Job No. 818
EO #1136

ATCOR

PARK MALL, PEEKSKILL, NEW YORK 10566 TEL: 914-739-9000

April 3, 1974

Chief, Transporation Branch
Directorate of Licensing
U. S. Atomic Energy Commission
Washington, D. C. 20545

Dear Sir:

In a letter dated August 14, 1972, ATCOR Inc. petitioned the Hazardous Material Regulations Board, Department of Transportation (DOT), to issue a special permit to enable a large quantity of radioactive material in the form of irradiated shroud cans to be shipped in the ATCOR Vandenburg Cask. The shipments of radioactive material are to be made for the purpose of disposal and are to be made from the LaCrosse Boiling Water Reactor plant in Wisconsin to Nuclear Fuels Services, Inc. in West Valley, New York. The DOT, pursuant to the provisions of Title 49 CFR 170.15 of the Department of Transportation Hazardous Material Regulations, issued to ATCOR a Special Permit No. 5805, Eighth Revision. The expiration date of this permit is December 31, 1974.

The fuel pool of the LaCrosse Boiling Water Reactor is nearly filled and space must be made available for the spent fuel assemblies from the impending refueling. The shroud cans must be shipped on short notice. We, therefore, request your review and approval for these shipments so that they can be performed as required without interference to the reactor reloading schedule.

Enclosed are seven (7) copies of the "Safety Analysis Report for the Shipment of Irradiated Shroud Cans from the LaCrosse Boiling Water Reactor in the ATCOR VNDB Cask" (SAR) for your review. This SAR provides full details of the proposed shipment, package description, design and evaluation.

Please contact me if you require any additional information concerning these shipments.

Very truly yours,

Robert G. Levesque
Operations

RGL/jbc

FROM:	DATE OF DOCUMENT:	DATE RECEIVED	NO.:
ATCOR Inc. Peekskill, New York	April 3, 1974	April 5, 1974	0862

LTR.: XX | MEMO: | REPORT: | OTHER:

TO: Chief, Transpo[r]tation Branch

ORIG.: | CC: XX | OTHER:

ACTION NECESSARY ☐ | CONCURRENCE ☐ | DATE ANSWERED:
NO ACTION NECESSARY ☐ | COMMENT ☐ | BY:

CLASSIF: U | POST OFFICE | REG. NO:

FILE CODE: Docket No. 70-150p0

DESCRIPTION: (Must Be Unclassified)
Ltr. trans.:

ENCLOSURES:
ATC-55 "Safety Analysis Report for the Shipment of Irradiated Shroud Cans fm the LaCrosse Boiling Water Reactor in the ATCOR VNDB Cask"
(7 cys rec'd.)

REMARKS:

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U.S. ATOMIC ENERGY COMMISSION MAIL CONTROL FORM FORM AEC-326 (8-60)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1973 — 503-135

ATC-55

SAFETY ANALYSIS REPORT

FOR THE

SHIPMENT OF IRRADIATED SHROUD CANS

FROM THE

LACROSSE BOILING WATER REACTOR

IN THE

ATCOR VNDB CASK

(From Reactor Site to Nuclear Fuel Services, Inc.
West Valley, New York)

ATCOR Job No. 818

Submitted By:

ATCOR Inc.
5 Westchester Plaza
Elmsford, New York 10623

August 3, 1972

ATCOR

CONTENTS

INTRODUCTION AND SUMMARY

This Safety Analysis Report is submitted in support of a request to obtain approval for the shipment of irradiated fuel element shroud cans from the LaCrosse Boiling Water Reactor (LACBWR). The LACBWR Nuclear Plant is a United States Atomic Energy Commission facility operated by the Dairyland Power Cooperative. A total of thirty-two (32) irradiated shroud cans are to be removed from the LACBWR and transported in two (2) separate shipments in the ATCOR Vandenburgh (VNDB) shipping cask to Nuclear Fuel Services, Inc., West Valley, New York for disposal.

ATCOR hereby requests that Special Permit No. 5805 be amended by adding a new paragraph (4g) to permit a seventh alternate cask loading. The contents of each package is to consist of large quantities of radioactive material, n.o.s., in the form of sixteen (16) irradiated fuel element shroud cans from the LACBWR. The packaging will be essentially as described in paragraph 2, except that for this loading, in lieu of a fuel basket, the contents will be loaded within a cylindrical tank of double wall construction with 1-1/8 inch of lead shielding between steel inner and outer walls of at least 3/16 inch thickness, 115 inches high by 35 inches O.D., with a bolted lid closure.

The ATCOR VNDB has been approved for numerous shipments of large quantities of fissile and radioactive materials. These shipments included spent fuel from the OMRE, BONUS, and EBWR for the United States Atomic Energy Commission. In addition, ATCOR has shipped Pathfinder boiler fuel and, subsequently, Pathfinder high enrichment superheater fuel. Large quantities of radioactive material were shipped by the United States Atomic Energy Commission in the form of control rods from the BONUS reactor for sea and land shipment. Also, large quantities of radioactive material in the form of control rods, dummy fuel elements and miscellaneous activated components from the Elk River Reactor (ERR) were shipped by ATCOR in the VNDB cask.

