. However, the analysis thus far performed has been sufficient to evaluate the optimum shipping cask size and decay time before shipment. An estimated 15% to 20% shield weight savings might result from the experimentation; however, present budget allows only refinement of the shielding calculations on analytical bases.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The work conducted during Phase I activity has evolved the following conclusions and recommendations:

1. The optimum fuel transfer arrangement for a boiling water reactor concept utilizes a fuel transfer flask. The fuel transfer cask is positioned on a lead filled shield cover which encompasses indexing mechanisms to precisely place the flask opening over any selected core element. Grappling tools, manually operated, penetrate the flask top center and will engage and lift the element into the flask. The flask is then moved to the storage receptacle, where it is precisely placed over a selected compartment and the element is lowered into place and released. The shield gate is closed at all times when the irradiated element is inside the flask. A conceptual flask design is shown in Dwg. AEL-731 (Fig. 1, Appendix B).
2. The optimum fuel transfer arrangement for a pressurized water reactor concept utilizes a spent fuel chute. The fuel is lifted by a manually held tool, placed in the chute and lowered into the hopper at the discharge end of the chute. The hopper is then rotated to a vertical position and the element is lifted with the same tool (or a duplicate) and placed in a storage compartment. The chute contains a removable seal which will withstand the pressure generated in a maximum credible reactor accident without leaking.
3. The optimum fuel storage arrangement is one in which the shipping casks are used as a storage receptacle. The casks would be placed in the peripheral shield tanks. If loading of the casks is done by transfer flask, no additional shielding would be required during fuel transfer because the flask would be lowered to an adapter plate placed on the top of the cask. When transferring fuel by chute to the cask, an auxiliary shield would be placed around the top of the cask. This shield would be U-shaped and would be placed with the opening toward the reactor. To minimize risk of damage to the peripheral tanks, it is desirable to have one fuel chute for each shipping cask required so that casks need not be moved after loading. Adequate cooling of the casks by natural convection can be achieved by design modifications to the cask to permit adequate flow area. The spent fuel will be cooled in the casks for not less than 90 days prior to shipment. Reduction in decay heat generation will then permit draining and sealing of the cask for shipment. During shipment, heat dissipation will be through the cask walls, and the cask surface temperature will remain below the maximum allowable limit of 180°F.

4. Based on best available figures for shielding, four casks will be required to house the PWR, 7 x 7 Type 2 core if a maximum gross weight of 20,000 lb is not exceeded. If the maximum gross weight of 27,500 lb per shipping cask is allowed, only two casks would be required to ship this core. The BWR, rod-type element would require six casks to ship the entire core with the 20,000 lb weight limit and four casks to ship the core within the 27,500 lb weight limit. If only part of the absorber loading is shipped, due to the longer life expectancy, further reductions in size or quantity of shipping casks may be realized.
5. The spent fuel shipping cask shielding analytical studies performed thus far are sufficient to provide an adequate basis for shield thickness determination, as well as optimum cask size and optimum decay time. Experiments and/or additional analytical calculations will be required to reduce conservatism in the shield thickness and provide the best final design.

9.0 BIBLIOGRAPHY

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APPENDIX A - TABLES

TABLE 1
SHIPPING CASK AND TRANSFER FLASK DATA SHEET

Reactor Concepts:

BWR Rod Type Core	- 24 elements, 9 cruciforms
BWR Plate Type Core	- 60 elements, 8 or 9 cruciforms
PWR Type 2, 7 x 7 Core	- 45 elements, 7 absorbers
PWR Type 3, 5 x 5 Core	- 25 elements, 5 absorbers

Shipping Cask Data:

		<u>BWR</u>		<u>PWR</u>
	Rod	Plate	Type 2, 7x7	Type 3, 5x5
No. of casks required	6	5	4	2
Elements per cask	4	12	11 or 12	12 or 13
Absorbers per cask	2 or 1	2 or 1	2 or 1	3 or 2
Element length, in.	47.863	32	31.625	31.625
Absorber length, in.	49.175	37	23	23
Lead shielding, in. *	8.75	10.2	10.0	11.0
Bare cask weight, lb	17,950	19,150	18,650	21,100
Loaded cask on skid, lb	19,950	20,560	20,150	22,600
Basket opening, in. sq	5.875	5.875	3.0	3.0
<u>Transfer Flask Wt., lb</u>	22,200	16,350	14,000	14,000