The shipment of LACBWR irradiated shroud cans herein considered is similar to the shipments from ERR, authorized under the Fifth Revised Special Permit No. 5805, in that the radioactivity material consists of dry, solid, non-fissile materials. In this case, the radioactivity is exclusively by neutron induced activation of the stainless steel shroud cans.

Structural integrity of the VNDB cask for the shipment of large quantities of radioactive materials has been previously demonstrated to meet the standards in the current regulations of the U. S. Atomic Energy Commission and of the Department of Transportation. Detailed in this report are areas of investigation peculiar to this petition which have not been previously considered.

Details of Shipment

A total of two (2) identical separate exclusive use shipments are to be made by a common carrier, each to remove sixteen (16) irradiated shroud cans from the LACBWR, Genoa, Wisconsin to Nuclear Fuel Services, Inc., West Valley, New York. Each load of sixteen (16) shroud cans will be placed in a shielded waste tank (ATCOR Drawing No. 818-D-01) which in turn will be placed within the ATCOR VNDB cask for shipment.

Calculation of the radioactive inventory indicates that the equivalent of approximately 35,000 curies of Co-60 are to be buried in all. It is estimated that a typical shroud can will contain the equivalent of about 1,100 curies of Co-60. The decay heat load generated by this curie content is only about 300 watts per shipment which causes only minimal increases in internal and surface temperature. The surface temperature of the cask will increase, for example, less than 4° F above ambient.

It is estimated that the maximum dose rate will be less than

Details of Shipment (Cont'd)

10mr/hr at six feet. However, the actual assignment of the transport index will be based on radiation measurements taken three feet from the surface of the loaded cask for each shipment.

The cask will be positioned on a cradle built of structural steel equipped with hold-down devices. The cradle will be secured to the vehicle during transit of the shipment.

I. DESCRIPTION

IA. LACBWR Irradiated Shroud Cans

The thirty-two (32) shroud cans are identical. They are constructed of stainless steel. The overall dimensions are 5.823 inches square (maximum) and 105.38 inches in length, as illustrated in Figure 1. Each shroud can weighs approximately forty-seven (47) pounds.

Radiation levels as measured at LACBWR for a typical single can are:

57mr/hr through 6 feet of water

It is estimated that a typical shroud can contains about 1100 curies of Co-60.

Figure 2 illustrates the arrangement of the irradiated shroud cans within the shielded waste tank.

IB. Shielded Waste Tank

The shielded waste tank, as designed, is constructed of concentric carbon steel shells with lead for shielding between the resulting annulus, and in the tank cover and bottom sections. ATCOR Drawing No. 0818-D-01 illustrates the design of the waste tank.

The shielded waste tank is a right circular cylindrical tank which weighs about 8,000 pounds. Overall dimensions are 35.0 inches O.D. and 115 inches in length. These dimensions correspond closely to the dimensions of the cask cavity to limit motion of the contents within the ATCOR cask during transportation.

The inner and outer shells of the tank are constructed of 3/16 inch

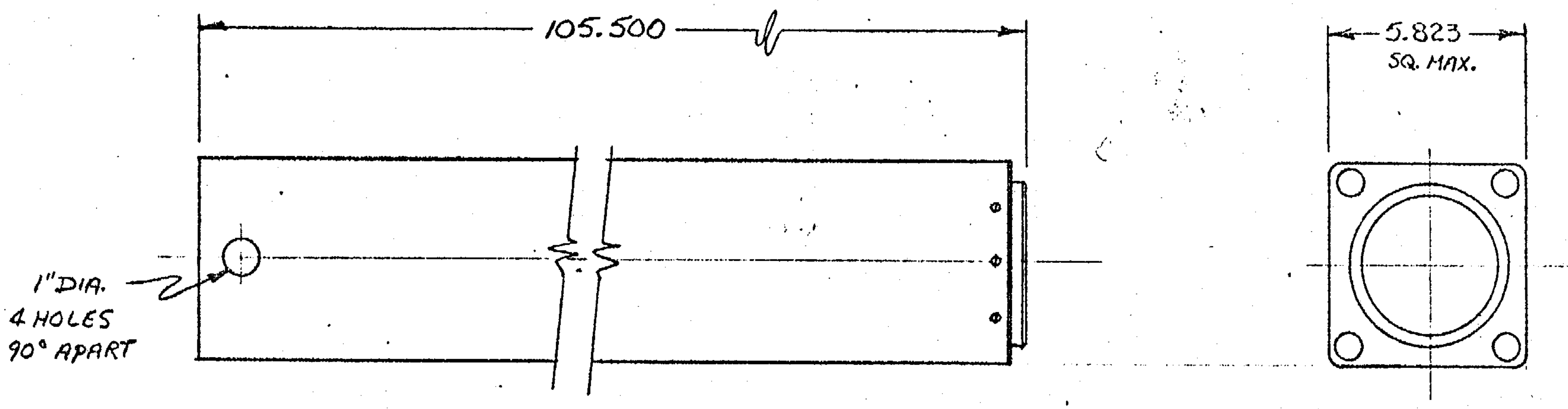


FIG. 1

LACBWR IRRADIATED
FUEL ELEMENT SHROUD

SKA-818-2

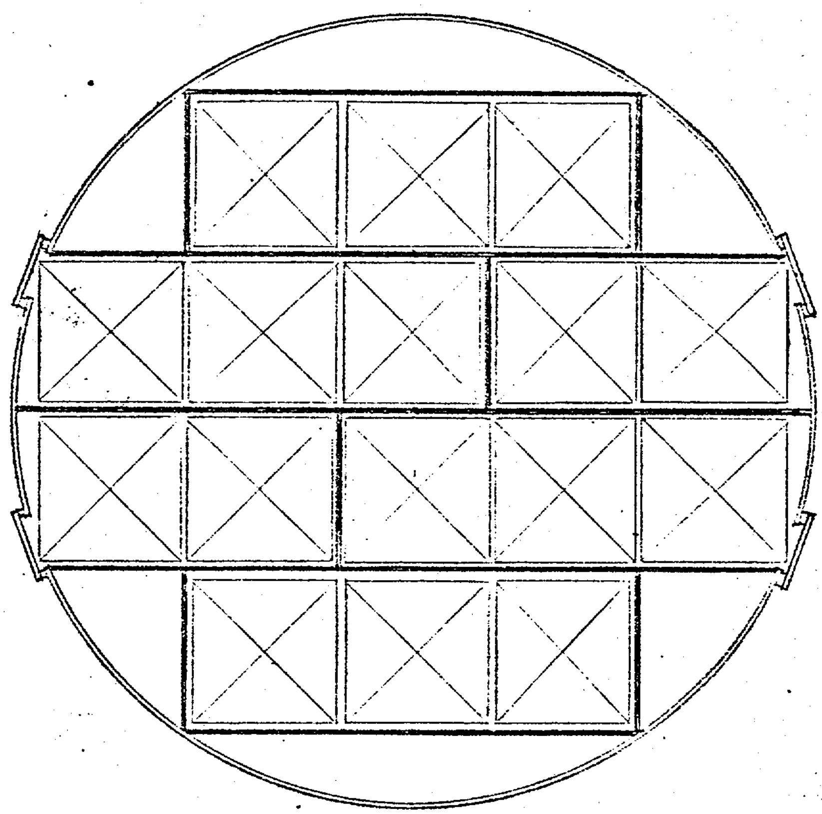


FIG. 2

LOADING CONFIGURATION FOR LACBWR
SHROUD CANS IN SHIELDED WASTE TANK

SKA-818-3

IB. Shielded Waste Tank (Cont'd)

plate with 1-1/8 inches of lead within the annulus. Four (4) recesses are provided on the inner shell to accommodate the corners of the four (4) shroud cans which would otherwise cause interference. A grid structure of 1/8 inch carbon steel plate is provided to facilitate placement of the shroud cans within the waste tanks. The sixteen (16) shroud cans in an individual shipment fit tightly within the shielded waste tank to restrict movement during transportation.

The bottom of the shielded waste tank and the removable cover are constructed of double 3/8 inch carbon steel plates with 1 inch of lead in the space between the plates. Two (2) guide pins are provided to aid in positioning the cover which is secured with six (6) 1/2 - 13 UNC bolts.

Slings are provided on the bottom of the shielded waste tank to facilitate removal at the disposal site. Lift devices are provided on the tank cover for normal handling operations.

IC. ATCOR VNDB Cask

The cask is constructed of two (2) concentric steel shells welded to a flat plate at the ends. The 6.0 inch space between the inner and outer shells is filled with lead. The internal dimensions of the cask are 36 inches I.D. x 116.5 inches long. The equivalent of 6.8 inches of lead is provided through the side of the cask.

The total thickness of the outer shell is 1 inch and is fabricated from 1/2 inch Type 304 stainless steel (outer) and 1/2 inch A285 Grade A steel (inner). The thickness requirements were set by

IC. ATCOR VNDB Cask (Cont'd)

structural requirements based on a 40-inch drop to a 6-inch diameter piston. The cask outside surface is finished to an equivalent 63 RMS finish for ease of decontamination.

Two (2) 8-inch diameter trunnions are provided for cask handling. Two (2) 4-inch diameter trunnions are designed to be bolted to the lower portion of the cask for tilting the cask. The two (2) 4-inch trunnions are removed during shipment and bolted to the turning mechanism frame.

The cask will be positioned on a cradle built of structural steel equipped with hold-down devices. The cradle will be secured to the vehicle during the exclusive use shipments.