* Shielding based on preliminary data. Later shielding figures from Alco ROC code adjusts figures to the following for 90 day decay period:

	<u>Shielding</u>
BWR, PL-2, 1/6 Core	9.67"
BWR, SM-2, 1/5 Core	10.04"
PWR, SM-1, 1/4 Core	10.85"
PWR, SM-2, 1/2 Core	11.12"

TABLE 2
DECAY HEAT GENERATION RATES, PL-3 CORE

The following decay heat generation rates are based on the assumptions of 8 tMW reference power and infinite reactor operation of a pressurized water core.

Decay Power Values (Based on Clancy-Stehn Curve)

P/P_0	One day	-	0.0049
	90 Days	-	0.0012
	One Year	-	0.0007

<u>Fraction of Core</u>	<u>Decay Heat</u>	<u>Generation</u>	<u>Btu/Hr</u>
Full	133,790	32,760	19,110
1/2	66,890	16,380	9,560
1/3	44,590	10,920	6,370
1/4	33,450	8,190	4,780
1/5	26,760	6,530	3,820
1/6	22,300	5,460	3,190

Single Hot Element Heat Generation Rate after 24 Hr Decay*

PWR, 5 x 5 Core Type 3	PWR 7 x 7 Core Type 2	BWR Plate Type	BWR Rod Type
8,020 Btu/hr	4,455 Btu/hr	13,379 Btu/hr	8,360 Btu/hr

* Values based on 150% of average

TABLE 3
FUEL TRANSFER TOOLING FOR THE PL-3 REACTOR

1. Vapor Container Sling
 2. Reactor Vessel Cover Sling with Adjustable Leg (1)
 3. Bolt Tensioner for Reactor Cover (2)
 4. Retrieving Tool
 5. Stationary Element Handling Tool with Balancer (3)
 6. Control Rod Element and Absorber Tool with Balancer (3)
 7. Tool Holder for the Following Tools (4)
 - a. Reactor Cover Nut Runner
 - b. Stud Cap Runner
 - c. Jack Screw Runner
 - d. Core Cover Nut Runner (5)
 - e. Core Cover Handling Tool (5)
 - f. Dry Well Cover Nut Runner (5)
 - g. Control Rod Cap Removing Tool (5)
 - h. Fuel Chute Plug Tool (5)
 - i. Shipping Cask Adapter Plate Tool (6)
 - j. Shipping Cask Cover Pedestal Tool (7)
 8. Shipping Cask Sling
 9. Miscellaneous Hand Tools, Jacks, etc.
-
- (1) Can be used for dry well cover of PWR, if required.
 - (2) Two required. Remotely operated for PWR. Used for both pressure vessel and vapor container on BWR.
 - (3) Two required. Used only with PWR. Tool for BWR is part of the transfer flask assembly. Also used for spent fuel chute hopper.
 - (4) Two required.
 - (5) Used on PWR only.
 - (6) Used only if fuel transfer is by flask.
 - (7) Used only if fuel is stored in shipping cask for cool down.

TABLE 4
REFUELING TIME ESTIMATE FOR BOILING WATER REACTOR
FUEL TRANSFER BY TRANSFER FLASK

1.	Completely Filled Reactor Vessel with Water	90 min
2.	Drain Water from Upper Shield Tanks, Remove and Store	105 min
3.	Remove Shielding from Control Rod Drive Housings	45 min
4.	Remove and Store Control Rod Drive Units	135 min
5.	Unbolt, Remove and Store Vapor Container Dome	180 min
6.	Remove Drive Thimbles, Delatch and Remove Control Rods and Extensions	180 min
7.	Crack Open Reactor Cover Flange Nuts	75 min
8.	Drain Vessel to Flange Level and Remove Cover Nuts	75 min
9.	Remove and Store Reactor Vessel Cover	45 min
10.	Place Shield Cover over Flange in Proper Position	60 min
11.	Transfer Core by Transfer Flask (55 min per unit)	1,815 min
12.	Remove shield cover and place in storage	45 min
13.	Load Entire New Core in Reactor	90 min
14.	Replace and Secure Reactor Vessel Cover	300 min
15.	Replace Racks and Extensions, Latching to Control Rods	90 min
16.	Replace Drive Thimbles, Vapor Container Dome and Drive Housings	360 min
17.	Replace Upper Shield and Fill with Water	120 min
18.	Drain Reactor Vessel to Operating Level	20 min