II. HANDLING PROCEDURE FOR ATCOR CASK

A. Initial Checkout and Off-Loading

1) Inspect trailer, cask, cradle, hook and turning mechanism for damage.
2) Move cask, aboard trailer, into position under the mobile crane.
3) Remove two hold-down straps (wt. 485 lbs.)
   a) Remove lock wires and the 1¼" x 5" long bolts that secure the straps.
   b) Attach an eyebolt to the hold-down straps.
   c) With the crane, lift the hold-down straps off and place them on the ground.
4) Remove the 4" trunnions from the cradle (or truck locker) and bolt them in place on the cask.
5) Place two 1¼" wire rope slings around the cask and attach the slings to the hook of the crane.
6) Lift the cask in the horizontal position and lower onto planks on the ground.
7) Block cask; slack cables.

B. Transporting Cask to Containment

1) Roll cask on planks until lifting trunnions are almost in vertical position.
2) Move crane until once again centered over cask.
3) Lift cask in horizontal position and move into position over station railway dolly.
4) Lower cask onto dolly. (Baseplate toward building)
5) Strap cask to dolly using strap chains.
6) Remove the two 1¼" wire rope slings.
7) attach monorail chain falls to dolly and cask.
8) Lift dolly and cask to height necessary to clear floor of building.
9) Move dolly on monorail into building.
10) Lower cask and dolly onto railway.
11) Move cask and dolly into the containment vessel.

C. Upending Cask Inside Containment

1) Place the two 1¼" wire rope slings around the cask and attach the slings to the hook of the polar crane. Take out slack.
2) Remove strap chains around cask.
3) Lift the cask in the horizontal position and move dolly out of the way.
4) Lower cask onto planks on the containment floor and block to keep from rolling.

II. HANDLING PROCEDURE FOR ATCOR CASK (Cont'd)

C. Upending Cask Inside Containment (Cont'd)

5) Roll cask until lifting trunnions are horizontal.
6) Upend cask to vertical position.
7) Place cask in the vertical position on the containment floor.

D. Insert Liner

1) Remove the locking wires from the cask closure bolts.
2) Remove eight 1½" bolts and nuts.
3) Back the four tapered lead-in bolts all the way out. (Use special underwater tool to check clearance)
4) Lift bell section off the baseplate and place on floor alongside.
5) Check baseplate closure seals for damage.
6) Place cask liner onto baseplate using tapered pins for alignment.
7) Replace bell section over liner onto baseplate.
8) Tighten four tapered lead-in bolts.

E. Cask Leak Test

1) Remove vent plug and attach a 12' length of tygon tubing to the vent.
2) Remove drain line cap and install drain valve. Attach water supply to drain valve.
3) Raise tubing 12' above cask.
4) Open drain valve. Introduce water into cask until vent tubing is full.
5) Close drain valve. Remove water supply.
6) Check cask for leaks.
   NOTE: Replace gaskets if necessary. All gaskets are reusable and should be replaced only when leaking.
7) Drain cask of all water by opening drain valve. (The water in cask may be contaminated and should be drained to contaminated drain.)

F. Cask Loading

1) Break torque on the four tapered lead-in bolts, but do not loosen or remove.
2) Lift cask and move into position over pool.
3) Tie vent line tubing off to side of pool.
4) Lower cask to bottom of pool. Adjust position as required with tag lines.

F. Cask Loading (Cont'd)

5) Take index reading of crane position to ensure alignment when remating cask with baseplate.
6) Unbolt the four 1½" bolts in the baseplate using special underwater tool.
7) Lift bell section out of the pool maintaining alignment as it is raised with tag lines.
8) Rinse bell section while hanging over pool. Then move to set down area.
9) Using hooked tool, secure grasp on liner cover lifting device.
10) Using underwater tool, remove cover bolts and remove cover.
11) Load contaminated hardware into liner basket.
12) Replace liner basket cover and tighten all bolts.
13) Lift bell section and move to position over the pool.
14) Lower bell section over liner basket and onto baseplate.
15) Tighten four 1½" lead-in bolts.
16) Lift the cask from the pool so that the drain valve clears the pool surface. Close drain valve and check for leaks. (Make radiation survey of cask at it comes out of water)
17) After leak check, open drain and allow cask to drain into pool.
18) Rinse cask with clear water.
19) Move cask away from pool and place on containment floor as before.
20) Replace eight 1½" bolts and nuts and torque to 75 ft. lbs. Lock wire each bolt.

G. Transporting Cask from Containment

1) Decontaminate outside of cask using clear water and brushes.
2) Remove drain valve and replace drain line cap.
3) Replace vent plug.
4) Tilt cask to horizontal position and place upon planks on floor as before.
5) Roll cask until trunnions are almost vertical.
6) Lift cask in horizontal position and place on railway dolly.
7) Secure cask on railway dolly using strap chains as before.
8) Remove the two 1¼" wire rope slings.
9) Move railway dolly to outside door opening.
10) Attach monorail chain falls and lift cask and dolly to clean floor.
11) Move cask and dolly on monorail outside and lower to ground.

II. HANDLING PROCEDURE FOR ATCOR CASK (Cont'd)

H. Truck Loading

1) Place two 1¼" wire rope slings around the cask and attach the slings to the mobile crane hook. Remove the slack from the slings.
2) Remove the strap chains from around the cask.
3) Lift the cask in the horizontal position and place on planks as before.
4) Roll the cask until the trunnions are horizontal.
5) Recenter the crane and lift the cask in the horizontal position.
6) Position the cask over the trailer cradle and lower cask into cradle.
7) Remove the two 1¼" wire rope slings and place in cradle under cask.
8) Remove lower turning trunnions and replace in locker.
9) Lift the hold-down straps into position on cradle and replace all hold-down bolts. Lock wire all bolts.

III. WEIGHT ANALYSIS

		Weight (pounds)
1.	Cask	57,816
2.	Contents	
	a) Shielded Waste Tank	8,000
	b) Shroud Cans (16 at 47 pounds each)	752
3.	Skid	4,204
4.	Tractor and Trailer	32,910
	TOTAL (pounds)	103,682

IV. RADIOACTIVE INVENTORY AND SHIELDING

An estimate of the radioactivity inventory and dose rate at the side of the trailer has been calculated and is presented as an appendix to this Safety Analysis Report. Based on the maximum dose rate from a typical LACBWR irradiated fuel element shroud can, it was determined that curie content of a single can is less than 1,100 curies of Co-60, or about 18,000 curies in a shipment containing sixteen (16) shroud cans.

A dose rate of 10mr/hr at six feet from tne trailer was calculated. This estimate is conservative, since the calculational method has, by experiment and calculation, been shown to overestimate the dose rate. An additional degree of conservatism was also introduced in that the maximum specific activity calculated was used over the length of the shroud cans; whereas the specific activity decreases significantly towards the end of the cans.

While the dose rate has been calculated, actual dose rate measurements will be used to determine the transport index. In this way, compliance with dose rate limitations can be assured.

V. ACCIDENT CONDITIONS

The VNDB cask has been approved by the Department of Transportation as a suitable container for shipment of large quantities of radioactive materials (Special Permit No. 5805). The structural integrity of the VNDB cask was previously demonstrated for hypothetical accident conditions with the cask containing 8,700 pounds within the cavity (Pathfinder boiler fuel plus basket). The contents of a typical LACBWR shroud can shipment is the same (8,700 pounds) as the completed Pathfinder boiler fuel shipments, and will therefore present the same acceptable structural load under normal or accident conditions as previously demonstrated. The contents of the VNDB cask for the intended shipments and the contained radioactivity are all in metallic forms. It is highly unlikely that there would be any release of radioactivity in case of accident.

While no loss of lead is expected due to the thermal test, it was previously shown that about three inches of lead shielding must be lost before this limiting dose rate under accident conditions is achieved - that is, 1000 mren/hr at three feet.

APPENDIX

CALCULATION OF RADIOACTIVE INVENTORY AND DOSE RATE

DAIRYLAND POWER Cooperative reports a dose rate of 57 mr/hr at a distance of six feet for a typical shroud can in water. This reported activity level is used in the following hand calculation for a line source to determine the specific activity, hence curie content of the source. Further, this calculated specific activity is used to generate an equivalent volume source based on the arrangement of sixteen shroud cans within the ATCOR VNDB cask. A hand calculation is then made of the dose rate at a detector point located six feet from the trailer bearing the loaded ATCOR cask.

Determination of Activity:

For a finite line source

$$\phi = B \frac{S_L}{2\pi a} F(\theta, b_1)$$

Reactor Shielding Design Manual, Theodore Rockwell

Solve for S_L

$$S_L = 2\pi a \phi / B\, F(\theta_1, b_1)$$

For Co-60 with two gammas, γ_1 & γ_2

$$S_L = 2\pi a \phi \left[BF(\theta_1, b_1)_{\gamma_1} + BF(\theta_1, b_1)_{\gamma_2} \right]^{-1}$$

$$S_L = 2\pi \times 6\,ft \times 30.48 \frac{cm}{ft} \times 57 \frac{mr}{hr} \left[\quad \right]^{-1} = 6.55 \times 10^4 \left[\quad \right]^{-1} \frac{mr\text{-}cm}{hr}$$

$\gamma_1 = 1.17$ Mev
$\mu_1 = 0.065\ cm^{-1}$
$t' = 6$ ft. water $\times 30.48\ \frac{cm}{ft}$
$= 183$ cm water
$\mu_1 t = 0.065 \times 183 = 11.9$
B = Dose buildup factor
$B(11.9, \text{water}) = 29$
$\phi \approx 36^\circ$
$F(36^\circ, 11.9) = 2.3 \times 10^{-6}$
4.8×10^2 photons/cm²-sec = 1 mr/hr