Total Time = 63 Hr, 50 Min

TABLE 5
REFUELING TIME ESTIMATE FOR PRESSURIZED WATER REACTOR
FUEL TRANSFER BY SPENT FUEL CHUTES TO
SHIPPING CASKS

1.	Loosen, Remove and Store Vapor Container Cover Nuts	150 min
2.	Remove and Store Vapor Container Cover	45 min
3.	Fill Dry Cap, Unbolt, Remove and Store	60 min
4.	Loosen, Remove and Store Reactor Cover Nuts	135 min
5.	Remove and Store Reactor Vessel Cover	45 min
6.	Remove and Store Core Cover	15 min
7.	Remove and Store Control Rod Caps	15 min
8.	Loosen, Remove and Store Fuel Chute Plugs (4 req'd)	30 min
9.	Position Auxiliary Shield on Top of Cask (4 times)	60 min
10.	Transfer Fuel Elements and Absorbers	495 min
11.	Install Pedestal on Casks and Position Covers (4 req'd)	120 min
12.	Load New Core in Reactor	270 min
13.	Replace, Seat and Tighten Fuel Chute Plugs	30 min
14.	Replace Control Rod Caps and Core Cover	30 min
15.	Reposition Reactor Cover and Tighten Nuts	300 min
16.	Position Dry Cap, Tighten Bolts and Drain	75 min
17.	Position Vapor Container Cover and Secure Nuts	330 min

Total Time = 36 Hr, 45 Min

TABLE 6
CORE DATA

<u>Core</u>	<u>PWR-7x7 Type 2</u>	<u>PWR-5x5 Type 3</u>	<u>BWR- Plate</u>	<u>BWR- Rod</u>
Volume fraction of fuel	0.0192	0.0240	0.0125	0.2045
Volume fraction of stainless steel	0.1904	0.2370	0.1230	0.1125
Active fuel length, in.	21.75	22.0	28.0	38.3
Equivalent core radius, in.	11.2	8.30	13.0	18.1
Fuel enrichment (% U-235)	93	93	93	4.8
Average fast flux, neutrons/cm ² -sec	1.4x10 ¹⁴	1.6x10 ¹⁴	5.1x10 ¹³	3.4x10 ¹³
Average thermal flux, neutrons/cm ² -sec	1.4x10 ¹³	1.2x10 ¹³	1.0x10 ¹³	5.2x10 ¹²

TABLE 7
SOURCE AND SHIELDING DATA
(10 DAYS AFTER SHUTDOWN, INFINITE OPERATION)

<u>Core</u>	<u>PWR-7x7 Type 2</u>	<u>PWR-5x5 Type 3</u>	<u>BWR- Plate</u>	<u>BWR- Rod</u>
Macroscopic cross section of core, cm ⁻¹ (0.75 Mev γ 's)	0.1274	0.1586	0.08244	0.2722
Macroscopic cross section of core, cm ⁻¹ (2 Mev γ 's)	0.0768	0.0957	0.04974	0.1367
(1) Source Strength, Photons/cm ³ sec (0.75 Mev γ 's)	5.6x10 ¹¹	6.6x10 ¹¹	2.4x10 ¹¹	9.9x10 ¹⁰
(1) Source Strength, Photons/cm ³ sec (2 Mev γ 's)	2.0x10 ¹¹	2.3x10 ¹¹	8.2x10 ¹⁰	3.4x10 ¹⁰
(2) Source Strength, Photons/cm ³ sec (0.75 Mev γ 's)	5.6x10 ¹¹	6.6x10 ¹¹	2.4x10 ¹¹	9.8x10 ¹⁰
(2) Source Strength, Photons/cm ³ sec (2 Mev γ 's)	1.8x10 ¹¹	2.1x10 ¹¹	7.6x10 ¹⁰	3.1x10 ¹⁰