$\gamma_2 = 1.33$ Mev
$\mu_2 = 0.060\ cm^{-1}$
$t = 183$ cm water
$\mu_2 t = 11.0$
$B = 22$
$F(36^\circ; 11.0) = 5.7 \times 10^{-6}$
4.3×10^2 photons/cm²-sec = 1 mr/hr

$$S_L = 6.55 \times 10^4 \frac{mr\text{-}cm}{hr} \left[\frac{29 \times 2.3 \times 10^{-6}}{4.8 \times 10^2} + \frac{22 \times 5.7 \times 10^{-6}}{4.3 \times 10^2} \right]^{-1} \frac{\text{photon/cm}^2\text{-sec}}{\text{mr/hr}}$$

$$= \frac{6.55 \times 10^4}{4.3 \times 10^{-7}} = 1.5 \times 10^{11} \frac{\text{disintegrations}}{\text{cm-sec.}}$$

Assume S_L remains constant over the length of a shroud can – a conservative assumption

$$\text{Curies} = \frac{1.5 \times 10^{11} \frac{dis}{cm\text{-}sec}}{3.7 \times 10^{10} \frac{dis/sec}{curie}} \times 105'' \times 2.54 \frac{cm}{in} = \underline{\underline{1100 \text{ curies/can}}}$$

Generate equivalent volume source which consists of sixteen cans homogenized within the shielded waste tank

Using a pitch of 6.25" for shroud cans within shielded waste tank

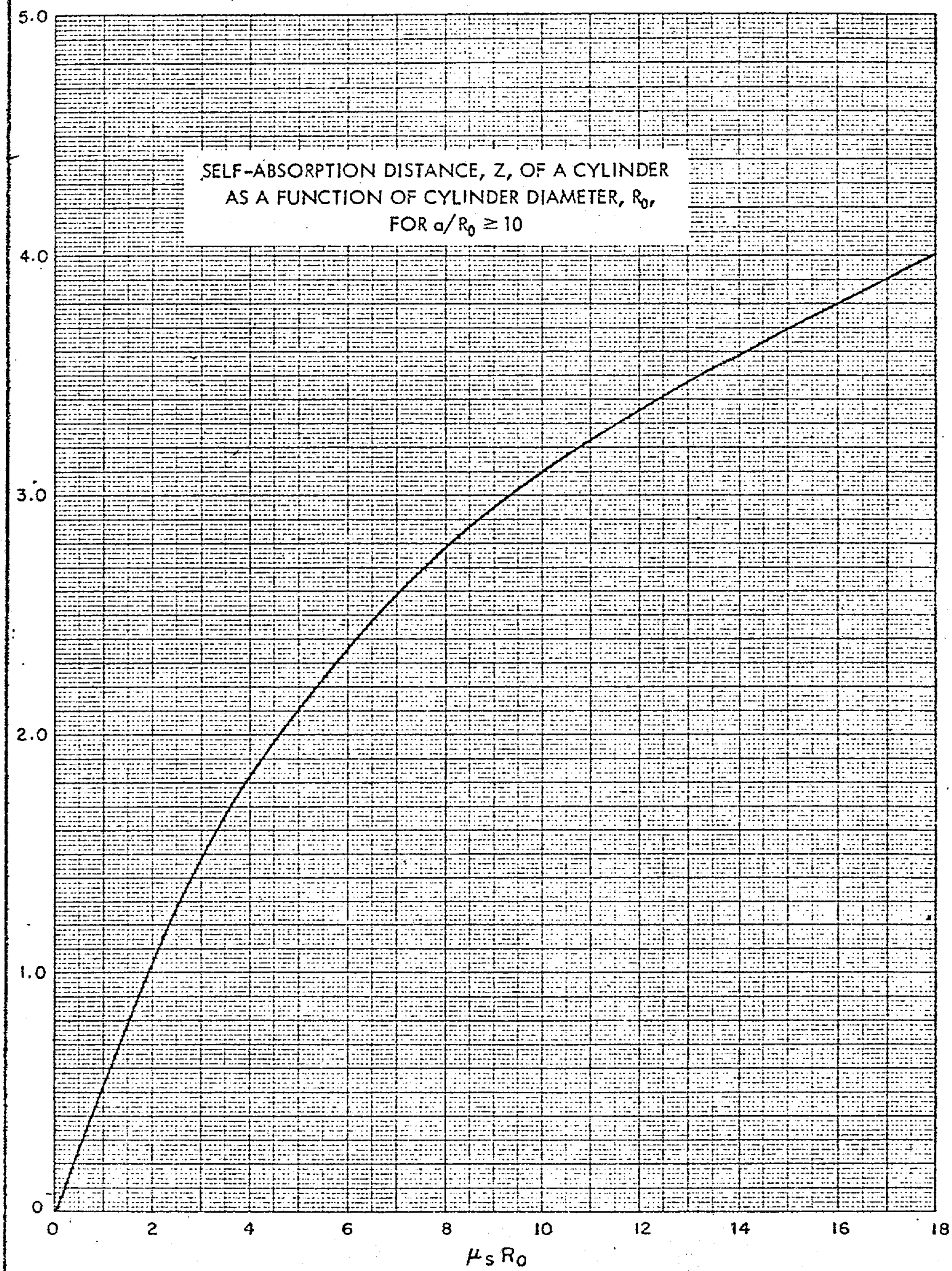
$$\text{Area} = 16 \text{ cans} \times 6.25''^2 \times 2.54^2 \frac{cm^2}{in^2} = 4030\ cm^2$$

$$\text{Equivalent radius } R_0 = \left(\frac{4030}{\pi}\right)^{1/2} = \underline{35.8\ cm}$$

$$\text{source volume} = 4030\ cm^2 \times 105'' \times 2.54 \frac{cm}{in} = 1.08 \times 10^6\ cm^3$$

$$S_V = \frac{16 \text{ cans} \times 1100 \text{ curies/can} \times 3.7 \times 10^{10} \frac{dis/sec}{curie}}{1.08 \times 10^6\ cm^3} = \underline{\underline{6.03 \times 10^8 \frac{dis/sec}{cm^3}}}$$

-from Reactor Shielding Design Manual, Rockwell



Dose Rate Calculation – Six feet from side of trailer with sixteen shroud cans within shielded liner inside of VNDB cask.

$$\phi = \frac{B S_V R_0^2}{2(a+Z)} F(\theta, b_2)$$

To calculate Z (equivalent self shielding of volume source)

shroud can weight = 47 pounds
Avg. density of homogenized source region =

$$\frac{16 \text{ cans} \times 47 \frac{lb}{can} \times 454 \frac{gm}{lb}}{1.08\times10^5 \text{ cm}^3} = 0.316 \frac{gm}{cm^3}$$

For γ_1 (1.17 Mev.)

$\mu_s = 5.5\times10^{-2} \frac{cm^2}{gm} \times 0.316 \frac{g}{cm^3} = 1.73\times10^{-2}\ cm^{-1}$

$\mu_s R_0 = 1.73\times10^{-2} cm^{-1} \times 35.8\ cm = 0.62$

For γ_2 = (1.33 Mev.)

$\mu_s = 5.2\times10^{-2} \frac{cm^2}{gm} \times 0.316 \frac{g}{cm^3} = 1.64\times10^{-2}\ cm^{-1}$

$\mu_s R_0 = 1.64\times10^{-2} cm^{-1} \times 35.8 cm = 0.59$

$a + R_0$ = ½ trailer width + 6 feet to detector
= 4′ + 6′ = 10′ = 304.8 cm.
R_0 = 35.8 cm (see pg. 2)
a = 304.8 − 35.8 = 269 cm.
a/R_0 = 269/35.8 = 7.5 ≈ 10

For γ_1:
$\mu_s Z = 0.32$
$Z = 0.32/0.0173 = \underline{18\ cm.}$

For γ_2:
$\mu_s Z = 0.31$
$Z = 0.31/.0164 = \underline{19\ cm.}$

$$b_2 = \mu_s Z + \mu t$$

Cask shielding and shielded

	Steel	Lead
basket	= 0.125″ steel	
waste tank inner shell	= 0.187″ steel	
" " Lead		= 1.125″ lead
" " outer shell	= 0.187″ steel	
cask inner shell	= 0.250″ steel	
cask lead		= 6.0″ lead
cask outer shell	= 1.0″ steel	
TOTALS	1.75″ steel	7.13″ lead

SP 112573

For γ_1 (1.17 Mev.)

$$\mu t = 0.70\,cm^{-1} \times 7.13'' \times 2.54\,\frac{cm}{in} + 0.43\,cm^{-1} \times 1.75'' \times 2.54\,\frac{cm}{in} = 14.6$$

$$b_2 = 0.32 + 14.6 = 14.9$$

$$B = 5.3$$

$$\theta = \tan^{-1} \frac{\frac{105''}{2} \times 2.54\,\frac{cm}{in}}{a+z} = \tan^{-1} \frac{133}{269+18} = 25^\circ$$

$$F(25^\circ, 14.9) = 9.3 \times 10^{-8}$$

Dose rate, mr/hr (1.17 Mev γ)

$$= \left(5.3 \times 6.03 \times 10^{8}\,\frac{\text{Photons/sec}}{cm^3} \times 35.8^2\,cm^2 \times 9.3 \times 10^{-8}\right) \Big/ \left(2.0 \times 287\,cm \times 4.8 \times 10^{2}\,\frac{\text{Photon}/cm^2\text{-sec}}{mr/hr}\right)$$

$$= 1.4\ mr/hr$$

For γ_2 (1.33 Mev.)