- (1) With stainless steel activation
(2) Without stainless steel activation

APPENDIX B - FIGURES

Figure 1. Fuel Transfer Flask

039

WEIGHT OF STEEL PARTS 18.44 LBS
WEIGHT OF LEAD SHIELDING 14.970
TOTAL WEIGHT 163.4 LBS

PRELIMINARY LAYOUT			
ALSO PRODUCTS INC. SCHENECTADY, NEW YORK ATOMIC ENERGY DEPT.			
MODEL FL-3	DESIGNED BY J. J. J.	DATE 10/1/54	APPROVED J. J. J.
CHECKED BY J. J. J.	DATE 10/1/54	APPROVED J. J. J.	
TITLE: FUEL TRANSFER FLASK			
DRAWN BY: J. J. J.			
MODIFIED BY: J. J. J.			
LAYOUT NO. AEL 731

A- FLASK
 B- ELEMENT GUIDE
 C- SECTION GUIDE
 D- SHIELD COVER
 E- WATER LEVEL, TRANSFER
 F- WATER LEVEL, OPERATING

G- LOCATING ADAPTER
 H- SHIPPING CASK
 I- REACTOR VESSEL
 J- SHIELD TANK

Figure 2. Refueling Concept Using Transfer Flask

LAYOUT	
ALSO PREPARED BY:	ATOMIC ENERGY DIV.
PL-3	REACTOR DIV.
REVISION:	1/1/55
APPROVED:	1/1/55
TITLE: BWR COMPLEX	
LAYOUT NO. 101-740	

Figure 3. Boiling Water Reactor Complex

Figure 4. Primary System, PWR Complex C-5

Figure 5. Spent Fuel Chute Concept

Figure 6. Primary System Complex A-3, PWR

Figure 7. Storage Cask Forced Cooling System, PL-3

- A - Spent Fuel Shipping Cask
- B - Cooling Coil
- C - Surge Tank Reservoir
- D - Pump
- E - Pump Bypass Valve
- F - Skid Tank

Figure 8. Cask Cooling System

6 ELEMENT CASK (4 CASKS REQUIRED)

WEIGHT OF BARE CASK = 20,760[#]

WEIGHT OF LOADED CASK ON SKID = 23,160[#]

5 ELEMENT CASK (5 CASKS REQUIRED)

WEIGHT OF BARE CASK = 19,700[#]

WEIGHT OF LOADED CASK ON SKID = 21,900[#]

OPTIONS: 3 - SIX ELEMENT AND 2 - FOUR ELEMENT CASKS
 2 - SIX ELEMENT AND 3 - FOUR ELEMENT CASKS

4 ELEMENT CASK (6 CASKS REQUIRED)

WEIGHT OF BARE CASK = 17,950[#] AND 18,400[#]

WEIGHT OF LOADED CASK ON SKID = 19,950[#] AND 20,460[#]

Figure 9. Cask Sizing Based on PL-2 Core (BWR Rod Type)

- A. BWR SM-2 Cluster Elements, 9 Cruciforms, 5 Casks;
 Weight Empty = 19,150 lb
 Loaded Weight on Skid = 20,650 lb

- B. BWR PL-2 Pin Type Elements, 9 Cruciforms, 6 Casks;
 Weight Empty = 17,950 lb and 18,400 lb
 Loaded Weight on Skid = 19,950 lb and 20,460 lb

- C. PWR SM-1 (or SM-2) Plate Type Elements, 7 Absorbers; 4 Casks;
 Weight Empty = 18,650 lb
 Loaded Weight on Skid = 20,150 lb

Figure 10. Optimum Shipping Cask Arrangement

625 049

625 050

Figure 12. Proposed Skid - Spent Fuel Shipping Cask

LEAD REQUIREMENTS FOR 10 MR/HR DOSE AT 1 METER - CM

Figure 13. Shielding Requirements for Shipping a
PWR - 7 X 7 Type 2 Core

Figure 14. Shielding Requirements for Shipping a
PWR 5 x 5 Type 3 Core

625 052

Figure 15. Shielding Requirements for Shipping a BWR Plate Type Core

625 053

Figure 16. Shielding Requirements for Shipping a BWR Rod Type Core

625 054

Figure 17. Shipping Cask Shield Reduction for Partial Cores

625 055

Figure 18. Shipping Cask Dose Attenuation

625 056