$$\mu t = 0.63\,cm^{-1} \times 7.13'' \times 2.54\,\frac{cm}{in} + 0.40\,cm^{-1} \times 1.75'' \times 2.54\,\frac{cm}{in} = 13.2$$

$$b_2 = 0.31 + 13.2 = 13.5$$

$$B = 5.2$$

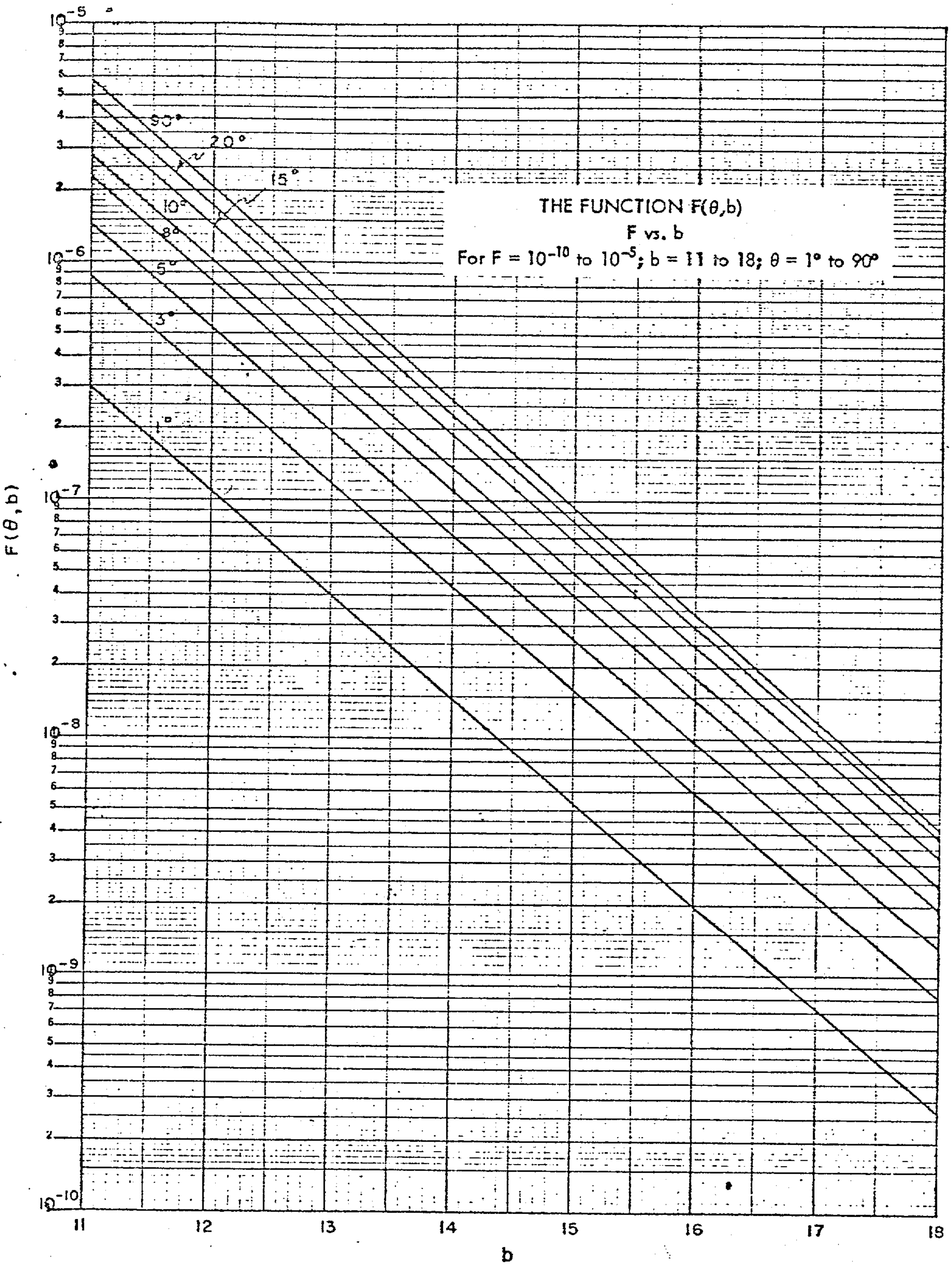
$$F(25^\circ, 13.2) = 5.3 \times 10^{-7}$$

Dose rate, mr/hr (1.33 Mev γ)

$$= \left(5.2 \times 6.03 \times 10^{8}\,\frac{\text{Photons/sec}}{cm^3} \times 35.8^2\,cm^2 \times 5.3 \times 10^{-7}\right) \Big/ \left(2.0 \times 288\,cm \times 4.3 \times 10^{2}\,\frac{\text{Photon}/cm^2\text{-sec}}{mr/hr}\right)$$

$$= 8.6\ mr/hr$$

Dose rate at six feet = 1.4 mr/hr (1.17 Mev)
8.6 mr/hr (1.33 Mev)
10 mr/hr


THE FUNCTION F(θ,b)
F vs. b
For F = 10⁻¹⁰ to 10⁻⁵; b = 11 to 18; θ = 1° to 90°
F(θ, b)
b
90°
20°
15°
10°
8°
5°
3°
1°
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
11
12
13
14
15
16
17
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